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—*Editor.*

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(Sd/-) *V. S. Chopra*

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Protection of Structures and Plants from Corrosion

J Scott*

Corrosion can cause severe reduction in efficiency and loss of earnings. Corrosion costs constitute about 1.5% of the G.N.P. in Britain. Apart from direct losses there may be many indirect losses which are likely to be heavier than direct corrosion losses. Since high variations in corrosion rates are possible, it is obviously important for the maintenance engineer to know what is the corrosion rate in his factory (or on a site for future works). Badly designed corrosion protection systems may prove to be worse than with no protection at all. The maintenance engineer who is quite new and who tries to derive reliable technical knowledge in a short space of time, should make use of his country's standards institution.

ALMOST all materials are weakened or eaten away by exposure to air or water but not all of them corrode. Wood that has not decayed from fungal attack, yet has been weakened by exposure to the weather, has weathered. Metals and sometimes masonry or concrete corrode. Rusting is the commonest sort of corrosion, but applies only to iron and steel.

HOW MUCH CORROSION?

Corrosion engineering began with the birth of the food-canning industry in the early 1800s. Later, in 1825, a British polar expedition was supplied with canned foods. The ship was lost but some of the cans were saved and their contents eaten nearly a hundred years later by a few adventurous people who suffered no harm. Food cans in the 19th century were massive tinned steel structures to be opened with a hammer and chisel and preferably also a vice. They are now made of steel only one two-hundredth of an inch (0.005 inch or 0.12 mm) thick, covered with a protective coating of tin that may be only one or two hundred-thousandths of an inch (0.00001 to 0.00002 inch or 0.0002 to 0.0005 mm) in thickness. The tinning may be thicker but is unlikely to be more than one ten-thousandth of an inch (0.0001 inch or 0.0025 mm) thick.

To the scientist there are two types of corrosion, "dry" corrosion, the direct oxidation of a metal like iron or copper when heated (a slow burning), and "wet" corrosion, of which rusting is one type even though the rusting metal is never in contact with water. This paper will deal mainly with wet corrosion because it concerns all maintenance engineers.

Moisture is present in varying amounts in all air. When the maximum amount is present, in rainy weather, the air is saturated or at 100 per cent relative humidity. In the Sahara desert the day time relative humidity is always very low, probably well below 30 per cent.

*Expert from United Kingdom

The overall cost of Corrosion to the USA alone, according to the US Bureau of Standards, is about $ 10,000 million a year.

The "saturated" value increases with temperature; hot air can hold more moisture than cold air.

Rusting is not appreciable when the humidity in the air is less than 60 per cent of the saturated value for that temperature, that is, at relative humidities below 60 per cent. When iron or steel rusts in air, water is drawn out of the air to react with oxygen and form rust on the metal surface.

Rusting, since it can take place in damp air, is probably responsible for most of the direct costs of corrosion. If we limit ourselves to the world's petroleum industry alone, we shall see that there is a very large amount of steel exposed to rusting. In 1967 some 400,000 km of oil pipelines and nearly 1 million km of natural gas pipelines were in existence.

The world's steel industries make a large amount of sheet metal, much of it protected against corrosion by a coating of zinc or tin. The consumption tonnages of galvanized steel sheet and of tinplate show that corrosion prevention is a most important part of industry.

In the US automobile industry, consumption of hot-dip galvanized steel rose from some 45,000 metric tons in 1955 to 670,000 tons in 1966, about fifteen-fold in 11 years. In 1968 in the USA alone, 5.6 million tons of tinplate (including terne plate) were produced, as well as 4.7 million tons of galvanized steel sheet. World output of these two types of anti-corrosive sheet is probably around 20 million metric tons each.

No less than 10 million tons of US steel a year are used in the replacement of corroded parts and products in the USA.

The overall cost of corrosion to the USA alone, according to the US Bureau of Standards, is about $ 10,000 million a year. But the actual money spent yearly on corrosion control in every form (largely painting and replacement of steel and iron) costs the USA more than $ 7000 million, Britain about $ 500 million and the world as a whole about $ 40,000 million. The British and US corrosion costs are about 1.5 per cent of the gross national product of these countries. These are the direct losses from corrosion. But there are other losses from corrosion, not usually accounted against it and therefore called indirect losses, that may well be heavier than the direct costs. For example, the shutting down of an oil refinery because some tubes have corroded dangerously and must be urgently replaced, may cost about $ 800 per hour or about $ 20,000 per day in lost production. The cost of a shutdown suffered by a generating station for the same sort of reason may be smaller, at least in a developed country, where the power station will be interconnected with others, but the operator will still have to pay about $ 10,000 per day for the power he buys from neighbouring generating stations. The cost of the spare parts replaced may well be only $ 100 or so.

Before such a failure, corrosion can cause severe reductions in efficiency and loss of earnings. For example the clogging of pipes with rust or other corrosion products can increase the pipe friction against which the pumps must work and will thus reduce the flow of valuable fluids. The piston rings and cylinder walls of internal combustion engines continually suffer corrosion from burnt gases during working periods and from condensed corrosive water during idle periods, resulting in loss of compression, high oil and fuel consumption, and high transport costs. A

small amount of copper lost by corrosion of copper tubing to a fluids circuit may seriously damage a b.tch of soap worth hundreds of dollars. Pipework and containers in dairies and other food-processing industries have to be made of costly stainless steel because the acids in milk and other foods would damage ordinary steel, quite apart from the possible toxic effects of such reactions. But the intensity of corrosion can vary greatly and there are many circumstances where corrosion is so slow as to be negligible.

Corrosion is generally severest in sea water, fresh water or wet earth, depending on the corroding influences in the ground or the water.

Corrosion is generally severest in sea water, fresh water or wet earth, depending on the corroding influences in the ground or the water. But buried or submerged or partly submerged structures such as pipelines or jetties are usually so large and expensive that it becomes essential to obtain the advice of a consulting engineer on how to protect them since it is then economic to pay for his advice. The consultant must be contacted early, either before or during the design stage because his views will affect the design. The corrosion consultant, who may also be the structural designer, will state what type of metal to use and what surface coatings to apply to it as well as any other protection that may be needed, indicating the most practical, economic or durable combination of methods. But this specialized information, although indispensable for large buried or submerged structures, is not necessarily useful to the maintenance engineer in his daily concern with the pipes, stanchions and tanks around his works, because it would be impracticable and too expensive to treat them all in the same way.

Submerged or buried structures will, therefore, not be discussed at length in this paper. It will be largely concerned with the prevention of rusting in damp air. Luckily, many figures have been published on the corrosion rate of bare mild steel in air at different places. A corrosion rate is usually understood to be the loss of metal from one side of a metal plate and it is therefore equal to half the loss of thickness. Steel and cast iron have very similar corrosion rates.

Corrosion Rates of Iron and Steel in Air

The corrosion rates of iron and steel in the air of his neighbourhood are of the greatest possible interest to the maintenance engineer. He must know whether his area has a corrosive or relatively non-corrosive atmosphere. The rates vary in an extraordinary way from zero in a dry desert or mountain climate to 0.95 mm yearly at a site close to a surf beach in Nigeria. This is probably because rusting is almost completely non-existent when the air has a relative humidity below 60 per cent. Therefore, in most of France and Central Europe there is much less rusting than in the United Kingdom or other western coastal areas of Europe where the relative humidity is often above 70 per cent. In Siberia or the Alps the air is not corrosive because the Alpine or Siberian air contains no industrial impurities, and these, mainly smoke, are important causes of corrosion. In these places the relative humidity of the air also is usually low.

Only 1200 metres inland from the Nigerian surf beach where a bare mild steel surface loses 0.95 mm depth in a year, the corrosion rate drops to 0.04 mm yearly, mainly because there is less salt in the air. Moisture and dirt (including chemicals like salt) are the two most important causes of corrosion in air.

The figure of 0.95 mm of yearly corrosion is worth emphasizing because many light-guage cold-rolled steel sections have a total thickness only a few times as much as this annual corrosion loss. In other words, these sections if exposed without protection would probably

lose more than half their strength, though not half their metal, after the first year, and in a few years would be worn through.

Annual corrosion rates in the non-industrialized areas of industrialized countries are about 0.05 mm yearly, sometimes as little as half this. In the south of England and in the outer suburbs of Berlin, the corrosion rate is 0.05 mm yearly. In industrialized areas, corrosion rates are at least double, some 0.10 mm (0.004 inch) yearly (Sheffield, England and Pittsburgh, USA). In the heart of industrial England, in Derby, the corrosion rate is even higher, nearly 0.18 mm (0.007 inch) while in the middle of a large chemical works corrosion takes 0.25 mm (0.01 inch) off a bare steel surface every year.

Since such high variations in corrosion rates are possible, it is obviously important for the maintenance engineer to know what is the corrosion rate in his factory (or on a site for a future works). Exposure tests should be made for as long a period as possible, working in a friendly way with a corrosion research organization in one's own or another country. This involves leaving pieces of metal to be tested in the open, marked with some means of identity that cannot be hidden by rust (for example a pattern of drilled holes), weighing them before exposure and afterwards when the rust has been removed by brushing, or some other standard method. Most research organizations, except some of those that are financed by private companies, are happy to co-operate in this way with workers in other countries, sharing their results and increasing their own total of results.

Apart from climate and air pollution, another variation in corrosion rates is caused by the type of steel. A very small percentage of copper in mild steel (only 0.02 per cent) will reduce its corrosion rate to a fraction of what it is without copper. Steels made partly from scrap metal often contain nearly this amount of copper. The extra cost of copper-bearing steel compared with mild steel is small, about 5 per cent or less.

Low-alloy steels have lower corrosion rates even than the copper-bearing steels. They have about 2 per cent of alloying elements excluding carbon. The high-alloy steels have even lower corrosion rates, for example, a common stainless steel is described as 18-8, meaning that it has 18 per cent chromium and 8 per cent nickel. Another stainless steel referred to in this paper is described as 18-10-3, meaning that it has 18 per cent chromium, 10 per cent nickel and 3 per cent molybdenum.

It is also interesting that corrosion is fastest in air containing sulphur dioxide even though the sulphate content of the rust (formed by the sulphur dioxide) is extremely small. Nearly all the rust is iron oxide and water. Another curiosity is that air polluted with pure sulphur dioxide is much less corrosive than air containing the same content of sulphur dioxide contaminated by some particles of charcoal. One would think that charcoal being a reducing agent would oppose oxidation. On the contrary, it encourages it. Evidently it is the smoke in the air of industrial countries that makes for rusting, since the smoke contains both sulphur dioxide and particles of carbon in the form of soot.

Is Corrosion-Prevention Worthwhile?

When the maintenance engineer is asked by his employer "Will this metal corrode?" he must answer "Yes" unless the metal is gold or one of the platinum metals. Even some of these corrode because, like chromium, they are protected from corrosion by a thin, non-porous film of their own oxide that forms in air and sticks tightly to the metal. There are, in fact, no metals used in industry except these noble metals that are not in some circumstances seriously corroded by water or air. Air consists from this point of view of oxygen, nitrogen, water, carbon dioxide and the usual industrial pollutants—sulphur dioxide, hydrochloric acid, ammonium sulphate and sodium chloride.

The question is better put this way: "In what conditions of use will corrosion be reduced to an economic level?" The answers to

this question may be found as suggestions in this paper. In greater detail they will be found in publications or from organizations listed in subsequent section or from corrosion consultants.

Corrosion protection rarely costs more than a few per cent of the cost of the structure, and can, if the structure is built of ordinary steel, be expected to double or triple its life. It will, therefore, be well worth while for a bridge or similar structure which has a long expected life, but less worth while for a temporary structure. The maintenance engineer's problem is to find out, first of all, the life required for his structure and then to determine the most economic protection to ensure that this life can reasonably be expected.

Let us suppose that the engineer is faced with a construction job that will last two years at most, even if the weather is unfavourable. He has to build a cofferdam in the sea bed to keep out the sea for this maximum of two years. He must first inquire about the useful life of structures made of similar steel driven into the sea bed in his part of the world. It is unlikely that he would find evidence of serious corrosion in less than five years.

If this is found to be so, the maintenance engineer will need to take no further action for corrosion prevention because whatever anti-corrosion measures he takes will be expensive and unnecessary. Evidently this is quite different from the bridge that should last 100 years. The protection of bridges against corrosion must be investigated very early, in fact before they are designed. Final details of corrosion protection do not have to be decided then but the general scheme of protection must be known at an early stage because it may include the use of a special corrosion-resisting steel. The making of this steel has to be arranged with the steelworks; the steelmaker must plan it months ahead, and the remainder of the protection, including metal coating and probably painting may also be affected.

Low-Cost Corrosion Prevention

When the maintenance engineer is in difficulty with a large amount of exposed steelwork to protect and no paint to protect it with, there is one anti-corrosion material that he should remember, Portland cement. It is alkaline and for this reason protects iron and steel from rusting. There are many ways in which a cement-water or cement-sand-water mix can be applied to steel to prevent corrosion at a fraction of the price of paint. One way is to mix enough water with the cement to produce a creamy grout and to coat the steel with this by brushing. It may perhaps be more easily applied and may spread further if fine sand is mixed with the grout. In most countries, the price of cement is about one fiftieth the price of the cheapest paint.

THEORY OF CORROSION

Chemists believe that "wet" corrosion is electrochemical, in other words that it occurs in the presence of an electric currrent flowing between two metals dipping into a solution called the electrolyte, through which the current flows. To make a complete electrical circuit, the current flows from the first metal to the second metal not only through the electrolyte but also from the second metal to the first metal, completing the circuit, through some other conductor, usually metallic. The two metals must be different for corrosion to occur, but from the viewpoint of corrosion it is almost impossible for two parts even of a bar of the same metal not to be different. One will have different impurities from the other, forming in an electrolyte an electrolytic cell as explained above.

"Different" here means "at different levels in the galvanic series". The galvanic series is the sequence of the chemical elements in the order in which they dissolve (corrode) in a particular electrolyte, usually seawater or 3 per cent sodium chloride solution. Those at the top of the list dissolve (corrode) most easily, those at the bottom dissolve least easily and are described as "noble". Gold, graphite and platinum are at the bottom of the list.

The two metals dipping in the electrolyte are called electrodes. The electrode that dissolves (corrodes) is the anode; the other elec-

trode is the cathode, hydrogen is released at it or metal is deposited on it, for example in electroplating. Any metal is anodic to all metals below it in the series and cathodic to all those above it.

The galvanic series shows, theoretically, which metals should be used for the protective plating of other metals. Theoretically, in commercial practice (not in jewellery) no metal should be used for protectively coating any metal above it in the series. Thus, zinc, aluminium and cadmium are anodic to steel in the series and are used for plating it. Nevertheless, tin which is more noble than steel and is therefore below it in the series, is also used quite effectively for the same purpose though for shorter periods of time and in less severe conditions. It is true that once the corrosion of steel in tinplate has started, it continues much faster than in steel coated with zinc or cadmium or aluminium. Nevertheless, for its special purposes in food cans particularly, tinplate is useful.

One instance where two metals should be carefully kept separate is in galvanized steel water tanks. Any pieces of steel or even iron turnings, left in the water tank, will react with the zinc coating and will quickly wear it through.

Zinc or cadmium or aluminium coatings continue to protect a steel surface long after they have worn through and in fact the protection of a zinc coating on steel continues until only 10 per cent of the coating remains. After it has worn through the zinc continues to protect the underlying steel by acting as the anode in an electrolytic cell, and dissolves in preference to the steel. When a tinned surface on steel has been penetrated, the opposite occurs, the steel is dissolved in preference to the tin, and it is therefore destroyed by corrosion more quickly than the zinc-coated steel. This is why it is said that zinc, cadmium and aluminium protect steel "sacrificially".

Cathodic Protection

From 1 to 5 per cent of the cost of a structure is not much to pay for probably doubling or trebling its life, and this is the usual cost of cathodic protection. Cathodic protection is generally not used for small structures because of the appreciable amount of engineering design work connected with it, and this 1 per cent is therefore a considerable sum of money. If possible, therefore, cathodic protection is not used alone but in conjunction with protective coatings or wrappings over the metal. These reduce the area of metal exposed and thus the bulk of the cathodic protection plant and the current required. The current required is between 10 and 150 milliamps per sq metre of exposed metal but usually from 30 to 60 milliamps per sq metre. Naturally this current is applied only to the exposed metal and the protective coating makes a large saving.

In all types of cathodic protection the structure to be protected is made the cathode. Anodes are placed at some distance away from it in the soil or sea or other corroding medium, and are electrically connected to it, usually by cables. The anodes corrode in preference to the cathode. There are two general methods of cathodic protection, the impressed current method and the sacrificial anode method. In both methods the anode dissolves, though more slowly in the impressed current method, where the anodes may be of graphite which is about as noble as gold. As would be expected, a direct current is forced in at the anodes and out at the cathodes. In the sacrificial anode system the anode material is selected from a metal that is anodic to steel (or to the metal to be protected) in the galvanic series. In other words, the anode will quite naturally corrode in preference to the cathode structure.

Part of the Galvanic Series

ANODIC END (easily corroded)	Magnesium
	Zinc
	Aluminium
	Cadmium
	Steel or iron
	Stainless steel 18-8 (active)
	Lead
	Tin
	Nickel (active)
	Copper

	Nickel (passive)
	Stainless steel 18-8 (passive)
CATHODIC END (noble metals)	Silver
	Graphite
	Gold
	Platinum

In the sacrificial anode system the electric current is generated by the electrochemical difference between the two metals, and the main expense is the relatively frequent replacement of the sacrificial anodes. In the impressed current system there is an appreciable expense in the amperage that has to flow permanently through the system, and on large jetties protected in this way a number of power transformers may be needed. The maintenance engineer who considers applying cathdic protection, particularly the use of impressed current, should first make a rough survey of the area of exposed metal. The corrosion engineer who designs the system will need this information to make his estimate. It is important that an experienced corrosion engineer should be employed to design cathodic protection because in a badly designed system the corrosion may be worse than with no protection at all.

An experienced Corrosion engineer should be employed to design cathodic protection because in a badly designed system the corrosion may be worse than no protection at all.

The life of bare steel pipes in soil depends on the electrical conductivity of the soil. The higher the conductivity, the more corrosive is the soil. With low resistance (high conductivity) unprotected pipes could be expected to last only two or three years. Soils with low resistivity values, below 500 ohm/cm are highly corrosive. Mildly corrosive soils have resistivities above 2500 ohm/cm and in such soils pipes could be expected to last 20 years without protection. It should be remembered that a soil's resistivity depends very greatly on its water content, but if a normally dry soil is flooded it will be more corrosive than a similar soil that is normally wet. Dry soils often contain salts that become highly conductive when wet.

Passivation and Anodic Protection

The passivation of iron and steel became known nearly two centuries ago. It was noticed that they would not corrode if they were first boiled in strong nitric acid. The metal was then said to be passive or passivated. Later it was found that chemicals dissolved in water would have the same effect and these were called passivators. Passivity is not very permanent and can be removed from iron by knocking it, but in stainless steel it can be more durable. It is believed to be caused by a stable film of oxide that protects the metal from further corrosion. It can also be induced by passing a current into the metal concerned, in the opposite direction from cathodic protection. In cathodic protection the protected metal is the cathode; in passivation the protected metal is the anode, where ordinarily corrosion would be worst, hence the name anodic protection.

Naturally such a system has to be carefully controlled so as to ensure that the current is not so high that metal is lost to the solution. But an anodically protected plain mild steel tank has been used for containing strong sulphuric acid without serious corrosion. A circular steel tank is a relatively easy application because the cathode can be placed centrally at the same distance from all the walls. For the maintenance engineer working in chemical industry this method can be of interest because there is likely to be a chemist or chemical engineer who will supervise the essential instruments and take the readings needed so as to ensure safe working.

Corrosion inhibitors are regularly used in heating, cooling, hydraulic or refrigerating systems, and in pickling tanks to ensure that the acid attacks the mill scale and not the steel.

Corrosion Inhibitors

Very similar to passivators are corrosion inhibitors. Passivators act on the surface of the corrodible metal, but inhibitors act on the liquid, or on the air, Corrosion inhibitors are well known to users of paint and some of them are also pigments used in primers for iron and steel, for example red lead, calcium plumbate, metallic lead, metallic chromates, and when used in high proportions, metallic zinc. Another corrosion inhibitor known to car users in cold countries is the anti-freeze liquid, ethylene glycol, used in car radiators, but this has been known occasionally to decompose and corrode the radiator.

Some chromate inhibitors are poisonous and most of them are costly. It is, therefore, safer and more economic to use them in a closed (re-circulating) circuit than in a once-through circuit. Normally they are not used in a once-through circuit. All inhibitors for steel act more efficiently in alkaline than in acid solution. In fact, merely making the solution definitely alkaline, at a pH of 8 to 8.5* will appreciably reduce the likelihood of corrosion. The solution should thus always have a pH figure greater than 7, except for chromates which can be used even in slightly acid solution.

"Dangerous" inhibitors are so called because if misused they can cause intense local corrosion. The best inhibitors are dangerous, including sodium benzoate, sodium chromate and sodium nitrite. The corrosion occurs sometimes in the presence of dissolved chloride or sulphate. Every inhibitor should be used at a certain minimum concentration which differs with the environment. One way of eliminating the effect of chlorides or sulphates in the water is to provide a molecular concentration of inhibitor that is 15 times as strong as that of the chloride or sulphate. A common inhibitor for closed systems is sodium at pH 8.0 to 8.5 and at a concentration of 500 grammes per tonne. It kills bacteria including sulphate-reducing bacteria, being toxic. An alternative to sodium chromate is sodium benzoate with a small proportion of sodium nitrite and an appropriate product that kills bacteria but is non-toxic to mammals.

Corrosion inhibitors are regularly used in heating, cooling, hydraulic or refrigerating systems, and in pickling tanks to ensure that the acid attacks the mill scale and not the steel. The steel of the pickling tank itself is usually well protected, for example with 12 mm of sheet rubber, covered with a course of acid-resisting brick.

In cathodic or anodic protection, as well as in the application of corrosion inhibitors, the advice of a corrosion engineer or chemist is needed to ensure that the system is both efficient and safe.

Prevention of Corrosion in Boilers

Another highly technical subject in which the advice of a chemist is needed is the prevention of corrosion in boilers and the equipment connected to them. As with most corrosion troubles, there are several ways of preventing corrosion. Some of them may be used simultaneously, including feedwater treatment outside the bioler, treatment of the water inside the boiler by injection of chemicals with the feedwater, and treatment of the metal in contact with the steam or water. Almost every maintenance engineer will be concerned with a boiler, and some attempt must be made to mention the main points concerned with boiler corrosion, however incompletely.

*The acidity or alkalinity of solutions in water is measured by their hydrogen ion concentration. A neutral solution, one that is neither acid nor alkaline, has a hydrogen ion concentration of 10^{-7}. This is usually expressed by saying that the pH value of the solution is 7; pH larger than 7 indicates an alkaline solution, those smaller than 7 are acid.

xygen and carbon dioxide cause most of the sion of the steel in boilers. Hydrogen ·ide causes corrosion but is not so plenti- as the other two, and ammonia corrodes ›pper and its alloys including brass. In power ·ations, nearly all the steam is condensed to , pumped back into the boiler and re-used. ·is has the great advantage of reducing the ntake of impurities into the boiler. Conden- ; and associated pipework are under vacuum l they must be kept tight so that oxygen ıd carbon dioxide are not allowed to be absor- Some water is lost because of leakage ıd blowdown, roughly 0.5 to 3 per cent of the ·ating volume, and a corresponding volume ; to be pumped in continuously as make-up ıter.

All the make-up water must be treated. Most treatment plants include settling tanks, filters, de-aerators to remove oxygen and reaction chambers where the calcium salts, that produce scale, are precipitated by sodium salts. The sodium salts remain in solution in the boiler and do not cause scale. Scale is not corrosive and in fact protects steel from corrosion but it leads to inefficiency of the boiler and to overheating of the scale-covered steel, which may for this reason suffer high-temperature corrosion.

The total amount of salts in the feedwater is not reduced by this method; the calcium salts are merely replaced by the more soluble sodium salts. It will be obvious that the salts concentration in the boiler quickly builds up. (Modern boilers often have a throughput of 100 tons of steam per hour)

Salts concentrations in boilers must not be allowed to build up above certain levels that are known for each boiler. For boilers at pressures above 140 kg/sq .cm (2000 pounds per sq. inch) the maximum allowable solids are 500 grammes (dissolved) per ton and 5 grammes (suspended) per ton. For low-pressure boilers operating at pressures below 21 kg/sq. cm (300 pounds/sq.inch) the conditions are much easier, 3500 grammes per ton total solids including not more than 300 grammes per ton of suspended matter. These maxima must be kept to and this is the reason for blowing down boiler water. Blowdown removes sludge and dissolved salts and in large boilers is a continuous process.

From the viewpoint of the steel, it is important to keep the water alkaline and this may be done by introducing ammonia as ammonium hydroxide to hold the pH figure of the water at about 8.5. The ammonia reacts with the carbon dioxide and neutralizes it but does not react with the oxygen. All the oxygen must be removed by the de-aerator before the water enters the boiler.

For a high-pressure boiler in use at a site where the natural impurities in the water exceed 500 grammes/ton, it will be necessary to have demineralization equipment in the water treatment, so as to bring the minerals content of the water well below 500 gm/ton. An advantage of the use of ammonia is that it does not increase the impurities content of the water since it is removed with the steam but it attacks brass and copper in the condenser and elsewhere. Another other reagent used for neutralizing carbon dioxide is morpholine, C_4H_9NO, which does not corrode copper or brass but is expensive. Hydrazine hydrate, $N_2H_4H_2O$ or hydrazine phosphate, (N_2H_4) HPO_4 have also been used. They react with dissolved oxygen to form nitrogen and water, and at high temperatures the hydrazine decomposes into ammonia and nitrogen. Many of the boiler reagents in existence are used for other purposes than corrosion prevention, such as the prevention of foaming, but they cannot be discussed here.

Prevention of Corrosion in Idle Boilers

A boiler that is out of use for a short period, say less than two months, is kept corrosion-free by filling it with de-aerated alkaline water under pressure so that if leaks occur they are outwards and oxygen or carbondioxide are thus unlikely to be absorbed. Naturally if there is time the boiler should be cleaned before it is filled. The tightness of the valves and other fittings must be checked. The water must be analysed periodically to make sure that the pH

value and oxygen content are no worse than in normal operation.

For a long outage it may be worthwhile to dry out the boiler. It must be emptied, cleaned and dried out by blowing hot air through it at about 250° C. Steel pans measuring 80x35x15 cm are placed inside it containing a desiccant* such as calcium chloride, quicklime or silica gel spread uniformly over the floor of the pan. The weight of desiccant needed must be calculated from the volume within the boiler that has to be kept dry. It is usually from 1 to 2 kg per cubic metre of volume. The pans must be periodically inspected and their desiccant changed if it is wet or spent. This method is also worth using for plant or pipes in transit since drums and pipes are not usually difficult to seal. For transit packaging the desiccant is usually silica gel in small plastic or textile bags. Calcium chloride would be corrosive.

DESIGN FOR CORROSION RESISTANCE

A great increase of corrosion resistance can be obtained merely by careful attention on the drawing board to the geometrical shape and layout of stanchions, beams, purlins, tanks, reaction vessels and so on. This work must be done on the drawing board, any later stage is too late and this may be one reason why these important anti-corrosion details are so often omitted.

Geometrical Design

Corrosion cannot take place without water and the amount of corrosion depends on the duration of the exposure to water. In the good geometrical design of structures exposed to rain, therefore, all exposed surfaces are smooth and shaped to drain easily. Corners whether internal or external, are rounded. Outside corners are easily knocked and lose paint. Inside corners collect dirt and, therefore, moisture. Sharp outside corners are always difficult to coat with paint or protective metal and form the starting points for rusting. This is because wet paint naturally forms a rounded surface and the paint thickness on a corner is, therefore, much less than on a flat smoothly rounded surface (see 'stripe coat' under the heading Application of Paint).

All this implies that the ideal structural section for corrosion resistance is the cylinder the tube of round cross-section. This is but round tubes are a little more to weld than rectangular-section tubes because the roundness makes for curved weld lines. Rectangular tubes can be joined by straight line welds. Their corners are rounded iinside and out, and to prevent corrosion inside they merely need to be sealed, like round tubes, by welding a plate over the end. Such tubes are now available in long lengths, up to about 13.5 metres. Tubular sections, whether round or rectangular, have a much smaller external area to be painted than joist or channel or angle sections of comparable strength. Unfortunately they are more expensive than joists of the same beam strength, i.e. they have less beam strength for the same weight per unit length.

Joists, angles, channel or tee sections all have internal corners where dirt can collect and absorb moisture that causes corrosion. Angle or channel sections, however, have the advantage that if placed with their hollow side down, they have a well drained upper surface and are unlikely to corrode fast.

If drainage is important for structural sections it is even more so for pipe runs and tanks because they should be dried out and cleaned periodically. Small tanks must be built with the bottom sloping towards a drain cock. Large tanks must be built sloping to a sump that must be accessible for emptying. There must be no place where liquid can collect and not be removed. When it is unavoidable to use different metals in the same system, the flow of water should be from the anodic metals in the system towards the cathodic metals, for example from zinc or aluminium to iron.

The undersides of tanks can form typical crevices where corrosion can start. The best way to avoid crevice corrosion underneath a metal tank is to lift it well clear of the floor so that the space beneath is at least large enough

*A desiccant is a drying agent, a substance that absorbs water from the air.

to crawl under and inspect it. This
that the floor should be lowered.
is to remain for some years the ex-
lowering the floor should be worth
saddle or pad of metal should be
the underside of the tank where it is
1. On this pad is welded a brac-
ch the stanchion is bolted. In the
stanchions it should not be forgo-
should be shorter at the end con-
rain cock because the tank must
ard this end.

Steels

on of welds should be avoided; but in
weld metals should preferably be
than the basis metal. Where stain-
expensive corrosion-resisting steel
to carbon steel, it is wise to weld first
joint area a stainless steel weld pad
the carbon steel is later welded. If
steel is welded directly on to the
steel, the stainless steel is likely to be
the weld, and corrosion will probably
The designer must specify the
(welding electrodes) and the type
so as to ensure that the welds are cor-
ıt. The welder should not have
such decisions himself. On one occa-
a welder had to choose the filler
welding an aluminium storage tank
ı nitric acid, the tank had to be re-
all the joints began to leak.
had not been fully specified and the
chosen the wrong filler metal.

ded welding processes make
welds with fewer slag inclusions than
metal-arc welding processes. Tanks
acid are likely to fail at slag inclusions.

steel, particularly for tanks con-
acid, must be protected against attack
grain. Properly heat-treated austeni-
steel has good resistance to nitric

steels have excellent corrosion resistance
are several different types, the most cor-
being described as austenitic. These
resist high temperatures since they do not
temperatures below 850°C.

Corrosion cannot take place without water and the amount of corrosion depends on the duration of the exposure to water.

acid on its rolled surface. Generally this is the only surface that is exposed but at welds any leak can expose end grain and corrode the plate as a whole. It is, therefore, vital that welds shall be made absolutely leak-proof. An upright plate that has to be welded to a horizontal plate must be bevelled on both edges before welding, so as to make a full-penetration weld. If the edges of the plate are not bevelled, the weld is likely to be porous and to leak and thus to allow end-grain attack. Full penetration welds of this type have been watertight and acid-proof for years.

Proper heat treatment of joints after welding also helps to increase the corrosion resistance of carbon steel to nitrate solutions for example. The advice of a metallurgist is needed for the proper temperature, duration and type of heat treatment.

Water Treatment

The treatment of boiler water to prevent corrosion in the boiler was discussed under Theory of Crrossion. Similar problems are met with in process water. In every works the water used is likely to be corrosive and should be analysed so that a chemist can determine how its corrosiveness can be simply and cheaply reduced. The carbonate balance can be controlled, for example, so that a film of carbonate is laid on to metal in contact with the water, to protect the metal. The acidity or pH of the water can be adjusted and the pH value should be kept above 7. The oxygen content of the water can be reduced. If there are no suitable salts in solution to deposit a protective film on metal in

contact with the water, a content of sodium silicate amounting to only 20 to 30 parts per million in the water will start the formation of a protective film. After the film has begun to be formed the content can be reduced to 4 parts per million. Other additives such as water glass or sodium phosphate or sodium metaphosphate can also be used to prevent corrosion but always with the advice of a chemist or corrosion engineer.

Pipe Corrosion

Corrosion in pipes may be caused partly by the high speed of the liquid flowing through them. If pipes need replacing too often, it is advisable to try replacing them with pipes of larger diameter, In this report there is no space for discussing pipe-flow formulae and in any case they do not take corrosion into consideration. The maximum pipe velocity should, if possible, be kept down to a reasonable level, say below 2 metres/second, particularly for acid or alkaline liquids.

If pipe corrosion is troublesome and speeds cannot be reduced, an effort should be made to reduce the temperature of the flowing liquid. This is usually not possible, but hot spots can and must be avoided. They are the places where corrosion usually starts. A heating coil should be at or near the centre of a vessel. A metal flue should not be allowed to have flue gases that are so cool that moisture condenses in it. Damp flue gas is one of the most corrosive fluids in existence, particularly if there is sulphur in the fuel, and, therefore, sulphur dioxide in the flue gas.

Location of the Factory

The location of a works is important in anti-corrosion design though it is usually not possible for the maintenance engineer to change it. Sites to which acid fumes or other smoke are brought by the prevailing wind must be avoided and, of course, the choice of process water is important. The annual penetration by corrosion into steel left unprotected in the open in the UK is usually not below 0.025 mm (0.001 inch) and the loss of thickness on two surfaces will, of course, be double of this. Worse losses can be suffered without disas but these figures do show the need for some sort of protective coating to steel in an industrial environment. One company, however, set a figure of 0.075 mm (0.003 inch) annual loss in pipe wall thickness as the design maximum for pipes carrying 99.6 per cent sulphuric acid in 145°C. Many industrial sites do suffer even worse corrosion rates for bare steel exposed to the weather, as pointed out earlier.

Crevice Corrosion

One of the commonest locations for corrosion is in crevices in tanks or in structures of steel or other metals. Riveted joints that have not been caulked, or lap welds that have not been sealed by a double fillet can collect moisture and will corrode fast. If the crevices cannot be sealed by welding or caulking, they can be filled with one of the fillers used by decorators or by a mastic sealer. Moisture is sucked in to unsealed narrow gaps of this sort by capillary action*. Because such water cannot be removed except by boiling, it is certain to cause corrosion. The design of the welds is important, double butt welds should always be used if possible. If lap welds are used they should be double, in other words, welded on both sides.

That crevice corrosion is not caused only by capillarity is proved by the fact that it happens also under water where capillarity cannot exist. Even when an effective corrosion inhibitor is used in the correct proportions in the liquid, its protection usually does not extend to crevices unless additional stirring is used and even this is not usually successful.

An example of the elimination of crevice corrosion is given by the Corrosion Advice Bureau of the British Iron and Steel Research Association (BISRA) in connexion with the re-design of mild steel pit tubs used for carrying coal out of British coal mines. The roun-

*The rise of oil or other fluid up a wick, or of any fluid up a thin tube, or the use of blotting paper are all examples of capillarity which is the sucking of fluids into narrow spaces, often against gravity.

ding of the bottom corners of the tubs (elimination of crevices) without changing the steel, increased the tub life by 30 to 50 per cent. After the re-shaping of the tubs, investigations were continued into the use of materials with better corrosion resistance.

The original mild steel tubs without galvanizing or other surface protection lasted only six years, resulting in an annual cost of around $11. Using bare Cor-ten copper-bearing steel, the total cost was increased by $2.4 or 4 per cent but the tub life was increased to eight or ten years, thus reducing the annual cost to $7. With galvanized mild steel the total cost compared with bare mild steel was increased by $10 or some 17 per cent, but the life was increased to 12 or 15 years, thus reducing the annual cost per tub to about $6. With galvanized Cor-ten steel the total cost compared with bare mild steel was some 21 per cent more but to only $4.5, less than half the annual cost of the original tubs.

Different Metals in Contact

Care must be taken when different metals are in contact with the same liquid. The introduction of copper water pipes into British houses that had previously had only galvanized steel pipes connected to steel tanks galvanized many years before, resulted in many leaking tanks that had to be replaced. Whether copper pipes are used or not, the inside of galvanized tanks must be carefully cleaned before the tanks are filled. Bits of iron or steel will speed up the corrosion of the zinc.

A stainless-steel cooler was surrounded by cooling brine in a carbon steel tank. The carbon steel tank was protected by an excellent anti-corrosive paint of epoxy resin but this was soon pierced by a galvanic current from the stainless steel, which probably started at pinholes through the epoxy paint. The corrosion "drilled" so many holes right through the carbon steel that the owners suspected sabotage. It would have been much too costly to change the outer tank for one made of stainless steel or some other noble metal so the design was improved by painting the stainless-steel sufrace that was in contact with the brine. This reduced the area of cathode and the rate of corrosion in proportion. Such holes, apparently drilled, are typical of pitting corrosion.

The same principle applies to different metals that are in contact in air. If the contact cannot be avoided, it may be possible to separate them by insulating washers, with an insulating sleeve round the bolt. But the insulating material also must be carefully chosen. A moist insulator is always more corrosive than a dry one and possibly more corrosive than none at all. The insulation material should be one that does not absorb water, or if it does, it should be tested wet to see whether it still protects against corrosion. Most plastics are both insulating and do not absorb water, like nylon. A simple test is to wet the insulator and then to test its electrical resistance, after its outer surface has been dried. If the resistance is less than it was in the dry state, the material has almost certainly absorbed water. Another, perhaps simpler, test is to weigh the material before and after soaking. An increase in weight, after surplus water has been dried off, almost certainly indicates that water has been absorbed.

In connexion with crevice corrosion and the use of different metals in contact, the Society of American Engineers' Committee on the Prevention of Corrosion in Iron and Steel recommends that joints should be completely sealed with mastic sealers to prevent the entry of moisture or air. This applies particuarly to welded joints. Different metals, the committee says, should not be used in contact with each other but if they are, a large anode area (aluminium, cadmium, zinc) should be used in conjunction with a small cathode area (steel). The steel should preferably be coated with protective metal. The joint should be insulated, with protective coating on both sections, especially on the steel side and with good ventilation and drainage. Gamma-ray or infra-red inspection is convenient and enables breakdowns to be avoided by detection of corrosion damage at the start when it is limited and replacement is easy.

In this connection it is worth relating an incident of unexpectedly fast corrosion of aluminium alloy pipe in a circuit connected to steel pipe. Flooding of oil wells that have finished their productive life is relatively common in many oilfields. The water injected into the "empty" well drives the oil to neighbouring wells and increases their output. It is desirable to keep oxygen out of the water so as to decrease corrosion of the steel tubes both in the well and out of it. One source of oxygen-free water is that found in deep wells, which unfortunately is often salty, particularly in the oilfields of the Gulf of Mexico. The oxygen can be kept out of the water when it has been pumped out of the well by keeping circuits closed and sealed and by covering open surfaces with a layer of oil.

For one offshore well on the Gulf coast, a source of oxygen-free water was avilable that contained 10 per cent salt. It was considered safe to use aluminium alloy pipe with a protective inner lining 0.25 mm (0.01 inch) thick, made of aluminium containg 2.5 per cent zinc. At the first inspection, however, a rusty, metallic-looking deposit which was electrically conducting in places, was found inside the pipe. When sections of the pipe had been cut through it was found that the inner protective layer had been completely replaced by the rust in only nine weeks of use. The 500 metres of pipe had to be scrapped and replaced by plastic pipe in spite of the risks of damage to the plastic on the sea bed.

It would be unfair not to follow such a story with others that have a happier ending. Corrosion at British sea porst is severe, and for many years British Rail have been fighting it at Harwich. Boats from here take trains across to the Continent and back. The bridge connecting the ships to the shore, over which the trains must pass, includes a number of beams that must move relatively to stanchions that are only 3 mm away from them. Rust had filled this space and locked some of the beams so that they could not move. The rust was removed without much difficulty, merely by hacksawing it through. And to insure that the rust did not return was also relatively little work but specialist advice was needed and a preventive maintenance plan had to be started. The stanchions were drilled at a number of points and fitted with grease nipples to enable a heavy-duty grease to be forced in. The particular grease chosen emits an anti-corrosive vapour so that points not reached by the grease do not start to rust.

Corroded gas tanks of sewage sludge digestion tanks at Mauchline, Ayrshire, Scotland were recently saved by a plastics coating and patching treatment that proved less costly than repairs with metal or metal coating. The inner surfaces of the tanks were grit-blasted to remove rust. During the grit-blasting some small holes were made in the tank walls. These holes were patched with fibre glass and resin. The protective coating was a zinc-rich primer followed by two brushed coats of solvent-based epoxy resin, providing a film 0.25 mm (0.01 inch) thick. The film is claimed to have high resistance to abrasion and chemical attack, including dilute mineral acids, alkalis, vegetable and mineral oils, greases, soaps and so on.

It is worth describing here the common measures now used in the UK to prevent the chimney corrosion caused by the burning of sulphurous fuels, particularly oil fuel, now becoming increasingly popular. Chimneys are corroded by acid condensates that attack their inner lining. The only way to prevent this corrosion is to keep the gas warm enough to prevent condensation within the chimney. (Preliminary removal of sulphur from oil or coal would be prohibitively expensive).

Within a chimney, the dewpoint of water is about 60°C (140°F) but it is more important to know the temperature at which the acid gases, sulphur dioxide and sulphur trioxide, condense, which is between 115° and 135°C (240° to 280°F). The flue gases can be kept warm either by raising the temperature at which they leave the boiler, which is thermally inefficient, wasting heat and therefore money, or by raising the temperature at which they leave the chimney. This is achieved by insulating the chimney.

In dwelling houses a common way is to line the brick chimney with a plastic tube that has

a smaller cross-section than the brickwork and, therefore, keeps the flue gases warmer and increases the flue gas flow rate. Both of these tendencies together reduce condensation within the chimney but even if it does occur, the plastic lining does not corrode. In industry, chimneys are often made of steel and another method is common. An inner shell of thinner steel is erected within the outer structural steel chimney tube. The ring-shaped gap between them is filled with glass wool or other suitable insulation. The gap must be wide enough for the insulation needed. If the exit temperature of flue gases is not above 135°C, there is a chance that the point at which acid begins to condense will merely be moved higher up the chimney and the situation may be no better than without insulation. In fact it may be worse, since the condensate can drip down along a greater length of the chimney walls than previously, thus exposing more of them to corrosion.

PROTECTIVE COATINGS : PAINT

This section deals with the painting of iron and steel and the metal coatings on them. The prevention of corrosion of other metals is not discussed, mainly because of shortage of space, but they corrode less than steel or iron.

Surface Preparation

Before painting starts, the surface to be painted must be so cleaned that the paint will stick to it. For rolled steel, plates, sheets, beams, channel and angle sections and so on, this means removing all mill scale, the black skin of oxide formed in the rolling mill. Casting scale, the skin formed with the sand on the surface of a casting made in a sand mould, does not need to be removed so long as it is tightly held, because it continues to protect the casting after it has been covered with paint. But mill scale does not. If painted over, it will lift and destroy the paint in a very few years.

Proper surface preparation is more important than anything else for the success of a protective coating, whether the coating is paint or plastic or metal. A few modern, quite exceptional paints can be put on to damp or even moderately

Proper surface preparation is more important than anything else for the success of a protective coating, whether the coating is paint or plastic.

rusty surfaces but they are unusual. The best method of preparation generally is blast cleaning (shot-or grit-blasting), followed in effectiveness by pickling, flame cleaning and wire brushing, and lastly hand cleaning, the most inefficient and expensive method, even with power tools.

Pickling, the soaking of steel members in acid, to remove scale and rust, was formerly used much more than now. It has fallen into disfavour because it is a wet process and it is difficult to avoid a thin film of rust forming on the steel as it dries. In new installations, pickling (always preceded by de-greasing) is now used chiefly for cleaning thin material. Sheet metal or thin plate below about 2 mm thick cannot be blast cleaned because it becomes dented by the impact of the grit or shot.

A disadvantage of flame cleaning is that the steelwork is usually left to weather in the open for about a year, so that slight rusting shall lift the mill scale from the surface of the steel. Flame cleaning must be followed by wire brushing to remove the broken scale. Unfortunately the wire brush cannot remove all the rust, nor will it remove tightly held scale. A further difficulty with wire brushing is that it may be done on an erected steel framework, with all the obstacles to good work that height above ground can bring.

Whichever method is used for preparing the surface, it should be followed as soon as possible, preferably within four hours, by a first coat of protective metal or a priming or pretreatment

coat. A well prepared iron or steel surface is in an extremely sensitive condition. It begins to rust as soon as it has been cleaned, and this rusting must be stopped as soon as possible by the first surface treatment. One of the treatments that precedes priming is adequate, for example phosphating or etch priming.

Impact Cleaning

It was established some years ago that impact cleaning (blast cleaning) methods were the best surface preparation for iron and steel. Hand cleaning is not only slow but very inefficient and expensive in labour. Even power-operated hand tools, such as vibrating needles, wire brushes and so on are less effective than impact cleaning. These power tools have the disadvantage that if they do remove all the scale and dirt the surface of the metal is likely to be polished and it may be difficult for modern paints to stick to it.

Impact cleaning is the throwing of hard particles of metal or mineral against the dirty surface so as to remove all scale and rust down to bare metal. In one method the abrasive is thrown by a jet of compressed air or water under pressure; in the other method no air or water is used and the shot or grit is thrown by an impeller wheel. In the United Kingdom, since 1949, it has been forbidden to use sand or other mineral grit containing free silica because of the danger to the health of the men who breathe the silica dust. In Britain, at least, it is therefore no longer correct to speak of sand blasting.

If the operator has to work in the enclosure containing the blast-cleaning machine, he must be provided with protective clothing that covers him completely, including a hood with an independent air supply, so that he does not breathe the dust. Zinc or aluminium dust can be highly inflammable and lead pigments removed from old paint are poisonous to breathe.

Good modern practice is to clean plates or sections at the mill where they are rolled, by impeller blasting with shot, commonly of cast steel. Shot blasting has the advantage that dirt can be easily separated from the shot. The shot, if used in a plant where it can be recovered, can be of high grade, of regular size and shape, ensuring that the metal surface is not excessively roughened. Cleaning of steel at the rolling mill is, of course, a factory process and better work can be done at the factory than in the shipyard or on the building site.

Similarly, if the prefabrication primer is applied in the rolling mill, it will probably be applied in better conditions than would be possible elsewhere. The prefabrication primer immediately follows the blast cleaning and must be one that is compatible with the welding or other processes that are to be used on the steel. If the steelmaker is told what fabrication processes are to follow his primer, he will ensure that the primer will suit them. Whether welding is manual or automatic, excellent results can be obtained with the right primer applied in the right quantity. Most of these primers will protect the steel for six weeks; others such as zinc dust primer in epoxy resin, for six months.

Since hull corrosion can increase a ship's power requirements by 20 per cent, it is understandable that shipyards were among the first large-scale users of impact cleaning for steel plate. The shipbuilders understood that the most important single process in protecting steel is the preparation of the surface before painting. A carefully thought out paint system, on a well prepared modern steel bridge, generally has some eight years of life. Exceptionally it may go to 20 years. Such schemes cost more than conventional painting because they include metal spraying under the paint, but the cost of painting the bridge for its first 50 years is expected to be halved.

To prevent corrosion of the steel of the new Severn Road Bridge in the west of England, the de-icing material is not salt but a mixture of urea with sand. It is more expensive than salt but is no more corrosive than tap water. Since the function of a de-icing chemical is merely to lower the freezing point of the water, and this can be done by any chemical with a high solubility in water, the search for a non-corrosive, low-cost de-icing material for roads in frosty countries is continuing. The serious

corrosion on car bodies should thereby be reduced.

A blast-cleaned surface must be adequate in two ways. It must be clean enough and must be rough enough, but not too rough. Two British standard grades of cleanliness have been accepted, the first grade being unnecessarily high and expensive for many types of steelwork. The first quality finish, "white metal", is clean metal roughened by blast cleaning everywhere. Its cost is roughly double the cost of the second best surface in which only 90 per cent of the area needs to be clean metal but no single area of 6.25 sq cm (1 sq inch) may contain more than 20 per cent of its area discoloured by continuous scale, rust, old paint, or other dirt. The surface finish to be provided must be agreed between the contractor and the maintenance engineer. A Swedish standard for surface finish of steel was one of the first published standards of this type and its diagrams of the grades required are interesting. The British standard (BS 4232: 1967)* also has diagrams showing the grades.

Anchor Pattern

The roughness or "anchor pattern" of an impact-cleaned surface is particularly important when the surface is to be protected with modern fast-drying, high-build paints. These often have a lower wetting power than conventional paints and may, therefore, stick less well. The roughness of a surface can be measured by the height of the peaks. Peaks are always covered with less paint than valleys and they, therefore, begin to rust first. Shipbuilders regard peaks of 0.075 mm (0.003 inch) as not excessively high for surface specified to be 90 per cent clean, provided that the absolute maximum peak heights are not more than 0.1 mm (0.004 inch). It is better for the anchor pattern to be too smooth than too rough.

Grit size is important. Research by a shipowner (Shell) into the use of blasting grits of various sizes for the treatment of ships' rusted plate has shown that only a very small percentage of oversize grit (0.05 per cent by weight) will produce peaks that are much too high. Shot-blasted plates or sections do not have high peaks because the shot is of uniform size and clean. Good practice is, therefore, to shot-blast at the rolling mill. The results of the Shell research showed that the grit should be accurately sized from 0·2 to 1.0 mm (0.008 to 0.04 inch), a much smaller size than was previously thought correct.

Air pressure is important, though perhaps more to the blasting contractor than to the owner of the steelwork, because a drop in air pressure below 6 kg/sq. cm (80 pounds/sq. inch) greatly reduces the efficiency of the blast and increases the time taken to clean the steel as well as the grit consumption per square metre. Pressure at the nozzle should therefore preferably not fall below 7 kg/sq cm (100 pounds/sq inch) and never below 6 kg/sq cm. This means that the pressure at the compressor should be at least 20 per cent more than at the nozzle, possibly 50 per cent more if the compressor is far from the nozzle. Nozzle operators should be provided with a pressure gauge to fit on to the hose so that they can check the actual nozzle pressure. Below 6 kg/sq cm, blasting should be frobidden except when a low-grade finish only is demanded.

Blast-cleaning plant is expensive and so is grit. Expensive plant of this sort deserves to be protected at least with a shed to keep the rain off, and all blast cleaning should be carefully planned and supervised, as the serious engineering operation that it is. Accurately sized grit is more expensive per ton but more economical to use because it cleans the steel better and faster than badly sized grit with a high proportion of dust.

Pre-priming Coats

Painting, including priming, can be preceded by a number of rust-inhibiting or temporary protective coatings, one of which is phosphating. The five types of phosphating accepted in the UK are described in BS 3189: 1959, which gives general details of treatments including those for creviced components. Other temporary protectives against corrosion are

*BS—British Standard. The numbers before the colon are the distinguishing number of the publication. The numbers after the colon are the date of its appearance.

described in the Packaging Code, BS 1133: Section 0:1966. The 118 pages of Section 6 list ten types of temporary protection of metal surfaces against corrosion, divided broadly into the two classes of films and corrosion inhibitors. They are regarded as "temporary" protectives because they can easily be removed from the metal. If not removed they should give protection for an indefinite length of time. Some of the film types can be sprayed on from a pressurized container and do not interfere with subsequent welding. Other films are thick, hard and described as strippable because they can be readily torn off. One particularly interesting type of film dries slowly and is described as "water-displacing" because it can safely be applied to a wet surface.

Corrosion Inhibitors

The corrosion inhibitor types are usually not films but greases or oils applied by dipping or brushing or smearing, or (for engine hydraulic systems) by circulating through the system to be protected. Another interesting corrosion inhibitor (contact inhibitor) gives off a vapour which inhibits corrosion on metal surfaces near it in air. Such methods of pre-treating steel or iron parts are more applicable to small pieces than to the considerably larger members found in building or bridge structures.

Contact inhibitors have several uses. They can be used dry or dissolved in water, for example in industrial or domestic or automobile cooling systems to prevent rust. Boiler water was discussed under Theory of Corrosion. In packaging they are held undissolved on the waxed wrapping paper in contact with the surface to be protected. Some contact inhibitors are sodium benzoate, sodium nitrite and sodium carbonate for steel; soluble chromates may also be used but they are slightly poisonous and may irritate the human skin. Some of these substances need the free access of air so as to be effective in preventing corrosion.

A further help in preventing the corrosion of packaged steel parts is to wrap them in watertight and preferably airtight plastic film and to leave packets of desiccant in the film, that will maintain the relative humidity of the air below 50 per cent. At this relative humidity, rusting is very slow and the growth of moulds is also unlikely, however hot the weather may be. Rusting, in fact, does not become serious until well above 60 per cent relative humidity. The desiccants used are silica gel, activated alumina or some activated clays. The amount of water that desiccants can absorb is usually less than 27 per cent of the dry weight of the desiccant. The packaging should be as airtight as possible so as to reduce the bulk of the desiccant needed to maintain a low relative humidity within the package.

For structural steelwork like a bridge, that has to stand for 100 years or so, the painting should be preceded by metal coating of the steel, whether in the works by hot-dip galvanizing or on the site by spraying with aluminium or zinc. Metal coatings are expensive and unless thick they are also porous but they do greatly increase the protection given by the paint put on the structure and their rough surface is a good ground for paint.

Many paints will not stick to fresh zinc, whether galvanized or sprayed, but pretreatment primers usually overcome this difficulty and they also dry within a few minutes. The original pretreatment or etch primers, still used, consist of a dispersion of a zinc chrome in an alcoholic solution of polyvinylbutyral resin; or of an alcoholic solution of phosphoric acid. Generally the coat is thin and must be followed as soon as possible by an ordinary primer and a full paint system. Etch primers are also used on bare blast-cleaned steel to help the primer stick to the metal, and to give it immediate protection. Prefabrication primers have a very similar purpose, for protection during the period of fabrication.

Primer, Undercoat and Top Coat

A conventional paint system usuallyh as three coats, the primer, the undercoat and the top coat, often more than one coat of each. The primer or priming coat is the first coat and is usually put on by brush unless the surface is in first class condition. Brushing pushes the primer into every crevice of the metal and

protects it better; ordinarily the primer is followed at least by an undercoat to give colour and a top coat to give gloss. The main function of the pimer is to hold to the metal and to stick to the undercoat that is put on over it. The undercoat has to provide thickness, colour, opacity and a good ground for the top coat while filling small depressions in the primed surface. The finishing coat or top coat has to stick to the undercoat and to provide good colour and gloss, though much of the colour may be provided by the undercoat shining through it. Usually a paint with high gloss is relatively translucent and the bulk of the colour must therefore come from the undercoat. The gloss is also protective because rain flows off it easily. When the gloss has disappeared it is usually wise to plan the repainting.

Airless Spraying

An exception to the rule about brush application of primers is the airless-spray method of priming ships' hulls. To enable the paint to flow it is often applied hot, at temperatures from 71° to 99°C. Airless spraying is done at higher pressures and velocities than compressed-air spraying of paint. The gun throws the primer on to the metal at high speed, enabling it to penetrate the surface as it should. Because there is no compressed air there is no rebound of the paint from the surface and the work is healthier for the painter than spraying with compressed air.

To achieve good atomization, high pressures of 200 kg/sq cm are best. The nozzle bore must then be small and consequently the paint must be uniform and free of bits larger than say 0.1 mm. The nozzle diameter must be watched for signs of wear. Quite small wear and consequent increase of nozzle bore will reduce the velocity disproportionately for the same consumption of paint per hour and the paint also is less well atomized. Plant for airless spraying is expensive, as will be realized from the pressures used, but for the large areas of paint on ships' hulls the method can be profitable.

For a structural steelwork that has, like a bridge, to stand for 100 years or so, the painting should be preceded by metal coating of steel by hot-dip galvanising or spraying with aluminium or zinc.

Compatibility

Every paint system, to be successful, must be thought out as a whole and discussed with the paint manufacturer or the painting contractor. If this has been done, the protection given by any paint system is proportional to its thickness, provided that the steel has been shot-blasted or grit-blasted and that all the work is done to specification.

It is necessary to discuss the paint system with the paint maker because it is all-important that paints in the same system shall be compatible with each other. Compatible paints blend perfectly and look well. Incompatible paints may react chemically with each other in an undesirable way, or the upper coat may dissolve and lift the lower coat or may be slow to dry. There are many possible results of incompatibility and all are undesirable. Usually all the paints of one type from one maker are compatible. Therefore the simplest way of ensuring compatibility is to discuss the job with one paint maker and to use only his paint.

High Build Paints

Apart from the many types of purely decorative paint, there are three types of protective paint applied to metal. The first and oldest type is oil-based paint containing linseed oil, that dries by reacting with the oxygen in the air. Secondly there are the newer paints that

harden by many different chemical processes, including many "two-pack" paints that do not react with air, and thirdly those paints that dry wholly or mainly by the evaporation of solvent and without chemical action.

The most interesting paints for corrosion prevention are found in the last two classes. The maximum thickness of paint that can be put on in one coat of the old oil-based paints is about 0.025 mm (0.001 inch), which means that much work is needed to achieve a thick system and, therefore, good protection. Specially formulated paints of chlorinated rubber can be applied at a thickness of 0.1 mm per coat or a total thickness of 0.2 mm for two coats with primer. One such paint was successfully applied to damp and rusty steel sheet piling in Belfast Dock, Northern Ireland. A minor disadvantage is that it must be applied by airless spray because it dries by evaporation of its solvent alone. Brushing a second coat over the first would soften and disturb the lower coat. Some advantages of using the airless spray, apart from the greater thickness per coat are that the method is healthier for the painter than compressed air spraying and there is less paint lost by rebound. The advantages of applications of great thickness are that labour charges are greatly reduced and the time taken to do the painting also is smaller.

Two general rules for painting that are broken by this chlorinated rubber paint are that paints hould neither be put on in damp air (at relative humidities above 85 per cent) nor on to a damp surface. Both these rules were broken together. The sheet piling was, however, protected during painting by scaffolding with sheets hung over it, and warmed with propane gas warm-air heaters inside the sheeting. Excess water was wiped off the piling some hours before the paint was applied.

Paints that allow such large thicknesses to be applied in one coat are called high-build paints. In a chemical works with highly corrosive conditions, the steelwork and operating units were painted with two coats of red lead graphite primer, followed by two coats of epoxy resin paint, giving a total thickness of 0.25 to 0.37 mm. Epoxy resin paints can, however, be applied by airless spray in one coat 0.37 mm thick.

Epoxy resins, in the last ten years, have also been combined with an old material, coal-tar pitch, that can be applied in coats 0.12 mm thick. Many other high-build paints exist and even more are being developed, and will come into being as the labour costs of painting increase still further. (In the section on Plastics, some other high-build linings are described.)

Application of Paint

Paints generally should never be put on at any temperature below 4°C (40°F) and they dry and harden better as the temperature rises. Condensation of moisture (dew or frost) is likely at these low temperatures and this moisture damages wet paint. Since paint dries and hardens slowly at low temperatures, its period of vulnerability at these temperatures is long. The danger to the paint, therefore, increases as the temperature falls. In any case, the maker's instructions about the method of application should be followed.

Paint systems break down most easily at nuts, bolts, rivets, edges and other projections and in crevices. The paint is always thinner on outer edges because it tends to form a surface that is rounded outside. It is, therefore, accepted good practice to give an extra coat of priming paint to these areas. The paint has a slightly different amount or type of pigment from the first primer and so is called a stripe coat.

Because black bolts and their nuts need so much more surface preparation and because this is difficult to achieve once they have been fixed, they should not be used as permanent fixings. Other types of bolt should be used, that already have surfaces prepared for painting, for example by sherardizing or galvanizing.

PROTECTIVE COATINGS OTHER THAN PAINT

Paint is still the commonest type of protection for corrodible metal, but although paint

sales continue to rise, other methods of protection are also gaining in importance. Metals can be protected by coating them with plastics or other metals. Electroplating has been in use for many years, but it is a factory process and it is only since about 1920 that an outside process, metal spraying, has been available for use on building sites, in shipyards and elsewhere in the open air.

In plating, the metal to be protected is submerged in a solution of a salt of the metal to be used for coating. An electric current is passed through the solution which is therefore called an electrolyte. The current enters and leaves the solution by two plates called electrodes. One of these, the anode, loses metal into the salt solution, the other, the cathode is the object to be plated and acquires a corresponding amount of metal from the solution, brought by the electric current.

Plating is not practicable on a building site, partly because of the large size of the vats to contain the electrolyte, the cleanliness needed and so on. Other techniques for applying protective coatings include many methods of phosphating, some of which may be applied outisde the factory. Phosphating is a treatment usually in a hot solution of phosphoric acid with metal phosphates, slightly etching the metal surface and forming a rust-inhibiting coat on it. It is a pretreatment and inhibiting coat and must be followed by a full paint system including primer. Bonderizing, Coslettizing, Jenolizing, Parkerizing and Walterizing are all phosphating methods.

Metal coating includes many processes, some of which are becoming increasingly important. The oldest method, invented more than 200 years ago in France but now in full commercial use for at least a century, involves dipping iron or steel in molten zinc. Although called hot-dip galvanizing, there is nothing galvanic about the process and the name is misleading. The process by which it protects the steel is, however, galvanic, and is explained under Theory of Corrosion. Of the other important metal-coating processes, metal spraying can be done anywhere, but electroless plating (chemical plating) and electroplating are factory processes.

Another factory process for zinc coating is sherardizing, tumbling small articles in a heated barrel with zinc dust. Galvanizing is suitable for large or small articles but steel girders may often be too large. In sherardizing, the zinc forms an alloy with the iron and is not a mere coating.

In galvanizing, the zinc is usually a mere skin, only sometimes alloyed with the iron.

Metallizing or metal spraying has been developed mainly for spraying zinc or aluminium but other metals can be sprayed, including nickel, chromium, copper, cadmium, tin or their alloys. Any metal coating protects the underlying surface if it completely envelopes it. Since sprayed metal is rough, it does not completely seal the underlying surface until the thickness is about 0.075 mm (0.003 inch). This is also a common thickness for hot-dip galvanizing. Even when they are worn through, coatings of zinc, aluminium or cadmium continue to protect iron or steel by acting as anodes and dissolving in preference to the iron. Galvanizing is generally the most economical way of metal coating and is therefore usual for low-cost articles with a short life, such as motor-car parts.

In specifying a metal coating it is important to state the thickness of the metal coating required and whether the surface is to be ground and polished after application. Grinding and polishing will greatly improve the finish but will also make it more expensive though a gloss on the paint will be obtained more easily. The unground, rough sprayed metal is, however, a good base for paint.

Tinplate and Terne Plate

In many ways the most interesting of all metal coatings is tin. It can be applied like zinc, not only by dipping in the molten metal (hot tinning) or by electroplating or metal

spraying, but also by the tinsmith's and plumber's method of wiping. Peeling or scaling of the coating is practically unknown. Because tin is a valuable metal there is a tendency to reduce the thickness of the coating on tinplate below the smallest thickness possible with hot tinning. The thinnest coatings are not applied by hot tinning but electrolytically. Although the first commercial electrolytic tinning line was built as recently as 1937, 70 per cent of the world's tinplate is now made by electroplating and only 30 per cent by hot tinning.

Terne plate is less decorative than tinplate but has excellent corrosion resistance. It is steel sheet coated with an alloy that is mainly lead, with about 10 per cent tin to make it stick to the steel. It has wide industrial uses in roofing sheet, automobile petrol tanks and so on.

The steel in modern tinplate can be exceedingly thin. A common thickness for the steel in the modern food can is 0.12 mm or 0.005 inch. Previous to about 1950 the thinnest sheet was 0.25 mm or 0.01 inch.

Tinplate is a surprising material. It would not be expected to contain food without serious corrosion because the tin coating is so porous and thin (often 0.0004 mm or 0.000015 inch) that a piece of tinplate left in the rain will rust immediately. Tin also is more noble than iron and cannot be expected to protect it sacrificially in the way that zinc protects iron. Luckily this relationship is reversed by the juices of many canned foods so that iron then becomes more noble than tin and can be protected by it. Rusting also is made unlikely by the absence of oxygen in the can and by the fact that many modern food cans are lacquered inside.

Thicknesses of Metal Coatings

For severe outdoor conditions in an industrial area or at the seaside, critical loadbearing steelwork should be protected with at least 0.06 mm (0.0025 inch thickness or 1.5 ounce/sq ft) of galvanizing or sprayed zinc, covered with two coats of paint.

Sherardizing is typically for small articles but they can be up to 6 m (20 ft) long, provided that they fit conveniently into the standard box which is 40 cm (16 inches) square. Sherardizing is well suited to the coating of screw threads, since its thickness can be more closely controlled than that of galvanizing. The minimum thickness of sherardizing is from 0.007 mm (0.0003 inch) to 0.05 mm (0.002 inch) for parts subject to heavy corrosion.

Several British Standards use a coding for the thickness of metal coatings that is worth explaining. Thus Ni 12S indicates a thickness of 0.0012 inch (0.03 mm) of nickel on steel, a plating suitable for car bumpers and hub caps. Ni4S with only 0.0004 inch (0.01 mm) of nickel on steel is more suitable for indoor uses. BS 1872:1964 deals with electroplated deposits of tin of five different thicknesses from 0.005 mm (0.0002 inch) to 0.03 mm (0.0012 inch) on iron, steel, nickel alloys, copper and copper alloys.

Small screws and their threads present a special difficulty in plating. The clearance between corresponding points of the male and female thread is only about 0.025 mm (0.001 inch). The corresponding permissible thickness of coating, however, must be even less, 0.005 mm (0.0002 inch) because of plating tolerance and the slope of the thread. Greater thicknesses than these are liable to prevent the screw passing into the nut. If it is forced in, the coating will be stripped.

Chemical Plating

Many chemical or "electroless" plating processes have been patented for depositing nickel or copper on metal to prevent corrosion, on plastics for decoration and for electronic circuitry. No electric current is used and no electrodes.

In one electroless nickel plating method, the nickel is deposited chemically from solution on to the steel, producing a nickel plate of high quality used on cars, that is much more uniform than electroplated steel. A disadvantage of some electroplates is that areas remote

from the anode receive less metal than areas near it. Even on objects with intricate contours, the electroless plating thickness does not vary by more than plus or minus 15 per cent. The metals that can be protected by electroless plating include steel, cast iron, aluminium, copper, titanium and alloys of these metals, as well as many non-metallic surfaces. The composition of the plate, which might be described as a nickel phosphide, is some 92 per cent nickel and 8 per cent phosphorus. The adhesion to the protected metal is good and the plate is hard and corrosion-resistant. The deposit thickness can reach 0.125 mm (0.005 inch) but is usually less because the plating rate is only about 0.025 mm per hour. The minimum thickness is 0.008 mm (0.0003 inch).

Engineering parts coated with this electroless nickel plate include piston rods, crankshafts, valve inserts, and pump parts. It is also used for applications where iron would contaminate a chemical or a food, for example in dough trays, reaction vessels, petrol tanks, tank wagons, screw conveyors and so on.

Chromizing

Chromizing, sometimes called chromium diffusion, is a heat treatment that puts a layer rich in chromium on the surface of iron, steel and some other metals. The layer resists wear and corrosion at high or low temperatures. Since the chromium has to penetrate the surface of the steel, large thicknesses of chromizing are impossible, the usual economic limit is 0.05 mm (0.002 inch) and the absolute limit almost double this thickness. The resistance to corrosion in tap water or air or many mild chemicals including salt water is good but for any stronger chemicals it is best to use the special "chromizing" steels. In mild steels the chromized layer is not very hard but on high-carbon steels it is excellent and enables the steel to be used for such heavy duties as gear wheels.

Chromium Plate and Hard Plate

Unlike chromizing which is a heat treatment, chromium plate is an electroplate or rather two electroplates, sometimes three. To ensure that the chromium sticks to the metal below it, nickel is first plated over the steel, and sometimes a layer of copper is placed over or under the nickel. Somewhere in this sandwich there must be a polished surface, and it is usually easiest to polish the copper or the nickel because they are soft. Chromium cannot be polished because it is too hard. The chromium thickness is only 0.00025 mm (0.00001 inch), the nickel and the copper are both about 0.025 mm (0.001 inch) thick. Chromium plate is thin and decorative, not to be confused with hard plating or hard chromium plate which is much thicker, deposited direct on the steel and not decorative but very resistant to wear and corrosion.

Anodizing

Anodizing as a process for protecting aluminium that is so well known and so often used that it is worth describing briefly. The aluminium article is made the anode in an acid bath and oxygen, as would be expected, is liberated around it because of the electrolysis. The aluminium is oxidized, the oxide film becoming thicker at the rate of 0.001 mm in 3 minutes. For exterior architectural work in Britain the usual thickness required is 0.025 mm (0.001 inch) and for trim on cars about 0.003 to 0.008 mm. The oxide film, after it has been formed in the acid bath, is still soft, so the article is removed and immersed in boiling water. The operation is known as sealing and is a hardening and strengthening process for the oxide film. From the viewpoint of corrosion protection it is as important as the acid bath and the water must be very pure. Sometimes steam at 100°C is used instead of water. The minimum time required for sealing is 4 minutes per 0.001 mm.

Concrete Floors

The binder in most modern concretes is Portland cement because this is usually the lowest in cost and the most easily available. It always contains a proportion of free lime, $Ca(OH)_2$. Also called slaked lime, this is an

alkali and its alkalinity enables the cement to protect iron and steel from rust. It is, therefore, worth remembering that its cost is around 25 dollars per ton. Paint is much more expensive, 25 dollars will buy only about 5 gallons. But the disadvantage of concrete made with this cement is that it is relatively easily attacked by acids.

There are two ways of protecting a concrete floor against acids, by giving it a slope, and by using acid-resistant material. Whatever the material, the concrete must be self-draining: pools of liquid must never form on the floor. This means that the minimum allowable slope over the whole wetted area of floor should be 2 per cent. To prevent ponding in small areas, the lowest spot under a 2.5 metre long striaght edge should not be more than 3 mm below the edge. For the more corrosive chemicals, the floor should slope more steeply. It slopes either towards a trench in the concrete, that can be covered with a metal grating, or into a central drain.

If the chemicals are not too strong, the concrete may need no special coating and the slope alone will be enough to prevent the concrete being attacked. This is particularly true if care has been taken to make ordinary good concrete that is not porous. This can be achieved by paying a little extra for the concrete and ordering the contractor to make concrete with a minimum 14-days crushing strength (on 15cm cubes) of about 400 kg/sq cm (5500 pounds/sq inch). This is a relatively high-strength concrete but strength in concrete is achieved by eliminating porosity and this low porosity is required for good corrosion resistance. For a concrete which depends for its acid resistance on a special surfacing, such strength might be unnecessary and about 200 kg/sq cm might be adequate.

For a higher acid resistance than is obtainable with good concrete made from ordinary Portland cement, one of the more expensive cements can be used. Rapid-hardening cement costs about 10 per cent more than ordinary Portland, but is chemically the same cement, ground more finely. Sulphate-resisting cement is a little more expensive again, and high-alumina cement costs about three times as much as ordinary Portland. It is best to obtain specialists' advice on these matters but to find out for oneself the prices of the local materials beforehand. Plastic-coated floors are discussed in another Section.

Expansion joints, also called shrinkage joints, should be placed at regular intervals in all concrete floors, at least every 6 metres in long runs of floor, and all round the edges. They should be at least 1 cm wide. The joints ensure that the unavoidable shrinkage of the concrete takes place along predetermined lines, and is thus not unsightly nor dangerous to the floor.

Other points to be remembered in the building of concrete floors are: metal pipes passing through a floor should do so in a sleeve (another pipe in which they fit loosely, which does not corrode). The tops of concrete foundation piers should be treated with a sand-cement topping to slope the concrete away from the steelwork. It is sometimes possible now to design the floor so that some of the shrinkage joints run along the line of the drain trenches. Synthetic rubber materials for making the joints can take up the movement and resist the acid without bursting. The movement will in any case be small if the joints are spaced at no more than 6 metres.

If all the joints can be fitted into drain trenches, this eliminates the problem of joints passing through the area of the floor that has a 'finished' surface. The rubber jointing material should prevent leakage through the bottom of the drain trench.

It is fair to say that bare concrete resists no acids but many alkalis, though its life will be very much longer in acid conditions if it is well made and well sloped. Epoxy and polyester floors resist both acids and alkalis and are discussed with other synthetic materials in the Section on Plastics. Asphalt flooring and polyester flooring are not recommended to withstand solvents or mineral oils. Tiles, bricks

and bare concrete are all noisy, plastics relatively quiet.

Concrete as a Corrosion Preventive

For civil engineering work, concrete is often used to protect steel from the earth, the sea or the weather. It has also been successful as a lining 25 mm thick (1 inch) inside steel water pipes. In these uses it protects the metal mainly against knocks or abrasion since it sticks well to bare steel. Generally the underlying metal is bare and the concrete by its alkalinity acts also as a corrosion preventive. It is suitable in massive structures where its weight is no disadvantage and the impact-or corrosion-resistance are also needed, as in jetties. The steel should generally be covered with at least 7.5 cm (3 inches) of concrete. This is a considerable expense, not only in concrete but also in formwork and secondary reinforcement, and it also has the disadvantage that a stanchion becomes 15 cm thicker or a beam becomes 15 cm wider, so it is not always cheap. But under this adequate cover, corrosion failures in steel are rare.

Guniting (concrete spraying or cement gunning) is a method of shooting sand and cement mortar through a compressed-air-operated gun on to a surface that needs protection. It is commonly used to repair bridges from which the concrete cover has been knocked off or to thicken a concrete cover that is inadequate. For this purpose the cement gun is irreplaceable. It does maintenance work that can be done in no other way. Because the mortar is gunned on, it can be applied to vertifaces or undersurfaces without difficulty. The high pressure of the gun has another advantage. It produces a dense, strong concrete that hardens quickly because it is thrown on at a low water content. This also enables a high thickness to be achieved at each pass.

Another common use of the cement gun that may sometimes help the maintenance engineer is to shoot asbestos mixed with cement and water onto steelwork inside a building so as increase its fire resistance when the building ıtains much material that will burn. Like all concretes and all gunites, this protects the steel from corrosion because of the alkalinity of the Portland cement. Its fire resistance comes from the fact that it provides a thermally insulating coating on the steel. But sprayed asbestos, though an excellent material in many ways, is not cheap.

Any cement materials gunned on to steel must be held on to it by light reinforcement. Usually chicken wire is used, light steel wire netting with a mesh of about 5 cm (2 inches) square. This must be wired on to the metal before gunning starts.

Anti-Corrosion Tapes

Anti-corrosion tapes (wrappings) have been in use since the early 1930s in severely corrosive conditions where lighter coatings of paint or metal have been found inadequate, or for protecting metal in an inaccessible position where repainting is not possible and a life of at least 20 years is needed. The tape is wrapped round pipes, stanchions, beams or other metal, overlapping and leaving no metal exposed. Tapes are not beautiful but they are immediately effective, unlike paint which needs time to dry and cannot be put on in any weather. Their chief use nowadays is to protect buried pipes, and for the effective protection that they give they are not expensive.

Most tapes have a textile base, coated with an adhesive, but polyethylene and PVC sheet are also now being used. The textile is usually woven cotton, jute, nylon or glass fibre. If glass-fibre, felt or tissue is used, it is generally backed with a strengthener. The coating is often a soft grease such as petroleum jelly or wool grease or a soft form of oxidized bitumen or coal tar pitch, though these generally need to be heated before application. The coating can also be a natural or synthetic rubber or resin. The tape also carries fillers and corrosion inhibitors such as chromates, phosphates and tannins as well as stabilizers and anti-oxidants if it contains rubber materials. The bituminous types are generally used only to resist high temperatures.

Grease-coated cotton tapes are the easiest to apply since they can easily be wrapped round awkward surfaces such as bolt heads, rivets, pipe couplings and so on. Bituminous-coated tapes need to be heated with a blow lamp before application; grease-coated tapes have the advantage of no fire risk since they can be put on cold.

If the object to be protected is wet it will need first to be dried either by applying a water-displacing composition or by some other means so as to make sure that the tape is in contact with the whole area. If the pipe is to be buried it may be necessary to protect the tape, especially a greased cotton tape with a tougher outer wrap.

Anti-corrosion tapes generally should be chemically inert and should resist acids and alkalis, soil, seawater and atmospheric pollution. Petroleum jelly fulfils these requirements best. Bitumen and coal-tar pitch are often slightly acid and they have the further disadvantage that they are liable to crack. An exception to the rule about chemical inertness in tapes is that they contain corrosion inhibitors of an alkali such as lime. The purpose of including tannin in the tape is to kill the sulphate-reducing bacteria which are believed to be the main cause of corrosion of buried iron or steel pipe in Britain, though it is not yet proved that tannin has this effect.

Both grease-coated tapes and bituminous tapes have an indefinitely long storage life in any climate, except that bituminous tapes must not be allowed to warm up excessively or they will stick together. Tapes with rubber content should generallybe used within 6 to 12 months of manufacture.

Tape is not always the cheapest coating but its long-term protection may make it worth while. For buried pipelines one alternative is to apply a hot bituminous coating in the factory and to coat the joints on site with either tape or hot bitumen. Another possibility for a continuously welded pipe is to apply hot bitumen on the site before burial. Factory-applied coatings are easily damaged in transit and site-applied coatings are difficult to apply perfectly. But site-wrapped, cold-applied tape can cover the pipe without leaving any metal exposed. It is nonconducting and, combined with cathodic protection, will reduce the power demand, and may ensure many years of trouble-free operation.

PLASTICS

Reactors and other chemical plant made of plastics alone will not be discussed in this paper because almost any shape and size of corrosion-resistant duct or vessel known to chemical engineering can be made by plastics fabricators, including chimneys, fractionating towers and the 350-metre long hose mentioned in the next paragraph. Stationary pipework made of plastics is now so well established that most of the hundreds of miles of pipe installed yearly in the USA for transmitting natural gas are made of plastics. Plastics manufacturers are generally well enough organized to send the inquiring maintenance engineer as much printed material as he needs about chemical plant made of their materials, particularly since most units are made as one-off or small-batch jobs.

A German company, Vredestein, can serve as an example for the uniqueness of many plastics installations in chemical plants. In 1968 Vredestein claimed to have installed the largest rubber hose in the world. Of butyl rubber built on to nylon fabric, it was 19 cm (7.5 inches) in diameter and 350 metres long. A company in the north of Holland had found that its underwater pipeline was too severely corroded to discharge its usual load of was chemicals at 70°C. The pipe was first cleaned of deposits by pulling a go-devil through it. The hose was then pulled into the pipeline flat and afterwards inflated. Insertion of the pipeline, it was claimed, took only 90 minutes.

A general introduction to linings and coatings will be more useful to the maintenance engineer than a discussion of chemical plant. In the two next headings, coatings are rega

for convenience as being thinner than 0.5 mm (0.02 inch) and linings as thicker.

Plastic Coatings (thinner than 0.5 mm)

Generally, plastics are not put on at coating thicknesses less than about 0.15 mm which is the maximum for many conventional paints. Plastic coatings can be applied to concrete as well as to metal and are usually resistant to continuous immersion in many chemicals, being more corrosion resistant than conventional paints. The best properties are obtained by heat treatment. The hardness can be anything between glass-hard and rubbery. The thermal and electrical insulation are usually good but electrically conductive coatings can be made by incorporating conducting filler material. Repairs are often possible on the site.

The coatings that are paint-like are best applied at temperatures above 20°C. Some of them should, for best results, be stoved at 150 to 200°C, but nevertheless few of them can be used at temperatures above 90°C and this is one serious drawback of plastics. Their cost is also fairly high but this would not be a serious drawback if they had all the desirable properties.

The surface preparation of mild steel for a plastic coating is very similar to that for receiving ordinary paint, possibly rather more rigorous because the chemicals contained are stronger than those usually left in contact with paint. The steel must be de-greased with a solvent that is then removed by heating, and the surface is cleaned by grit blasting. It should be remembered that the absolute minimum thickness of steel that can be grit blasted is about 0.5 mm and this is only possible with metal of the highest quality. Dust is removed after grit blasting and the coating is applied as soon as possible but always within four hours. After the coating has been applied it is tested for thickness by thickness meter and any deficiencies are made good by additional coats where needed. To achieve a good gloss, the last one or two coats are usually not pigmented. Stoving may be done between coatings.

Stationary pipe-work made of plastics is now so well-established that most of the hundreds of miles of pipes installed yearly in the USA for transmitting natural gas are made of plastics.

Continuity can be tested by some electrical method to ensure that there are no pinholes in the coating. Most plastic coatings are excellent insulators so the design of such a testing method, at least for a coating over metal, is not difficult. Coatings which contain conducting meterial such as carbon black, like neoprene, cannot be tested in this way. High-frequency alternating current spark testers are not suitable because the spark may puncture a thin coating. For the thinnest coatings a direct current voltage of some 10 to 30 volts can be used, with a sponge as a probe, soaked in brine with a wetting agent. Brine is not always very penetrating and it may not enter the pinholes. A more severe test is a high-voltage direct current tester with variable voltage from 0 to 5000 volts. For coatings about 0.2 mm thick, a voltage of some 2000 volts has been found suitable. So as to make the overall testing easy and rapid, the probe should be shaped to the contour of the vessel.

Because plastic coatings have to be stoved, there is a limiting size to the articles to be coated, which must be small enough to enter the oven. With coating materials like polyurethane, however, that do not need stoving, objects of any size can be coated. Polyurethane has good resistance to acids and alkalis from pH2 to pH13 as well as to solvents, oils and fuels. In hot water the highest continuous working temperature is about 50°C but higher temperatures can be tolerated for a short time.

Plastic-coated factory-made sheet metal (steel or aluminium) which began to be produced around 1960, is interesting. In Britain the sheet dimensions are about 1.2 m maximum width, with a coating on one or both sides, from 0.1 to 0.4 mm thick. Some attractive colours are available. When the steel sheet is coated on one side only, a number of fabrication operations are possible, including deep drawing several centimetres deep, bending, drilling, sawing, punching, shearing and roll forming and welding after removal of some of the coating. The operations other than welding do not affect the plastic coating. Corrosion in the drilled holes can be prevented by the use of plastic-coated bolts with plastic washers or stainless steel bolts or completely plastic fasteners. The coating ordinarily is polyvinyl chloride (PVC). Some applications of plastic-coated sheet include partitioning in factories in corrosive environments, and the manufacture of refrigerators or laboratory furniture. Some further details about coatings are given later, under "Rubber linings".

Plastic Linings (thicker than 0.5 mm)

Plastic linings can be applied in the form of sheet, using adhesives to fix them on to the metal or other material to be protected, and joining the sheets together as needed. Other methods of applying linings are: dipping followed by heat treatment, flame spraying, fluidized sintering, and finally the methods of painting, by spray or brush. The thickest linings are probably about 10 mm thick, anything thicker is probably called a mortar, or if horizontal, a screed or topping, especially when laid over a concrete floor.

Mild steel and concrete are the materials most commonly protected, occasionally non-ferrous metals. As usual, careful surface preparation is needed and the surface should be potected as soon as it has been cleaned. Steel articles to be lined should be strong enough not to distort under load. The steel should be smooth, with no rivets or bolts; welded construction is essential and welds must be without porosity and ground smooth. Internal angles must be radiused or chamfered to make them less sharp. All re-entrant corners must be avoided. Concrete surfaces also must be smooth. Projecting fins should be ground flat and holes should be filled with cement mortar. Alternatively, a rubber latex-cement mortar screed or plaster can be applied to the concrete as a backing to the lining. The minimum radius of corners should be 1.5 cm. Brickwork, before coating with plastics should first be plastered or screeded with sand-cement or latex-cement mortar.

Many of the commoner plastics are available in sheet from 1.5 mm to 6 mm thick, but some of these cannot be made to stick to other materials. The polyethylenes, unplasticized PVC and polypropylene can, however, be made to stick by laminating them to a backing sheet that will adhere, though this is more expensive. For instance, unplasticized PVC has been laminated to plasticized PVC that adheres well.

After they have been blast cleaned, steel tanks are primed with an adhesive primer and then with the adhesive itself. The lining may, if it needs protection from knocks and abrasion, be itself lined with a course of brickwork, as in hot-acid pickling tanks for de-scaling steel.

Synthetic Rubber Linings

The synthetic rubbers are materials of special interest. There are several types, including neoprenes, butyls, nitrile rubbers, polyisobutylenes, Thiokols, and chlorosulphonated polyethylene, known as Hypalon. Most of them have good chemical resistance but for each application there is likely to be one that is the best.

Neoprene, though not highly corrosion-resistant, resists seawater and mineral oils and abrasion. It can be applied cold in thicknesses up to 3 mm by brushing, spraying or dipping. The corrosion resistance can be heightened by a top coat of Hypalon which also is obtainable in pleasant colours.

Nylon coatings also can be thick, up to 8 mm (minimum 0.2 mm) and have good chemical resistance except to mineral acids. Their resistance to solvents makes them useful in de-greasing units. The great thickness possible

with nylon linings enables them to be placed over rough castings and this eliminates the cost of fettling the casting.

PVC coatings can be applied thickly by dipping. PVC is resilient and not so expensive as most plastics though perhaps more difficult to apply than some of the expensive ones. Sprayed PVC can be put on as a coating in thicknesses from 0.017 mm (0.007 inch) to 0.1 mm (0.04 inch).

Polyethylene (polythene) is the most easily applied of all plastic coatings and is highly corrosion resistant. Coatings are applied as powders by spraying or dipping. Of the two grades available, high-density and low-density, the high-density polyethylene has the higher melting point, is tougher, less decorative and sticks better to metal than the low-density material. By fluidized sintering, coating thicknesses can be obtained between 0.25 mm and 3.1 mm.

Polytetrafluoroethylene (PTFE) though costly, is one of the most interesting plastics now in production, because of its great variety of excellent properties. Unfortunately coatings made of PTFE are prorous and thus useless for most anti-corrosion purposes. It has a very low coefficient of friction, is non-wetting and reisistant to nearly all chemicals and its properties remain unaffected over the wide range of—80°C to+250°C. It can be applied in coatings between 0.012 mm and 0.15 mm (0.0005 inch to 0.006 inch).

Polytrifluoromonochloroethylene (PTFCE) forms a completely non-porous, corrosion-resistant coating in thicknesses from 0.1 mm to 0.3 mm (0.004 to 0.012 inch) built up by spraying in thicknesses of 0.025 mm (0.001 inch) at a time. Its chemical resistance is not so good as that of PTFE but being non-porous it is stronger and more useful for resisting corrosion. Great care is needed in preparing the surface of the metal to be protected; corners must be radiused, welds must be ground down and pores filled with metal. The expense of the surface preparation limits its use to applications where high corrosion resistance is essential .

Fluidized Sintering and Flame Spraying

Apart from the usual methods of applying paint, by spray, brush or roller, there are other ways of applying plastic linings, using fluidized sintering and flame spraying.

In fluidized sintering, the hot object is in a fluidized bed of cool powder of the plastic coating or lining. The object is heated to a temperature above the softening point of the plastic and the dipping thus produces a fairly uniform coating which is later stoved to fuse it smooth. A fluidized bed is a layer of powder that is blown upwards at a rate high enough to keep it "boiling" but not so high that powder is blown away. It is used because its resistance to the entry of an object to be dipped is low. A disadvantage of the method is that the thickness of the coating depends on the heat capacity of the metal and therefore on its thickness. Thicker metal receives more plastic than thin metal.

Flame spraying is a job at which at least two men must work together. It is a little more risky than fluidized sintering so far as the burning of the plastic is concerned, but it can be used for lining objects that are too large for fluidized sintering. The first man preheats the metal surface with a gas flame and the second man follows, applying the plastic by flame spraying. A final heating by flame is needed to fuse the plastic into a homogeneous lining.

Mortars, Screeds or Topping

The latex or synthetic resin or synthetic rubber screeds or toppings over floors are known as monolithic surfacings and were first used in the USA in the early 1950s. These synthetic resin cements are used to form mortars in somewhat the same way as Portland cement with the important exception that the mix cannot be made sloppier and weaker by adding water. The cements include epoxide, furane, phenolic, polyester resins and cashew-nut shell liquid (CNSL). Usually there are two main components, the resin, a syrupy fluid to which the accelerator (hardener or catalyst) a watery fluid,

is added when the cement is to be used. A third component is also provided, a filler that fulfils the function of the sand in a cement mortar. This filler may be contained in the accelerator. One difficulty in using these cements is that their hardening rate depends on temperature to a much greater degree than that of Portland cement. It may be that in summer the cement will have to be mixed in small batches that do not harden before they are placed. However, usually in winter large batches can be mixed. As with Portland cement mortars the mix ratio of cement to filler varies from 1:1.5 to 1:4 by weight.

The cements are provided for the market either in two-can or three-can packages, which after mixing form the mortar. The mortar is used for jointing brickwork or for bedding and jointing floor tiles or channel blocks. The cements have good corrosion resistance but the ceramic blocks are even more corrosion resistant, and it is therefore best to make the joints as thin as possible. The chemicals which severely attack ceramic blocks are the strong ones, hydrofluoric acid and strong caustic alkalis. There is no difficulty in explaining to the bricklayer that the joints should be thin but it is not always easy to get him to make thin joints. In good quality work, joints are as thin as possible but this takes more time than with thick joints. Therefore the joint thickness should be worked out beforehand, bearing in mind the unevenness of the blocks and it should be stated before work starts. It is usually best for such work to be done by a specialist contractor.

Screeds (horizontal layers of mortar) of synthetic resin cements are made of similar materials to the mortar but with a slightly coarser filler (aggregate) and are applied in thicknesses of 3 to 10 mm. A Portland cement mortar screed is much thicker, at least 50 mm. Such great thicknesses are not possible with synthetic resins because of their high cost. Where extra thickness is required, it is provided in the base concrete that is much less expensive. Epoxy resins adhere well to ordinary concrete.

In workshops where the floor is liable to be often flooded with corrosive liquid, it is necessary to provide a complete tanking, rising some 15 or 30 cm up the walls all round. The tanking may consist of acid-resisting asphalt or such sheet materials as polyisobutylene, plasticized PVC or a synthetic rubber. The membrane used for tanking must be continuous and the sheets must be either joined by adhesives or welded by hot-gas welding or by some other method.

Cost of Corrosion-Resisting Floors (early 1969 basis)

Conventional red quarry tile floors, 18 mm thick with Portland cement mortar joints, cost 18 dollars/sq metre and with epoxy-polyamine joints about 22.5 dollars. Engineering brick floors are correspondingly thicker and more expensive.

With chlorinated rubber or epoxy resin or urethane, a floor coating costs from 4 to 12.5 dollars/sq metre, with thicknesses from 0.12mm for chlorinated rubber to 3 mm for polyurethane. Asphalt flooring 43 mm thick costs around 12.5 dollars/sq metre, latex 6 mm thick about 18.5 dollars, and epoxy-polyamine or polyester with glass reinforcement, 3 mm thick, costs about 22 dollars/sq metre.

FASTENERS

In this section are discussed some materials for bolts, nuts, screws and so on, as well as appropriate methods of using them. Bolts and nuts, being the commonest engineering fastener, are of the greatest interest. What is true of them is often true of other fasteners, such as rivets, split pins or window latches.

Fasteners cost more in labour to put in than to buy. All those named here are low in first cost but their placing is important for the structure and can be expensive. Unfortunately most bolts are made of easily corrodible steel and they are often placed in situations where they attract water by capillary action and are more likely to corrode than the rest of the structure. Boatbuilders have recognized these facts for many years. Corrosion-resistant fasteners of every type are, therefore, in regular use on boats

and ships. Other users are only just beginning to understand what boatbuilders have always known.

If fasteners cost more to put in than to buy, it is obviously even more costly to replace them. Therefore where corrosion is likely and the structure is planned to last for a number of years, it is advisable to use corrosion-resistant fasteners.

Where corrosion is likely and the structure is planned to last for a number of years, it is advisable to use corrosion-resistant fasteners.

Relative Costs of Bolts of Different Materials

It is interesting to know the relative costs of bolts of the same size, made of different materials. Applied to an uncoated carbon steel bolt, the extra costs of protective coatings are: hot-dip glavanizing 13 per cent, sherardizing 17 per cent, heavy zinc electroplating 30 per cent, cadmium plating 40 per cent. An 18—8 stainless steel bolt costs from three to five times as much as the plain carbon steel. In spite of this heavy extra cost there are many places where stainless steel alone is suitable. An even better steel for specially corrosive situations is the 18-10-3, with 3 per cent molybdenum. Near British power stations burning pulverized coal, where the fine ash falls on the roof, stainless steel hook bolts are now used for holding roofing sheets down to the purlins. Ordinary mild steel bolts were found to corrode too quickly. For bolting precast concrete units together, one material that does not make unsightly rust marks on the concrete is stainles steel. Silicon bronze and aluminium bronze have also been used but they are less readily available than stainless steel.

Austenitic stainless steel self-tapping screws, whether 18-8 or 18-10-3, are usually not hard enough to cut threads in for example, window frames of the same material. It may, therefore, be necessary first to use a self-tapping screw of the same dimensions but of a different material such as hardened ordinary carbon steel, so as to cut the thread in which the stainless steel screw can be fixed.

Aluminium alloy self-tapping screws also cannot be used in window frames of the same material. Plated hardened carbon steel screws have given satisfactory service, so have screws made of stainless steel.

Those who are not familiar with the various grades of protective coating available on builders' hardware should be warned against copper-plated steel articles that have an excellent appearance in a heated shop but in the damp air will remain rust-free no longer than bare steel.

Cathode/Anode Size Ratio

Even though the electrochemical theory of corrosion may be true there are many situations in which it has had to be disregarded, particularly in the use of fasteners. Corrosion is not inevitable, especially if the metals are kept clean and dry. If the general rule that different metals should not be used together has to be broken, there is a further rule that must be followed. This is that the cross-section of the anode must be large and that of the cathode small. The anode is the part that loses metal, therefore it must be bulky so that it is not excessively weakened.

As an example of this principle, two assemblies were tested in a 5 per cent solution of common salt. This is a rather stronger solution than seawater, which is 3.5 per cent total salts but 3 per cent common salt. Aluminium alloy screws inserted into 18-8 stainless steel sheets were severely corroded after only 7 days testing. The anodic (aluminium) area was too small. But when 18-8 stainless steel screws

were inserted into aluminium alloy sheet they were still in good condition after six months' immersion in the same solution. The aluminium alloy sheet was pitted, as would be expected, but was not destroyed.

For similar reasons, ordinary steel bolts should not be used in stainless steel or copper panels, even if the bolts are plated. Stainless steel bolts also should not be used in direct contact with zinc-coated steel of any type, especially in polluted or seaside air, so as to avoid rapid corrosion of the zinc near the bolt.

In case it is unavoidable to use different metals together, it may sometimes be practicable to plate the noble metal so as to reduce the corroding voltage between it and the corroded (anodic) metal. Thus stainless steel bolts, used for fixing aluminium alloy panels on aircraft, can be cadmium plated. Another alternative to insulation, for preventing local attack on aluminium, is to use a chromate (inhibitor) sealing compound on the surfaces in contact, or to use plastic-coated stainless steel bolts.

Protective Coatings on Bolt Threads

The thickness of a coating can seriously affect the fit of a bolt into its nut; looseness and tightness of fit are both undesirable. This does not apply to wood screws or self-tapping screws, which can take any zinc coating thickness up to 0.05 mm (0.002 inch) without difficulty. For use out of doors, such screws are usually passivated with chromate. For bolts and nuts, however, the coating can be only about one tenth of this value, some 5 microns or 0.0002 inch. Being so thin, it is usually put on by electroplating which is more closely controlled than hot dipping.

Zinc is the most widely used protective coating for bolts. Zinc coating is much less costly and therefore much more used than cadmium but cadmium is useful in particular situations of high humidity or for protecting steel in soft water or for reducing the potential between metals in aircraft. The two main disadvantages of cadmium are that it is expensive and its vapour is toxic, so it is ordinarily used only as a thin electroplate. Perhaps the best overall protection for bolts is given by a tin coating over cadmium but this is relatively expensive. It resists acid water well. A 5-micron (0.0002 inch) cadmium coating is adequate to resist neutral or alkaline water.

Other useful coatings for fasteners, though perhaps more costly, are chromium, tin-nickel alloy, or bronze. Compared with zinc, all these metals are hard, chromium extremely so, and they, therefore, resist both abrasion and corrosion.

Thread Friction

Thread friction must always be kept in mind in the choice of the bolt metal or coating metal for the thread. Cadmium coatings usually lubricate the thread but zinc coatings tend to increase the friction, especially if they are uneven, which is likely with galvanizing and possibly sherardizing. In modern steel structures it is important to use a bolt that does not need oiling, for the following reason. A fixing method for steel structures, now being increasingly used is the high-strength (friction-grip) bolt. If the bolt is oiled this should be done only very sparingly because oil should never reach the contact surfaces of the plates or other members gripped by the bolt. The security of the joint depends on the clamping of the plate contact surfaces, and the clamping effect will be reduced by oil between the plates.

Threads which are zinc-coated by sherardizing are usually smoother, with less friction than hot-dipped threads. Electroplated threads are smoother than either, but the coating is thinner. Sherardized thicknesses are from 0.02 mm (0.0008 inch) to 0.04 mm (0.0015 inch) but hot dipping can give even thicker coatings, to 0.075 mm or 0.003 inch though 0.025 mm or 0.001 inch is possibe. It is often satisfactory to use nuts tapped after hot-dipping, and to rely for corrosion resistance on the zinc coating over the bolt threads. Sometimes sherardized self-tapping screws may have soft threads which is a disadvantage for this type of screw.

For every corrosive situations where the

fastener strength does not have to be so high that a steel bolt is essential, an all-plastic fastener has been produced. It can be used, for example, in mines with very corrosive water. This three-piece unit is not threaded in the ordinary sense but is quickly inserted into a hole through metal or wood or plastic sheet. A 90-degree turn in one direction or the other will lock or unlock the fastener.

Monel Metal Bolts

An interesting alloy, Monel K500, with the strength of a high-grade steel (minimum yield strength 55 tons/sq inch) has recently been used for making permanently corrosion resistant bolts in tall buildings where corrosion could endanger human life. Monel K500 contains 66 per cent nickel, 29 per cent copper, 2.75 per cent aluminium and 0.9 per cent iron approximately. It is, therefore, expensive but it is also strong and corrosion-resistant. Bolts made of this alloy support armoured-glass panels over a shopping centre in London and over Sydney Opera House they support the precast slabs on the roof. Some of the latter are 2.5 metres long (8 ft) and they are 25 mm in diameter (1 inch). Monel K500 was chosen because it will resist the salty air of Sydney as well as the dilute hydrochloric acid that will periodically be used for washing the outside of the building. The same alloy is being used to replace high-tensile brass fasteners in the movable window-cleaning gantries that are hung outside many tall modern buildings.

INSPECTION AND TESTING OF METAL OR PAINT COATINGS

The up-to-date maintenance engineer will have noticed that plastic coatings have been omitted from the title of this section, but this is because they can be regarded as paint and tested in similar ways. Plastic linings and coatings were discussed in an earlier Section. The *four essentials in coatings*, whether of paint or metal or plastic, that give long protection to the underlying metal are: *thickness*, *uniformity*, *adhesion* and *ductility*, which for paint is usually called flexibility. Uniformity here implies the absence of thin patches. Tests for adhesion and ductility can be found in the standards literature, but the first two qualities are of the highest interest to the maintenance engineer because he can control them, and the thickness, of course, controls the cost. In an industrial environment the combined paint and metal coating (or either if used alone) should not be less than 0.125 mm (0.005 inch).

Visual Inspection

Visual inspection of coatings, apart from being essential because it is quick, is usually also reliable, so far as it goes, but it does not indicate thickness. Metal coatings and paint, should be seen to be continuous. Hot-dip galvanizing is liable to have lumps or blisters that usually imply an inclusion of something that will weaken the zinc. The sparkle of new galvanizing, called spangle, though decorative, is of no value for anti-corrosion purposes and attempts are being made to reduce its scale. Sprayed zinc or aluminium coatings are always rougher than hot-dip galvanizing but should in any case never show black spots or blisters. Electroplated surfaces are the smoothest type of metal coating. They are usually also the thinnest because they are the most expensive.

Thickness Measurements in General

Coating thicknesses can be determined by destructive or non-destructive methods. Generally speaking, only non-destructive methods will be of interest to the maintenance engineer unless he has a chemical or metallurgical laboratory at his disposal. Some of the destructive tests, that do not involve thickness measurement, measure the resistance of a standard painted or metal-coated panel to the corroding effect of salt spray or kerosene or scratching or impact or bending or some other way of stripping it. These tests are all described in the standards literature, but it is worth pointing out that "test panels" in the sense used here are pieces of aluminium or steel sheet, usually measuring 15 by 10 cm, sometimes 10 by 5 cm.

Every manufacturer aims to apply the most uniform protective coating that he can, so as to give the highest protection at the lowest cost.

The four essentials in coatings whether of paint or metal or plastic, that give long protection to underlying metal, are: thickness, uniformity, adhesion and ductility.

The accurate measurement of thickness can provide the information needed to lower the cost of protection and to improve its quality. Without discussing the mathematical theory of probability it is possible to understand that for every job there is a certain minimum number of thickness measurements to be made so as to achieve an appropriate degree of certainty about the product. In manufacturing, at least one product in ten must be fully inspected, with occasional spot checks of doubtful products. Using an instrument that gives immediate readings, not only the routine measurements, but also the spot checks are easily and quickly made.

Non-destructive Measurement of Thickness

Thickness-measuring instruments based on four different principles are mentioned here but many others exist. In Great Britain alone there are more than 20 makers of instruments for measuring paint thickness and about the same number who make instruments for measuring the thickness of metal plating. All these instruments give immediate readings but each one has its most suitable field of use. The maintenance engineer should make wide enquiries before deciding to buy an instrument. The four principles of operation mentioned below are: beta-ray back scatter measurement, eddy-current measurement, thermo-electric measurement and magnetic measurement. The last is the oldest method and possibly the most suitable for measuring paint thicknesses on iron or steel.

The beta-ray back-scatter instrument is used mainly for measuring coating thicknesses of precious metals on semi-conductors, electrical contacts, printed circuits, and electronic or watch components. It can measure the thickness of a coating on a wire of only 0.2 mm diameter.

The eddy-current instrument is considered best for measuring insulating films (paint) on non-ferrous metals, and involves a high-frequency alternating field in the instrument. Provided that the coating metal has a smaller conductivity than the basis metal, non-ferrous coating metal thicknesses can also be measured. Anodic coatings on aluminium and its alloys can be measured. In appropriate circumstances, coating thicknesses as small as 0.2 thousandth of a micron can be measured.

The third instrument was developed recently by the British Non Ferrous Metals Research Association (BNF). The BNF thermo-electric thickness tester measures the thickness of metal plating by the principle of the electrical voltage (thermocouple) produced at a heated contact between two different metals. The point of the meter is heated and brought into contact with the metal coating. An electrical conductor from the point leads to a direct current amplifier. The other connexion to the d. c.) amplifier is brought round from the iron or steel basis metal beneath the coating.

The magnetic (or electromagnetic) instrument is well established but can only be used on a basis metal that is magnetic (usually iron or steel), and is only suitable for measuring the thickness of a non-magnetic coating. Nickel is magnetic, though much less so than iron or steel, and the instrument could not be used for measuring the thickness of nickel plating on steel.

Early types of the magnetic instrument had several disadvantages which are now overcome. They could be used only for measurements on a flat surface and away from the edge of the

metal. Also it was essential to re-calibrate* the instrument after taking it into an electric train or tram or near any other electric motor or generator. At least two calibration surfaces are needed for all these instruments. One of these is an uncoated metal plate to show the zero reading, the other is a metal plate coated with a known uniform thickness of the protective coating, to show the desired reading. Modern designs of the magnetic instrument may have overcome the serious disadvantage that readings had to be taken in the middle of large flat areas, because at least three "pencil" magnetic instruments exist, while on the larger modern instruments a small lightweight probe is used for taking the readings.

Inspection of Painting

The paint should be chosen after discussion of the job with the paint manufacturer or the painting contractor and should if possible be made according to the standards of the country where it is to be used. Simple tests of the paint's ease of brushing or spraying, drying time and viscosity, as batches come in, can be made by non-specialists and will show whether the paint in the later batches is the same as in the first batch. Flow cups or cup viscometers (BS 1733:1955) are simple instruments for measuring viscosity (also called consistency) and the flash-point test is also not very time-consuming.

Since the value of the paint is only a small fraction of the cost of the structure, it is obviously false economy to buy the cheapest paint but the most expensive also is not necessarily the best. Some trouble should be taken to find out the best coating for the job, whether metal coating is to be used or paint, and the type of surface preparation.

Probably the most expensive single task in applying the protective coating is the surface preparation of the steelwork. It also has more effect on the life of the paint than any other work put into the anti-corrosion scheme. The most important inspection work is, therefore, the inspection of the surface after preparation. Methods of preparation have been discussed in the section on painting. Here we are concerned with the inspection and approval of the surface by the inspector working for the maintenance engineer, and with its final cleaning before priming.

Standards of surface preparation of steelwork are perhaps the least advanced of all standards in the painting industry, but they do exist, however imperfect. The maintenance engineer or his inspector must come to an agreement with the contractor about the quality of the blast-cleaned surface that must be obtained.

Blast cleaning can contaminate the steel surface in several ways and these must be avoided. The compressed air must discharge an air blast without oil or moisture, therefore without mist. It must be dry. This can be verified by opening the compressed air valve and blowing to waste for a few seconds. If water or oil or mist is discharged, blasting must be stopped until the inspector is satisfied that the blast is dry. There should be a drain cock at the lowest point of the blast supply and it should be opened at least twice daily so as to discharge any oil or water that has collected. It is difficult to provide a completely dry air supply from a compressor, but it is possible. The air circuit may have to be re-designed, passing the air through a dryer after the drain cock, and possibly also through a pre-heater. Similarly, oil from the compressor must be kept out of the air line. This can be prevented by the use of good equipment and regular preventive maintenance, without excessive oiling. Such difficulties are unlikely with impeller blasting but this is ordinarily used only at factories. For site work, compressed-air blasting is usual.

If the grit or blasting shot are to be re-used, care must be taken that grease or old paint are removed from the steel before it is blasted, otherwise the grit will become dirty and foul the steelwork when it is re-circulated.

*The calibration of an instrument is the adjustment of its scale readings so that they give correct values. For example the Celsius thermometer is correctly calibrated when it reads 0° at freezing point and 100° when water boils. Calibration surfaces for thickness-measuring instruments carry known thicknesses of coating (one of which may be zero) to enable the scales of thickness testers to be correctly set.

Agreement with the blast-cleaning contractor on the correct standard of finish is usually achieved by a mutually accepted standard of comparison. This is a piece of steel, at least 10 cm square and 6 mm thick that has been blast cleaned to the agreed standard and sealed with a suitable varnish. The standard surface should be one that can be regularly achieved in practice and the surfaces obtained should not be rougher than the standard. It is better for the surface to be too smooth than too rough. Excessive roughness means that peaks may occur that will not be adequately covered with the paint or sprayed metal. Stated in another way, the same amount of paint will cover a larger area of smooth surface than of rough surface and will be uniformly thicker over a smooth surface than over a rough one.

To prevent rusting, some immediate treatment must be given to blast-cleaned steel, either a metal coating or a prefabrication or pretreatment primer. If the prepared steel surface becomes rusty it must be blast-cleaned again.

Maintenance painting also needs careful inspection. All dirt, salts, grease and so on must be removed from the surface before painting starts. If small areas are to be painted, surrounding areas of good paint must not be too much damaged by the surface preparation, and the new paint should overlap the edge of the old paint.

Instruments, Painting Conditions

Instruments required by the painting inspector for any type of painting will include a thermometer, a hygrometer, a thickness gauge for wet paint, and a thickness tester for dry paint or metal coatings. The hygrometer shows what is the relative humidity of the air. At relative humidities above 90 per cent with rising temperature (and above 85 per cent with falling temperature) painting should be stopped. The same applies to painting at temperatures below 4°C (40°F). These temperatures and relative humidities should be discussed with the painting contractor so as to make sure that he fully understands their meaning, and perhaps slightly modified if he states a good reason. Special care should be taken to watch the temperature and relative humidity after blast cleaning because compressed air cools the steel and may cause dew to fall on it. There should, of course, never be any painting out of doors during rain, mist or snow. Such conditions can ruin wet paint and correspond to relative humidities of 100 per cent or more.

The electrical continuity testing of plastic coatings or non-conducting paint was briefly discussed under Plastics.

SOURCES OF INFORMATION

In his search for information, the maintenance engineer will find that the names of the trade associations are particularly worth knowing. They can usually flood the enquirer at short notice with many pages of beautifully illustrated and well-produced material that costs him no more than a postage stamp and the trouble of writing a polite, preferably typewritten letter. They exist to promote the interests of their own trade and are, therefore, supported by the large companies in it. It is also worth remembering that, although they must tell the truth, they are particularly liable to emphasize the advantages of their own products and to say as little as possible of their disadvantages. In spite of this, their publications are extremely useful; the staff answer letters promptly and can be helpful in many other ways.

Institutes or institutions, being learned societies, however, are rather different. They are much less wealthy, being supported only by the subscriptions of the men and women qualified to practise their particular trade or profession. Although sometimes understaffed, institutions usually have information that is low in cost, high in quality and impartial. Every institution that has a stable existence possesses its own monthly or at least quarterly journal that reports matters of technical interest to its members. If a letter sent to an institution is not answered, and this may be because of shortage of staff, it is best to write again. The request for information should be re-written in a way that is easier for the institution to respond to, or that will bring the institution a small payment for a publication.

Research associations are a type of organization that is perhaps peculiar to the United Kingdom. They exist like trade associations to help their own particular trade, but by research, not solely by publicity. They also are supported by the subscriptions of their members but they receive Government support, often as much as the sum subscribed by their members. This means that they must conform to certain Government expectations and in particular the information they publish has to be of a high standard. None of the bias possible to a trade association is approved of and their publications must be impartial. One example is the Corrosion Advice Bureau of BISRA, the British steelmakers, which produces excellent publications, many of them free. Usually all information from a research association has to be paid for.

The maintenance engineer who is starting from a point where he knows very little and has to acquire as much absolutely reliable technical knowledge in a short space of time, should approach his country's standards institution. If his own country does not have standards on the matter of inquiry, he should investigate the standards of other countries. These foreign standards are usually available for reading at the headquarters of local standards institutions and can sometimes be bought from them.

A very large number of products are involved in the struggle against corrosion: corrosion-resisting steels, other corrosion-resisting alloys or metals, metal-spraying or plating products, hot-dipping, shot blasting, a very large number of paints, primers, undercoats, top coats and all their pigments, binders, thinners, corrosion inhibitors and passivators, quite apart from the building industry and all its techniques of damp-proofing, heating and ventilating and air conditioning that reduce the relative humidity of the air and its dust content and make it less corrosive.

In most countries, almost the only book that covers all these subjects effectively is the Standards Yearbook. Sometimes in the smaller countries the field is covered the more conveniently because all the material is referred to in one volume. Even if all the material is referred to in one book, however, the standards and codes concerned must still be read, either in a reference library or after purchase. The author of this report knows the UK best and has found that the Yearbook of the British Standards Institution (BSI) gives pointers to a very large amount of more or less co-ordinated information, almost all that a beginner to an industrial subject needs. There is certainly a vaster quantity of diverse and useful information in the standards yearbooks of larger countries but the information is not always conveniently summarised in one book.

Although sometimes understaffed, institutions usually have information that is low in cost, high in quality and impartial.

In case the previous paragraph should give a wrong impression, it should be pointed out that the standards yearbook merely indicates which are the standards or codes to be referred to and read on any particular subject. Standards generally are accepted rules, sometimes having the force of law, for the dimensions and quality of products. Dimensions are ordinarily defined in one standard, quality in another. Codes of practice are recommendations for good practice. They do not have the force of law but they explain the background and sometimes give a list of articles to read on the subject. For example British Standard Code of Practice 2008: 1966, "Protection of iron and steel structures from corrosion", gives a list of 93 literature references, mainly in English, but also in French, German and Russian.

As a matter of interest, in 1969 the BSI had more than 5000 published standards, was undertaking new work or revisions at the rate

of 500 standards or codes a year and had some 2400 projects in hand.

Drafts are the early form of codes and standards before they have been approved for publication. They are therefore not printed but written out in typescript and are then known as "Drafts for comment". The process of receiving comments in the draft, discussing them in the appropriate committees and agreeing on the final text takes several years for most publications, and therefore there is always a large number of documents in draft form. By tactful inquiry it is occassionally possible to obtain copies of the draft if any copies of it remain. Periodically, when a draft has reached a certain stage, it is reproduced in a limited number of copies that are circulated to those interested, for them to send in their comments. When a draft is ready for comment, this is usually announced in the monthly journal of the standards institution that is producing it.

The special importance of institutes or institutions, in the UK at least, arises from the fact that every individual working in a specialist subject must join his specialist institution as a means of progress in his work. Therefore every important specialist belongs to the institution concerned and can be found by writing to it. The literature of the institutions is useful but their members can be even more so because accepted good practice does not find its way into the literature for some years.

Of the institutions listed below, a few publish journals that are solely concerned with corrosion prevention, as will be seen from their titles. The others publish matter of occasional interest to the maintenance engineer.

A. Selected Scientific Institutions

American Iron and Steel Institute, 150 East 42nd Street, New York 17.

American Welding Society, 345 East 47th Street, New York 17.

CEBELCOR (Centre belge d'etude de la corrosion) Avenue Paul Heger, Grille 2, Brussels, Belgium.

Electrochemical Society, 30 East 42nd Street, New York.

Institute of Metal Finishing, 178 Goswell Road, London EC1.

Institute of Metals, 17 Belgrave Square, London SW1.

Institution of Chemical Engineers, 16 Belgrave Square, London SW1.

Institution of Civil Engineers, Great George Street, London SW1.

Institution of Corrosion Technology, 14 Belgrave square, London SW1.

Institution of Mechanical Engineers, Birdcage Walk, London SW1.

Institution of Structural Engineers, Upper Belgrave Street, London SW1.

Institution of Water Engineers, 11 Pall Mall, London SW1.

Iron and Steel Institute, 4 Grosvenor Gardens, London SW1.

Metal Finishing Association, Saint Dunstan's House, Carey Lane, London SW1.

National Association of Corrosion Engineers, 2400 West Loop South, Houston, Texas 77027 USA.

Oil and Colour Chemists' Association, Wax Chandlers' Hall, Gresham Street, London EC2.

Royal Institute of Chemistry, 30 Russell Square, London WC1.

Society of Chemical Industry, 14 Belgrave Square, London SW1.

Steel Structures Painting Council, 4400 Fifth Avenue, Pittsburgh, Pa. USA.

Stanford Research Institute, Menlo Park, California 94025 USA.

B. Selected Research Associations

British Welding Research Association, Abington Hall, near Cambridge, England.

Building Research Station, near Watford, Herts, England.

Corrosion Advice Bureau, British Iron and Steel Research Association, 140 Battersea Park Road, London SW11.

Forest Products Research Laboratory, Princes Risborough, Bucks. England.

Rubber and Plastics Research Association, Shawbury, Shrewsbury, Shropshire, England.

Water Research Station, Ferry Lane, Medmenham, near Marlow, Bucks. England.

C. Selected Standards Organizations and Other National Bodies

American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, Pa, USA.

British Standards Institution, 2 Park Street Mayfair, London W1.

Comite europeen des associations de fabricants de peintures et d'encres d'imprimerie, 42 avenue Marceau, Paris 8° France.

U.S. National Bureau of Standards, 318 Washington DC, 20234 USA.

U.S. Atomic Energy Commission, Washington D.C. 20545 USA.

U.S. Bureau of Mines, "C" between 18th and 19th Street NW' Washington D.C. 20545 USA.

The publications of U.S. Government organizations can generally be obtained from the US Government Printing Office, Washington DC, 20402 USA. The U.S. National Bureau of Standards publishes three monthly journals and is the main agency of the US Government for basic and applied research in physics, chemistry, mathematics and engineering. It is, therefore, unlike the standards organizations of most countries, which usually do very little research. The USA Standards Institute (before 1966 known as the American Standards Association) publishes nothing itself and does not itself initiate or write standards. The ASTM is probably the most interesting of these three organizations to the maintenance engineer.

D. Some Trade Associations and Commercial Research Stations

Aluminium Federation, 60 Calthorpe Road, Five Ways, Birmingham 15, England.

Copper Development Association, 55 South Audley Street, London W1.

GKN Fasteners Corrosion Laboratory, Birmingham, England.

Tin Research Institute, Fraser Road, Greenford, Middlesex, England.

Zinc Development Association, 34 Berkeley Square, London W1.

E. Books on Corrosion Prevention

Anti-corrosion Manual, 1964, Scientific Surveys Ltd., 11a Gloucester Road, London SW7.

Corrosion, by L.L. Shreir 1963, Newnes, London, 2 volumes.

Finishing Handbook and Directory, annually, Sawell Publications Ltd, 4 Ludgate Circus, London EC4.

Manual of Maintenance Engineering, Factory Publications, Mercury House, Waterloo Road, London SE1.

Packaging Code (Temporary protection of metal surfaces against corrosion during transport and storage), BS 1133 Section 6 1966, British Standards Institution, London.

Painting of Buildings, BSCP 231:1966, British Standards Institution, London.

Protection of Iron and Steel Structures from Corrosion, BSCP2008: 1966 British. Standards Institution, London.

F. Periodicals Concerned with Corrosion Prevention

Anti-corrosion Methods and Materials, monthly Sawell Publications Ltd, 4 Ludgate Circus, London EC4.

British Corrosion Journal, Institution of Corrosion Engineers, 14 Belgrave Square, London SW1.

Corrosion, National Association of Corrosion Engineers, 2400 West Loop South, Houston Texas, 77027 USA.

Corrosion Prevention and Control, monthly, Scientific Surveys Ltd., 11a Gloucester Road, London SW7.

Materials Protection, National Association of Corrosion Engineers, 2400 West Loop South, Houston Texas 77027 USA.

Product Finishing, monthly, Sawell Publications Ltd. 4 Ludgate Circus, London EC4.

A number of other journals have useful articles from time to time including: Chemistry and Industry. Chemical Processing, Industrial and Engineering Chemistry, Materials and Methods, Metal Industries, Revue Metallique, Sheet Metal Industry. The regular or occasional publications of the bodies listed under A, B, C and D above are also most interesting. ●●●

Purpose of Running in Process

The main purpose of running-in process of an engine is to bring the shape or surface finish of the mating surfaces of the cylinder-liner and the piston rings to their optimum value. During this process, sometimes, abnormal wear of the piston rings on the cylinder-liner sets in and badly damages one or both of these parts, leading to costly replacements and delays. The usual mode of this abnormal wear is by the process of scuffing. This sets in when a breakdown of the lubricant film occurs, resulting in 'metal to metal' contact of the mating surfaces. The resulting damage, usually snowballs in a very short time. The phenomenon of lubrication of piston rings in an engine is made more difficult by a variety of other factors, like:

i. high temperature in the ring zone;

ii. high specific loding at certain stages of the engine cycle, especially when the speeds are below the average surface speed of the piston;

iii. presence of combustion and other breakdown products of fuels and lubricants, which might (a) by nature, hinder the lubricating ability of the fluid film (e.g. act as abrasives); (b) have a size comparable with the film thickness at crucial points of contact.

—*Chemical Age of India*, January 1971, page 199.

Chemical Cleaning of Process Plant

M B Newton*

Chemical Cleaning is intended here as use of chemical solutions or solvents for the removal of deposits, scales, slimes or other debris usually from the internal surfaces of process plant. Though chemical cleaning is more expensive in material costs, and probably in capital costs for equipment, it has the advantage of completely removing deposits and surface stability after cleaning when compared to the conventional mechanical methods.

The choice of material for use in Chemical Cleaning should be on the basis of two requirements : (i) The material must dissolve or disintegrate the deposits so that they may easily be removed. (ii) The material used must not attack the metal from which the plant is constructed or must be inhibited to prevent such attack.

The success of any Chemical Cleaning operation lies in good design and planning. Another factor to be considered is to ensure that the plant insurance is not jeopardised by carrying out Chemical Cleaning process by unskilled personnel.

CHEMICAL Cleaning is by no means a new tool in the repair and maintenance of process plant. The Company for which I work has operated successfully in this particular field for almost forty years, and during this period, the use of chemical solutions has become widely accepted as a rapid and efficient way of removing deposits from industrial plant.

At this stage we should define broadly what is meant when we speak of 'process plant' in the context of this paper. This is perhaps best illustrated by reference to the Report of the Process Plant Expert Committee published by Her Majesty's Stationery Office recently. This defines the chief users of the process plant supply industry as follows:

Chemical Industry

Petrochemical Industry

Gas

Oil

Electricity Generation.

The list is by no means exhaustive, and some of the above sections contain a very wide spectrum of different industries.

*Clensol Limited, Hainault, United Kingdom

The plant itself can obviously consist of a variety of combinations of various items of plant, such as, pipelines, pumps, reactors, contact towers and heat exchangers of all types.

The term chemical cleaning is intended here to include the use of chemical solutions or solvents for the removal of deposits, scales, slimes, or other debris, usually from the internal surfaces of process plant.

Why is Chemical Cleaning Necessary ?

If the field of chemical cleaning is considered as a whole, the vast majority of cleaning operations are carried out on heat exchangers, taking the term in its broadest sense.

Examples of such heat exchange systems are boilers, condensers, coolers, water cooling jackets, heat exchangers, feed water heaters, evaporators, industrial hot water systems, calorifiers and similar plant.

In most types of plant listed above, water is used as the cooling medium, except that, in the case of boilers and heating systems, the water itself is heated. The total effect in all cases is that heat is transferred from an external source into the water. This heat transfer usually takes place through metal surfaces (for example tube walls), which separate the heated and the heating media. When the metal surfaces are clean, heat can easily pass through, but if the metal becomes fouled by scale or deposits, the rate of transfer of heat between the two systems is reduced. In the case of a boiler, the reduction in heat transfer may be sufficient to cause the boiler metal to become overheated, and to fail under the effect of pressure of steam within the plant. In, say, a condenser, however, the results are less serious mechanically, but the unit operates at a much lower efficiency if deposits impair the free transfer of heat.

Deposits Caused by Water

When water is the heated medium, deposits may result from the effects of heat on dissolved salts in the water, such as hardness salts, which produce scale. Alternatively, in soft water areas, or where water supplies are treated to reduce hardness, the effect of heat may induce corrosion of the metal surfaces, and deposits of iron oxide or rust may result. Again, in other areas, local water supplies may encourage organic growths in the plant.

Any of these types of deposit (and the list is not exhaustive) will reduce heat transfer rates as described previously, and they eventually must be removed in order that the plant may function efficiently and safely.

Product Fouling and Other Deposits

In addition to those depoists formed in heat exchangers which derive from the chemical changes occurring in water used in them, heat exchangers may also become fouled on the product side. For instance, an oil cooler may build up deposits of oxidised or partly decomposed oil on the outside of the tubes through which the cooling water flows. The total effect will, of course, still be that the efficiency of the heat exchanger is reduced. (A later section will deal with means of determining the economics of lossess caused by this fouling when compared with the cost of chemical cleaning). Furthermore, fouling can happen in heat exchangers which do not use water in any shape or form. An example of this is in the Furnace type heater often used in refineries. In this case, sulphide deposits usually result from the action of sulphur in the petroleum products forming scales on the parent metal of the heater. These again reduce heat transfer rates, and must be removed in order to restore the heater to its original efficiency. Reboilers on reformer units are similarly affected. (Special cleaning methods are necessary in order to avoid danger from poisonous gases formed in the cleaning process).

Other Plant Systems Which May be Chemically Cleaned

Besides heat exchangers, many other plant systems may be in need of chemical cleaning owing to fouling. For example, long pipelines carrying unstable water supplies often become restricted due to the drop-out of temporary

hardness scales. Pipelines similarly may be attacked by corrosion which forms tubercules, restricting the flow of the water in the pipe. Both these types of fouling may be treated by chemical cleaning. Many other systems respond to chemical cleaning, a further example being the removal of deposits from a spray tunnel in which car bodies are cleaned and treated before being finally painted. The circulating spray systems in such a tunnel very often become clogged with deposits, and it is possible to clean the system quickly and conveniently, with the minimum of shutdown period and with no dismantling, by chemical methods. Deposits on the gas side of boilers may be removed by spraying the ash deposits with chemical solution prior to washing down of the unit with treated water.

Precommission Cleaning

A particular field of chemical cleaning which is sometimes overlooked is that applied to process and industrial plant in general, before the plant is commissioned. While this may, at first sight, have no bearing on the maintenance and repair of process plant, it does, however, play a most important part in preventing teething troubles during the early life of the plant.

New items of process plant are usually supplied in a "commercially clean" state from the manufacturers, but in many instances, the condition deteriorates during the delivery and erection period.

Furthermore, during the construction of the plant, the interconnecting pipework usually deteriorates, and the whole plant collects general debris in the shape of dust, weld scale and even general rubbish (including such unlikely objects as bottles and old boots.)

While chemical cleaning is not the best means of removing the latter foreign matter, it will remove millscale, rust, dust and similar contamination from the plant.

If these contaminants are left behind, it is highly likely that the presence of one or all of them will make itself felt sooner or later during the operation of the plant.

For instance, in boiler plant, millscale (the blue black surface oxide on manufactured steel articles) gradually becomes detached, and can cause not only choking of blowdown valves, but also may promote corrosion processes by the very fact of its *incomplete* removal. Similarly, the presence of silica in general dust will cause high silica concentrations in the boiler water, which is most undesirable in high pressure plant, and usually results in the wastage of much feed water on initial startup. Chemical plant, in general, will also benefit from cleaning before commissioning where rust and general debris results in contamination of the early output.

Chemical cleaning includes the use of chemical solutions or solvents for the removal of deposits, scales, slimes, or other debris, usually from the internal surfaces of process plant.

In general, therefore, the need for cleaning both new and used process plant is firmly established, and all that remains is to convince plant managers that the chemical methods of achieving such internal cleanliness is well worth the extra attention necessary.

The following text is written with this one object in view.

ECONOMICS OF CHEMICAL CLEANING, AND A COMPARISON WITH MECHANICAL METHODS

How Much Can Chemical Cleaning Save ?

It is customary for us to find that, as chemical cleaning contractors, we are frequently called in at the last moment to clean process plant which is on the verge of becoming unusable due to deposit build-up, or has, in fact, ceased to operate for the same reason. It would obviously be much more expedient if chemical cleaning could be arranged to take place at such a time that unscheduled shutdowns due to breakdown of the plant are avoided. It is, however, difficult to decide the point at which the cost of the chemical cleaning process, vis-a-vis the monetary saving resulting from such cleaning, can be balanced.

An article in British Chemical Engineering suggested a practical means for determining the *most economical time to clean* heat exchangers. There is no reason why this method should not be extended to cover the cleaning of all process plant where the losses due to fouling can be estimated over successive fixed periods of time.

The monetary losses due to fouling are plotted against the time axis, where the units of time are those most convenient, depending on the rate of fouling in the unit. These monetary losses in process plant operation may result from either reduced output due to lower efficiency caused by fouling, or by increased fuel costs made necessary by the extra energy involved to maintain the output. For example, if the heating coil in an evaporator becomes fouled, the output from that evaporator will become steadily less as the fouling increases. The drop in output results in a direct financial loss which may be recorded as a monetary loss per day or per week whichever is most convenient. On the other hand, it may be necessary to increase the heat input to the evaporator to maintain it's original output, in which case, the monetary loss will be represented by the extra cost of fuel involved to maintain output at the original level.

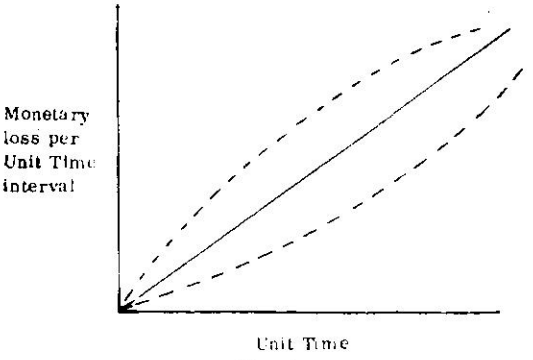


Fig. 1

A curve can, therefore, be plotted for monetary loss per unit time due to fouling, against those time units. If this curve is commenced immediately following cleaning, the curve will start from the origin and will take one of the three shapes shown in figure 1, depending on whether the fouling is increasing at a constant rate, or whether the rate is increasing with time or decreasing with time.

At any period of time, the total monetary loss will be represented by the area under the curve. (See Fig. 2) This area may be calculated by

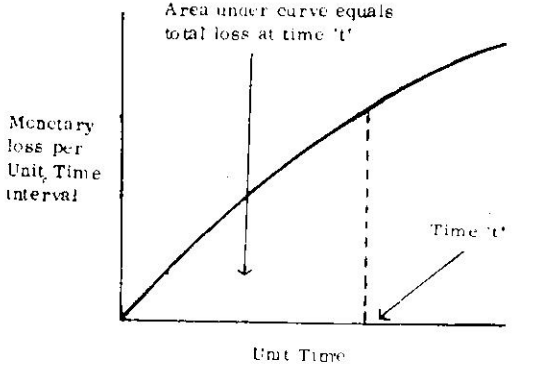


Fig 2

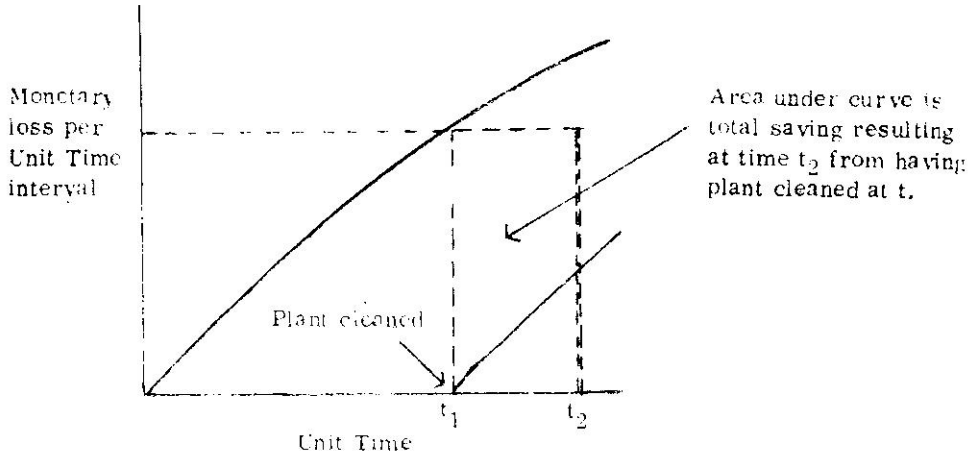


Fig. 3

simple graphical means, or may be determined by the use of a planimeter.

If we now consider the curve which is obtained both immediately after cleaning, and which shows a build-up to a maximum when cleaning is again carried out, we should obtain the curve shown in Figure 3. It is now obvious that the monetary saving per unit time achieved by the cleaning process can be represented by the shaded area above the curve. (Assuming that the fouling resistance would have remained constant.) Thus, at any given instant of time the savings resulting from chemical cleaning can be compared with the monetary losses accumulated to that date.

The most economic time to clean again must obviously be when the total savings resulting from the previous cleaning are equal to the monetary losses incurred by the increase in fouling, i.e., when the two areas above and below the curve are equal.

The method must be further developed to include the actual cost of the cleaning operation. These costs result from the following items:

Loss of Production, Loss of Efficiency — due to shut-down for cleaning purposes

Cost of Materials

Cost of Labour

Depreciation of Cleaning Equipment.

For most economical working, the cost of cleaning should be equal to the savings calculated from the area over the curve. If the cost of cleaning is greater than the saving obtained at any particular time, then obviously the expendi-

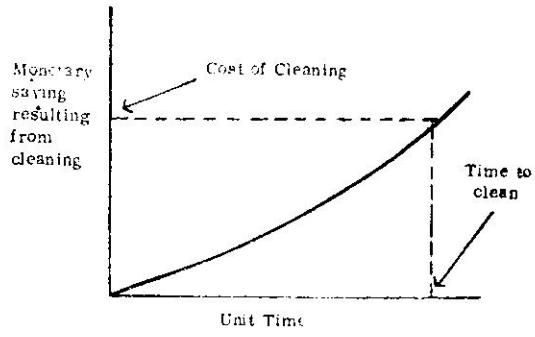


Fig. 4

ture incurred is excessive, but if, on the other hand, the savings are shown to be greater than the cost of cleaning, then the fouling has been allowed to proceed too far. In either case, the situation is uneconomic.

A simple method of finding the best time to carry out chemical cleaning is to construct a further curve of the savings against time since cleaning, as in Fig. 4. The values for the savings are derived from the shaded portion above the fouling loss curve shown previously, the area of the curve being calculated as before or by using a planimeter to estimate the saving over specific time intervals. Time to clean is then obtained from the curve by drawing a line from the value of the cost of cleaning on the ordinate parallel to the absissac.

Where plant needs to be cleaned regularly due to fouling, the above method presents a means of obtaining the maximum economic benefit from chemical cleaning. The method assumes that the fouling pattern is the same for each period of operation of the plant even though the rates of fouling may vary according to seasonal changes. Typical fouling patterns can be produced for each item of plant following which the above method is easily applied.

Advantages of Chemical Methods of Cleaning

Mechanical Methods: Prior to the wide acceptance of chemical cleaning as a maintenance tool, mechanical methods of cleaning process plant were the only ones available. These included scraping, chipping, rubbing or brushing away debris of all sorts from the plant, the use of "bullets" fired from compressed air for cleaning heat exchanger tubes, while "pigging" was, and still is, widely used as a main means of cleaning long pipelines. Mechanical or physical cleaning has, however, received a tremendous boost by the introduction of high pressure water jetting pumps, in which the cleaning process is accomplished using very high pressure multi-stage pumps to deliver a relatively small flow of water through special nozzles. Amazingly good results have been obtained using this method, limited only by the ability to apply the jets of water to the area to be cleaned. Deposits which sometimes prove unresponsive to chemical cleaning are very often removable by this method.

In certain cases, particularly where very resistant deposits consisting mainly of carbon are concerned, it has been found that a combination of water jetting and the use of chemical solutions is necessary to achieve the maximum efficiency in cleaning. The instances are, however, few and far between, and in general one method or the other suffices. All in all, most mechanical cleaning involves a good deal of "sweat and strain" while producing mediocre results.

Chemical Methods and Their Advantages: Although most mechanical methods of cleaning are simple to carry out, the results are often far from satisfactory from several points of view. With the introduction of safe chemical methods of carrying out plant cleaning, however, the plant manager has available a most efficient maintenance tool.

The *advantages* which may be claimed for the chemical methods of plant cleaning when compared with mechanical cleaning may be considered under three main headings:

Speed—and hence economy
Accessibility
Results

Speed: When considering mechanical methods of cleaning plant, the first operation after isolation is always "dismantle", and herein lies the great advantage of the chemical method.

Taking the simplest case, the cleaning of a shell and tube heat exchanger on the tube side, we can compare the two methods as follows:

	Mechanical	*Chemical*
Break flow & return connections	2 hours	2 hours
Fit adaptors & circulating equipment	- -	1 ,,
Remove Water Box	6 hours	—
Clean (say 500 tubes)	17 ,,	2 hours
Flush each tube	3 ,,	¼ ,,
Break connection	—	½ ,,
Reinstate water box	8 hours	—
Reinstate flow & return)	3 ,,	3 hours
	39 hours	8¾ hours

With *larger plant*, the chemical method becomes even more attractive, since both the breaking open of water boxes, and the mechanical cleaning process itself occupy a longer period. The chemical cleaning method, on the other hand, does not require a proportionately longer time to complete the actual cleaning phase—only a greater volume of solution. Furthermore, in the case of heat exchangers, it is possible to chemically clean two units in series—and include the interconnecting pipework in the clean. Similar advantages in time apply in the case of such plant as water tube boilers—the physical action of pushing a brush through each tube in the unit occupying a very much greater time than by the use of chemical solutions. If the deposits are hard—the advantage is even more marked, since the use of descaling cutters again expands the time required in mechanical operations.

Against this advantage, *the chemical cleaning is more expensive in materials costs, and probably in capital costs for equipment.* The labour required, while to some extent necessarily of a higher calibre than those used in mechanised methods, are usually less in numbers, so these factors balance. On the credit side, however, the great saving in using chemical means lies in the reduction of outage time, and this can be even further reduced by the fitting of blanked branches on the plant which is required to be cleaned, thereby removing the necessity of breaking flow and return connections each time cleaning is carried out.

Accessibility: The previous section has compared chemical and mechanical methods of cleaning on plant which *can* be cleaned by both methods. In more and more instances nowadays, we find that chemical means are the *only possible* means of cleaning process plant. For instance, many modern water tube boilers have no points of access from which brushing of each tube can be carried out. Compressor cooling water jackets are another example of the advantage of accessibility which chemical methods exhibit. Similarly, when considering a shell and tube heat exchanger, we often find that deposits on the shell side of the tube bundle form a solid mass between the individual tubes. There is a remote possibility of mechanically removing such fouling if the bundle can be withdrawn from the shell, but absolutely none if this is not the case.

This type of fouling often occurs in the modern package type of firetube boiler, and chemical methods are the only way of cleaning this type of plant under these circumstances.

Long lengths of welded pipe run can only be cleaned by physical means if high pressure water jetting equipment and crawler hoses are available, or unless provision has been made for 'pigging'. Simple fill and soak chemical techniques will, in many cases, provide the simple answer to this problem.

Results: The results of the cleaning process, whether it be carried out by mechanical or chemical methods should be judged on the following criteria:

(a) Completeness of removal of deposits

(b) Absence of removal of plant materials

(c) Stability of surface after cleaning.

(a) *Completeness of removal of deposit* is much more likely to be achieved in chemical methods than in mechanical, provided that the correct cleaning solution has been chosen, and that conditions of use have been correct.

Mechanical methods invariably leave small adherent particles of deposit, which eventually on the return to service of the plant act as nucleii for the recommencement of buildup of fouling—hence the "period of immunity" of newly cleaned surfaces is reduced with consequent loss of efficiency and the earlier need for recleaning.

(b) *Absence of removal of the plant materials* is obviously essential. While many engineers regard the thought of filling a piece of plant with acid (even though it is inhibited) as completely unthinkable, they will cheerfully allow the valuable components of the same plant to be scratched and scored by scaling tools

When properly applied, chemical methods remove less parent metal from the plant than heavy manual scaling techniques, and leave a surface which is smooth and less liable to corrosion.

without any qualms. Using modern inhbitor materials, and when properly applied, chemical methods remove less parent metal from the plant than heavy manual scaling techniques—and leave a surface which is smooth and less liable to corrosion.

(c) *The stability of the plant surface after cleaning* can be ensured by selecting the appropriate passivation method to follow the chemical cleaning process. These produce a 'deactivated' metal surface which is uniformly covered with a suitable oxide or other stable coating, and so is less susceptible to atmospheric corrosion. On the other hand, mechanical methods may leave the metal surfaces in a roughened condition which not only provides nucleii for subsequent fouling, but also has in the crevices and scratches a potential seat for future corrosion.

Conclusion

Taking all three criteria into account, viz., speed, accessiblity, and results, the chemical method has most decided advantages over mechanical means of cleaning, and the most positive of these, speed, becomes more advan tageous as plant size increases.

METHODS USED IN CHEMICAL CLEANING PROCESSES

Materials

When considering which material to use for a chemical cleaning process, two factors must be borne in mind, namely:

The material must dissolve or break down the deposit sufficiently for it to be removed from the plant.

The material used must not attack the materials of construction of the plant.

Inhibited Acids: The most widely used materials in chemical cleaning processes are undoubtedly the inhibited acids. Obviously, if acid solutions were used alone they would not comply with the second requirement given above, and the metals used in the construction of the plant would be badly affected by the cleaning solution. Inhibited acids are therefore used, and these normally consist of the ordinary commercial acids treated with chemicals which have the effect of allowing the diluted acid solutions to dissolve unwanted deposits and oxides, but prevent the attack by the acid on the metal of construction of the plant. These inhibitors vary very widely, and the earlier ones were often simple inorganic chemicals or even natural products such as glue. Nowadays, however, much more complex materials are used—these are normally organic chemicals which are stable at elevated temperatures and which reduce attack on the parent metal to very small proportions. The most widely used inhibited acid solution is undoubtedly that based on *hydrochloric acid.* This material was probably the first used in chemical cleaning methods as we now know them, and it still remains the most generally acceptable material today. It is possible to inhibit this aicd most effectively using modern materials, and the concentrated acid is easy to handle and is reasonably cheap.

Inhibited hydrochloric acid, when used under the correct conditions, is highly effective for the removal of rust, millscale, and other oxides of iron, water scales and deposits, and it can be used in contact with a wide range of construction materials. Depending on the type of deposit to be removed, and on the time available, it may be used in many cases at ambient temperature. Solubility of more resistant deposits is, however, increased when higher temperatures are used, and the time required for a cleaning

operation can similarly be reduced by using hot solutions. It must be borne in mind, however, that the attack on the parent metal also increases with increasing temperature, and it is essential that an efficient inhibitor is used which is capable of withstanding the elevated temperature conditions. Many commercial inhibitors which are perfectly good at ambient temperatures and indeed up to temperature as high as 140°F. (60°C.) decompose above this temperature. The result is not only that the parent metal is attacked to a greater extent, but also that the decomposition products of the inhibitors often produce treacly deposits inside the plant. Selection of the correct inhibitor is, therefore. essential.

Inhibited hydrochloric acid may be used in dmixture with other materials in order to amprove its performance when in contact with imore acid sensitive materials. It may, in certain cases, be used to clean brass, by the addition of suitable chemicals to control dezincification. Similarly, by the addition of flourides, the effect of the inhibited acid solutions on deposits containing silicates is much enhanced. Normally this type of deposit is resistant towards chemical cleaning, and very often presents a difficult problem when considering removal. For this purpose, hydroflouric acid or one of the soluble fluorides such as ammonium bifluoride or sodium fluoride may be used in proportions of approximatey 1% by weight.

Although hydrochloric acid is suitable for use in plant containing carbon steels, it is generally considered to be not suitable where stainless steels are encountered. This is due principally to the danger of stress corrosion cracking which is initiated in austenitic stainless steels by the presence of the chloride ion. While it is possible that by very thorough washing such danger could be avoided, it is normally considered good practice to avoid the possibility of any such attack.

Sulphuric Acid has also been used extensively in chemical cleaning processes. This acid when inhibited has proved to be a good solvent for many types of deposit, with the exception of the hardness scales, i.e., those containing clacium salts. It is cheaper than hydrochloric acid when considered on a degree of acidity basis, but it is not so easily handled as the aforementioned product. Furthermore, the efficiency of inhibition is not so great as that in the case of the inhibited hydrochloric acids. There is a tendency for the inhibitors available for this material to break down after being in use for a certain period of time. This need not be too serious if adequate chemical control can be ensured for the chemical cleaning process, but this is usually the exception rather than the rule in most operations. Sulphuric acid is, however, often acceptable when dealing with austenitic stainless steel plant, although this too is excluded by the Electricity Generating Boards in the U.K.

The use of *sulphamic acid* overcomes many of the problems inherent in the use of sulphuric acid, in that the acid is a solid material, which is relatively easy to inhibit efficiently, although the solutions are of similar acidic strength to the commonly used mineral acids. It does, however, have the disadvantage that on an acid for acid basis, its cost is realtively high. It may, however, be used for dissolving clacium based scales, since it forms soluble sulphamates unlike sulphuric acid which forms insouble sulphates. It is, unfortunately, not particularly effective in the removal of rust and millscale, but it is claimed that this action may be increased by admixture with other acids. This, however, complicates the process unnecessarily. It's one great advantage is that despite it's relative strength, it is more easy to inhibit when dealing with the acid sensitive metals. It thus provides an effective reagent for the descaling of nonferrous metal equipment, and is even permissible where soldered or brazed joints are present.

The other common inorganic mineral acid, *nitric acid*, is not used to any large extent in everyday chemical cleaning, principally because of the difficulty of inhibiting this material. It is, however, used very largely in the precommission cleaning of stainless steel items of plant. In this respect, it is used in admixture with sulphuric and hydrofluoric acids as a paste for removing weld oxides from fabricated strctures, again in admixture with hydrofluoric acid as

a cleaning agent for the surface of mild steel plant, and it is used alone for passivating such stainless steel fabrication following the chemical cleaning phases.

Organic acids, and in particular, *citric acid,* have been widely used in recent years in the chemical cleaning field. Citric acid is expensive, but it has been used to a great extent in the cleaning of Power Station plant. It is usually used in 3 % solution at high temperature with the pH value of the solution adjusted to approximately 3.5 with ammonia or ammonium bifluoride. Under these conditions citric acid is a most effective solvent for rust and millscale, and, since it has no bad effects on austenitic stainless steel, it is most valuable in cleaning plant containing these materials. Citric acid for a while enjoyed almost universal acceptance in the post-commission cleaning of power plant since it was feared that the use of stronger mineral acids was causing damage to the parent metal structure. It was, however, found that the cleaning effect of this material was not so marked as that of inhibited hydrochloric acid, and the latter material has now returned to favour. This has been assisted by the discovery that the aggressive nature of well inhibited hydrochloric acid solutions is no greater than that of the inhibited citric acid.

Other organic acids have been used in addition to citric acid. Mixtures of *hydroxy acetic acid* and *formic acid* have been used extensively in the United States and to a lesser extent formic acid and acetic acid have been used by themselves for the chemical cleaning of more acid sensitive materials.

Sequestering agents such as *ethylene diamine tetra acetic acid,* commonly called E.D.T.A. have been proposed and to a small extent used for some years for the removal of calcium based scales in sugar evaporators and similar plant. Recently, methods have been developed to use derivatives of this material for the removal of iron oxide and copper oxide deposits from boilers. The advantages claimed for such methods are that the alkaline solution is used to remove such deposits resulting in less metal attack and a more passive finish. Unfortunately, it seems necessary to apply such solutions at elevated pressures and temperatures in order to produce results equivalent to the more widely used acid, and under such conditions, the attack rates become comparable with those of the inhibited hydrochloric and similar acids.

Degreasing Agents: In many cases deposits of a greasy or oily nature are required to be removed. Chemical cleaning in such cases is usually accomplished using degreasing solutions which may fall into one of the following three classes:

The alkali/synthetic detergent mixtures

Organic solvents

Emulsifying solvents.

In many cases where acid cleaning is to be carried out, it is essential to remove grease which is also present in the deposit. This is to prevent the grease or oil from repelling the acid solutions, and hence masking the deposits from the action of the acid.

Alkali/synthetic detergent degreasing solvents are widely available commercially, and make use of such materials as caustic soda, the alkali metal phosphates, the alkali metal silicates, sodium carbonate, etc. These materials are used either singly or in admixture together with suitable commercial synthetic detergents. The materials are usually applied as hot solutions to the plant to be cleaned, and agitation or circulation is essential to improve emulsification or solution of the greasy material.

When choosing a degressing material, it is still important to take into consideration the material of construction of the plant. Aluminium and zinc and their alloys with other mtals will be attacked by solution of too great an alkalinity, and special precautions must be taken in these cases.

The organic solvents used in chemical cleaning processes are usually of the chlorinated hydrocarbon type. These materials are non-

inflammable, and have a high capacity for mineral oils and greases. They may be used either by washing the plant with a quantity of the solvent itself, or may be applied as vapours using an external vapouriser to supply vapour of the solvent to be applied to the plant to be cleaned. Inside the plant the vapour condenses, and the condensing solvent washes down the walls of the plant, freeing them from oily deposits. Examples of such solvents are trichlorethylene, perchlorethylene, methylene chloride etc.

The emulsifying solvents are a class of chemicals used in chemical cleaning methods which are most versatile and easy to use. Many types are available commercially, but they usually consist of kerosene or an aromatic solvent depending on the type of deposit to be removed. The solvent itself contains an emulsifying agent. Oily deposits are removed by application of the emulsifying solvent to the plant, and this results in solution of the oily material in the solvent. As much of the solvent as possible may then be drained off, the remaining solvent being washed away by water. The presence of the emulsifying agent causes the solvent and its dissolved oil content to be readily emulsified and so removed easily from the plant. It is possible to use premixed emulsions of these solutions to remove oily deposits, such methods usually employing heated solutions.

Other specialised solvents are used for particular examples of chemical cleaning. For instance, algaecides may be used for the removal of slime or mould growths in cooling systems. However, such applications are of limited applicability, and so are generally outside the scope of this paper.

To repeat, therefore, the *choice of a material for use in a chemical cleaning process must be examined on the basis of two requirements:*

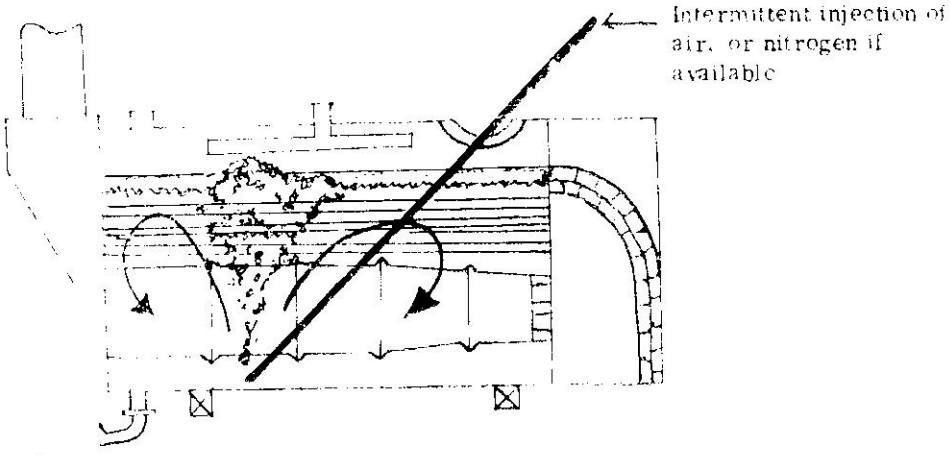
1. the material must dissolve or disintegrate the deposits so that they may be easily removed.

2. the material used must not attack the metal from which the plant is constructed, or must be inhibited to prevent such attack.

Methods

"*Sit & Soak Methods*": The commonest method, and by far the most widely used method of chemical cleaning processes, is probably the "sit and soak" method. This is simply to fill the plant which is to be cleaned with a premixed solution of the chemical cleaning reagent. Alternatively, the unit may be filled with water, and the chemical solution or reagent is then added and stirred into the general bulk of the water. This method can produce good results provided that its limitations are realised. It obviously works best where there is an evolution of gas resulting from the action of the cleaning agent on the deposit. This is, of course, the case where temporary hardness scales are being removed, these consisting of calcium carbonate which evolves carbon dioxide when treated with inhibited acids. The evolution of gas generally mixes the solutions rapidly, and prevents local stagnation. The process is allowed to continue until the maximum amount of scale has been dissolved, fresh reagents being added if necessary. The solution may, of course, be stirred mechanically, or by blowing air through it from a compressor through a suitable discharge tube. (See Fig. 5.)

Auto Circulation: This method was developed from the sit and soak method where gases are evolved. Very briefly, it depends on the fact that the density of a column of liquid containing gas bubbles is less than that of the liquid itself. In practice, the equipment to be cleaned is connected from its lowest point to a suitable container in which the chemical cleaning solutions can be placed by means of flexible hoses. The container is placed at a sufficiently high point to enable solvent to flow by gravity into the plant. A return hose is taken back from the top of the plant to the container. In the plant gas is generated because of the reaction between the solvent and the carbonate scales, and the resulting liquid gas mixture flows back to the container by virtue of its lower gravity. (See Fig. 6.)

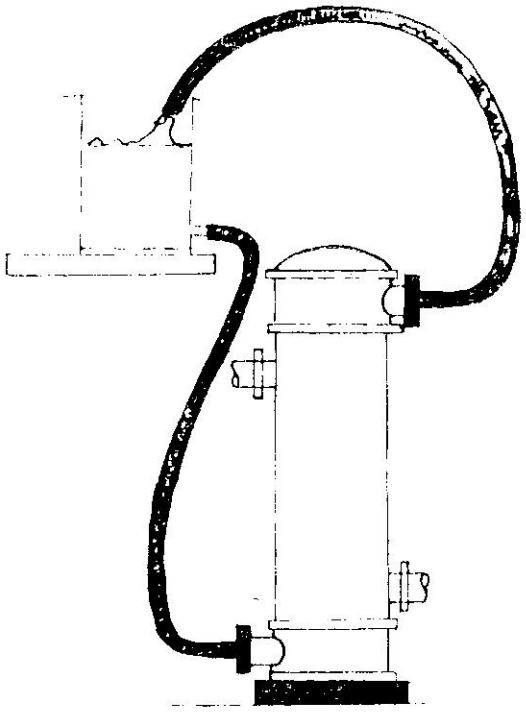


'Sit and Soak' Cleaning Method (Economic Boiler)

Fig. 5

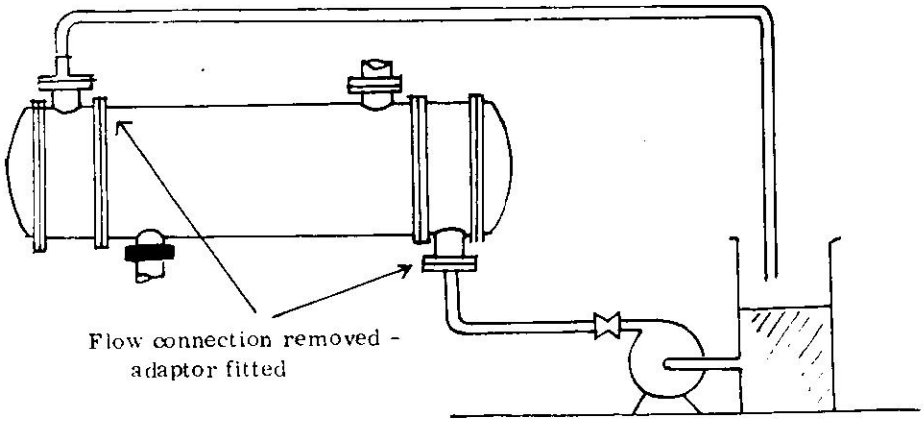
Pump Circulation: Where auto circulation cannot be used, circulation may be induced in the unit by using a suitable pump. (See Fig.7.) In its simplest form a pumped circuit takes off its supply from the lower part of the unit to be cleaned, and returns the cleaning solution to the top of the unit. In this way, stagnation of the cleaning solution is avoided, and a fresh supply of solvent is continuously put into contact with all parts of the plant. It is rarely possible to improve cleaning processes using this method by the velocity effect alone. If sufficienty high velocities are used to scour away resistant deposits, then metal attack would almost certainly take place due to breakdown of the inhibitor film. It is important when considering pumped circulation to study the design of the circuit with some care. The factors which must be taken into account when considering this type of circulation are the limiting flow velocity which will be dealt with in a later section, combined with the necessity for recycling the solution within the unit in a reasonable space of time, in order to avoid local stagnation and saturation of the cleaning solution.

Gas Induced Circulation: In the section on auto circulation, mention was made of using compressed air or similar gases in



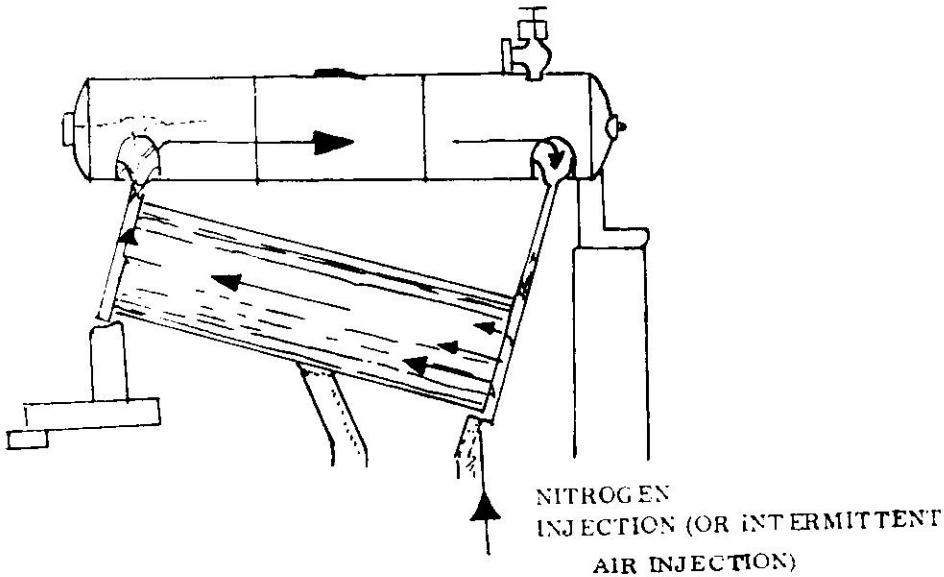
'Autocirculation' Cleaning Method (Heat Exchanger)

Fig. 6



Pump Circulation Method (Heat Exchanger)
Fig. 7

order to stir up the solution in a vessel or other item of plant. By introducing the air or gas at a suitable place within the plant, it is possible to induce a circulation comparable with that which may be produced when using an external pump. An example of this type of circulation is included in Fig 8, which shows the use of air to induce circulation in the chemical cleaning solutions used in a simple water tube boiler design.



Gas Induced Circulation (Simple Water Tube Boiler)
Fig. 8

Foam Cleaning Methods: Several types of apparatus, some of them covered by patents, have been designed to produce chemical cleaning solution in the form of a relatively stable foam. These foams are pumped much in the same way that a liquid may be pumped into the plant to be cleaned. Inside the plant the foam bubbles break on contact with the surface, and the chemical cleaning solution from which the foam was formed, runs back down the walls of the plant as a solution. The advantage claimed for this type of cleaning is two-fold:

1. The amount of chemical reagent needed is relatively small.

2. The weight of cleaning solution inside the plant is small compared with that if the plant were to be filled.

The first reason may be somewhat of a disadvantage if the types of deposits to be removed are of a nature which will react with the cleaning solvent. The small volume of solution used in this respect becomes a disadvantage, because the solution rapidly becomes exhausted by reaction with the deposit. On the other hand, if the deposit is loosened by the foam, then this may be a valid way of removing it. Similarly, oily deposits may be removed by using a foam made from degreasing solvents. The second advantage is obviously of great value when plant is to be cleaned where the design is such that it will not support the weight of chemical cleaning solution which would be necessary to fill it.

Foam methods, although apparently having advantages, are little used in the United Kingdom.

Spray Methods: In certain types of plants, it may be possible to introduce chemical cleaning solutions in the form of sprays. For example, when it is required to clean a large tank, it is usually possible to arrange for some sort of manifold which will supply solution to all parts of the internal surfaces when charged by a pump. Alternatively, rotating heads may be used which distribute the solutions over the whole interior surface of the vessel. Such methods have the advantage of using only moderate amounts of cleaning solutions, and are thus much more economical than filling the vessel. The same disadvantage may apply in this case, namely, that the solution may become exhausted, and it is necessary to maintain control over this aspect of the operation. Spray methods are obviously limited to the cleaning of surfaces which are easily accessible, for example, the interior of tanks, or the exterior surfaces of surface condensers.

Paste: Where local areas of plant are to be cleaned, and where it is either impossible or uneconomic to fill the plant, the application of chemical cleaning solutions in paste or gel form may be considered. This method obviously has an advantage over the spray method previously reported in that the application of the material may be confined to small localised areas. The method employs the usual solutions used for chemical cleaning, namely, inhibited acids, and these are transformed to a paste-like consistency by mixing them with an inert absorbent material such as barium sulphate. The resulting paste is then applied to the metal surfaces by means of trowels or spreaders, and is left in position for sufficient time for the chemical cleaning reagent to have the desired effect. It is, of course, obvious that such a method will produce rapid saturation of the chemical cleaning reagent, since fresh supplies of the solution are not repeatedly brought into contact with the surfaces. The paste is then washed away with water and if the required results have not been obtained, the process is repeated. Inhibited acids may also be transformed into gels by using suitable organic thickening agents, although the majority of these have only a limited life in such solutions. These gels are again applied by painting or pasting the area to be cleaned. The type of application where these methods are used is, for example, the cleaning of weld areas in fabricated steel tanks, particularly in stainless steel structures. In these cases, the welds are initially ground to remove excess metal, but the weld area is usually surrounded by a discoloured surface due to heat staining by formation of oxides. In these cases, a paste containing sulphuric, nitric and hydroflouric acids is applied, the pasting agent usually being barium sulphate

in this case. There is, of course, no reason why other chemical cleaning solutions should not be used for paste methods, with the one limitation that the amount of fresh solution in contact with the surface to be cleaned is minimal.

Vapour Methods: Mention has been made previously of the use of organic solvents such as chlorinated hydrocarbons for the removal of greasy and oily deposits from industrial plant. If oily deposits are to be removed using liquid organic solvents, then a succession of washes must be employed, since otherwise the residual film of solvent left in the plant will redeposit oil on final evaporation. The use of solvent vapours, however, avoids this disadvantage, since by distilling a solvent, fresh solvent forms continuously on the metal surfaces by condensation. On running down the walls of the vessel, the condensed vapour dissolves the oily material and returns this to the vapouriser. Subseqeuntly, the solvent distills off again, leaving behind the contamination.

The method is valuable where contamination is relatively light, and where the proportion of solvent insoluble materials in the deposit is small. Should there be a high proportion of insoluble material, the usual effect is for vapour treatments to remove the oily matter from the contamination, but leaving behind much of the solvent insoluble material in the form of dusty deposits on the oil-free surfaces. The use of solvent vapours is obviously to be preferred from the economic standpoint, since the amount of solvent employed is very small compared with that needed to carry out repeated washings using the liquid solvent.

In certain types of plant, it may be possible to introduce some of the required solvent into the bottom of the unit, and then to heat this by introduction of steam coil or similar heater. The solvent vapour then distils and diffuses through the plant, condensing on the cooled surfaces with the cleaning effect described previously. At the end of the process, all of the contamination within the plant is concentrated in the residual solvent at the bottom of the unit, and may be drained away, so removing the maximum possible contamination while using the minimum amount of solvent.

A second type of vapour phase cleaning involves the use of steam as a carrying agent. For example, should the plant to be cleaned be in the form of a long pipeline, steam is blown through the line and cleaning chemicals are injected into the steam. Under carefully controlled conditions, inhibited acids may be used in this method to remove millscale and rust from steel surfaces. The conditions are, however, quite critical and it is possible, under certain circumstances, to produce much heavier quantities of metallic oxides than were previously present. Another aspect of this type of cleaning is, of course, the use of alkali detergent mixtures in saturated steam for the removal of greasy deposits. This process is widely used in cleaning motor vehicles where small portable steam generators of the coil type are used. The detergent chemicals are either introduced into the water supply of such equipment, or may preferably be injected into the discharge lance of the equipment by use of an ejector device. The second method is, of course, preferable since the possibility of choking of the steam coil by accumulated chemicals is avoided.

The Equipment

The equipment required for carrying out chemical cleaning processes may be divided broadly into the following main headings:

Storage

Transfer

Mixing and Dissolving

Circulation

Disposal

The factors to be taken into account when the choice of equipment is made are as follows:

The equipment must be adequate to do the work in the engineering sense.

The equipment must be sufficiently resistant to the materials used to ensure satisfactory performance.

The equipment must not be so heavy or expensive as to make the operation uneconomic.

Storage: Normally, in small chemical cleaning operations, the storage of the chemicals to be used presents no problem. The materials are handled and used from the containers in which they are supplied. If somewhat larger operations are to be considered, then some suitable storage tank must be provided in order to achieve maximum economy in the purchase of chemicals. For example, it is much cheaper to buy hydrochloric acid in bulk delivery than by the purchase of smaller containers, and if chemical cleaning operations are being carried out sufficiently frequently to consider the purchase of a storage tank, then obvious economies can result.

The conventional storage tank for aggressive materials, such as the concentrated inhibited mineral acids are metal tanks suitably lined with protective material. Usually such lining takes the form of a hardened rubber, and although such tanks are initially expensive, the life is usually long, provided that they are not damaged mechanically. Where it is required that the tank should be portable, however, a tank fabricated from plastic materials is to be desired because of its lighter weight and hence ease of transport. The tank is usually made from fibreglass, lined with a material such as P.V.C., or the tank may be constructed from ploythene, in which case, no lining is required, although some mechanical stiffening is usually necessary. The tank is transported empty to wherever it is required, and is then set up on a firm flat base and the required chemical is delivered to it by bulk tanker delivery. A different form of transportable storage tank is provided by the rubber inflatable type of tank—this takes the form of a pillow-like bag. This may be transported from site to site, rolled up on a lorry, then once again, on reaching site, a firm base is provided and the chemical solutions delivered to the bag from a bulk tanker.

The disadvantage of both types of portable tank is that they are mechanically not strong, and must be protected from accidental damage. In the case of the rigid plastic tanks particularly, suitable venting must be ensured, otherwise, collapse of the tank will result on withdrawing the solution.

Transfer: It is obviously desirable to avoid manual transfer of corrosive solutions where possible. In small-scale cleaning operaions, the use of the containers in which the cleaning materials are supplied is expendient, but here again, the handling of the materials can be made much less hazardous by the use of suitable transfer pumps. The simplest way of accomplishing this transfer when small quantities of material are to be moved is to use a carboy siphon. The limitation here, of course, is that the solution containers must be placed at a higher level than the vessel into which they are to be discharged. Alternatively, a small carboy emptying pump of the dip type may be used. This consists of a small pump mounted on a tube which is long enough to reach to the bottom of the container to be emptied. The small pump is electrically or air driven and can usually deliver the contents of the carboy or vessel to a height of approximately ten feet above the container. Where larger supplies are to be transferred, the use of a chemically resistant positive displacement pump is advisable. The materials are obviously quite corrosive in their concentrated state, so that complete resistance to the chemical solution is essential in this case. Another suitable pump for transporting relatively small quantities of acids is, for example, the Duplex Pump, a positive action diaphragm type. The pump will deliver approximately ten gallons per minute of solution against a head of 100 lbs. sq. in. Where larger quantities of solution are to be transported, a centrifugal pump is, of course, desirable, here again, the construction materials must be resistant to the concentrated chemicals. When using pumps for the transfer of the chemicals, the usual practice is to use chemically resistant hoses for the purpose of transporting the liquid. Natural rubber hoses are available, which are suitable for most of the reagents used, and these may be secured by mechanical clips of the Jubilee

Clip type. Obviously this method is not practicable where high heads are encountered and in this case suitably lined metal pipework must be employed.

Mixing and Dissolving: Before the chemical reagents may be used in the chemical cleaning process, they must either be suitably diluted with water, or if they are solid, they must be dissolved in the solution. It is, therefore, common practice to use a mixing or dissolving tank in the chemical cleaning circuit. These obviously will not necessarily be of very large capacity compared with the circuit to be cleaned, since the solution used to fill the cleaning circuits may be introduced either batch-wise, or continuously, using suitable techniques. For ease of portability, the most popular tanks in use for this purpose are usually made from fibreglass with suitable resin lamination. Such tanks are relatively rigid and easily transported. They are also sufficiently resistant to the chemicals in use to be satisfactory for the purpose. They are, of course, not as strong mechanically as lined metal tanks, but the ease of transportation far outweighs this disadvantage. A mixing tank is usually provided with a suitable branch outlet so that it may be connected to the circulating pump used for the circulation of the chemical cleaning circuit. The same type of tank may be used for dissolving solid chemicals prior to their addition to the plant. Usually this is achieved by introducing (preferably) hot water into the tank and mechanically agitating the solutions with either compressed air or suitable paddles. Where larger quantities of materials are to be handled, the use of a suitable mechanical stirrer is preferable. Alternatively, good mixing may be achieved by use of pump to agitate the contents of the tank, the pump withdrawing solution from the base of the tank and discharging it back into the top.

The most convenient size of tanks for this type of operation is usually found to be between 100 and 300 gallons (500—1,500 litres).

Circulation: The choice of circulation equipment is, of course, governed principally by the *size* of the circuit. The quality of equipment to be used will depend principally on the economics of the cleaning process. For example, if the single operation is being considered, it is obviously not practical to consider the purchase of an expensive chemically-resistant pump. In such circumstances, it is quite adequate to employ a simple centrifugal pump and to accept the fact that the pump efficiency will fall off rapidly in use owing to erosion on the surfaces. On the other hand, if repeated cleans are to be considered, it would be wise to look into the purchase of a totally resistant pumping unit, many of which are currently available on the market.

In addition to the chemical requirements of the pumping unit, the normal hydraulic factors must be taken into account. It will be shown in a later section that certain limits of circulation velocity are required, and these must be borne in mind when choosing the equipment. Secondly, the head at which the circulating pump will operate must be taken into account, and a pump which is capable of achieving this head must be chosen. Where large quantities of solution are to be circulated, it is desirable to consider the use of multiple small pumps rather than of one large unit. In this way, the success of a chemical cleaning operation is not jeopardised by the failure of the one unit, sufficient circulation being available using the remaining units to ensure satisfactory completion. In choosing pumps for such multiple operations, however, the usual hydraulic conditions must be taken into account, e.g., a pump with a flat efficiency curve should be chosen.

The motive power for the pump is, of course, chosen to suit local conditions, but a diesel engine is often used for chemical cleaning operations, since they are most flexible and are usable in most situations.

Disposal: Disposal of the used chemical solutions usually presents one of the most difficult problems associated with the use of the process. It is possible by neutralising the used solutions chemically to discharge them into the normal drainage system. Alternatively, it is usual to store the used solution in tanks similar to those used for storage of the undiluted chemicals until they can be removed by

tanker for disposal elsewhere. Consultation with the appropriate authorities in good time avoids trouble later.

Truck-mounted Pump Complex: It is common in the United States to use complexes built up of the various items and these are mounted together on a suitable truck unit. Pumping equipment, chemical mixing tanks and storage, heating equipment and the necessary valves and manifolds are all interconnected permanently in such an arrangement.

This arrangement is most convenient when repeated cleaning operations of a similar type are envisaged, but is rather inflexible in character should operations of a different type and size be contemplated.

Heating Equipment: It is often desirable to use warm solutions to accelerate the rate of dissolution of deposits in chemical cleaning processes. For small operations, a suitable steam generator may be used, these producing steam or hot water by direct flame heating in a small coil type boiler. They may be used to heat tanks containing chemicals by either direct injection or by producing hot water in place of steam. Alternatively, direct flame type heaters may be used, which use bottled gas supplies to heat tanks of water by the use of suitable plate type heaters. This type of equipment is less susceptible to breakdown than the steam generators, but are usually somewhat slower in raising temperature.

Electrical methods of heating may, of course, be considered where adequate power supplies are available, immersion type heaters being most widely used.

Where large operations are envisaged, the use of such portable types of heating methods are not suitable and the use of a small portable steam boiler is required. These can often be mounted on a suitable trailer unit and are thus available for towing to the site where they are required.

CRITERIA FOR SUCCESSFUL CHEMICAL CLEANING

The criteria on which the success of a chemical cleaning operation is judged are:

The complete removal of the deposit or contamination.

The absence of attack on the parent metal of the plant.

The production of a stable surface following the cleaning process.

Removal of the Deposit

It is obviously most advantageous if a solvent can be found which will competely dissolve the contamination. This is, unfortunately, infrequent. In areas where water of high temporary hardness is present, deposits usually consist of calcium carbonate scales, and in this case alone, almost 100% solution of the deposits can be achieved using inhibited hydrochloric acid. Usually, however, the deposits encountered are only partially soluble, and the best that can be expected in these cases is, that sufficient of the deposit will be dissolved to ensure the breakdown of the remainder. Under these conditions, the insoluble residue is usually left in the form of a sludge where it can be washed away by adequate flushing.

It is good practice to test the deposit prior to choosing the chemical cleaning solvent, if suitable samples of the contamination can be obtained. It must be remembered, however, that the conditions pertaining in a beaker in the laboratory are very much different from those which will be encountered in the plant itself. For instance, if pieces of scale are broken away from a boiler, and are then tested in the beaker in a laboratory, it must be remembered that, in the latter circumstance, all sides of the deposit are attacked by the cleaning solution. In practice, however, only the outermost face is exposed at any one time to the action of solvent. This, of course, means that in the laboratory a

more favourable indication is sometimes found than is achieved in practice. In general, it can usually be taken that if 50% solubility is achieved under laboratory conditions, then the process has a reasonable chance of success in practice.

Solubility can, of course, be increased by using heated solutions, and this is very often employed in practice as a means of dissolving the less soluble deposits with inhibited acids. It is, of course, essential in these cases to consider the second criterion, namely the absence of attack on the parent metal when choosing suitable solvents. Many chemical cleaning solvents which are perfectly satisfactory at ambient temperatures, are totally unusable at elevated temperatures.

If the deposit contains a large proportion of insoluble residues, then flushing must be adequate to remove this at the completion of the process. This is especially necessary if pendant superheater or similar type tubes are being cleaned. In these tubes, the acid cleaning solution will deposit insoluble residues at the bends, which may cause subsequent blockage of the tubes. It is, therefore, most essential that the flushing rates following chemical cleaning are sufficiently high to remove these insoluble residues. In the small bore tubes, it is usually accepted that a flushing rate of 4 ft. per second is desirable to achieve satisfactory removal of debris. It must be emphasised, however, that this is usually too high a circulation rate for inhibited acids and the safe maximum value in most cases for acid circulation is accepted as 1—2 ft. per second in small bore tubes.

In many cases where the deposit is not 100% soluble, increased solubility may be achieved by a suitable pre-treatment. This is the case, for instance, where sulphate scales are involved. These are not very soluble in the inhibited acids, and it is common practice to 'boil out' the unit containing such a scale with an alkali treatment prior to the application of inhibited acids. The application of alkali modifies the scale and often improves the solubility of the subsequent acid process.

It is also beneficial to boil out items of plant which have been chemically cleaned where the deposits are not 100% soluble. This is very often a much more positive method of removing adherent remaining deposits where all surfaces cannot be contacted by jets of water subsequent to the acid cleaning process. In these cases, it is normal to employ alkaline solutions—say, of up to 1% caustic soda solution, or 3% or 4% sodium carbonate solution, these solutions being boiled out at atmospheric pressure in the plant to remove adherent residues. This treatment is again followed by copious rinsing with water.

Prevention of Attack on Parent Metal

The second criterion is, of course, that the chemical cleaning solution shall not damage the item of plant to be cleaned. In cases of doubt, it is advisable to consult chemical cleaning consultants who will advise on the type of cleaning agent best suited for the purpose. However, there are general rules which assist the choice of an inhibited acid for removing a particular type of deposit when in contact with different metals. A table detailing the more common chemical cleaning reagents, and the metals in contact with which they are suitable, (bearing in mind the deposits which are required to be removed) is appended.

In general the inhibitors now available for use with mineral acids are extrenely effective, provided they are used in accordance with the directions given. It must, however, be borne in mind that some inhibitors are only effective at low temperatures, and may break down if temperature is raised. In addition the destraction of the inhibiting properties of the material such breakdown is often accompaniedby the formation of 'treacly' deposits which add to the difficulties within the plant.

Flow Rates: When considering the use of inhibited mineral acids, the effect of velocity mentioned above must be carefully considered. As the velocity of the cleaning solution is increased, the extent of corrosion by direct attack of the cleaning reagent on the parent metal is increased linearly. Under most circumstances, it is usually accepted that the safe maximum value

for the circulation of chemical cleaning solutions in relatively small pipework is 1 ft.—2 ft. per second (0.3—0.6 metres/second). It must be borne in mind, however, that this figure cannot be pplied to pipework of all sizes since, obviously, the turbulence effect produced in small pipework by such velocities is very much greater than those produced in large-bore pipework. In such cases, consideration of the Reynolds Number is a much more effective criterion, but such consideration is beyond the scope of this paper. Where the safe velocity of circulation has to be exceeded because of other factors within the plant (for instance, at the inlet points of plant where reasonable overall circulation is required) more severe attack can be expected, but there are special processes available on the market which reduce such attack to extremely low levels by the use of sophisticated techniques. Such a process is the VECOM KF Process patented in England and on the Continent. Details of the process are availalble on request. It must be borne in mind that the factors affecting both the removal of the deposit, and the extent of attack on the parent metal are the same. These are velocity, time, temperature and concentration. It is essential that the values chosen for these factors are carefully considered in oder to achieve the best overall results.

Preparation of a Stable Surface Following Cleaning

Need for Passivation: When the metallic surfaces of a plant have been chemically cleaned, those surfaces are usually in a very active state, and unless some positive action is taken, the surfaces will rapidly deteriorate, and much of the benefit of cleaning will be lost.

This is particularly so in the case of plant made from mild steel, when freshly cleaned surfaces are very susceptible to rerusting. This comment applies to both inhibited acid cleaning processes, and solvent degreasing (alkaline degreasing agents leave steel surfaces in a reasonably passive condition for reasons which will become obvious later). Where solvent degreasing has been carried out, the steel surfaces are completely freed from oily residues, which would, in ordinary circumstances protect the metal from deterioration by rusting (which is, of course, caused by moist air).

Acid cleaning processes, on the other hand, completely remove *all* oxides from the surfaces of the parent metal, in addition to those deposits which are the reason for carrying out the cleaning process. These surface oxides are the barrier between the parent metal and the oxygen in the air. Under reasonably dry conditions, the oxides prevent continued attack on the metal—and hence are essential to the preservation of the plant. At the completion of the cleaning process, we have a metal surface which has been stripped not only of its undesirable deposits, but also of its surface layer of protective oxides.

In many instances, a protective oxide layer will commence to grow immediately upon returning the plant to service, but generally speaking, it is better to follow the chemical cleaning process with a "passivation" phase which is designed to produce a stable, uniform oxide layer on all of the exposed metal surfaces.

In the case of boiler plant, this is most important, since a boiler relies for its survival on the uniform layer of magnetic iron oxide formed on those surfaces in contact with water. Rupture of this uniform layer leaves a small area of the metal surface which is most susceptible to attack—hence on-load corrosion. Fortunately, in boiler plant, it is relatively easy to produce a uniform film by "boiling out" the unit, but in other plant, this method is not so readily available.

Passivation Methods Available

MILD STEEL—Two basic methods of passivation of mild steel are available for use after acid cleaning. The first method aims to promote the growth of a uniform oxide film, the second to convert the surface film to a stable compound, the most widely used being the phosphate process.

Stable oxide formation takes place on mild steel particularly well in the presence of alkalies

when heat is applied, and the film is even more uniform if reducing conditions can be achieved.

For example, in the case of boiler plant, both of these conditions can be achieved, and it is usual to 'boil-out' the unit following an acid clean. For this purpose, the water in the plant is treated with alkaline chemicals. In the case of low pressure plant, a 1% W/W solution of sodium carbonate may be used. If it is possible to apply up to 100 ppm of sodium sulphite and maintain this, then the desirable reducing conditions are also achieved.

The boiler is then heated, and pressure is raised without exporting steam. All drains are operated from time to time. The process is continued for 12-24 hours, at the end of which time, the unit is blown down under pressure, and ventilated to dry quickly. A stable dark grey or balck surface is obtained. Higher pressure units usually boil out with trisodium phosphate, and start with lower concentrations, about 1,000-2,000 ppm, again using sulphite or hydrazine as reducing agent.

Where the unit cannot be heated under pressure, some degree of passivation is obtained by simply heating alkaline solutions in the unit under atmospheric pressure. For instance, a 1% sodium carbonate solution may again be used. If direct heating of the plant is not possible, then circulation of a hot solution of alkali is advisable. Temperature should be maintained in the circuit as high as possible by injection of steam if available.

Where the heat is not available, the methods available become rather more complex. Essentially they depend on the sequestration of iron from the metal surface, and oxidation under alkaline conditions.

If no other method is available, circulation of a cold 3% solution of sodium carbonate will reduce the tendency towards rerusting, and will effectively neutralise any remaining acid residues.

Conversion coatings, the most widely used of which is the phosphate conversion, are produced by the action of chemicals on the clean metal surfaces. A very presentable phosphate film may be produced on mild steel by immersing it in, or filling units made from it, with a warm dilute solution of phosphoric acid (2% w/w) for about 15 minutes. A bright silver grey surface results, which is quite stable when dry. (more stable phosphate coatings may be obtained by using proprietary mixtures which incorporate metal phosphates, giving much more permanent results). Here again, the phosphate coating produced by the simple method are very good, provided that heat is available.

Phosphate coatings may be produced in the cold, but they are much less stable and are not uniform.

OTHER METALS—The passivation of metals other than mild steel is not of quite such importance since, in general, the rate of deterioration of the cleaned surfaces is not so rapid.

Stainless steel should, however, be passivated following cleaning, and this is usually accomplished by immersing it in nitric acid of about 20% v/v strength. Brass and other copper alloys sometimes need treatment following cleaning, and this is usually accomplished by applying oxidising agents such as sodium dichromate in sulphuric acid solution.

Importance of Flushing: Where acid cleaning processes (and in fact all chemical processes using aqueous solutions) have been carried out, it is most essential to remove all traces of cleaning chemical from the plant before attempting passivation. The flushing process should also remove all debris resulting from the loosening of deposits in the plant, otherwise this debris will mask the underlying surfaces and prevent the passivation from acting on these.

Where mild steel has been cleaned, particularly when hydrochloric acid has been used, the metal surface is very active, as explained before. Furthermore on draining away the acid solution, the metal surface is left covered

with a film of acid containing dissolved iron. If this is washed away by filling the unit with water, the iron in the film will be thrown out of solution in the form of a gel on the metal surface. This gel will trap chloride residues from the cleaning solution, and these will not be flushed away by subsequent washes. The chloride residues remain on the metal surface and are very active in promoting subsequent rerusting.

This can be avoided by including a complexing agent for iron, for example, citric acid in the first rinse water applied to the unit. This solution at 0.1% concentration will prevent this drop-out of iron gel.

Subsequent plain water washes remove all traces of iron and chloride residues. The passivation process then has the most positive chance of producing a stable uniform protective surface.

All in all, the treatment of the plant subsequent to the cleaning process is almost as important as the clean itself—the proverbial 'ha' porth of tar'.

EXAMPLES OF CHEMICAL CLEANING PROCESSES

Descaling of a Heat Exchanger

The type of descaling solution required should be decided taking into account the analysis of the deposit which is causing the fouling, together with the materials of construction of the plant. Table 1 will give general guidance.

If possible, some estimation of the amount of chemical required should also be made, since this will indicate how much cleaning solvent will be needed to dissolve all of the deposit. Whenever possible, it is best to carry out tests to determine the solubility of the scale, and also to estimate the amount of chemical required so that the solution does not become exhausted.

A very rough estimate of the amount of inhibited hydrochloric acid required in the case of a typical steam plant deposit may be obtained by assuming that the unit weight of the concentrated acid will remove unit weight of the scale.

Using Pumped Circulation: The circuit is set up as shown in Figure 7.

(i) Isolate the unit by closing the water inlet and outlet valves, or by spading off the lines.

(ii) Drain the Unit.

(iii) Connect the delivery of the pump by hose or pipework to the lowest available point on the water inlet side. If no suitable connection is available, it may be necessary to break the line and fit an adaptor.

(iv) Connect a return pipe or hose to the highest available tapping point, e.g., thermometer pocket socket on the water outlet pipe. Return this pipe or hose to a small tank, which should be fitted with a suitable branch at the bottom to enable it to be connected to the pump suction.

(v) Connect pump suction to the tank.

(vi) Fill the tank with the descaling solution diluted with water to the recommended level as shown in the appended table. Mix well.

(vii) Pump the solution into the unit.

(viii) Continue repeating items (vi) and (vii) unil the unit is full and liquid returns to the tank by the upper or return hose.

(ix) It is possible, with some experience, to fill the unit by adding water and chemical solution continuously in the required proportions to the tank, while the pump is running.

(x) Circulate the diluted solution by pumping. If further addition of chemical is

required, this may be added to the tank from time to time.

(xi) The completion of the process will be indicated in the case of a carbonate scale by the cessation of gas evolution. Check that this is not due to complete neutralisation of the acid solution by adding some of the cleaning solution from the tank to a piece of washing soda, (sodium carbonate) in a suitable jar. If no gas is evolved, further addition of acid is required.

(xii) In the case of non-carbonate scales, the wasing soda test will also confirm that the acid is still active. However, no easily recognised sign indicates the end of the process in this case, and only experience will indicate the amount of contact required if no chemical analysis is possible.

(xiii) If the solution can be tested for residual acidity, the completion of the process is indicated when the acidity does not decrease further with time. In cases where rust deposits are being removed, the iron content of the solution may be determined, and the stabilisation of this figure again indicates completion of the process. (Examples of typical chemical monitoring of cleaning processes are shown later.)

(xiv) Drain the unit, neutralising the effluent if necessary with caustic soda liquor, soda ash or lime *after the solution has been drained from the unit.* Do not add neutralising agents to the solution in the unit.

(xv) Flush out the unit thoroughly with clean water, preferably from the top downwards in order to remove all undissolved debris.

(xvi) Fill and drain the unit with clean water, repeating until all acid residues have been removed.

(xvii) In order to completely remove all traces of acid, the final fill may be made with a solution of a suitable alkali such as soda ash at a level of 1 lb. per 20 gallons of water.

(xviii) Thoroughly wash out any instrument connections or "dead legs" in the unit before putting it back on line.

Using 'Auto Circulation' Methods—Without Pump: The circuit is set up as shown in Figure 6. In this method, circulation relies upon the evolution of gas resulting from the action of the cleaning agent on the scale—which only happens with carbonate, or temporary hardness deposits. The method is applicable only to this type of deposit.

(i) Isolate the unit as in case of Pumped Circulation.

(ii) Drain the unit.

(iii) Site the cleaning solution tank so that it's outlet branch is higher than the top of the unit to be cleaned.

(iv) Connect the outlet branch of the tank to the lowest suitable point on the water inlet side, using hose.

(v) Fit a hose to the highest available point on the water outlet, and return this to the top of the tank.

(vi) Fill the tank with a suitable diluted solution of the inhibited acid continuing until a return of solution is obtained from the return hose.

(vii) The return of solution via the top hose, will continue until gas evolution ceases since the specific gravity of the acid/gas mixture is less than that of the liquid alone.

(viii) When gas evolution stops, add further inhibited acid to the tank; if the action

recommences, continue making additions of fresh solution until the process is completed.

(ix) Drain the unit, and flush out thoroughly as described in Pumped Circulation. (xv—xviii)

Descaling of an Electrode Steam Boiler by the 'Fill and Soak' Method

This type of boiler provides steam by heating water by passing an electric current through it between two electrodes.

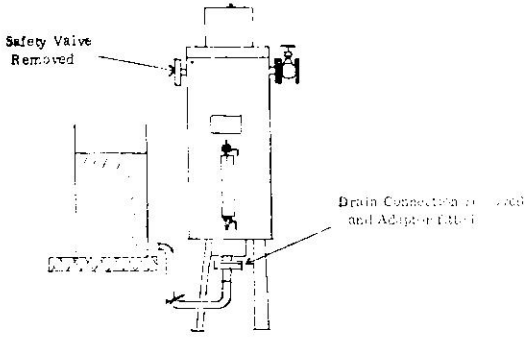
The materials of construction make it necessary to use a cleaning solution which is less aggressive than inhibited hydrochloric acid, and inhibited formic acid is acceptable.

(i) Drain the unit. Remove safety valve to provide vent to atmosphere. Close gauge glass cocks.

(ii) Obtain a suitable tank with bottom outlet connections. (A cut down oil drum with a welded in spigot is suitable).

(iii) Connect the outlet of the tank to the blowdown drain of the unit (or any convenient branch near the bottom of the boiler). Rubber hose is suitable.

(iv) Place tank at a level so that the top of the tank is about three inches above the level of the upper gauge glass fitting of the boiler. (see Fig. 9.)



Alkali degreasing of oil cooler
Fig. 9

(v) Pour into the tank a solution made up of one part by volume of inhibited formic acid with fifteen parts of cold water. The solution will drain by gravity into the unit.

(vi) Continue adding solution until the height of liquid in the tank remains static at a point about level with the upper gauge glass fitting on the boiler.

(vii) Allow solution to remain in the unit for 16-24 hours then drain down, flush out thoroughly with cold water to remove any undissolved sludge and neutralise as described in paragraph (xvii) under Pumped Circulation after filling and draining several times with water.

(viii) Inspect unit, and if necessary, repeat process if deposits are too heavy to be removed in one application.

(ix) Reinstate connections and return unit to service.

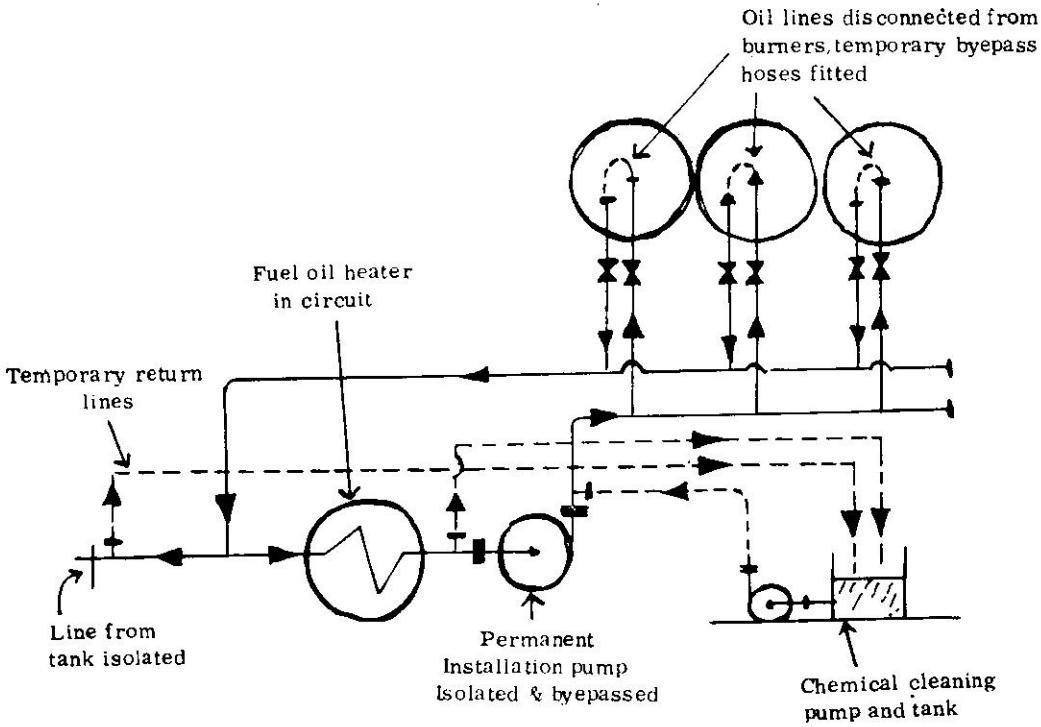
Precommission Cleaning of Fuel Oil Lines on Furnace

Owing to the possibility of detached pieces of scale and rust causing choking of the small jets in oil burners, precommission cleaning of fuel oil systems is often employed. The following is an example of the progress of such a cleaning operation. The circuit was as shown in Figure 10.

(i) The system was filled with hot water which was available on the plant. Circulation was started via the pump.

(ii) Steam was injected into the steam side of the fuel oil heaters to raise the temperature to 95°C., while still in circulation.

(iii) Heat was cut off, and inhibitor and wetting agent were added while circulating via the tank.



Precommission Cleaning of Fuel Oil System

Fig. 10

(iv) Citric acid solution was added slowly in order to give an initial concentration of about 4% w/w of acid.

(v) Ammonia was then added to raise the pH value of the solution to about 3.5 units.

(vi) Circulation continued, with periodic testing of the solution for residual "free" citrates (i.e., that uncombined with iron). The following figures were obtained:

	Total Citrate	Total Iron	"Free" Citrate
0.000 hours	4.10%	0.2%	3.42%
00.30 hours	3.92%	0.4%	3.06%
01.00 hours	3.84%	0.5%	2.14%
01.03 hours	3.78%	0.5%	2.10%
02.00 hours	3.74%	0.5%	2.01%
02.30 hours	3.71%	0.5%	2.01%
03.00 hours	3.71%	0.5%	2.01%

(vii) The results indicated the end of the process, so the unit was drained and flushed with a 0.1% solution of citric acid.

(viii) The system was purged with clean water at a rate sufficient to ensure a flow of 4' per second in the largest pipework, the circuit being flushed through all available points to remove solid debris.

(ix) The system was passivated by circulating demineralised water containing 300 ppm of hydrazine and 50 ppm of ammonia, heated to 90°C. for 12 hours, then

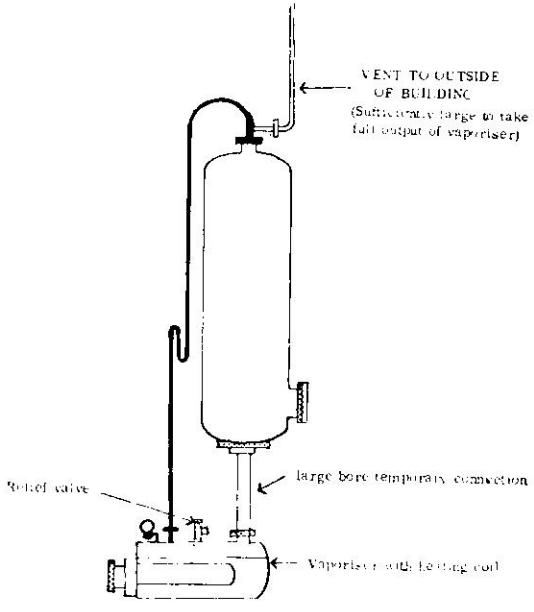
draining. (This is a more sophisticated method of passivation often used in power plant cleaning.).

Vapour Degreasing of Large Vessel

This method describes the use of trichlorethylene vapour to degrease a large vessel contaminated with oil.

The equipment is shown in Figure 11, together with the method of connection to the vessel.

The method relies on the fact that trichlorethylene vapour, (fed to the vessel from the vapouriser) condenses on the cool surfaces of the vessel and runs down. The condensed solvent dissolves the oil film on the unit, returning this to the vapouriser. Fresh solvent redistils continuously leaving the oil behind. As the unit warms up, the vapour level rises and eventually reaches the top of the unit—hence cleaning all surfaces.



Vapour degreasing of large vessel
Fig. 11

This method is not satifactory where heavy insoluble deposits are present together with the oil. In such cases, degreasing with alkaline detergent mixtures is necessary.

When all contamination has been removed, the vapouriser is disconnected, all connections are removed, and the unit is blown out with air to remove all gases.

N.B. Trichlorethylene vapour must be used with care, and the suppliers of the solvent will advise on precautions to be taken when using this.

Alkaline Degreasing of an Oil Cooler

The problem, to remove oxidised oil deposits from the shell side of an oil cooler is shown in Figure 12.

Method:

(i) Drain all oil from the unit.

(ii) Fill the unit with water in which has been dissolved a proprietary degreasing mixture suitable for use in contact with materials of constructions of the plant, at the concentration recommended by the manufacturer.

(Alternatively, a mixture containing equal parts of caustic soda and trisodium phosphate, together with about 2% of a synthetic surface active agent is suitable for mild steel plant when used at up to 5% concentration.)

(iii) Heat the water by introducing steam into the unit, either via a drain connection or by passing steam through the tubes.

(iv) Scum off the surface of the liquid by overflowing the solution from the top branch—this removes surplus oil and economises in the use of the cleaning chemicals. Continue heating.

(v) When no more oil can be scummed off, drain the unit.

(vi) Wash out thoroughly with water.

(vii) Inspect and repeat if necessary.

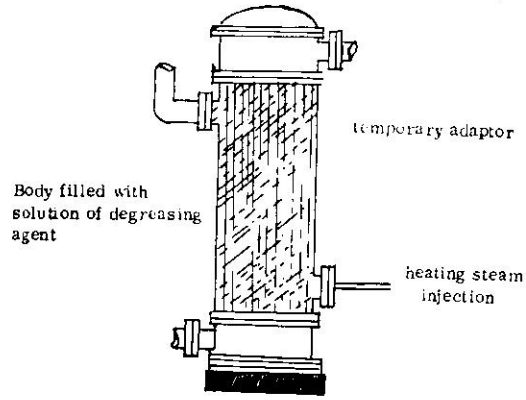
Chemical Cleaning of Absorbtion Column and Gas Coolers on Nitric Acid Plant, using Inhibited Sulphamic Acid

The use of sulphamic acid was necessary because of the variety of materials of construction present, which included austenitic stainless steels. The system was fouled with water hardness scale.

(i) The system was filled with water and circulation established.

(ii) The system was inhibited by adding sufficient inhibitor for the circuit dissolved in a small quantity of acid solution, 500 lbs. of acid 10 lbs. of inhibitor.

(iii) Acid injection then continued, the following results being obtained (see Table on page 584).



Alkali degreasing of oil cooler

Fig. 12

MANPOWER & TRAINING FOR CHEMICAL CLEANING

What Sort of People Are Needed?

When chemical cleaning operations are examined, the work involved can be separated into three main sections:

Design and planning of the cleaning operation

Mechanical preparation

Operation and control of the process.

If these sections are looked at further from the standpoint of personnel requirements, a broad picture of the type of people required in order to carry out the cleaning process is obtained.

Design and Planning

This section will obviously include the person who has overall charge of the cleaning process. His responsibilities will be:—

1. Having or acquiring a good working knowledge of the plant to be cleaned.
2. Being able to assess the most economical time to clean.
3. Deciding the type of process most suited for the operation.
4. Designing the circuiting necessary for carrying out the process.
5. Preparing a programme for the cleaning operation and liasing with other personnel so that this may be slotted in to reduce outage to the minimum.
6. Ensuring the safety of personnel and plant during the whole of the cleaning process.
7. Supervision of all stages of the operation to ensure maximum efficiency.
8. Arrange all services required for the clean, water, heat, light, drainage.

From the above, it is seen that some specialized knowledge of chemical cleaning is neces-

Time	Acidity Residual	Total Amount of Acid added	Total Inhibitor added	Remarks
13.30	Nil	500 lbs.	10 lbs.	Circulating
14.00	0.05N	1000 lbs.	20 lbs.	-do-
14.30	0 05N	1500 lbs.	25 lbs.	-do-
15.00	0.07N	2000 lbs.	27 lbs.	-do-
15.20	0.07N	2500 lbs.	30 lbs.	-do-
16.30	0.27N	4500 lbs.	110 lbs.	-do-
17.00	0.28N	—	—	-do-
17.30	0.32N	5200 lbs.	—	-do-
18.00	0.36N	—	—	-do-
18.30	0 38N	—	112 lbs.	-do-
19.00	0.38N	—	—	-do-
19.15	—	5500 lbs.	—	-do-
19.30	0.38N	—	—	Closee off No, 1 gas cooler
20.15	0.38N	—	132 lbs.	Circulating
20.30	0.30N	—	—	Bad frothing, ceased adding acid
21.30	0.4N	—	—	Circulating
22.00	0.4N	6750 lbs	—	Circulating
22.30	0.4N	—	—	Circulating
23.00				Closed off valve on small exchanger to push acid up column,
01.30	Recommenced circulation, added remaining acid (total of 4 tons added to system).			
02.30	0.4N	4 tons	152 lbs.	Circulating
03.00	0.4N	—	—	-do-
03.30	0.4N	—	—	-do-
04.00	0.4N	—	—	-do-
05.00				Commenced draining
07.00				System drained, commenced filling for first wash.
09.30				System full, commenced circulating.

sary in this position. Items 1, 5 and 7 should be within the scope of any executive engineer or plant chemist, while the remaining sections are those requiring more detailed study.

Where the extent of chemical cleaning work is small, and the items of plant to be cleaned are not complex, it is probable that formal training is not necessary for the overall supervisor.

Most chemical cleaning companies will act as consultants, and will be prepared to advise on the type of process and the circuitry required for chemical cleaning operations. The technical literature issued by such companies gives general guidance in carrying out the process. Furthermore, most reputable companies will be prepared to send technicians overseas in order to supervise chemical cleaning work. If, there-

Table 1

Deposit	Cast Iron	Mild Steel	Copper Alloys	Stainless Steels	Aluminium Lead Tin Plating	Galvanizing
Carbonate Hardness Scale	1 cold 10%v/v 4 cold 10%v/v 5 cold 10%w/w	1 cold **15%v/v 4 70°C 10% v/v 5 70°C. 10% w/w	*** 1 cold 10%v/v 4 50°C. 10%v/v 5 50°C. 10%v/v	5 70°C. 10%w/w	4 70°C. 10%v/v 5 70°C. 10%w/w	4 Cold 10%v/v 5 Cold 10%w/w
Iron Oxide (rust etc.)	1 cold 10%v/v 2 cold 5%v/v	1 70°C. 15%v/v 2 60°C. 5%v/v 3 90°C. 5.0%w/w	*** 1 cold 10%v/v 2 cold 5%v/v 3 90°C. 3%w/w	3 90°C. 3%w/w *** (2)* 60°C. 5%v/v	3 (Ammoniated) *****	—
Water Formed Slimes	1 cold 10%v/v 2 cold 5%v/v	1 70°C. 15%v/v 2 60°C. 5%v/v	*** 1 cold 10%v/v 2 cold 5%v/v	5 70°C. 10%w/w ** (2)**60°C. 50%v/v	4 70°C. 10%v/v 5 70°C. 10%w/w	4 cold 10% v/v 5 cold 10%w/w
Calcium Phosphates (Boiler Deposits).	1 cold 10%v/v	1 70°C. 15%v/v	*** 1 cold 10%v/v	5 70°C. 10%w/w	—	—

1—Inhibited hodrochloric acid
2— „ sulphuric acid
3— „ citric acid
4— „ formic acid
5— „ sulphamic acid

* Cast iron is always attacked to some extent by inhibited acids.
** Hot solutions would foam too violently.
*** Plus dezidcification additives for brasses.
**** Some authorities prohibit.
***** Consult contractor.
****** Attack unavoidable

fore, the extent of cleaning involves only a small amount of work, which may be carried out, say, annually, then it would obviously be economic to arrange that the first process was supervised by an expert from one of the companies in the field, during which a suitable engineer or plant chemist could be given the essential training to be able to repeat the operation.

My company has carried out chemical cleaning operations on the above basis in all parts of the world, including Italy, Portugal, Nigeria, Hongkong, Singapore, and still benefit from this in the sale of chemical cleaning materials.

Where chemical cleaning is used continuously, and where the plant is large enough to set up a separate chemical cleaning section, the overall supervisor will, obviously, require a formal training in order that he can design and carry out cleaning operations on a wide variety of plant without having to enlist the aid of consultants on all occasions. Petroleum refineries are an example of the type of industry where chemical cleaning is required frequently, and often at very short notice. Other large industries, particularly those which have centralised control, such as the electricity generating industry, will also fall into the category where separate chemical cleaning services will be required.

If chemical cleaning contractors are available locally, it is doubtful whether it is possible to carry out cleaning processes more economically than they by the establishment of a central cleaning service, since obviously the contractor will be working on maximum deployment of his labour and equipment. Where such services are not available, then a self-contained section is the only answer.

Chemical cleaning is a relatively new science, and the literature available is mostly in the form of short papers describing specific cleaning operations. While a great deal of information can be gathered from these, it is probable that the difficulty in learning from them would be the proverbial one of "not seeing the wood for the trees." The only alternative for the training of overall supervisors would therefore seem to lie in them spending a specific period with a chemical cleaning contractor. In selecting a candidate for such training, his background education must obviously be studied closely.

In general, the bias in chemical cleaning supervision is towards an engineering background, but with a strong leaning towards chemistry. Much of the recruitment in the chemical cleaning contract field comes from the marine engineering group...If separate chemical control of the process can be exercised, then the knowledge of chemistry required will be of a very basic nature.

Recently there has been a swing towards chemical engineers or even chemists as leaders of chemical cleaning teams, with a proviso that chemists should be of rather a practical leaning than purely academical. Plant chemists usually acquire this attitude and so are able to carry the responsibilities required.

Although the practice is not yet well established, it seems certain that training of supervisors for the developing countries by the reputable chemical cleaning contractors could become common.

The most obvious approach would be for the engineer or chemist to spend at least six months working with and for a cleaning contractor. Providing that the training programme is well planned, it should be possible within that time to absorb the principles behind the practical methods used. Alternatively, it may be possible to arrange a period of training with one of the industries in the developed countries which use acid cleaning to a large extent within their organisation. Examples of these would be the electricity generation authorities, refineries and similar industries with a centralised organisation In a large organisation of this nature, it should be possible to acquire a fairly concentrated period of acid cleaning experience, although tha experience would be specific for one industry. It should be emphasised that the training should be mainly practical in nature. The basic che-

mistry involved is relatively uncomplicated provided that conditions are kept within the limits specified by the cleaning reagent manufacturers. A large part of the acid cleaning expertise is somewhat intuitive, and cannot be acquired from theoretical considerations alone.

The engineering aspects would be exhibited by following a chemical cleaning enquiry through from the initial survey, quotation, detailed survey, rigging, operation, inspection, and breaking down of the circulating plant.

One of the most important aspects of the training should certainly be the safety rules and regulations to be observed. Many of these are general for handling chemicals, but quite a few are specific to acid cleaning processes. It is obviously the responsibility of the supervisor to see that these rules are strictly observed, and this is one of the most difficult requirements of the job. The proper safety equipment must not only be available, but must be used.

A set of general safety rules for chemical cleaning operations appears at the end of this section.

Mechanical Preparation

The requirements of the personnel engaged in this section of the chemical cleaning work are essentially those required of pipefitters in general. In the smallest operations envisaged, the connections are made using flexible hose with clips, and the actual fittings to the plant are made using simple adaptors, easily fabricated in the fitting shop.

On larger operations, steel flanged pipework usually replaces flexible hoses because of the greater safety factor. This pipework need not be of the same standard as normally used to construct plant, since obviously, it's only requirement is to remain leaktight during the progress of the clean. As an illustration of this, I arrived in one African country to carry out the chemical cleaning of a boiler unit, only to find that the whole of the pipework provided for temporary connections had gone astray. A replacement set was, however, made on the spot by the maintenance staff using old sections of replaced boiler tube fitted together with chequer-plate flanges. Soft rubber tube jointing was used to take up the inevitable gaps in joints. The clean proceeded without mishap to a successful conclusion.

While it is true that the success of any chemical cleaning operation lies in good design and planning, it is equally true to say that mal-operation can just as quickly ruin it.

No special training is necessary in this particular section—if anything a slight relaxation of general engineering standards is permissible so long as the safety of the operation is not involved.

Operation and Control

While it is doubtless true that the success of any chemical cleaning operation lies in good design and planning, it is equally true to say that maloperation can just as quickly ruin it.

Once the mechanical preparations have been completed, the overall supervisor and his operators take over. The requirements of personnel in this section can be subdivided further as follows:—

1. Those who operate the circulation and valving of the plant.
2. Those who control the chemistry.

3. The labour element.

In small operations, the boundaries between the subgroups would obviously become indistinct, but if we consider a fairly large cleaning process, the individual responsibilities and duties of these groups can be defined.

First and foremost, all employees falling within this group must have basic training in handling chemicals. They must understand the safety precautions and be prepared to abide by them. Training in these requirements is very basic, and should easily be achieved by the overall supervisor.

The operators should be capable of operating the pumping plant under non-ideal conditions and, should be of a sufficiently high level of intelligence to be able to operate control valves, injection pumps, mixing equipment etc., under direction. They should furthermore be trained in the steps to be taken to minimise damage to the plant and possible injury to personnel in the event of spillage of chemical solutions. It is essential to pull up leaking joints, pump glands and similar abominations quickly, and not to await the arrival of the pipefitters.

In general, the operators should have some experience in plant operation, and should be trained as a team by the supervisor.

The requirements for chemical control staff are not stringent if the supervisor is experienced. The principal requirement is the ability to carry out site tests on the cleaning solution at frequent intervals, and to produce the results *quickly* with reasonable accuracy. The accent here is upon the word *quickly*. It is of no value in determining the progress and safety of the operation to produce very accurate results long after the acid has been drained. The principal requirements are for acid strength and iron concentration, the first to determine that sufficient reagent is present to complete the process, the second to confirm the absence of continued attack on the metal, both of them on reaching a stable level confirm the end of the cleaning process. Simple methods are adequate, titration for acidity and colormetric methods for iron, so no very high level of chemical achievement is necessary.

The requirements are thus well within the scope of a plant chemist and require no special training over and above that required for carrying out the day to day work.

To summarise, therefore, the necessity for formal training is restricted to one person, who should subsequently be able to pass on the essential knowledge required at lower levels. All must, however, be trained in safety precautions and first aid, for obvious reasons.

How Many People?

One of the advantages which chemical cleaning has over mechanical methods is that the manpower required is considerably less for carrying out any specific task. For example, my Company has recently completed the chemical cleaning of the largest Nuclear Power Station in the World, prior to the commissioning of the plant. This operation which involved the treatment of the two nuclear reactor boiler units, each containing four separate boiler circuits, was carried out using a basic team of eight men and two supervisors. The circuits contained some 100,000 gallons of water, and temporary pipework was laid to connect the boiler units with the circulating pumps. The preliminary pipework erection was carried out by the team as a whole over a period of some five weeks, the process itself occupied the team for one week, during which time they were split into two shifts of four men and one supervisor, and the final breaking away of the pipework occupied a further two weeks. Similarly, the turbine feed and condensate systems on the same power station were claned using the same labour force. Quite apart from the fact that mechanical methods could not achieve results which were obtained by chemical cleaning, the manpower involved to clean some 10,000 intricate tube sections in the boiler units by mechanical means would have far exceeded that used for the chemical process.

Where the cleaning of, for example, a small heat exchanger is involved, the manpower required is usually only two men. My Company, again in this field, operate on a two-man team basis, the whole of the equipment being taken to site in a light van, the men connecting the flexible pipework to the unit to be cleaned, the acid sequent being introduced on the first day, and the subsequent washing out and final treatment being completed on the second day. It is, of course, possible when actually working on the site to complete the chemical cleaning during a single day.

It is relatively easy to economise on manpower in this respect by good planning of the chemical cleaning process. In the larger operations, it is obviously advantageous to use chemicals in bulk, and to handle these by pumping directly from storage tanks into the cleaning circuit. Where smaller units are involved, labour saving devices such as carboy emptying pumps have been recommended previously, and will cut down considerably in manhours involved in carrying out the cleaning process.

HAZARDS OF CHEMICAL CLEANING

Personal Protection

The most obvious hazard in chemical cleaning processes is that resulting from handling the materials themselves. These materials are usually corrosive towards the skin, e.g. mineral acids or alkalis, and the usual precautions must be adopted when handling them. Gloves and goggles are essential, and some form of overall protection is obviously desirable. Protective aprons and sleeves are useful in that they reduce the amount of damage to overalls by corrosive liquids.

Where exceptionally corrosive materials are being handled, full protective clothing must be worn.

The main problem in ensuring that workmen employed in carrying out the chemical cleaning processes are fully protected lies in the difficulty of overcoming the reluctance to wear protective clothing. It is, however, the duty of management to see that such protective clothing is available and is worn. Where harmful vapours are present, suitable respirators or positive pressure breathing apparatus must be worn, even though these are uncomfortable particularly in hot climates.

Hazards Arising From the Process

The process itself must be carefully examined to ensure that no hazards arise as a result of the chemical reactions taking place within the plant.Where, for instance, carbonate deposits are being dissolved, large quantities of carbon dioxide are produced and good ventilation must be ensured in order to avoid any pockets of this gas from collecting in circumstances which may eventually prove dangerous.

It should always be borne in mind that a limited amount of attack on the parent metal always takes place when inhibited acids are being used. This means that when acid cleaning solutions are drained from a plant or vessel, the space inside may often contain sufficient hydrogen to produce a serious explosion if naked lights are allowed near the plant at this stage. It is thus essential that *no smoking or naked lights are allowed in the vicinity of a chemical cleaning process* until the euqipment can be proved to be completely gas-free. This is a most real hazard.

SAFETY RULES FOR OPERATORS ENGAGED IN CHEMICAL CLEANING PROCESSES

1. Wear the proper protective clothing and equipment.

2. Treat *all* materials as harmful, don't touch chemicals or resinues with bare hands. Wash away accidental contact immediately.

3. Keep yourself and your clothes clean. Remove and wash contaminated clothing before re-use.

A factor which must not be overlooked is the necessity for ensuring that plant insurance is not jeopardised by carrying out chemical cleaning processes by unskilled personnel.

4. Wash after handling chemicals—Don't eat, drink or smoke until you have.
5. Ensure safety of others by warnings and barriers where necessary.
6. Ventilate area of plant being cleaned. Cleaning processes may evolve inflammable, suffocating or poisonous gases. Special ventilation is required before entering plant for inspection purposes Watch for obvious gas pockets (light or heavy gases).
7. Don't smoke or use naked lights anywhere near plant which is being cleaned at any stage of the process.
8. Read and understand the safety precautions concerning Handling of Materials.
9. If in doubt, enquire whether your job presents any special hazard.
10. Obey specific instructions concerning cleaning processes. Mix chemicals only in order specified.
11. Wash away and neutralize where necessary accidental spillage of chemicals or cleaning solutions. Do not allow spillage to dry out.

IS CHEMICAL CLEANING FEASIBLE IN DEVELOPING COUNTRIES?

One of the major problems facing any chemical cleaning contractor is the recruitment and training of suitable operators. In the case of a process plant operator, however, it is necessary to have a maintenance staff composed of artisans of one class or another. In this respect, therefore, the plant operator has a nucleus of personnel who are of sufficiently intelligent calibre to be able to carry out chemical cleaning processes, provided that suitable trained supervision is available. A separate section has emphasised the necessity for ensuring that such supervision has a good basic training in chemical cleaning methods, and it must be emphasised that any attempts to carry out anything other than simple chemical cleaning processes without such supervision is to be discouraged.

A factor which must not be overlooked, particularly in respect of pressure plant such as boilers, is the necessity for ensuring that plant insurance is not jeopardized by carrying out chemical cleaning processes by unskilled personnel. In the United Kingdom, the chemical cleaning contractors carry insurances indemnifying the Companies against claims of around a million pounds, and these insurances are, of course, only issued on the basis of a firm understanding between the contractor and the insurer who, obviously, requires evidence that the technical standing of the contractor is good. Boiler Inspectors in general in the past have been somewhat reluctant to accept acid cleaning, but they now, in fact, as a body, recommend it. There is little doubt, however, that the plant operator would obtain the blessing of the Insurance Company providing that the method has been recommended by a reputable chemical cleaning contractor, especially if the supervisors of the process had received training from such a contractor.

A separate section of this paper has reviewed the type of equipment which must be used for the cleaning process. It must be evident from this, that equipment for carrying out a simple chemical cleaning process will usually be available where industrial development has been

taking place. From the foregoing, therefore, it is obvious that the only possible limitation on the feasibility of chemical cleaning in the developing countries lies with the availability or otherwise of the basic raw materials needed for the process.

Availability of Chemical Cleaning Materials in Developing Countries

In recent years, the chemical cleaning companies have realised the potential of the market in the developing countries. In most cases, however, such countries are supplied with made-up chemicals usually available only by export from the developed areas. In only a very few cases are the made-up materials being manufactured in the developing countries, but it is undoubtedly only a matter of time before such materials are made under licence throughout the world. In the meantime, however, the major problem is the acquisition of such made-up chemicals which usually involves carrying rather large stocks which are obtained by import from the developed countries.

This method, of course, does have the advantage that the experience of the manufacturing company can be drawn upon freely in obtaining these chemicals, but has obvious disadvantages in the high cost of import of such materials.

Since the bulk of the materials used in chemical cleaning is undoubtedly inhibited acid, it is an obvious proposition to consider the import of the inhibitor materials alone. As has been shown previously, nowadays such inhibitors are rather complex products which are usually unobtainable except in the highly developed countries. It is, however, usually possible to obtain the basic acids in those areas of the world which are at present developing industrially.

The most important material is, without doubt, hydrochloric acid, and this is becoming much more freely available throughout the world particularly where petroleum refining is carried out. The other basic materials usually used in simple chemical cleaning processes are as follows:

hydrochloric acid commercial, specific gravity 1.14 to 1.18

sulphuric acid C.O.V.

sulphamic acid technical

citric acid, anhydrous, monohydrate or 50% solution of monohydrate

caustic soda, powder, pellet, flake or solution

trisodium phosphate anhydrous or crystalline

nonionic detergents

anionic detergents

The less important chemicals, but those which are used to some extent in quite common chemical cleaning methods are as follows:

nitric acid commercial

hydrofluoric acid commercial

formic acid commercial

sodium fluoride

ammonium bifluoride

sodium metasilicate

soda ash

It is, of course, much more profitable for the chemical cleaning manufacturer to export a finished product for use overseas. Economically, however, this is not sound, and the solution probably lies in the fact that the chemical cleaning companies will make their experience freely available on the basis of acting as consultants to the process plant operators. In this way, the plant operators in the developing companies get the benefit of the long experience behind the chemical cleaning contractor operating in the industrial countries of the Western world. ●●



Repair and Maintenance of Machine Tools in Developing Countries

AS Pronikov*

A country's stock of machine tools—its technical level, structure and condition—to a considerable extent determines the national productive capacity and ability to solve technical and economic problems independently. The application of advanced repair and testing processes is essential to achieve high efficiency and economy in the overhaul of machine tools.

MACHINE tools, together with welding equipment, occupy a special position in relation to other machinery, such as that used in the textile industry, transport, light industry, printing and so on. Machine tools are used to produce parts of other machines, i.e., to manufacture new machines and instruments and repair existing ones.

A country's stock of machine tools—its technical level, structure and condition—to a considerable extent determines the national productive capacity and ability to solve technical and economic problems independently.

The structure and growth of the machine tool stock are closely connected with a country's level of industrialization. As the country develops, it continues to use general purpose machine tools of normal accuracy, but it makes increasingly extensive use also of precision tools, automatic tools and lines, specialized tools for specific branches of mechanical engineering, and heavy tools for parts of large machines.

Thus, Table 1 shows the number of types of machine tools put into production in the Soviet Union since the establishment of a domestic machine tool industry and indicate how the Soviet Union's need for machine tools has grown as its industry has developed.

Given a stock of machine tools, the problem arises of how to use them most efficiently and extend their useful life-time as long as possible. This can be achieved only through the organization of a special repair and maintenance system.

This is a very serious problem, for modern machine tools are highly complicated machines

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Table 1

Categories of Machine Tools Produced	Number of Types in Series Production in the USSR							
	1932	1937	1940	1945	1950	1955	1957	1965 (planned)
Precision	—	4	7	9	41	109	115	180
Automatic and semi-automatic	7	42	87	40	115	250	295	650
Specialized	6	39	54	47	141	346	370	620
Heavy	3	5	29	12	90	247	180	420
Total, all types	47	190	320	150	384	788	900	1,500

which include precision devices, hydraulic and electrical systems, high-speed and power transmission systems and automatic and control devices.

The functioning of a machine tool's units and mechanisms depends to a considerable extent on the methods used for operating, maintaining and servicing it.

If insufficient thought is given to these methods, great waste of resources and, most important, of foreign exchange can result. Such waste is due to two factors which arise when individual units and mechanisms are taken out of service prematurely.

First, there is an increase in the amount and, accordingly, the cost of repair work. Often the repairs may entail importing spare parts.

When the failure occurs in a complicated precision part, such as a precision lead screw, the bushings of a jig borer, a reading mechanism or the like, it is not always possible to repair and recondition it locally. This may be avoided by adequate methods of operation and servicing.

Secondly, wear and breakdowns increase idle time in repair and reduce the tool's use coefficient. Consequently, extra machine tools have to be acquired to do the same amount of work, and shop space as to be increased correspondingly.

Furthermore, improperly repaired and maintained machine tools may fail to meet their technical specifications, particularly as regards accuracy.

Thus it is important not merely to acquire a stock of machine tools but also to maintain it in efficient condition, which can be done by applying a repair and maintenance system and developing methods of increasing the reliability and durability of equipment.

It is important to train national personnel armed with modern technical ideas in this field.

ECONOMIC ASPECT OF MAINTENANCE AND REPAIR OF MACHINE TOOLS

Expenditure on the repair and maintenance of equipment accounts for a considerable proportion of production costs.

Research has shown that every year approximately 10 per cent of the stock of technical equipment undergoes major overhaul, 20-25 per cent intermediate overhaul and 90-100 per cent minor overhaul.

The loss of time and resources on keeping the stock of machine tools in good order is substantial, depending to a great extent on methods of operating and servicing the machines and the technology and organization of maintenance. For example, in an average-sized or small enterprise the cost of major overhaul alone is normally up to 60 per cent of the cost of a new machine in the case of medium-sized

turning lathes, up to 40 per cent in the case of universal milling machines and up to 75 per cent in the case of capstan lathes. It must also be remembered that before the major overhaul a machine tool undergoes two intermediate overhauls, each of which takes about half as much labour as a major overhaul, and six minor overhauls, each of which takes about a quarter as much labour as a major overhaul.

In addition, machine tools are periodically checked for accuracy, lubricated and given preventive treatment.

Thus, the cost of maintaining and servicing a machine tool during one maintenance cycle (i.e. up to and including the major overhaul) is greater than the cost of a new machine, and, if maintenance and repair is badly organized, can be several times greater.

A factor of no less importance in evaluating the economics of maintenance is the idle time lost by equipment during the various kinds of overhaul.

As an example, let us consider the periods of forced idleness for maintenance work on screw-cutting lathes and cylinder-and-core grinding machines of average size and complexity design. These data are taken from the standards for machine tool maintenance applied in the Soviet Union under which maintenance of all equipment is carried out in accordance with a special system known as the "planned preventive maintenance system."

The figures given in Table 2 are for maintenance teams working a single shift, and indicate how many days a machine tool must remain idle for the given type of maintenance.

Table 2

Type of Maintenance	Lathe	Cylinder Grinding Machine
Major overhaul	11	18
Intermediate overhaul	6.5	11
Minor overhaul	2.75	4.5
Accuracy checks	1	1.5

The cost of maintaining and servicing a machine tool during one maintenance cycle is greater than the cost of a new machine.

As was stated above, under the present maintenance system a machine tool undergoes two intermediate and six minor overhauls before its major overhaul. Accordingly, the number of days which a screw-cutting lathe, for example, will lose for maintenance from the time it is put into operation until its major overhaul is completed (i.e. over the period of the maintenance cycle) will be:

$$11+6.5 \times 2+2.75 \times 6 = 40 \text{ days}$$

A machine's operating life, before major overhaul, and similarly between intermediate overhauls depends to a large extent on the methods of operation. For example, a screw-cutting lathe working single shifts at a series production factory and turning out steel parts to a normal degree of accuracy will have a working life before major overhaul of four to nine years.

If the machine tool runs for eight years before major overhaul, it follows that the time lost for maintenance will amount to an average of five days a year. If the shop has sixty machines with the same average maintenance complexity as a screw-cutting lathe, the total idle time will be 300 days, i.e. the maintenance crew will have to work steadily all year round on maintaining the machines (not allowing for lubrication and preventive and other measures).

If, because of insufficient attention to operating methods, the maintenance cycle is four years, the relative volume of maintenance work will be twice as great.

A country's stock of tools—its technical level, structure and cond tion —to a considerable extent determines the national productive capacity and ability to solve technical and economic problems independently.

These figures show that great attention must be given to methods of maintaining and operating equipment. We have so know the reasons why a machine tool loses its efficiency, and the methods by which its reliability and durability can be increased; and in maintaining equipment up- o-da'e technological processes and methods must be applied. In addition, the equipment maintenance system must be so organized as to act in advance to reduce the progressive wear of equipment, bring maintenance costs toa minimum, andensure the proper preparation and planning of maintenance work and the efficient use of equipment.

CAUSES OF LOSS OF EFFICIENCY IN MACHINE TOOLS

In approaching machines and mechanical systems, the classical sciences such as mechanics attempted to idealize the conditions in which they functioned. The errors and inaccuracies caused in the actual performance of a machine by component wear, temperature deformation, defective materials, technological factors etc., were viewed as aberrations from the performance of the perfect machine and as undesirable and fortuitous phenomena.

Modern science, particularly cybernetics, takes a different view of the errors in a given system. Errors and inaccuracies in a machine's e: ecution of an assigned programme (e.g. a tec hnological process) are regarded as a natural fea ure of any real system. The need thus arises to investigate the sources and causes of adverse influences acting on machines and to study the machines' reactions to them.

A maceine cannot be completely isolated from the effects of its environment, nor can it be isolated from the influence of the processes going on within itself as it functions.

The units and working parts of a machine tool in an industrial shop are subject to the influence of energy in all its forms, which affect its technical performance.

Mechanical energy is not only transmitted through the various working parts of the machine as it performs the given technological process, but also acts on the machine as a whole in the form of vibrations transmitted by other equipment running in the shop, vibrations generated as the machine is fed material, and so on.

The forces at work in the machine are the product both of the technological process and of such forces as those arising from friction in kinematic couples or inertia in moving parts. These forces cannot be strictly defined since the very nature of their occurrence is bound up with complex physical phenomena.

It is, indeed, this degree of indefiniteness of the influences at work that gives rise to the errors and inaccuracies in the operation of mechanical systems.

Furthermore, even a constant force produces wear, deformation and fatigue, i.e., causes a component's parameters to change with time.

Thermal energy affects machine parts as a result of fluctuations in shop temperature, the operation of driving gear or electrical equipment, or heat generated during the cutting process.

These phenomena, too, affect the operation of both individual working units and the entire machine. Studies have shown, for instance, that as little as two hours' exposure to the sun (at mean latitudes) of the face of a cylinder-and-core grinding machine produces a shift in the

table guides, causing the table to deviate 45 microns from true linear displacement. Performance can be affected even more by the heat generated in electric motors, bearings, gearboxes, hydraulic systems, etc. Thus, oil heating in the hydraulic systems of power heads in standard-unit machine tools can increase oil losses and decrease feed. As a result, the duration of the working cycle in the machine or automatic machine line spontaneously increases and productivity falls. It is practically impossible to make accurate allowance for thermal effects.

Chemical energy also has an effect on machine performance. Air containing moisture and aggressive elements can cause corrosion in various machine parts. Emulsion used to cool a tool may drip on to essential machine parts, especially the electrical system, causing premature failures.

Electromagnetic energy in the form of radio waves (electromagnetic oscillations) permeates the space around a machine, and may affect the performance of the electronic apparatus which is being increasingly employed in modern tools.

Thus, all forms of energy attack the machine and its working parts, initiating a great many undesirable processes and creating conditions making for technically inferior performance.

Before dealing with the methods by which these harmful influences may be combated, let us briefly examine the processes that cause a machine to lose its working efficiency.

Some processes occurring in a machine and affecting its performance are *reversible,* since they alter the parameters of parts, units and the entire system within given limits, without tending to cause progressive deterioration.

The most typical example of a reversible process is the *deformation* of machine parts and units which occurs under the influence of external or internal forces. The sources of deformation in machine tools includes not only

A machine's operating time, before major overhaul, and similarly between intermediate overhauls depends to a large extent on the methods of operation.

deformation of the parts themselves but also deformation at surface junctions, e.g. slideways, bearings and other linkages. Deformation of parts and junctions alters the relative positions of machine units, including the position of the tool and the work-piece. The result is a loss of precision, the machine's most important technical feature. When the forces change, so does the deformation, and when the stress is removed elastic recovery takes place and the machine parts return to their original positions. It is for this reason that the deformation process is regarded as reversible.

If circumstances arise in which the forces change periodically and very frequently, vibration to the machine units occurs, i.e. rapid deformation changes of minor magnitude. Vibration also seriously affects the quality of work. It usually results in inferior surface finish.

Another example of a reversible process is the *temperature deformation* of machine parts and units.

Heat production in the cutting zone or in friction couplings and ambient temperature variations lead to temperature deformations which alter the original positions of machine units and consequently reduce precision. Thus observation of the position of a lathe spindle has shown that after some hours of operation (three to seven hours) the spindle is gradually displaced owing to the heating-up of the headstock face. The displacement reaches 20 to 120 microns and then stops, a certain degree of heat exchange being established. After the machine has been switched off, the spindle gradually returns to its former position.

All processes occurring in a machine affect its performance—causing errors, reducing the quality of the technological process, and necessitating periodic overhaul.

Machine tools can sometimes be adjusted to reduce inaccuracies due to temperature deformation, but this makes their operation more difficult.

Accuracy of work is particularly affected by temperature deformation in precision units and framework members.

Whereas reversible processes occurring in a machine tool lower its efficiency as compared with its potential performance in the absence of deformation, temperature effects and the like *irreversible processes* result in the progressive deterioration of the machine's performance with time.

The most typical irreversible processes in machines are wear, corrosion, the gradual redistribution of internal stresses and creep (the slow building-up of deformations).

The most important cause of loss of efficiency in machine tools is wear of machine parts. Wear is the result of a process of gradual change in the dimensions of machine part surfaces under the influence of friction. The process of wear arises out of numerous complex physical phenomena occurring on the friction surfaces of machine parts.

As the surfaces interact they deteriorate and give off minute particles. At various points of contact the temperature rises, changes occur in the structure of the surface layers and there develop chemical processes and processes connected with the molecular attraction of the contiguous materials.

The most common types of wear met with in machine tools are the following:

Abrasive wear, in which abrasive particles found on friction surfaces attack the surfaces by cutting or scratching and produce tiny chips. The particles usually enter the lubricating fluid from the outside and travel with it to the friction surface, but they can also be produced by wear in the couple itself, or they may be hard structural components at one of the abutting parts. In many cases, therefore, abrasive particles cannot be completely eliminated from the friction surfaces of machine parts. Even with efficient oil filtration and the isolation of friction surfaces, conditions for abrasive wear continue to be present.[2]

Fatigue in surface layers manifests itself in the scaling of minute particles of metal from the contact surfaces of machine parts. The appearance of fatigue in the surface layers does not mean the complete breakdown of the part, but there is usually a speeding up of the destructive process (gradual chipping).

Plastic deformation (warping) of surface layers is usually manifested in a displacement of the metal beyond the contact surface. It occurs as a friction, accompanying the process of wear, and in the absence of relative sliding motion. This type of failure is typical of materials having plastic properties.

In practice, the various kinds of surface deterioration develops concurrently, rarely occurring in pure form. To each type of friction surface there corresponds a basic form of deterioration, determined by the mechanical properties of the material, the lubricant, the magnitude of the stresses applied, the operating speed and other factors.

All processes occurring in a machine, whether reversible or irreversible, affect its performance, causing errors, reducing the quality of the technological process, and necessitating periodic overhaul.

PRINCIPAL METHODS OF INCREASING DURABILITY AND RELIABILITY OF MACHINE TOOLS

A machine tool's reliability and durability are the indicators of its performance as a function of time: that is to say, they define the magnitude and nature of the changes in its main characteristics which take place in the course of its operation.

A machine tool must have high initial qualitative and quantitative indicators; but that alone is not enough to make it an efficient machine. Those indicators must be maintained in the course of its operation.

The durability of a machine tool is its ability to carry out its operational functions with minimum expenditure for the replacement of worn parts, readjustment, repairs and servicing. The smaller the total money and time spent on maintaining the efficiency of the machine tool throughout its period of use, the greater its durability.[3]

As the indicator of a machine tool's durability, we may use the coefficient of durabilty nD, which equals the ratio of the operating time to the sum of the operating time and the time the machine is out of action for repair:

$$\frac{To}{To+T_2} = \frac{I}{I+\sum_{i=1}^{n}\frac{I_i}{T_i}}$$

where To is operating time of the machine tool,

T_2 is the time the machine tool is out of action for repair,

T_i is the service life of the- -th part or unit of the machine tool,

I_i is the time (amount of work) required to repair the- -th part or unit, including dismantling, reassembly and adjustment,

n is the number of repairable parts of the machine tool.

The coefficient of durability may vary from 0 to 1. The higher its value, the more durable the machine tool.

The time the machine tool is out of action depends on the service life of its component parts and units and the amount of work required to repair them.

Stoppages of the machine tool which lower its coefficient of durability may have the following causes: breakdown of individual parts, loss of efficiency of drives and mechanisms, changes in the initial service characteristics of the machine tool (precision, freedom from vibration) and so forth.

The coefficient of durability should be calculated on the basis of the machine's entire period of operation, or, at least, of a period equivalent to the length of its maintenance cycle (the length of time before a major overhaul becomes necessary).

The reliability of a machine tool is the indicator of its ability to carry out its functions continuously for a given period of time.

Uninterrupted operation is an important requirement for present-day industrial equipment. Flow-line methods of production, where the work is transferred from machine to machine, and automatic production lines make it essential for every unit to operate without interruption.

The reliability of a machine tool is determined on the basis of indices of probability. It may be defined as the probability (p) that the machine will operate without breakdown for a given length of time under normal operating conditions. If the probability that a machine tool will operate for one year without breakdown is $p=0.95$, for example, this means that out of a large number of machine tools of the model in question an average of 5 per cent will lose its efficiency in less than one year of operation.

What does "loss of efficiency" or, as it is called in reliability theory, "failure" mean in

relation to machine tools? Does a "failure" occur, for example, when it becomes necessary to change a drive belt or adjust a clutch?

The meaning of "failure" must be defined in the light of analysis of the operating and servicing methods used for machine tools of the given type. Brief "interventions" by the operator in the work process and the adjustment of the machine tool, when provided for in the servicing instructions and resulting from the relative imperfection of the machine tool itself, should not be included under the heading of "failures" (breakdown).

Thus, for example, the adjustment and replacement of a tool, the adjustment of individual mechanisms and preventive maintenance are included in the standard running adjustments and between-overhaul servicing of many present-day machine tools.

The more highly perfected a machine tool is, the fewer such "legitimate" stoppages it will have and the more sutiable it will be for continous operation.

Thus, in order to assess the reliability of a machine tool we have to take into account all interruptions of its operation (stoppages) which are not provided for in the servicing plan.

The most convenient period of time to select for the operation of the machine tool with a given of reliability is the period between two scheduled overhauls. The higher the guaranteed probability of operation without failure, P, the more reliable is the machine tool.

Of great importance for machine tools is reliability from the point of view of output quality, i.e. from the point of view of ensuring the desired precision of machining and quality of surface finish.

The production reliability of a machine tool, which is an index of its capacity to continue to satisfy the qualitative requirements of the production process for a given length of time, can also be evaluated from the probability that the machine tool will satisfy those requirements throughout the period between overhauls or for the period before intermediate overhaul, at which any loss of precision by the machine tool is made good.

The reliability and durability are the characteristics which define a machine tool's capacity to realize its technical potential in actual operation, its serviceability and its degree of perfection.

To improve the reliability and durability of machine tools, we have to combat the harmful influences which result in loss of efficiency.

The designer, the technician and the operator always have at their disposal a number of ways of achieving high indices of reliability and durability.

First of all, the machine must have *high resistance to external influences.* The units and mechanisms which make it up must be sufficiently sturdy, must be built on the frame principle, must have the smallest possible number of members, etc., so that they will withstand loads, undergo the least possible deformation and be as free as possible from vibration. Wear-resistant anti-friction materials must be used for friction couples, while all points of friction must be protected from dirt and thoroughly lubricated. Observance of these rules lays the foundations for good wear-resistance.

The causes of possible failure must be borne in mind in the design of the entire machine tool and its units, and precision mechanisms must be protected from shocks and other influences.[4]

The correct placement of driving gear, symmetry of design, and the use of materials with low coefficients of linear expansion help to improve a machine tool's resistance to temperature deformations.

Corrosion is combated by protecting the machinery with special coatings and paints and by the use of additives in oils and coolants.

The above and other similar measures will result in the production of highly perfected

machine tools of advanced technical performance.

The latest advances in mechanical engineering, materials and chemistry (lubricants and plastics) are continually being brought into use in up-to-date machine construction.

The possibilities of combating harmful processes are not unlimited, however. There are no completely wear-resistant materials. It is practically impossible to exclude all but liquid friction in all mechanisms, and there are no materials which do not suffer deformation and do not change their dimensions with temperature fluctuations.

When it is also borne in mind that the sources of internal and external influences on the machine tool remain and that increasingly exacting demands are being made as regards output quality, it will be seen that the above methods of combating harmful influences, while essential, are inadequate, being limited by the level of development of one or another field of technology—for example by the possibilities of producing wear-resistant materials.

The second way to increase the reliability and durability of machine tools is *to use the most highly rationalized methods of operating and maintaining equipment.*

The method of operation of a machine tool to a great extent determines its rate of wear and the rate of development of other processes resulting in loss of efficiency.

Systematic supervision of the functioning of the machine tool and of the lubrication of its moving parts, prompt adjustment of its various mechanisms, regular care and protection from accidental blows and damage are all essential conditions if the machine is to have the durability for which it was designed.

The system of planned preventive maintenance in operation in Soviet factories embraces not only overhaul operations proper, but also a complex of preventive operations which form part of the inter-overhaul servicing system.

Both the machine tool operator and the members of the maintenance staff (fitters, greasers belt-drive servicemen and electricians) take part in the inter-overhaul servicing operations.

Inter-overhaul servicing includes checks to ensure that the equipment is in good condition, that it is being operated correctly, that necessary adjustments are being made and minor faults corrected, and that proper lubrication is maintained.

In addition, the services included in the periodical overhauls, such as cleaning, changing the oil and flushing the lubrication system, and checking the equipment for precision and rigidity, also help to create proper conditions for correct operation.

In the operation of equipment, the protection of friction surfaces from dirt is of great importance.

The protection of friction surfaces from atmospheric dust, abrasives, and chips from the work material considerably affects their wear-resistance.

It is particularly important to protect the surfaces if the surrounding atmosphere has a high abrasive content. For example, when polishing machines are in operation, abrasive particles from the polishing discs accumulate in great quantities in the air and on the surfaces of the machines.

In such working conditions, therefore, rational operating procedures are extremely important, i.e. changing and filtering of lubricants, protection of mechanisms from abrasives, removal of dust from the working area, removal of the products of grinding and polishing, e.g. by magnetic separation, etc.[5]

The nature of the material being worked is an important factor in the fouling of the machine surface.

When cast iron is worked on lathes, milling machines or other machine tools, damage is

caused by scale or particles of grit falling onto the mechanisms; in the case of aluminium alloys, the harmful elements are hard aluminium oxides. Thus the rate of wear of lathe slides in light machining operations, even with shields (which only partially protect the slides), is three to four times higher in the machining of aluminium alloys than in that of steel or cast-iron parts.

This demonstrates the need for more effective ways of protecting the slides in the machining of aluminium.

In some factories machine tools may be seen operating without slide shields, the slides being protected only by felt padding. Measurements have shown that in such cases slide wear is two to three times greater.

In machine-tool operation, therefore careful attention should be given to the use of various protective devices to prevent fouling of key parts.

It is of great importance when operating machine tools to ensure that the lubrication system functions without interruption.

Defects in the lubrication system may cause accelerated wear and the breakdown of key parts of the machine. For example, if the flow of oil to the spindle of a polishing machine is cut off, not only are the sleeve bearings damaged but the spindle is often heated to the point where heat cracks appear on its surface and it breaks down. While working with machine tools, operators have noticed that abrasive and other dusts in a state of suspension in the air settle on the bed guides and combine with the oil to form an abrasive mixture.

This accelerates the process of wear, especially if the machine with oiled slides has been idle for a time. The extent of wear may increase by 30 per cent. For this reason experienced workers clean the slides thoroughly at the beginning of their shifts, particularly after non-working days.

Wear depends on the hardness of the abrasives falling into the lubricant.

In ascending order of abrasive capacity, these particles may be rated as follows: steel and cast-iron filings, scale, grit, and cutting particles from polishing discs.

It is also desirable when operating machi tools to check the wear of their key parts, particularly the slides. This may be done with special wear gauges developed in the USSR (7 ; 3) which measure precisely the amount of wear of the slides in industrial operation. The extent to which deterioration can be corrected depends on the methods and technological processes employed in machine-tool maintenance. In wear-resistance, accuracy and other characteristics, reconditioned parts or units should be as good as new ones.

The system of maintenance should be so organized that the restoration of the efficiency of equipment requires a minimum expenditure of time and resources.

A third way of improving and maintaining the technical characteristics of a machine tool is *to isolate the machine from harmful external influences.* This method is particularly applicable in the case of precision machines which are required to turn out a high-quality product.

Thus, in order to reduce temperature deformation, precision machines are placed in special temperature-controlled rooms or shops equipped with special devices to maintain the desired temperature, usually 20°C.

For example, co-ordinated boring machines, which are required to be exceptionally accurate in perforomance, are generally operated in temperature-controlled rooms; where that is not possible, each machine is placed in a separate room, where it can be better isolated from temperature changes, dust in the atmosphere and the vibrations of other machines.

Insulating machines from vibrations is also one of the methods of increasing their precision.

Many machine tools and other machines and equipment operating in any part of a factory subject the bed on which they rest to periodic stresses. The resulting vibrations are transmitted to other machine tools and if they reach a certain degree of intensity and frequency they can lower the quality of performance of the latter substantially.

The usual method of insulating machine tools from vibrations is to set them on individual beds, 2-3 metres deep in the case of medium-size precision machines and up to 5-6 metres deep in the case of some heavy and special-purpose machines.

Although placing the machine tool on an individual bed considerably improves its resistance to vibration, the process is a laborious one and makes it difficult to move the equipment about in the shop.

To an increasing extent machine tools are being placed on special resilient supports or vibration dampers. The resilient component consists of steel springs or grids, plastic packing, rubber, cork etc. If they are given the proper degree of rigidity, they damp vibrations transmitted from other machines and equipment.

Devices for removing dust from the air and strict atmospheric dust control are other widely used means of improving the accuracy of performance of machine tools. In some cases standards are set, specifying the permissible quantity of dust particles per cubic centimetre of air. This procedure is not only essential in connexion with the manufacture and assembling of certain key parts of instruments but also helps to maintain the efficiency of the machine tools themselves, since it considerably reduces the quantity of abrasives which can fall on their friction surfaces.

Isolating the machine tool from temperature changes, vibrations, dust and other external influences increases its efficiency but this method too has its limitations.

Firstly, internal causes of error remain, such as the heat generated by the working mechanism of the machine tool, abrasive particles produced by wear of the machine's parts, and vibrations produced by cutting and by the operation of the mechanisms of the machine itself.

Secondly, complete isolation is difficult to achieve because external influences are variable and to a certain extent indeterminate in nature. Thus the intensity and character of external vibrations affecting the tool depend on the operation of other machines and vary quite widely, while insulation from vibration is most effective only for vibrations of certain frequencies.

Thirdly, and lastly, the very principle of isolation from external influences stems from an old non-cybernetic view of mechanical error as something which can be eliminated.

For these reasons there has been a growing tendency in recent years to use a fourth means of improving the efficiency of today's complicated machine tools, namely *the use of special mechanisms which automatically regulate the parameters of the machine.* The use of these mechanisms makes it possible to maintain the fundamental characteristics of the machine over a long period of use, through inter-action with the environment, through the automatic reaction of the machine to changes in its operating conditions.

Like a living organism, a complicated machine should possess the function of automatically recovering its lost efficiency.

Such mechanisms are already being used on machine tools, ranging from the simplest devices which automatically eliminate gaps produced by wear, break the kinematic circuit in case of overloading and ensure uniformity of stresses within the mechanism, to systems which restore accuracy of performance, replace worn-out tools, react to the effects of temperature, etc.

For example, the following are coming into use: automatic regulation of the kinematic precision of the rolling chain in gear-cutting

machines, automatic regulation of the thickness of the oil layer in the slides in vertical boring and turning machines, active control and automatic minor adjustments in polishing machines, automatic elimination of vibration and imbalance in lathes, automatic compensation for wear in the tables of certain types of machine tools, and other self-regulation systems.[8] These automatic regulation systems are opening up broad prospects for the development of reliable and long-lasting machines, but they require that even closer attention be paid to the methods of maintaining and operating them. The more complicated the equipment used and the better its quality, the more important the correct organization of machine-tool servicing and maintenance becomes.

ORGANIZATIONAL PRINCIPLES FOR MACHINE-TOOL MAINTENANCE AND SERVICING SYSTEMS

In order to keep equipment permanently in working order with the minimum expenditure of time and resources, it is necessary to institute a maintenance system with strict rules concerning the basic measures to be taken for this purpose.

In the Soviet Union, a uniform planned preventive-maintenance system has been specially worked out for and is applied in all branches of industry.

Now thirty years old and steadily improved, this system has shown its great possibilities and the correctness of the underlying organizational principles.

The basic principles of the planned preventive-maintenance system are as follows:

1. All operations necessary to keep equipment in working order are divided into two groups:

(a) Servicing in the intervals between overhauls, which includes regular checking of the equipment and correction of faults, preventive measures, adjustment of mechanisms, and sometimes replacement of quick-change parts;

(b) Periodic overhauls, which are carried out in accordance with a plan laid down in advance and represent the bulk of maintenance operations.

2. Periodic overhauls in accordance with the plan are sub-divided into various types depending on the scale of the operation. There are usually three types of overhaul:

minor (type I)

intermediate (type II)

major (type III).

A machine tool which has undergone major overhaul must be able to meet all the basic demands placed upon a new tool.

3. All overhauls of a particular model of machine tool under the plan are carried out at regular intervals, the intervening periods being called "intervals between overhauls". The length of the interval is one of the main characteristics of the maintenance system and depends on the type of machine tool and its operating conditions.

4. The maintenance system also fixes the pattern of the maintenance cycle, i.e., the number of planned overhauls and the order in which they are carried out. Most machine tools now have a cycle of nine planned overhauls, in the following order: I-I-II-I-I-II-I-I-III.

This pattern is the same for all types and models of metal-cutting lathes and all operating conditions. The period of time over which it is completed, i.e. the period from one major overhaul to the next, is known as the maintenance cycle.

5. The expenditure of labour for a given type of overhaul is indicated by the number of machine-hours and man-hours allocated for it under the plan.

   The relationship between the volumes of major, intermediate and minor overhaul work is the same for all machine tools.

6. Machine tools are broken down into different categories according to their degree of complexity. Each category is assigned a conventional coefficient which compares the labour consumed by a machine tool in that category with the amount consumed by a standard tool. The tool taken as the standard was a general-purpose turning-lathe of average complexity, whose labour consumption is indicated by a complexity coefficient R=10.

7. The standard values for the volume of overhaul work are average figures and are used to plan the total volume of overhaul work in a workshop or enterprise. Deviations are allowed for, depending on the actual state of a machine tool when overhauled.

The basic idea behind these principles underlying the maintenance system is that by establishing a maintenance cycle with a permanent pattern, preserving average ratios between the volumes of work involved in the different types of overhaul and comparing different types of equipment by placing each in a maintenance complexity category, it is possible to plan maintenance in advance and to calculate the labour, equipment and time required.

On the other hand, the system allows for the variety of equipment and working conditions to be found in industry. It provides for different intervals between overhauls, allows for deviations from the average values for labour consumpation and lays down a whole complex of preventive measures to prevent sudden breakdowns and cumulative wear.

Standard rates have been worked out in Soviet Union for determining the expenditure of labour in mainteance of technological equipment.[1] From the standard rates it is possible to calculate in advance the periodicity of maintenance, the amount of time and resources to be expended on it, the amount of labour and equipment required, the cost of maintenance operations, the quantity of spare parts and other necessary data.

The standard rates are drawn up in such way that the labour consumption in the overhaul of each unit of complexity is determined; this value is then converted for the tool in question. Thus, according to the 1962 rates, the time to be spent per maintenance unit should not exceed the figure shown in Table 3.

Table 3

Overhauls & preventive maintenance operations	**Number of hours**	
	Mechanics, etc.	**Machine tools**
Cleaning	0.35	—
Checking accuracy	0.4	—
Minor overhaul (I)	0.75	0.10
Intermediate overhaul (II)	4.1 16.5	2.0 7
Major overhaul (III)	26	10.1

Thus, the labour consumption ratio for planned overhauls is:

I:II:III=6.1:23.5:36.1, or approximately 1:4:6.

These standard time rates are intended for planning and calculating the labour force required. In order to determine from them the number of hours required for maintenance of a given model of machine tool, the figures given must be multiplied by the complexity coefficient for the machine tool concerned.

For example, in the case of a thread-grinding machine with complexity coefficient R = 17, 17.(26 + 10.1) = 615 hours should be planned for major overhaul, 400 hours for intermediate overhaul, and so on. The standards give examples o how to make the calculations and tables of complexity coefficients for different types and models of machine tools.

Table 4 gives the most characteristic complexity coefficients for certain types of machine tools.

Table 4

Type of machine tool	Complexity coefficient
1. Lathes, medium size	9–13
2. Heavy lathes	17–19
3. Vertical drilling machines	3–8
4. Radial drilling machines	6–12
5. Open-side jig borers	20–35
6. Horizontal borers (medium)	16–18
7. Cylinder-grinding machines	10–15
8. Gear-cutting machines, medium size	10–12
9. General-purpose horizontal milling-machines	8–14
10. Planing machines, medium size	12–15

The length of the maintenance cycle in hours is calculated from formulae in which the operating conditions of the tool are expressed by empirical coefficients.

For metal-cutting lathes the value of T can be calculated from the formula:

$$T = 24{,}000\ \beta_1\ \beta_2\ \beta_3\ \beta_4 \text{ hours}$$

where β_1 is the coefficient for the type of production, with values $\beta_1 = 1$ for mass and large-series production, $\beta_1 = 1.3$ for series production and $\beta_1 = 1.5$ for samll-series and unit production. The coefficient β_2 relates to the type of material worked on the machine tool, with values $\beta_2 = 1$ for structural steel, $\beta_2 = 0.7$ for high-strength steel, $\beta_2 = 0.75$ for aluminium alloys and $\beta_2 = 0.9$ for cast iron and bronze. The coefficent β_3 relates to operating conditions, with values $\beta_3 = 1$ for normal operating conditions, $\beta_3 = 0.7$–0.8 for dusty and humid conditions, $\beta_3 = 1.1$ —1.2 for high-precision tools in machine-shop conditions and $\beta_3 = 1.3$—1.4 for tools housed separately. The coefficient β_4 relates to the size of the machine tool, with values $\beta_4 = 1$ for light and medium-sized tools, $\beta_4 = 1.35$ for heavy tools and $\beta_4 = 1.7$ for especially heavy and special-purpose tools.

The formula for the interval between overhauls t, with nine planned overhauls per cycle, is $t = \frac{T}{9}$ hours.

When equipment is worked on a single-shift basis, its rated annual working time is 2,000 hours.

The inter-overhaul period can be determined roughly from these functional relationships and then corrected in accordance with the specific operating conditions and methods.

Suppose, for example, that it is necessary to determine the duration of the maintenance cycle for a heavy turning lathe (complexity coefficient R = 17, $\beta_4 = 1.35$) working two shifts in small-series production conditions ($\beta_1 = 1.5$). The tool processes mainly high-strength steel and cast iron $\left(\beta_2 = \frac{0.7 + 0.9}{2} = 08.\right)$ and humidity in the workshop is very high ($\beta_3 = 0.7$).

$T = 24{,}000 \times 1.5 \times 0.8 \times 0.7 \times 1.35 = 27{,}000$ hours, or

$$T = \frac{27{,}000}{2 \times 2{,}000} = 7 \text{ Years}$$

t = 9.5 months—the inter-overhaul period.

On the basis of these data, the machine's maintenance schedule can be drawn up and the labour consumed and the time spent idly in maintenance can be determined as above.

There are three main systems of maintenance in industrial enterprises -centralized, decentralized and mixed.

Under a centralized maintenance system, all maintenance work is carried out at the factory with the labour and resources of a chief mechanical engineer's section and its maintenance machine shop. This kind of organization is typical for plants with a small amount of equipment.

Under a decentalized maintenance system, all kinds of maintenance operations -- inter-overhaul servicing and periodic overhauls, including major overhauls -- are carried out under the direction of shop mechanics by so-called "shop maintenance units", which are general maintenance squads. The maintenance machine shop under the chief mechanical engineer carries out only major overhaul of complex units. In addition, it manufactures and reconditions equipment parts for the shop maintenance units when this requires special technology.

Under a mixed maintenance system, all kinds of maintenance, except major overhauls, are carried out by shop maintenance units and major overhauls (and sometimes intermediate overhauls of large assemblies) by the maintenance machine shop.

SCOPE OF EACH TYPE OF OVERHAUL AND DETERMINATION OF SERVICE LIFE OF MACHINE-TOOL PARTS

The scope of the planned periodic overhauls depends on the design of the machine tool and the conditions under which it is operated.

A *minor overhaul* entails the replacement or reconditioning of a small number of worn parts, the adjustment of the machinery, and checks that the machine tool is in staisfactory condition and that its lubrication system is functioning properly.

A major overhaul entails complete restoration of the efficiency of the machine tool.

An *intermediate overhaul* entails a greater amount of maintenance work, including the partial truing-up of the machine tool and the restoration of any precision which has been lost. It is carried out without removing the machine tool from its bed.

A *major overhaul* entails the complete restoration of the efficiency of the machine tool. The tool is normally completely dismantled and degreased and its parts are sorted, on the basis of measurements and visual inspection, into three categories.

The first category covers serviceable parts which do not need reconditioning and are fit to serve for another maintenance cycle.

The second category covers parts which require reconditioning because of surface wear, deformation or other reasons. The most suitable reconditioning process is specified for each part (e.g., building up the part by welding, chromium plating or other methods, grinding to the reconditioned dimensions, etc.).

The third category covers parts which it is impossible or uneconomic to recondition. Such parts are replaced with new ones made to the same technical requirements. Typical parts which fall into this category are roller-contact bearings, friction clutch plates and so forth. In order that the various parts may be correctly sorted into categories and their suitability for further service in the machine tool properly evaluated, it is essential to set maximum permissible limits of wear for them and establish their service life.

This is an extremely complicated matter, as the parts of any machine tool have to satisfy the most varied requirements. So far, no completely satisfactory method of calculating maximum wear levels has been developed.

The criteria (characteristics) of the maximum wear of machine tool parts may be divided into two groups.

The first group comprises criteria relating exclusively to the proper functioning of a given assembly or part.

This covers cases such as the breakage of parts as a result of wear (the teeth of slow-speed worm gears), the wearing away of the case-hardened layer, resulting in a sharp increase in the rate of wear (the slide blocks of link gear), and the breakdown of liquid friction (slider-type bearings), etc.

In many cases, however, the functioning of an assembly cannot be considered in isolation from the functioning of the mechanism or the machine tool of which it is a part.

The criteria in the second group relate to the performance by the machine tool or mechanism of the functions for which it is intended. The most typical criterion of this group, as far as machine tools are concerned, is precision of machining.

Table 5, for example, gives lists of figures claculated by the author which show, for various degress of machinery precision, the maximum wear of lathe slides (measured at the point of greatest wear) which will permit those precision requirements to be satisfied. The figures in the table show only the reduction in precision due to wear of the slides, and do not take into account the influence of other factors (such as the rigidity of the slide rest, the spindle and other parts and wear of the cutting tool).

This table shows that there is a direct connexion between the permissible wear of the slides on the one hand and the desired precision of machining and the dimensions (length) of the workpieces on the other hand.

When the workpieces are short and a large allowance is made for variations in their diameter, the permissible wear may be very considerable. However, operational and overhaul considerations and the need to avoid vibration of

Table 5

Maximum Permissible Variation in diameter of workpiece in microns	Class of Precision at d=50—80mm	Maximum premissible wear of slides, in mm. when turning workpieces with lengths of up to :					
		25mm	50mm	100mm	200mm	300mm	400mm
13	1	0.16	0.08	0.04	0.02	0.013	0.01
20	2	0.24	0.12	0.06	0.03	0.02	0.015
30	2a	0.40	0.20	0.10	0.05	0.035	0.025
60	3	—	0.40	0.20	0.10	0.07	0.05
120	3a	—	—	0.40	0.20	0.13	0.10
200	4	—	—	0.65	0.32	0.21	0.16
400	5	—	—	—	0.65	0.43	0.32

the slide rest make it inadvisable to allow the wear to exceed 0.2mm.

In many cases, the maximum permissible wear of key parts of each model of machine tool can be established on the basis of practical overhaul and operating experience.

In order to determine the service life (T) of a part, it is necessary to know the nature of the wear process in the part as a function of time and the maximum permissible value of wear U_{max}. As in the majority of cases, normal wear takes place at a constant rate γ=const., then for known values of γ and U_{max}. the service life of a part will be:

$$T=\frac{U_{max}}{\gamma} \qquad (2)$$

The value of the rate of wear γ is determined either on the basis of measurements or from experience of operation of machine tools of the type in question.

Formula (2) for determining the service life of machine tool parts is applicable to parts which are replaced only when they become unserviceable, i.e., when their wear has reached the value U_{max}.

Quick-change parts which are replaced when the machine tool is serviced between overhauls fall into this category.

In the case of parts which are reconditioned or replaced during the periodic planned overhauls, the acceptable values of wear U_o will be equal to or less than the maximum permissible values U_{max}, as the parts must not become unserviceable in the interval before the next overhaul. If the inter-overhaul period, i.e., the period between two planned overhauls, is T_1, then over that period of time the wear of the part will increase by an amount γT_1. The maximum acceptable amount of wear U_o, after which it is essential to replace or recondition a part at the current periodic overhaul, will therefore be:

$$U_o=U_{max}-\gamma.T_1 \qquad (3)$$

Bearing in mind that $\gamma=\frac{U_o}{T}$ (where T is the service life of the part before overhaul) we have:

$$U_o=U_{max}-\frac{U_o \cdot T_1}{T} \qquad (4)$$

$$U_o=\frac{U_{max}}{1+\frac{T_1}{T}} \qquad (5)$$

If a given periodic overhaul is the Kth since the last overhaul of the part, then the service life of the part will be $T=KT_1$ and the formula for calculating the acceptable wear will take the form:

$$U_o=\frac{K}{K+1}U_{max} \qquad (6)$$

For example, a part has a case-hardened layer 0.8 mm in depth and the maximum permissible wear is U_{max}—0.65 mm (80 per cent of the depth of the case-hardened layer). Should the part be recoditioned if, when measured at the third periodic overhaul, its wear is found to amount to 0.55 mm?

Let us calculate U_o according to formula (6):

$$U_0=0.65\ \frac{3}{3+1}=0.49\text{mm}$$

The part must therefore be reconditioned, as although its wear is less than U_{max} it will not last until the next periodic overhaul.

If the maximum permissible amounts of wear and the service lives of the main parts of the machine tool are known, the scope of the various types of overhauls can be defined more accurately, the durability of the machine tool increased and the cost of maintaining it reduced.

THEORETICAL BASES FOR ESTABLISHING THE MAIN PARAMETERS OF A MAINTENANCE SYSTEM

The main parameters of a maintenance system are a maintenance-cycle pattern appli-

cable to all machine tools and an inter-overhaul period which takes into account the special features of the equipment and the way it is operated.

The maintenance cycle pattern and the interval between overhauls must be such that through fuller utilization of the service lives of the machine tool parts and assemblies, other things being equal, the equipment is idle for overhaul for the shortest possible time and expenditure on its overhaul is kept to the minimum.

In order to select the best values for these parameters, it is necessary to determine how their values influence the durability of the machine tool—the coefficient n_D (see formula (1)).

When using formula (1) in connexion with periodic overhauls it must be borne in mind that:

(1) The periodicity of overhauls will be defined by the minimum service life T_1 of the parts subject to periodic overhaul;

(2) At each overhaul, all parts whose service life will expire before the next overhaul must be replaced.

In order to analyse the maintenance-cycle pattern, all machine-tool parts which are subject to periodic overhaul must be divided into groups according to length of service life.

Each group comprises parts whose service life, TI, is within the range $n_i.T_1 \leq zT_i < (n+1)T_i$, where n is the ordinal number of the group of parts in question and T_1 is the minimum service life, which determines the periodicity of overhauls. For the n^{th} group of parts, the periodicity will be $n.T_1$, as parts of the first group will be overhauled after T_1 hours, parts of the second group after $2T_1$ hours, and so forth. The number of groups of parts (n) overhauled at the periodic overhauls is determined from the relation $n = \frac{T_{max}}{T_1}$, where T_{max} is the service life of the most durable part.

If the maintenance-cycle patterns used are analysed from this point of view, more advantageous variants than the nine-period pattern may be found.

It is a fact that although the pattern shows the first two periodic overhauls as being of the same type (minor overhauls), this is an index only of their average scope. In reality, these two overhauls will be different from each other, as after the period T_1 (the period between overhauls), the first-group parts will be overhauled, while after the period $2T_1$ both the first-group and the second-group parts will be overhauled. The amount of overhaul work carried out on the second occasion will consequently be greater, although both are classified as minor overhauls and the time and resources allocated for them are identical.

It can similarly be shown that the volume of overhaul work involved in the first and second intermediate overhauls in the cycle will be different in each case.

In the interests of more accurate planning of maintenance it is therefore desirable that there should be, not three, but four types of overhaul (the fourth type being termed a complete overhaul).

As the author's calculations show[3,6], it is more advantageous from the point of view of reducing equipment idle time to use a 6-period pattern with a I-II-III-II-I-IV cycle and a ratio of volumes of overhaul work of I:II+II:IV =1:2:4:6.

The change to a cycle pattern with four types of overhaul requires a higher level of maintenance organization and will constitute a further development of the maintenance system.

Attempts are now being made in the Soviet Union to introduce optimum maintenance-cycle patterns which take into account the work which has been done in this field.

The existing maintenance system, which

has been of great economic value to industry, will thus be further developed and perfected.

The length of the period between overhauls (T_1) is that basic parameter of the maintenance system which reflects the special features of the equipment in question and the nature and intensity of its operation.

The length of the period between overhauls must be determined after the maintenance-cycle pattern has been selected: it is thus the second task in establishing the basic parameter of the maintenance system.

The aim in determining the length of the period between overhauls and the maintenance-cycle pattern must be to achieve the highest possible durability of the equipment. The optimum period will be that which, other things being equal, gives the higest coefficient of durability (or the minimum loss of machine time on overhauls, which amounts to the same thing).

The main consideration in selecting the optimum period between overhauls ($T_1 = T_{opt}$) is to establish such a ratio between the amount of work carried out at the periodic overhauls and the amount carried out in the course of servicing between overhauls as will make possible the minimum expenditure of labour on overhauls in the given conditions.

When the length of the inter-overhaul period is extended, a larger number of parts will be replaced in the course of the servicing between overhauls. The result of this is that while the durability of individual parts is more fully utilized during the servicing interval, the amount of assembly and disassembly is increased.

On the basis of these considerations, the author proposes the following formula for calculating the optimum interval vetween overhauls:

$$T_{opt.} = \frac{1.8}{K}\left(\frac{T_k}{T_1} + 1\right)\left(\beta - \sqrt{\beta^2 - 1}\right) \cdot T \quad (7)$$

where T is the length of the actual interval between overhauls established in practice;

K is the number of overhauls in the cycle (K=6 or K=9);

T_K is the actual time required for a complete overhaul (in hours) for a length of cycle K.T.

T_1 is the actual amount of time required for a minor overhaul (in hours);

$\beta > 1$ is a coefficient which indicates the increase in the amount of time spent on the overhaul of machine-tool parts and assemblies in the course of inter-overhaul servicing beacuse of increased assembly and disassembly work.

β is normally between 1.5 and 3. This formula permits the calculation of the value of $x = \frac{T_{opt.}}{T}$ which is an index of the advisibility of lengthening or shortening the period between overhauls in the given operating conditions: i.e., it makes possible more accurate correction of the value of T established from the norms.

The coefficient β greatly influences the value of $T_{opt.}$

If the time spent on assembly and disassembly work can be reduced by using quick-change parts and introducing wear-compensation adjustments, the interval between overhauls can advantageously be lengthened.

If changes are made in the overhaul and operating conditions of the equipment, the inter-overhaul period should also be adjusted accordingly.

Improvements in overhaul methods, in the durability of the individual parts, and in the design of machine tools will be fully effective in increasing the durability of the equipment provided that the main parameters of the maintenance system—particularly the maintenance-cycle pattern and the length of the inter-overhaul period—are correctly selected.

Shop maintenance units form part of production shops. Their purpose is to carry out inter-overhaul servicing and to perform individual repair work on the various types of equipment.

ORGANIZATION OF MAINTENANCE SERVICES AT THE PLANT

The organization of maintenance work at the plant must provide for the execution of all technological processes necessary for maintenance operations, receipt of spare parts from the machine-tool factory and overhaul of individual assemblies or machine-tools at special maintenance centres.

The organization of maintenance, as shown above, depends upon the types and number of machine-tools at the plant.

The plant's maintenance machine shop usually comprises the following sections or units: (1) a machine-tool section; (2) a fitting shop; (3) a welding shop. In large maintenance machine shops there is a further department for restoring and increasing the wear resistance of parts, with sections for metalization, chrome plating, dementing, heat treatment, etc.

The machine shop is headed by a superintendent, subordinate to the factory's chief mechanical engineer, and the various sections or units are headed by foremen, under the shop superintendent. Also under the latter's authority are a technological office, a planning office and other administrative units.

Shop maintenance units, as has already been shown, form part of production shops. Their purpose is to carry out inter-overhaul servicing and to perform individual repair work on all the various types of equipment installed in each workshop. The scale of operation of a shop maintenance unit depends on the system of maintenance followed at the plant.

Under a centralized system of maintenance, in which work is carried out exclusively with the labour and resources of the appropriate workshops of the chief mechanical engineer's sections, the shop maintenance unit is responsible only for inter-overhaul servicing. Where the workshops of the chief mechanical engineer's section have insufficient work, they are also made responsible for inter-overhaul servicing.

Under a decentralized system, the shop maintenance units carry out inter-overhaul servicing of mechanical equipment and all types of overhauls, except major overhauls of the most complex units. They are also responsible for inter-overhaul servicing and minor and intermediate overhauls of electrical and diesel equipment.

Under a mixed maintenance system, major overhauls of production-shop equipment are carried out by mechanical and electrical repair shops.

The Model Regulations recommend the establishment of shop maintenance units in workshops where the total number of maintenance and repair operations runs to upwards of 600—700. In small workshops independent maintenance units are not set up. Such shops are served by so-called central district units (one unit for several shops), headed by district mechanical engineers, who are subordinate to the chief mechanical engineer.

Central district units are staffed by squads of fitters, attached to production sections, bays or shops. The size of each squad is established according to the labour requirements for the projected maintenance operations according to an annual schedule and for carrying out the inter-overhaul servicing of the equipment assigned to the squad.

In choosing the particular system of maintenance for the factory as a whole, account is taken of its effect on the structure of the central maintenance-service apparatus—the chief mechanical engineer's section. With a decentralized system of maintenance, when the bulk of the work is undertaken by the shop maintenance units, it is advisable to augment the latter's planning and accounting staff and correspondingly to simplify the structure of the central maintenance-service apparatus, making the latter responsible only for the methodical direction and supervision of the shop maintenance units' work.

The structure of maintenance services in the chief mechanical engineer's section also depends on whether there is an independent chief mechanical engineer's section at the plant. If there is such a section, one of its functions is to ensure the correct use and planned maintenance of all power equipment.

An independent chief power engineer's section is usually set up at large plants which have a large amount of equipment and use substantial quantities of power. In factories using small amounts of electricity and having small power installations, a combined chief mechanical engineer's and power engineer's section is formed, which includes a power-engineering office and is responsible for the work of the electrical and diesel shops.

In plants with large numbers of machine-tools of the same kind and in mass-production factories, it is advisible, in order to cut down machine idle time during repair, to carry out repairs by the unit system.

The essence of the unit system of repair is the removal of machine-tool units requiring repair and their replacement with spare units, either previously repaired, re-built or newly purchased. In metal-cutting machines, such interchangeable units include the headstock, the apron and the carriage saddle, the drive mechanism, the spindle-casing, the grinding and turret heads, etc. The range of interchangeable units and interchangeable parts must be made more and more comprehensive, and the rebuilding (repair) of these units and parts must be centralized.

In the maintenance of machine tools and other equipment, correct choice of technical proces es to be used to restore the impaired efficiency of the various units and parts is important.

In addition to the unit system, there is the successive-unit system of repair and overhaul, in which the units of the assembly are overhauled in a particular sequence during normal breaks in the operation of the equipment. During meal-breaks and on rest-days and non-working shifts, different units requiring overhaul are dismantled and their worn-out parts replaced.

The successive-unit system is particularly well suited for the repair of standard-unit machine-tools and other tools where the various sub-assemblies are individually designed.[9]

The more equipment is standardized and the more its individual units and assemblies are unified, the simpler will the organization of maintenance services become.

It is expedient, therefore, in equipping any given factory, to use the minimum number of machine-tool contractors.

In the Soviet Union, efforts are now being made on a broad front to produce machine tools in various technological versions and types on a single base, to standardize regular machine parts and assemblies, and to unify construction.

These measures not only reduce the cost and

increase the quality of machine-tool production but also simlify their repair and maintenance substantially.

TECHNICAL PROBLEMS OF MACHINE TOOL MAINTENANCE

In the maintenance of machine tools and other equipment, correct choice of the technical processes to be used to restore the impaired efficiency of the various units and parts is important.

This is a somewhat complex problem, because, firstly, the range of repairable parts is extremely wide; secondly, the parameters of the parts have to be fully restored in repair, and in many cases increased wear resistance and toughness are called for; and, thirdly, expenditure on repairs and idle time during repair must be kept to a minimum.

In addition to the ordinary methods of mechanical machining, extensive use is made of electroplating, metal improvement processes, pulverization and other technical processes to restore the dimensions of the worn parts.[10]

Processes to harden the surface of parts and increase their wear resistance and fatigue strength are also used.

These include heat and thermo-chemical treatment, electric spark surface toughening, and surface toughening by rolling and shot-peening.

In repairing equipment, it may also become necessary to modernize individual units, replace some materials by others, and economize in the use of non-ferrous metals. In some cases, therefore, bimetallic parts have to be made—e.g. slider bearings, worm wheels and lead screw nuts using bronze for the friction surface and steel or cast iron for the main body of the part.

Metallo-ceramic parts are also used—for example iron-graphite bushings and plastic parts.[11] All this calls for special equipment and skilled labour.

In the repair of machine tools, particular attention has to be given to the technical processes for reconditioning or repairing certain parts, since their quality determines the precision of the machine tool.

Normally, the most labour-consuming operation is the repair of machine-tool slides, since these determine the precision of movement of the basic units of the machine and the accuracy of their relative positions.

The technical processes for repairing worn slides are varied, and, depending on the circumstances, may be carried out by machining at the lathe, by the use of suitable appliances or by hand.

The machining of slides by planing, milling or grinding is the most exact and productive method of reconditioning worn slides. However, its use is not infrequently limited by the factory's lack of machine tools of suitable size and adequate precision.

The repair of bed slides with the help of suitable appliances necessitates no special equipment; the appliances used for the purpose are of simple construction and can be mace at any machine-building plant. But the drawback of this method is its high labour consumption as compared with machine work, since treatment with appliances normally takes place at a lower tempo, and usually necessitates a certain amount of manual labour in preparing the setting bases and some rather labour-consuming work in installing and setting up the appliance. Nevertheless, it is often preferable, because it can be carried out at the site of the machine tool, so that the bed does not have to be dismantled and reassembled, and time is saved on transporting it to the repair shop and back. This method is best suited to the repair of particularly large bed slides.

The repair of slides by hand (powdering, scraping, etc.) is the most labour-consuming

and outdated method, and is permissible today only in one of the following cases: (1) when the wear on the slides is so slight that hand reconditioning requires less time than mechanical methods; (2) when the equipment for mechanical treatment (machine tools and appliances) has not yet been obtained or made.

The Soviet Union has developed portable appliances for grinding and clean planing machine-tool slides in the process of repair, machanized scraping tools and technical processes and methods for machining slides with the use of machine tools.[10] Model technical processes have also been developed for repairing spindles, lead screws, precision worm couples and other key machine-tool parts.

The overhaul of the hydraulic equipment of machine tools presents special features of its own, including technical processes characterized by the use of precision and finishing work in the repair of hydraulic cylinders (honing) and hydraulic pump parts (grinding), and by checking to ensure precise clearances and relative positions in reconditioned parts returned to use.

Units are assembled with the help of universal and special appliances ensuring correct and efficient assembly.

In order to make sure of accurate assembly we have to apply the theory of dimension sequences and compensators,[12] since the method used to restore precision can then be selected on rational grounds; e.g. we can regulate or adjust the part, use trial and error or fit a compensator in one of the members of the subassembly.

To make sure af accurate assembly, we have to apply the theory of dimension sequences and compensators, since the method used to restore precision can then be selected on rational grounds.

Great importance for high-quality assembly attaches to the checking and testing of the machine tool after an overhaul.

Besides the familar tests for geometrical precision, efficiency, machining precision and surface quality obtained, methods of checking to determine the quality of separate sub-

Table 6

Maximum machining diameter of machine tool (mm.)		100	200	400	800	1,600
Force applied (kg.)		70	200	560	1,600	4,500
Maximum displacement relative to mandrel (mm.)	spindle	0.04	0.10	0.21	0.47	1.05
	tailstock	0.05	0.13	0.27	0.61	1.40

The use of technically advanced repair and testing processes is essential to achieve high efficiency and economy in the overhaul of machine tools.

assemblies are also being introduced into the practice of machine tool overhaul.

We may mention first the rigidity standards and methods of checking the rigidity of machine tools worked out in the Soviet Union.[13] For example, in the case of lathes a load is applied to the spindle and tailstock into which the mandrels are inserted. Force is created with the help of a special dynamometer, which exerts pressure on the mandrel at an angle of 60° from the horizontal (in the direction of total cutting thrust). Under the standards applied for normal precision lathes, the permissible displacements of the slide rest in relation to the mandrel are as in Table 6.

By means of rigidity testing we can ensure a high repair quality and detect any couplings requiring more careful adjustment.

In the case of gear-milling, thread-grinding and other precision machines, it is also desirable to check the kinematic accuracy of the mechanisms linking the rotation of the blank to the movement of the tool. For this purpose universal and specially developed tools are used.

The use of technically advanced repair and testing processes is essential to achieve high efficiency and economy in the overhaul of machine tools.

BIBLIOGRAPHY

1. *Edinaya sistema planovo-predupreditelnovo remonta i ratsionalnoy ekspluatatsii tekhnologicheskova oborudovinia mashinostroitelnykh predpriyaty (tipovoe polozhenie).* (*A unified system for the planned preventive repair and rational utilization of the technical equipment of machine-building undertaking. —Model Regulations*). Mashgiz, 1952.

2. M.M. Khrushchov and M.A. Babichev. *Issledovania iznashivania metallov.* (*Studies in metal wear*). Academy of Sciences of the USSR, 1960.

3. A.S. Pronikov. *Iznos i dolgovechnost stankov.* (*Wear and durability of machine tools*). Mashgiz, 1962.

4. A.S. Pronikov. *Raschet in konstruirovanie metallorezhushchikh stankov.* (*Planning and design of metal-cutting machine tools*). Izd. "Vysshaya Shkola', 1962.

5. A.F. Vlasov. *Udalenie pyli i struzhki pri obrabotke khrupkikh materialov.* (*The removal of dust and chips in machining brittle materials*). Mashgiz, 1961.

6. A.S. Pronikov. *Povyshenie dolgovechnosti stanochnovo parka.* (*Increasing the durability of machine-tools*). Izd. "Vysshaya Shkola", 1961.

7. M.M. Khrushchov and E.S. Berkovich. *Opredelenie iznosa detalei mashin methodom iskusstvennykh-baz.* (*Determination of wear in machine parts by the method of hypothetical bases.*) Academy of Sciences of the USSR, 1959.

8. A.S. Pronikov. *Samoregulirovanie v stankakh-avtomatakh.* (*Self-regulation in automatic machine tools*). Izd. "Moskovsky Rabochy", 1965.

9. B.T. Gelberg and G.D. Pekelis. *Remont promyshlennogo oborudovania.* (*The maintenance of industrial equipment*). Proftekhizdat, 1962.

10. *Spravochnik mekhanika mashinostroitelnogo zavoda.* (*Handbook for the machine building plant engineer*). Mashgiz, 1958.

11. *Plastmassy v mashinostroenii.* (*Plastics in machine building*). Collection "Machine building", 1964.

12. B.S. Balakshin. *Osnovy technologii mashinostroenia.* (*Fundamentals of machine-building technology.*) Mashgiz, 1959.

13. *Standarty na metallorezhushchie stanki. Normy zhestkosti.* (*Standards for metal-cutting machine-tools. Rigidity standards*).

Metallurgical Aspects of Foundry Equipment Maintenance

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The best metallurgy requires close attendance to equipment record cards, regular inspection, good supervision, with constant training and periodic updating of all personnel concerned. Good maintenance calls for inspection of critical machine areas each 620 hours of operation while on sensitive areas a shorter period may be advantageous. Lack of information or instruction concerning proper care or maintenance of equipments has rendered hundreds of pieces of machinery idle in developing countries.

THERE are a number of areas of the foundry which have had considerable emphasis placed upon them in recent years for improved productivity. These areas, of course, are not alone but all are metallurgically significant and each has its own critical maintenance problems. If we are going to look for reasonable success in upgrading productivity with satisfactory metallurgy, then maintenance in each case must be carefully examined.

The significant areas for upgrading metallurgy and consequently maintenance upgrading are the laboratory and automatic controls with improved equipment and technology for:

Moulding

a. Sand handling and conditioning materials
b. Material movement (handling) clays, coke, combustibles
c. Casting, cooling
d. Shakeout recovery and sand cooling
e. Pattern return and storage

Core-room

a. Materials preparation, sand mixing
b. Core making
c. Core delivery to moulding and core storage

Melting

a. Receiving, storage and raw materials technology
b. Charge makeup and metals charging
c. Metal melting, handling and metallurgical control
d. Pouring, ladles, inoculants

Cleaning

a. Casting movement and handling

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The principal reason for idle equipment in foundries is lack of information concerning the proper care and maintenance of machine or equipment.

b. Core knockout
c. Despruing and deffining
d. Grinding and trimming flash
e. Shot blasting and tumbling.

Intimately and figuratively concerned with the foregoing, has been a significant demand for better maintenance, on much more sophisticated equipment.

AGGRESSIVE MANAGEMENT, TRAINING, RECORDS

The best possible practice for producing satisfactory iron, steel, and its alloy, aluminum and other metal products are demanded, for the maximum savings of material, time, cost and general improvement in the value and quality of products. This study will confine itself especially to the area of foundry metallurgy, maintenance of machinery and equipment, so necessary to improve the end product value and further reduce downtime, particularly emergency breakdowns, in the normal production cycle. The particular areas with which this paper is concerned, are. Equipment, Lab Service, Produceability and Metallurgy.

Other important areas of the foundry *not* included in this paper are:

a. electric power and light
b. water supply and drainage
c. buildings
d. production technology.

Separate studies are suggested to cover these foundry areas.

It may be of interest to the reader to learn that the author's personal experience has shown, after visiting a number of foundries in underdeveloped countries that hundreds of pieces of equipment are idle. The principal reason for idleness is lack of information or instruction concerning the proper care and maintenance of a machine or unit of equipment. It is unfortunate and depressing to see very good (costly) machines productively neglected, due often to a lack of confidence on the part of personnel, who have been trained (briefly at least) to handle a wrench and hammer fairly well. But they often avoid the record keeping art and very often find a good excuse to avoid taking time to clean their hands and update the record card, or even make one out originally. Unless the supervisor or engineer in charge of maintenance is aware of this undesirable situation and takes steps to correct the deficiency, it will seriously downgrade another good maintenance organization. This is an important part of management's training programme for reliable maintenance practices. Another deficiency toward useful maintenance schedules is the timely ordering or the making of suitable replacement parts. Spare parts may require a lead time of, from four months to perhaps as much as eighteen months, from placement of order to receipt of delivery. The machine or piece of equipment should not remain idle for this long period. During progressive care, the decision will be made to replace on a predetermined schedule. This is only a part of good maintenance responsibility to be prepared at the proper time with suitable parts, hardware and materials to do the repairs satisfactorily. There will be a number of spare parts which must be carefully considered and ordered well in advance (perhaps as much as two years ahead of time) to have available for a possible emergency.

Management's training of personnel, for maintenance and metallurgical needs are necessary to be conducted as early as operations begin, for most satisfactory results. Too often, maintenance, particularly in the underdeveloped countries, is handled in a very undesirable and unorganized manner. This often leads to very poor control of the production cycles,

which in turn only results in a very unsatisfactory metallurgical product. The greater the emphasis that can be directed toward proper personnel instruction to provide them with the knowledgeable tools for the work that they are expected to accomplish cannot be overemphasized. Briefly the man in charge of maintenance must be one with keen analytical and broad practical knowledge, of equipment and of the processes.

Truly much of his time must be devoted to the constant training and surveillance of his staff, who are charged with the maintenance function, to assure proper machinery and equipment operation at all times. It is quite easy for one charged with routine responsibilities to become careless with their day-to-day functions, of carrying out such details as adjustment, timing, lubrication and the analytical aspect which are an integrated part of their responsibility. A speck of dirt or a drop of water carelessly overlooked in the maintenance of equipment can very easily, and often does, result in the complete failure of critical bearings or precision equipment in a matter of a few months' time, under otherwise normal operating conditions. The use of diagrams, charts, scales and visual instruction methods, are most important to the entire staff concerned with maintenance. Indeed the absence of knowledge on the part of the worker, or even carelessness on his part is extremely difficult to measure currently, in a monetary sense. The metallurgical quality of a product is never good enough for the replacement of an already failed unit. It may be assumed that the actual part failure was caused originally by, (1) unsatisfactory metallurgical knowledge of its required function, (2) by the lack of control during its production or, (3) maintenance during its productive life; therefore, when a part has failed, common sense tells us that the particular failure was caused by some very basic deficiency.

Record of Machine or Equipment

Complete individual records of all equipment and chronological history cards are most essential for the proper care and in planning a useful progressively scheduled maintenance programme. Details such as the following are necessary:

The man incharge of maintenance must be one with keen analytical and broad knowledge of equipment and of the processes.

a. manufacturer's data with name and address
b. serial number
c. type and model number
d. names of accessory or major components with manufacturer (if other names) including electrical data
e. date when equipment was made
f. date equipment was installed
g. by whom installed
h. lubrication schedule (record)
i. maintenance schedule (record)
j. rebuild or replacement schedule.

Without this record of accurate information, the maintenance staff will soon fail in routine application of good technology. Maintenance people generally are lax with most record-keeping activities. Records may be started, but more often never finished. Another serious

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deficiency is often the lack of the manufacturer's instruction book. These books are usually handed to a responsible official when equipment is first installed; however, it is the writer's experience that at least 90% of the time, these valuable reference books are rarely made available to the responsible maintenance personnel. It is the duty of good managers, to see that such items as maintenance information and instruction manuals are securely contained and made easily available to their maintenance staff. With the instruction manuals and information at hand, the maintenance staff should proceed to complete their record cards. Unfortunately, these cards are often neglected with the thought in mind that personnel will refer later to the maintenance book for any need that may arise. But this is insufficient, impractical and usually inefficient for the routine needs as they arise. The writer has often visited a foundry in a remote location, only to be informed that the manual for a piece of equipment, or a particular machine, was assumed to be kept by their main office staff, often hundreds of kilometers (miles) distant. This situation is altogether too common; measures must be initiated early by management to assure improved order with maintenance practices. It may be of some consolation for the underdeveloped countries to learn that even in the developed countries, maintenance instructions, at times, are slow or late to reach the responsible personnel. In the developed countries, however, it is the exception; whereas, in the underdeveloped areas it is a rule of accepted practice. Such poor practice necessitates critical analysis and upgrading.

Training Maintenance Management Personnel

There can be no substitute for effective training of personnel who are charged with the detailed care and upkeep of valuable machinery. In the foundry this can be far more critical than some other areas of industry. The abrasion of sands and the iron chippings, sprues, runners, hot or cold tailings, are severe and constantly break down the endurance of machinery and equipment in the foundry. Perhaps the one most essential factor which may govern foundry output more than any other is proper maintenance of equipment. This can only be fully realized when a reliable crew has been trained to handle such details as follows:

a. periodic predetermined lubrication
b. minor electrical adjustments
c. minor mechanical adjustments
d. functional inspection by personnel responsible for quality and production
e. a routine training and technical upgrading programme, to guide personnel charged with a, b, c, d, above
f. major repair, preparation scheduling, and realization, with minimum loss of time and production
g. choice of alternatives, should there be a failure of equipment at any particular time.

All of these factors should be phased into the training schedule, to prepare maintenance personnel for all emergencies that may arise. The maintenance workshop should have available a minimum of equipment necessary for making tests for analysis of wear and calculated life usefulness.

a. diameters (taper) (out of round) (over or under size)
b. lengths (thrust) (limits of lateral motion)
c. thrust measurement and determination of acceptable tolerance
d. bearings (out of round) (wear reduction) (tolerance limits)

e. journal or shaft (out of round) (taper) (wear)
f. gears (tooth measurement) (wear) (pitch diameter)
g. revolutions counter (tachometer)
h. contact pyrometer (temperature) (calculation of endurance)
i. contact, voltage use analyzer (overload) (voltage fluctuation)

The proper management of foundry maintenance is one of the most important keys in a successful foundry operation. If maintenance is weak, the entire production process will suffer. A capable engineer with well-trained supervision will do much in organizing a satisfactory programme of machinery and equipment care. Their maintenance manuals will be kept clean and available. Their subordinates will be regularly upgraded in their duties and gradually trained to be competent in additional classes of work.

Sessions of class training should be held at least once each week and more often if the need arises. Include the service manuals, drawings, charts, graphs, etc., also current review of machinery record cards to keep properly updated. The maintenance engineer should begin with and carry out training for the entire staff concerned with maintenance. If he is not competent to do so, then he should receive special training, or a competent engineer should be employed. There may be some aspects of training which could be turned over to a subordinate supervisor; however, a good start with a useful training programme, will pay dividends in an active, smooth operation and emergency-free production with quality metallurgy.

A useful training programme in maintenance management will pay dividends in an active, smooth operation and emergency-free production.

CARE, PREVENTION, PROGRESSIVE MAINTENANCE AND REPLACEMENT

Every well-organized maintenance programme must include its short and long range plan. All equipment when used shall wear and its rehabilitation time schedule will one day arrive. The maintenance organization must be prepared with its plan of implementation when the time arrives. Progressive maintenance is that detailed work, preplanned for an opportune shutdown, when repair can be carried out without serious cost of production time and with the least cost for maintenance. The maintenance record cards are designed to assist not only this work, but all other required on any particular piece of equipment. Long before the progressive schedule comes up, there must be plans. These plans must provide for all parts, hardware and necessary time to accomplish the needed work on the prearranged schedule. While the progressive schedule is being realized, a careful inspection must be made of other parts and/or units of the machine or equipment. Downtime and idle time is expensive. Most machines and equipment used in the foundry are expensive by any standards. It is, therefore, essential that each piece of equipment be kept operable, or if this is no longer economical, then steps must be taken to replace the unit or units concerned. A little very simple arithmetic will illustrate the value of machinery to calculated hours and

Most machines and equipment used in the foundry are expensive. Each piece of equipment must be kept operable, or if this is no longer economical, it must be replaced.

continuous operation on schedule. Let's assume the machine will operate one third of the actual time and no major repairs are needed for three years.

cost U.S. $ machine (equipment)	*U.S. $ per hour (24 hour day)*	*U.S. $ per hour (8 hour day)*
4,380.	0.50	1.50
8,760.	1.	3.
87,600.	10.	30.
876,000.	100.	300.
8,760,000.	1000.	3000.
87,600,000.	10000.	30000.

A small one-ton cupola, for example. will cost approximately $ 8760, which cost represents $ 3.00 per each hour of an eight hour day. Should it become necessary to shut down the foundry production, because of failure of this one key unit, the cost of the cupola alone immediately becomes a multiplier and the $3.00 hourly cupola loss becomes a staggering figure, of inestimable hourly loss consideration. These figures apply only to the idle equipment. To this must be added idle labour cost, plus any materials or other costs that may be involved. A well-planned, progressive and preventive maintenance programme, with a reasonably rigid schedule, will avoid such unforeseen shutdowns. At the least, let me say, the problem becomes minimized. Regular and routine inspection of all machines and equipment will produce very usable knowledge on its condition. The data which is most pertinent should be reported and recorded for benefit of all follow-up inspections.

In this way the proper timing for replacement of parts, or for complete machine replacements can be properly scheduled. Normally good maintenance calls for inspection of critical machine areas, each 620 hours of operation (about three months of eight-hour days); on sensitive areas of the machinery, a shorter period may very well be advantageous. The object, of course, is to learn the actual conditions under which reasonably accurate predictions and plans can develop, to provide the needed machinery and equipment care, while avoiding any emergency shutdowns.

CONTROLS, METALLURGY, LABORATORY

The maintenance of a foundry laboratory, usually is handled under conditions of great care. Personnel, for example, who are assigned to maintenance of very heavy equipment will not be assigned to adjust, calibrate or repair laboratory equipment. Such items as a balance (scales) and other delicate instruments must be maintained, usually by the manufacturer's service representative. In an underdeveloped country this is not possible. But it may be necessary to train personnel especially for this type of delicate maintenance work. A very capable automotive mechanic might be trained, at least for a part of the laboratory equipment. It is perhaps more practical to send the laboratory engineer on a combined training mission which will include the technical training to maintain his laboratory equipment. It would then be his responsibility to provide the instruction to a capable maintenance specialist. The engineer or technician in charge of maintenance is, of course, another logical specialist to receive specialized laboratory instruction. The author highly recommends that the specialized training be provided. He is aware of numerous metallurgical laboratories in serveral underdeveloped countries, that remain unused, depsite the fact that most equipment is good. A bad experience has resulted in complete lack of confidence in equipment and also personnel concerned with the laboratory. When foundry personnel can bypass the normal lab analysis, they become careless at once with their product metallurgical quality. It is, therefore, imperative, that complete confidence be generated and retained for reliability of all foundry laboratory actions and reports. Modern metals and metallurgy are today, far more complex, than during the 1935 to 1950 period. The importance of the foundry laboratory has now taken its rightful place, beside the melting unit. The melt must be known corre-

ctly; the lab, if properly used and properly operated and maintained, will provide the correct answers to those responsible. A hit or miss technique, cannot be accepted under any realistic circumstances. Satisfactory, reliable, progressive laboratory maintenance is most essential to any foundry. A programme of periodic inspection belongs in the laboratory as well as the foundry. A constant watch must be kept of calibrations on all instrumentation in the foundry, as well as in the laboratory. This action must be the responsibility of the laboratory maintenance and coordinated with all maintenance.

A hit or miss technique cannot be accepted. Reliable and progressive laboratory maintenance is most essential to any foundry.

Emphasis on Hand Tools

It has been said many times, that a workman can be easily judged by his tools. It may also be stated that a supervisor can be judged by the kind of tools he permits his subordinates to use. A workman using an improper tool can indeed destroy a machine or piece of equipment, faster than normal wear. The author would like to suggest that hand tools are most basic to any useful maintenance organization. But unless personnel are thoroughly oriented in the proper use of such hand tools, as well as the common power-assisted hand tools, maintenance costs may easily be escalated rather than reduced. Briefly stated, good maintenance requires good hand tools; but without suitably trained personnel to make the best use of such tools, you should expect to accomplish very little. With suitably trained personnel using proper hand tools, we can begin to organize a very useful maintenance programme. Such a programme will benefit metallurgy substantially. With exception to the power-assisted tools, regular hand tools are usually under the personal care of the user. A maintenance specialist needs a good supply of hand tools, but he should be expected to take good care of every one of them in his possession. Such care should not, however, consume more than one per cent of his total weekly work time. The power-assisted tools are usually provided by a foundry central tool supply organization. They are in substance loaned to the workman, to accomplish a specified task. All such tools must be inspected as soon as returned to central supply. Damage must be reported by the borrowing workman and repair or replacement action must be initiated at once. Here, as in the foundry laboratory, specialized training is required for service on the power-assisted hand tools, also for large or complicated precision measuring instruments and equipment. These items are all under the central tools organization. A record card must be made and kept for each item. All preventative and/or progressive maintenance must be recorded and updated at each inspection interval. In the maintenance of many kinds of equipment and in working with almost unlimited materials, the foundry maintenance organization must be fully equipped. By doing so, a serious breakdown will be far less disruptive and much less costly. A carbide tipped masonry drill, for example, will open a hole through a cupola wall, a furnace refractory wall, or perhaps concrete flooring in a few minutes time. To do so by hand chipping methods would take hours or perhaps days. A carbide tipped saw, as another example, will cut concrete flooring or brickwork, with the use of hand power tools in minutes of time. The author of this paper has seen strong men struggle for days, with heavy hand hammers, to do a job that the carbide tipped drill and carbide tipped saw could do in minutes, even if operated by small men or women. Therefore, proper training of supervisory personnel in such updated methods, to make their work much less burdensome, while expediting the rehabilitation effort of valuable machinery or equipment, to get it back on the production line. By the simple periodic voltage inspection of an electric motor consumed voltage on a piece

Well-made accurate patterns are basic to most satisfactory castings.

of equipment, serious overloads will be uncovered, which will alert good maintenance personnel, that analysis is needed of the equipment function. This procedure, properly implemented, can prevent motor burnouts, which often cause very costly and serious shutdowns while production is on line. Simple hand operated ramming air tools such as the common (so-called) air guns. for packing refractory (fire) clay or similar materials into the compact areas of furances or cupolas are most useful and essential tools. They should be available to all well-operated foundry maintenance organizations. It may be of interest to the reader to learn that after visiting many foundries, in several underdeveloped countries, the author could not find a single rammer tool available to any of the maintenance crews, assigned to cupola repairs. Nevertheless, repair costs were excessive and emergency shutdowns during production were constantly anticipated and burdensome delays endured. The electrical and/or air operated ramming gun is another item often neglected by supervisors of foundry maintenance personnel. Hand labour may be favoured for reasons of extending employment; however, for reasons of quality repairs. the rammer gun should receive high priority. Even to the extent of making work elsewhere. if it is desired to generate employment. The even pressure consistency provided by the tool, cannot be duplicated by simple hand operations. The foregoing are but three examples of many that can be cited. My objective in presenting these examples, is simply to point up the need for training maintenance supervision thoroughly, in the fundamentals concerned with their responsibility, thus providing them with the ability to improve metallurgy while they resolve problems with more efficient use of labour tools, materials, and savings of productive time.

FINISH PATTERNS PRECISELY

Basic to all casting work required in any foundry, are reliable pattern equipment. The maintenance record cards are used in all areas of the foundry. The pattern shop is no exception. It can well be that somewhat less maintenance will be necessary for the pattern making shop. Woodworking machinery and the woodworking materials used for patterns, generally are far less severe upon machinery to shape or fabricate. Of course, wood is not the only material used for patterns, but it is the most commonly adopted. Aluminium, aluminium alloys and epoxy resins are also used, but usually only when large quantities of the same casting design are made. When the normal 620-hour inspection is carried out regularly, the pattern shop maintenance should not present any serious problems. Maintenance work can be much more easily scheduled in the pattern shop than in most other areas of the foundry.

Patterns

A pattern is made to provide a suitable cavity in a sand mould, so that melted metal can be poured to the desired shape for solidification, to be thereafter known as a casting. Well-made accurate patterns are basic to the most satisfactory castings.

Much processing can be avoided by providing a quality refined pattern. Such detail as fillets and/or radius edges, can assist both metallurgy and processing. Sharp corners should be avoided at all times. If sharp corners are needed, they should be machined, not cast. A sharp fillet (concave radius) can be a source of crack by chilling, it can also increase the causes for a casting break, or weakness which may easily result in a casting failure after being placed in use.

A good, clean, finished surface on all areas of the pattern will be most helpful, first and foremost to produce a clean casting, free from rough edges as far as possible, secondly, to improve the strength of the casting and its metallurgical appearance, particularly follow-

ing sand or shot blast. A third, equally important reason for a clean casting, are the benefits to ease further processing, machining, assembly, finish, painting, etc.

A wood pattern will usually be considered for a small quantity of castings; as a general rule it would suffice for most maintenance requirements. Should larger quantities be required, then good practice would dictate that another pattern material be considered.

As a guide to those interested, the following are an indication of average quantities of castings that may be expected from one pattern, before replacement is needed.

Pattern Material	*Casting Quantities*
Wood	25 to 40
Plastic	18,000 to 25,000
Aluminium	30,000 to 65,000
Iron, Steel, Copper alloy or Magnesium	70,000 upwards

Wherever the jolt squeeze moulding machine, or pressure squeeze molding is employed, the harder pattern materials need to be considered. It matters not which pattern material may be selected, the need remains to carefully finish, shellac, paint, wax or plastic coat, any and all pattern surfaces, providing the largest practical concave or convex radius. Large castings sometimes dictate that very light pattern materials be considered. If this should be the case, then perhaps the lay-up method, of glass fibre with epoxy resin material, would provide the greatest benefits for accuracy, with corresponding lightness of weight.

HANDLING SAND, PREPARATION, MIX MULLERS, CLAYS AND MOULDING EQUIPMENT

This group of equipment with its machinery generally has the most severe service of any concerned with the foundry operation. It will be the screening sieves and separating units, which come into contact most with the sharp sand grains, that will require the greatest maintenance. Much attention should be directed toward the screen materials and the record cards too need close observation. There are wide variations in sand hardness: therefore, a considerable variation in the life cycle of screen equipment can be expected. The insection sequence (620 hour) should be increased with sand equipment, to provide a second cursory inspection, midway at least, between the 620 hour normal inspection period. The clay mixing and moulding machines (jolt, or pressure squeeze) do not endure quite the severe abrasion conditions found in the sand handling and mixing equipment. It must, nevertheless, be carefully observed for indications of wear. The mix muller is designed to withstand severe use; it does so extremely well. As a result, these units are often neglected in the underdeveloped countries especially. When they finally do fail to operate, the units can be idle for many months before replacement parts are obtained. The mix muller is a key machine for the sand mixing and moulding process; it must be carefully maintained. Use of the record card information as developed by the periodic 620-hour inspection, will assist immeasurably with reliability for this and other foundry units. Repair parts such as bearings and the bearing seals are very precise; they must be kept perfectly clean and free from dirt or sand, both before and after installation. There is no room for careless assembly, since a single day's operation could mean the end of an otherwise three or more year life, of a delicate bearing for foundry sand mix mullers, shakeout, clay blenders and screening equipment. If bucket elevators or conveyors are used, they also will require equal care and caution during repair. *All dirt* must be kept *out* of bearings.

MELTING UNITS, CUPOLAS, CRUCIBLES, LADLES

Twenty-five years ago in the more developed countries a 15 ton-per-hour cupola iron melting capacity, was considered large. It took 8 men using wheelbarrows, to charge material of about 18 tons into the cupola. Each man would maintain his own wheelbarrow and also

worked on the cupola repairs during shutdowns. In the 1970's a man sits in a traveling crane and does all the lift charging with the use of a magnet or charge bucket.

Other materials needed, are conveyed into the charge semi-automatically by a second man operating the cupola. The two men will melt 50 or more tons per hour, compared with 8 men to produce 15 tons per hour in the old days.

The foundry metallurgy and maintenance picture has also changed, even more drastically. The wheelbarrow mechanic now requires extensive training to maintain equipment, that now does the job of his 8 wheelbarrows. He must make repairs on the new equipment on schedule, while idle equipment production time is available.

New units demand the best of care, but the savings with better care will compensate extremely well when repairs are properly organised and carried out.

A piece of wire or a rivet is not now suitable for the repairs on present-day charging units. These new units demand the best of care, but the savings with better care will compensate extremely well, when repairs are properly organized and carried out.

Today's metallurgy requires precise control. Air volume, humidity and fuel consumption are now automatically controlled, regualarly. This was not possible twenty-five years ago, except in perhaps some limited instances.

The quality of iron and/or other metals, are known throughout the process. Preheaters and hot blast has been added to reduce coke consumption; high refractory usage has been greatly reduced, or eliminated, by the use of water cooled shells in the cupola and melting furnaces.

Actual labour per ton of production has been reduced, but the quality of labour has been continually pressed to upgrade. Foundry maintenance with metallurgy, consequently, has been subjected to extensive upgrading of quality, skills and schedules. The underdeveloped countries are aware of these changes and are trying to meet the demands for improvements with advanced metallurgical practices. Wherever high maintenance does exist, a thorough analysis must be undertaken to learn reasons for its existence.

Mechanical handling equipment can, if properly maintained, turn a losing foundry into a highly productive one. Often an answer is really simple, but analysis is needed, that means perhaps a meeting of the best minds available to determine which course of action should be followed.

In a pouring room operation familiar to the author, the maintenance costs for screens, hammers, chisels and remelting was excessive. Ten men worked a 16-hour day at keeping spilled metal collected. Another fifteen men worked constantly for their 16 hours, handling, sieving, separating and drying sand. Small basket sieves were used: each time a man dropped his basket, the screen would be bent slightly. It would occasionally be bumped back into the desired position. As a result, after two days use a new screen had to be installed by maintenance. This took another 3 men, the 28 total manpower required 2 supervisors, all required additional accounting labour cost.

With their social benefits and extra time for remelting of metal, this package loss amounted to a total yearly cost of over $ 150,000 (U.S. dollars). The cost for additional coke and the further maintenance cost on the cupola were not calculated.

It was decided to install semi-automatic pouring and screening equipment, since the screen maintenance cost alone was over $ 100 (U.S. dollars) per 16-hour day, with actual manpower costs extremely low.

A total savings realized after the second year of operation was well over $ 110,000 (U.S. dollars). With this example there are many others similar. However, a point is made, to analyze and evaluate constantly to reduce maintenance costs, while improving metallurgy usually. To do so intelligently, one must have complete production data and thorough knowledge of the particular process concerned. The cupola is probably one of the oldest units of metal melting equipment known to man, in his search for a means to produce products (parts) for either original equipment, or for parts needed in periodic replacement. The cupola must withstand the most severe changes in temperature that can be expected of almost any other kind of equipment. Yet, it must perform continuously throughout the extremes of those temperatures, which may vary upwards, to perhaps as much as 1700° C (degrees Centigrade), 3092° F, (degrees Fahrenheit). The manufacturer, building equipment such as the cupola, has had a vast and varied experience with his equipment, under very broad operating conditions. His instructions should be very carefully considered, both before and during all maintenance functions that may become necessary. The melting equipment can be said to make the foundry. Without melting of metals, there would be no foundry. The word foundry tells us that this is the place where metals are cast. When metals melt, we have a general temperature range as shown by the following table:

Material	*Melting Temperature* F°	C°
Steel	2850°	1565°
	3200°	1760°
Gray Iron	2550°	1399°
	2680°	1471°
Copper Alloy	1800°	982°
	2240°	1227°
Alum. Alloy	1250°	677°
	1400°	760°

The best metallurgy requires close attendance to equipment record cards, regular inspection, good supervision, with constant training and periodic updating of all personnel concerned.

While these figures do not apply to all material classes, they represent an approximation. As can be seen, the cupola or other melting unit must endure extreme high temperature ranges, wherever contact is made with molten metal. Consequently, maintenance in these hot areas is critical. Should there be any low grade materials, poor maintenance or a lack of close supervision during these critical repairs of a melting unit, it can result in failure. Certainly such ineffective, low quality workmanship must be avoided. The best metallurgy requires close attendance to equipment record cards, regular inspection, good supervision, with constant training and periodic updating of all personnel concerned. The furnace and cupola firewalls are most critical, major repairs sometimes follow each melt period on non-water-cooled units. This should not be the usual requirement, but unfortunately, it is a fact in many foundries. While visiting foundries in a number of underdeveloped countries, the author has seen cupolas, particularly, suffer the misfortune of having inferior refractory (firebrick, and (fire) clays installed, to make the repairs. The results are usually disappointing and often a repair disaster, with one or more tons of melted iron a loss. With the very high temperatures required for iron, steel, copper and their alloys, there can be no compromise with quality materials, for the cupola and melting area repairs. As mentioned earlier such repairs are always expensive, but metal cannot be otherwise melted satisfactorily. Therefore, the time-consuming lining repairs should not be considered, unless suitable refractory (fire) brick and clay materials have been obtained.

If possible, the guidance of the manufacturer of the equipment should be secured. This can be in written, verbal, drawing, sketch or diagram form, or a combination of all, including pictures. In many of the underdeveloped countries known to the author, there is often a language problem and the manufacturer who provides only verbal or written instruction, assures only a very limited service, to users of his equipment in a foreign country. A picture, drawing or diagram carries with it unwritten pages of technical interpretation that writing cannot replace. Personnel concerned with major cupola repairs must be guided very carefully during this type work. They are unable to read pages of written instruction and thoroughly understand its meaning. As a result of numerous unsatisfactory repair experience in the multiple foundries known to the author, I strongly suggest experts should be employed as often as needed to provide satisfactory melting equipment repairs, if it is at all possible. The second choice would be a special training mssion for one or more personnel who shall have reponsibility for future maintenance and repairs. Obviously, if training is given, it should be on the specialized equipment concerned.

There are many factors which determine the original selection of melting units. The conventional or refractory lined cupola is by far the most widely used. In many of the underdeveloped countries known to the author, this type is the only one generally available. In recent years the water-cooled type has been much more successfully employed, with a substantial savings in maintenance cost. The induction furnace and the arc furnace are now widely used in the more developed countries, with a great deal of metallurgical success and further savings in maintenance cost; also, the production cycle is extended many times by use of the water-cooled type induction or cupola units. If the arc type furnace is used, volume production demands should be high, or maintenance can be expected to rise to prohibitive limits. The cupola is substantially less costly for small batch production, but unless water cooling is employed, a major repair job on the lining can be expected in a few days operating time. The heating and cooling action of the "hot" refractory lining, is extremely detrimental to its life and the endurace of the melting area. As a consequence, the maintenance staff is usually faced with a repair job very often. The coreless type induction melting furance is best suited to a job shop operation; however, its initial cost is high. Therefore, a long period of ammortization must be kept in mind. The melting is sometimes accomplished jointly, first in the cupola as soon as melting takes place, the molten metal is tapped into the induction furnace crucible. Tapping must take place after preheating of the induction crucible lining, unless a previous batch has just been melted and the refractory remains at a high temperature. The need for a reliable supply of electricity in large volume (about 600 KW input for 10 tons iron per hour) is one of the requirements for use of induction melting equipment. If this is available to those seeking to reduce costs of the cupola repairs, then a close examination should be made of an installation of the induction type equipment. Coreless induction melting is often combined with an induction holding furnance and/or crucible, also a batch type preheater may be used. With this combination the initial cost will be considerably higher than the cupola, with or without water cooling. The operating and maintenance savings however will often outweigh the added initial cost for induction melting. Further savings may be available for a continuous casting line, even in job shops, providing, however, that weekly volume can be considered and reasonably regulated. Beyond the maintenance benefits, induction melting has a much more beneficial effect with good production control and quality of metallurgy. The important aspects of production and product quality control are not included in this writing, since it is an extremely valuable consideration and should be produced as a broad separate text.

QUALITY REFRACTORIES, HEAT RESISTANT LININGS

The manufacturer of the cupola may or may not manufacture the accessory equipment,

items such as the blower, thermostatic controls, the refractory (fire) brick and clay materials. The latter two must be carefully considered, relative to the actual conditions under which they are expected to operate. Should the operating conditions demand temperatures in the lower melting range, of perhaps 1200°C (2192° F), then the quality requirements of refractory (fire) brick and refractory (fire) clays, would be much less than those in the higher temperature ranges of 1600°C to 1700°C or more (2912°F to 3092°F). Fire bricks are normally manufactured by a specialty refractory, or a ceramic manufacturer, who may make a wide variety and quality of other products, which can be adapted to many different applications, under many different operating conditions. It is appropriate to mention here that a particular refractory (fire) brick of highly reputable quality may not be the most suitable for a specific application. The cupola operating staff, especially the maintenance supervision, must often judge, on the basis of all known methods, including trial and error, which of a wide variety of manufacturers produces the most satisfactory brick, for his particular application needs. It has been the experience of the author of this study, to have learned through practice, that a cupola refractory costing substantially more can ultimately be the least expensive. Refractory bricks are made under extremely variable conditions by each manufacturer. Each manufacturer uses ingredients which in turn have extremely variable qualities made under similar conditions during manufacture; yet the extremes of temperature and abuse that can befall the refractory (fire) brick in its desired application, may result in a totally unsatisfactory application. Let me present an example of a refractory product built to withstand very high temperatures, under constant operating conditions. When the refractory brick can be initially preheated slowly to its operating temperature, it can withstand the demanding high temperatures amazingly well and for long periods. Should the same refractory brick be placed in operation under conditions whereby, it is expected to withstand the same very high temperatures, but without the controlled preheating initially, this product can easily become a complete failure, even though it may have normally endured all other demands, under exactly the same conditions as the previous application mentioned. Indeed the careful consideration of products and their endurance to the temperature demands cannot be overemphasized. The harder materials, usually are much more brittle when placed under impact or heat shock conditions. It is well known that a cupola in one foundry, may operate for days at a temperature of, for example, 1400°C (2552°F), while the cupola in a similar foundry operating under very similar conditions will require much greater rebuilding (maintenance) than the former. The reasons for satisfactory or unsatisfactory product performances are rarely known to anyone, other than the technical management staff who are responsible, or those concerned with cost control or cost reduction analysis, in either the maintenance of the production of product. Therefore, a critical requirement exists for rigid and constant analysis, in order to achieve the maximum results for productivity. It has been the experience of the author to know of excessive maintenance of equipment, which were entirely reflected by the desire for higher employment of manpower, in order to make work for the staff. Under these conditions it is often difficult for non-technical management to evaluate the most economical refractory brick for the specific purpose, for which it must perform. The best quality of refractory product, used under abnormal or unspecified operating conditions, may result in its immediate failure when required to withstand any abnormal hazards to which it can be subjected. If the product is expected to withstand or endure abnormal conditions or abuses, then the best quality products should not be considered. A compromise, therefore, for a slightly inferior quality may easily result in a much more satisfactory and economical application.

STABILIZE METALLURGY, FURNACES, HEAT REDUCTION (COOLING)

One of the most restricting factors to the production line is the time-lag which follows pouring of foundry castings. This equipment, generally found lacking, or as makeshift units,

The flexibility of manually operated equipment vs automatic or semi-automatic processing should be very carefully analysed if maintenance costs are to be kept under control.

consisting of blowers, exhaust fans, or similar types of circulating equipment positioned in such a way as to remove the radiated heat as it leaves the casting shakeout area. When this type of equipment can be strategically built-in with the cupola air intake as preheated air, it can serve a most useful and economical purpose. Such combinations of equipment will do much to reduce the burden of foundry maintenance. Since it permits heat exchange or transfer to effectively reduce the severe hazards of heat shock with expansion and contraction.

Let me explain it in this way. It is generally well known that when boiling water comes in contact with glass, usually it is a disaster for the glass, unless certain precautions are first taken, to carefully preheat the glass. When this is done properly, the glass will withstand very high temperatures.

The refractory materials compare similarly to glass in this respect. By preconditioning the refractory materials properly the foundry maintenance manpower load can be substantially controlled while maintaining the production line equipment in a most satisfactory way.

As mentioned earlier in this text, one of the worst situations that may confront the refractory in the furnace or direct heat reduction units, is the uncontrolled heating and cooling action.

Much can be said for automation, much more should be considered, as we look toward the automatic processes to answer a serious foundry metallurgy control problem. The latitude given and the flexibility of manually operated equipment vs. automatic or semi-automatic processing should be very carefully analyzed, if maintenance costs shall be kept under control.

The melting furnace refractories, whether the are the induction type, or the cupola types, are all fragile when we think about heating and cooling alternately. When the heat goes up, it must be kept up without undue fluctuation. When cooling down, the heat must be gradually reduced under control.

The foundry maintenance staff is charged with the responsibility of keeping the equipment operable and in its best condition. They must constantly be alert to improved metallurgy, methods, and a philosophy which will help reduce the demands for their vigilance, while helping to improve the end product and its entire process.

The cooling of castings must either be controlled at shakeout or the castings must be furnace annealed to avoid chills.

Some types of castings will require heat treatment anyway, in order to produce their desired metallurgical qualities. It is, however, much more economical to control the cooling process initially, than to reheat the castings after they are cold.

It is in the interests of an efficient maintenance organization, to make such recommendations that overall equipment upkeep is reduced and that the process is blended into any benefits that can be realized through a reduced maintenance requirement, also by extending the life of costly equipment.

When sufficient volume of product is needed, a conveyor type cooling furnace may be most desirable. This type furnace would permit a variation of heat, spaced to control gradual

cooling (or heating) of foundry materials. Hot sand from the mould shakeout is often used for control of casting cooling. It is, however, usually inefficient and except for very small volume of castings, should not be considered. A small volume would be in the 15 to 30 ton range: smaller lots of castings made at any one time should be avoided. High operating and maintenance costs on small lot production will soon ruin the foundry, except perhaps for emergency casting, where costs are not an important factor.

When small quantities of castings must be made repeatedly, consideration should be given to combining two or more foundries into a joint operation.

It has been the author's experience in several underdeveloped countries, that each workshop or even a maintenance specialty shop, will attempt to cast his needs, no matter how small the casting volume may be. Such practice should be avoided except perhaps for an owner desiring his own reasearch.

USE MOULD BOXES

In a number of the underdeveloped countries visited by the author, it was learned that their casting industry just grew, without aid of serious technical development. As a result, many of the foundries continue with very primitive methods.

Some foundries actually may be classed as reverting their technology. To further illustrate this point, a foundry which had been in existance for many years, serving small industry, received a sizable order for spare parts. Because their mould boxes had been poorly maintained and skills to make new ones were untrained, an immediate problem arose.

The responsible personnel thought, what they should do. The idea that came was, to bury a bottom mould into the ground. Now this provided an extra mould box to use for the top. It seemed like a good idea, as was done by the early Romans, long ago. But as it was with the Romans, if there is any moisture contained in the ground, and in most places except for the deserts, moisture is always found in the near surface areas the casting will be rough. The foundry mentioned here was no exception and moisture was in the ground. This fact was notconsidered, apparently at least. So the moulds were made, hundreds of them, and buried into the ground surface. The cupola was charged, the iron (five tons) was melted and poured. The management were happy that the job could be finished so easily and so soon. The next day the molds were opened, the castings cleaned, desprued (sprues removed) to prepare for machining. Now a close examination of the casting showed some very rough surface areas, some much worse than others, many with holes in the surface, some of which were quite large.

The manager was called; then the customer was called, to ask if he would accept the defective castings. His answer was *no*, he had a new product and could not accept them, since there was no way of covering the unsightly appearance, on his finished product. So now what to do? The maintenance crew were called, a meeting was arranged, where a suggestion was made to repair the castings, weld them by filling the holes. Another suggestion was made, to melt a pot of lead and dip each casting into the molten lead bath, to fill the unsightly casting holes, then paint over the surface. It seemed like another good idea, except that some of the holes simply would not hold the lead, during the subsequent handling process. As one may guess, at this point no thought had been given to metallurgical quality. To the author's knowledge, about 30% of the castings were salvaged, by either welding up the holes or dipping the castings in lead or grinding out surface blemish. All this at extra cost of time and labour, to a hard pressed foundry structure. Beyond the extra cost, was a badly hurt reputation for the foundry.

In retrospect, the ground moisture found a highly attractive source in the drier sand and clay mould, burried in the ground. Moisture is

Mould boxes are not a cure-all, but they are part of good moulding and casting practice. They are beneficial to metallurgical control.

further attracted by heat and heat will vapourize the moisture at once.

Unwanted vapour in a casting mould, is a disaster for the casting, no matter what the metal may be. The heat and vapour combined generate steam and steam trapped in a small pocket of sand or clay is explosive. The explosions are numerous under conditions of ground or other undersirable moisture. A very common cause of blow-holes, surface roughness and porosity.

Mould boxes are extremely simple to make. They are most valuable to control metallurgical quality, to prevent undesired moisture fromfinding its way to an attractive (dry) mould source. The boxes can be used for months or perhaps years, with only very limited maintenance required.

The metallurgy as well as the product can be expected to suffer any and all the ill effects of the outside elements, when mould boxes are not maintained operable and available.

Mould boxes are not a cure-all, but they are part of good moulding and casting practice. They are beneficial to metallurgical control. Their use aids maintenance by reducing the volume of sand and clay handled per ton of castings. With suitable mold boxes and proper copes and drags, with wood or metal plate (boards) to unitize the cope and drag. Metallurgy then has its chance of survival, assuming that metals and other elements are satisfactorily controlled.

The American Society For Metals, Metals Park, Ohio, 44073, has recently (January 1970) published an excellent volume of over 470 pages and pictures, entitled; Metals Handbook, Volume 8, Number 5, Forging and Casting. The author suggests that this book should be in the hands of every foundry, interested in improving the practice of metallurgy and casting in general. The above source (ASM), also the American Foundrymen's Association, have in fact much valuable data, books, slides, film, literture and information in general, on the broad metals field and metals processing.

First Use of Petroleum

Lubricants are very necessary in our age of machines. They provide the slippery film that reduces wear and heat between moving parts. Practically all lubricants in use today are derived from petroleum which is one of the naturally-occurring hydro-carbons that frequently includes natural gas, natural bitumen, and natural wax. The word 'petroleum' is derived from the Latin *petra* (rock), and *oleum* (oil).

The first actual use of petroleum is said to have been in Egypt, which imported bitumen, probably from Greece, to be used in embalming, as it was a widespread belief of Egyptians that the spirit remained immortal if the body was preserved.

After-Sales Maintenance in Automotive Field

M Bosia*

In the automotive field, sales and service must form an inseparable binomial. This article deals with the after-sales maintenance practices which have been evolved by FIAT after careful study and examination.

TODAY every automaker realizes that its fortunes depend upon its capabilities to be competitive in the fields of quality, price and supporting sales-service organization.

To strengthen their positions in the various markets in view of the competition growing stronger because of the progressive lowering of customs duties (affecting in particular the European automakers) and because of the constant increase in general industrial output, it is imperative not only to rely upon a proficient, intelligent and continuous action in the above-mentioned fields, but particularly to be able to offer the clientele a reliable service.

This objective can be accomplished through a planned utilization of human resources and the proper use of material means such as facilities, equipment, tools, etc., so that the service network may possess those repair and maintenance techniques indispensable to offer the best in service, since the automobile, like other similar consumer items, would lose some of its reliability should an efficient service not be available.

In other words, one may state that, particularly in this sector, sales and service must form an inseparable binomial. It is obvious that every automaker sets up its own service network according to established criteria and standards depending both upon the type of its own organization and the number, features and operating conditions of its product, as well as upon its understanding about the practical application of the concept of maintenance.

It is also obvious, however, that the gist of such concept is interpreted in like manner by every automaker inasmuch as its scope is that of ensuring a long life and normal performance to the vehicles on the road throughout the years

* FIAT S. P. A., Italy

As a consequence, every automaker is aware of the importance of relying upon an efficient network staffed with qualified personnel capable of applying the most up-to-date techniques, so as to be able to carry out quickly and efficiently those unavoidable repairs and/or replacements the vehicle may require through its lifetime.

It is, however, understandable that this line of action must be supported by a concurrent execution of periodical maintenance operations, as every automaker always recommends to the clientele by stressing the importance of obtaining the best results out of the vehile; it is at this point that the concept of maintenance has its full and valid meaning.

The mode and schedule followed in carrying out the maintenance service is at any rate evolving constantly because of the progressive improvement of manufacturing techniques introduced by the manufacturers also on account of commercial factors created by the competition. Nowadays, for instance, there is a tendency among automakers to make use of "Diagnosis Stations" in their service network in order to obtain a standard checking of cars in a better and quicker way, with a view to advising the owner about the maintenance operations the car actually requires; this system has the advantage of saving the clientele time and expenses.

Concurrently, as refers more strictly to the service field, the manufacturers face ever-increasing difficulties in training enough service personnel to cope with the need of assisting an always greater number of vehicles on the road. Further more, it has become necessary nowadays to shorten as much as possible the time needed for the repairs to satisfy the present-day requirements of the clientele. These two facts call for the introduction of rotation units, such as engines, transmissions, rear axles, etc., which may be either new or rebuilt at centralized workshops and then distributed to the service network to be installed on the vehicles.

These general considerations having been made, it would be appropriate to illustrate the most important facets of this subject, omitting obviously the strictly technical side of the question as it is not pertinent. We will, therefore, limit ourselves to describe the set-up and organization of the Service, showing as a matter of instance and for information what FIAT has undertaken in this field.

In fact, as it is also the case for other manufacturers, FIAT has kept on improving and expanding its network, with special attention being paid to the service and spare parts distribution sectors.

In the beginning the FIAT network has developed most in those industrial countries which have offered and are offering the best export prospects. Later on, and following the general trend, the Company has committed itself and enlarged its operations in the markets of developing countries by creating manufacturing and assembly lines often in joint venture with local economic sources. Along with these activities, the company has built in such areas up-to-date service facilities for cars, trucks and tractors and planned heavy investment for improvements and expansions purposes by adding new service centres. During 1969, the FIAT sales and service network abroad has been enlarged by butting into operation or completing Branches and Service Centers in more than 20 countries.

Wherever possible the Company have made the network more far-reaching in order to offer a quicker service for the benefit of car owners by developing for instance, in cooperation with large oil companies, Service Centers located on highways, main auto roads, airports, etc. Furthermore, a "Holiday Service" by travelling services vans is operational along the main auto routes, in Italy and other countries, during the summer for tourist cars, even of different Makes. Also, a new standard dignosis and maintenance system consolidated in the "FIAT Dignosis Station" is being introduced in the service network.

Finally, since the efficiency of service given by the organization is strictly connected with the prompt availability and fast distribution of spare

parts, the company, in all areas where it operates, has taken painstaking care in improving this sector of activity by employing the most upt-to-date systems and means of controlling and distributing spare parts.

Service Central Set-Up

To supervise the service sector, automakers avail themselves of a central department having the assignment in general of studying and coordinating all service activities in the markets where they operate.

To supervise the service sector, automakers avail themselves of a central department for coordinating all service activities in the markets where they operate.

In FIAT, for example, these tasks are accomplished by the Central Service Department through its two most important sections, as follows:

— liaisons with Factory departments,

— liaisons and close control of Organization; relationship with clientele.

The relevant activities of specialized Central Department offices relating to the second of the above-mentioned sections are briefly described here:

— studying and designing of general layouts and size of inner departments of Branches, Service Centres and Dealer facilities: in this connection special Free-of-charge assistance is given to Dealers whenever required;

— studying of installation of general and specific equipment, machinery, tools, etc;

— studying of labour flow, methods and time of repairs; designing, testing, manufacturing and distribution of special tools;

— studying of the Organization and operation of spare parts warehouses which are supervised, as needed, by specialized technicians at the site;

— Planning of programmes to strengthen the Service in the various countries; studying of all problems connected to the after-sales service; backing up of local organizations by making available in Italy or sending abroad the necessary technical personnel as required; Distributors' warranty administration;

— editing and distributing shop manuals, handbooks and various other publications, all translated in the main languages; preparation of other training aids such as films, slides, wall charts, etc.;

— Central Service School for formal instruction and upgrading of our service personnel at all levels; training and specialization of different categories of service network personnel and local personnel.

As far as the last section is concerned, it can be said that great importance is attached to the education and training given by the Central Serice School to service technicians who, besides other duties, are also entrusted with teaching and training personnel at the site. To carry out this activity, several thousand training days have been given by field engineers at the Dealers' premises during 1969; to this, however, one should add about 10,000 days for instructing local personnel at the Central Service School, as well as further 25,000 days given at the Service Schools of FIAT Branches.

The criteria followed by FIAT in training the above-mentiond personnel has originated from the experience that the best results can be obtained through a type of preparation made up of basic teaching at field level integrated, according to circumstances, with advanced training at the service schools.

Furthermore, owing to the increasing necessity to train more and more service personnel and to strengthen the education sector to keep it in the vanguard, a new Service School will become operational next year in Turin.

The "introduction card" of its facilities reads:

- covered area 7,600 m²(76,000 sq.ft)
- developed area 13,000 m² (130,000 sq. ft)
- 20 classrooms for technical instruction
- 20 laboratories for training on the job
- 2 workshops
- 1 movie theatre/conference room with 250 seats
- 1 linguistic laboratory
- most modern teaching means and equipment such as video tape recorder, closed circuit television, etc.

The new Service School can accommodate daily about 500 trainees supervised and taught by over 70 bilingual instructors, according to programmed teaching and working plans.

Spare Parts

The overall picture of the Central Service Set-up cannot be considered complete without mentioning, however briefly, the important area of spare parts.

In the case of FIAT, there is a Central Department in charge of spare parts supply planning, stocking and distribution to the after-sales network. The spare parts flow from both the production line and outside suppliers to a Central Depot in Turin, where they are stocked and then distributed according to the requirements of the Service Organization as well as of the centrally-programmed provisions. The stock control and administration is carried out entirely by an electronic computer.

The spare parts distribution system is in short as follows:

- Italian and foreign branches with their own warehouses, obtaining the spares directly from the Central Depot and distributing them to the network of Agents in their respective operating areas;
- foreign Distributors directly supplied by the Central Depot and distributing them to Agents and sub-Agents in their respective operating areas;
- spare parts shops directly supplied by the area Branch and/or Distributor. The spare parts distribution flow is illustrated in Fig. 1

Fiat Service in the World

The importance that every major automaker gives in maintaining a reliable and comprehensive service network in the countries where they operate is demonstrated in the case of FIAT by the existing 12,000 service centers (inclusive of minor service stations) with a total covered area of about 5,000,000 m² (approx. 50,000,000 sq. ft) and with a technical labour force of about 100,000 units. Figs. 2 and 3 show the set-up of the service network and, for each continent, the number of direct branches and dealers, their covered service area and personnel.

Service in Developing Countries

As it is known, developing countries are understood to be those not yet in possession of

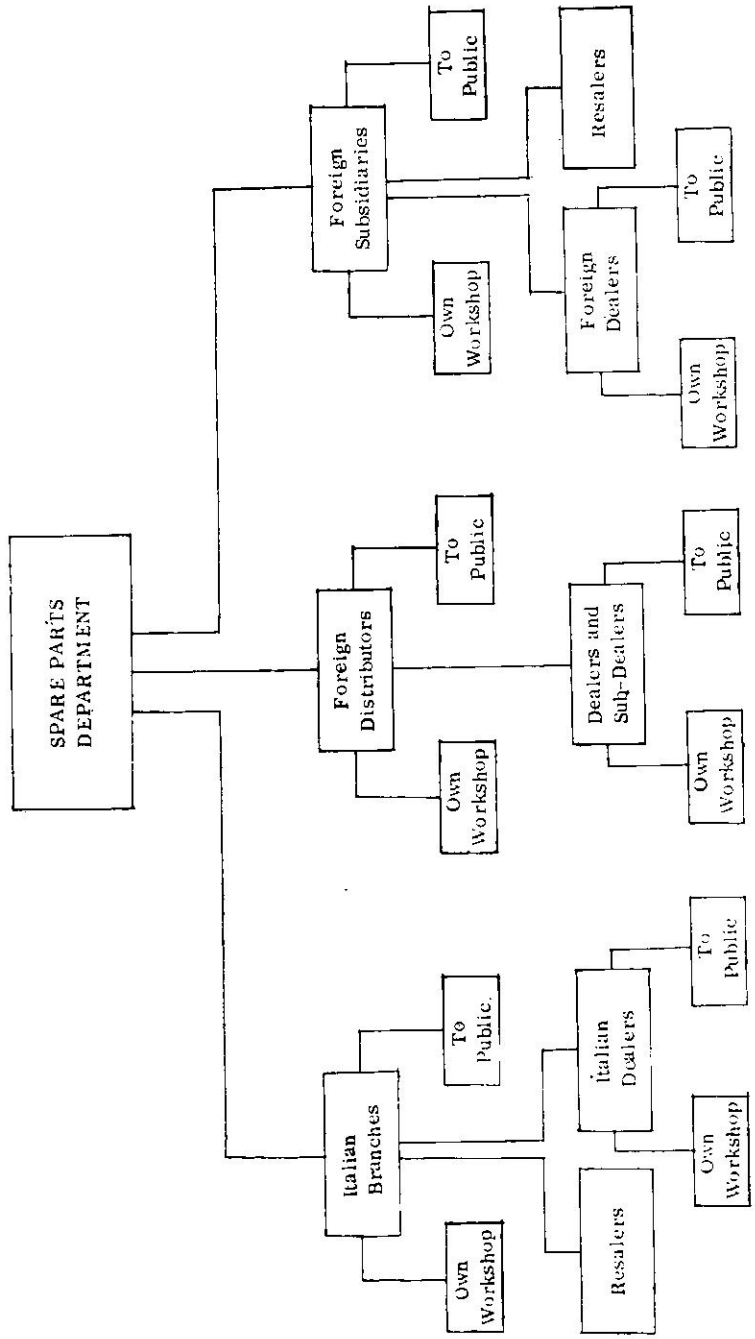

SPARE PARTS DEPARTMENT
Italian Branches
To Public
Own Workshop
Foreign Distributors
To Public
Own Workshop
Foreign Subsidiaries
To Public
Own Workshop
Italian Dealers
To Public
Own Workshop
Dealers and Sub-Dealers
To Public
Own Workshop
Foreign Dealers
To Public
Own Workshop
Resalers
Resalers

Fig. 1

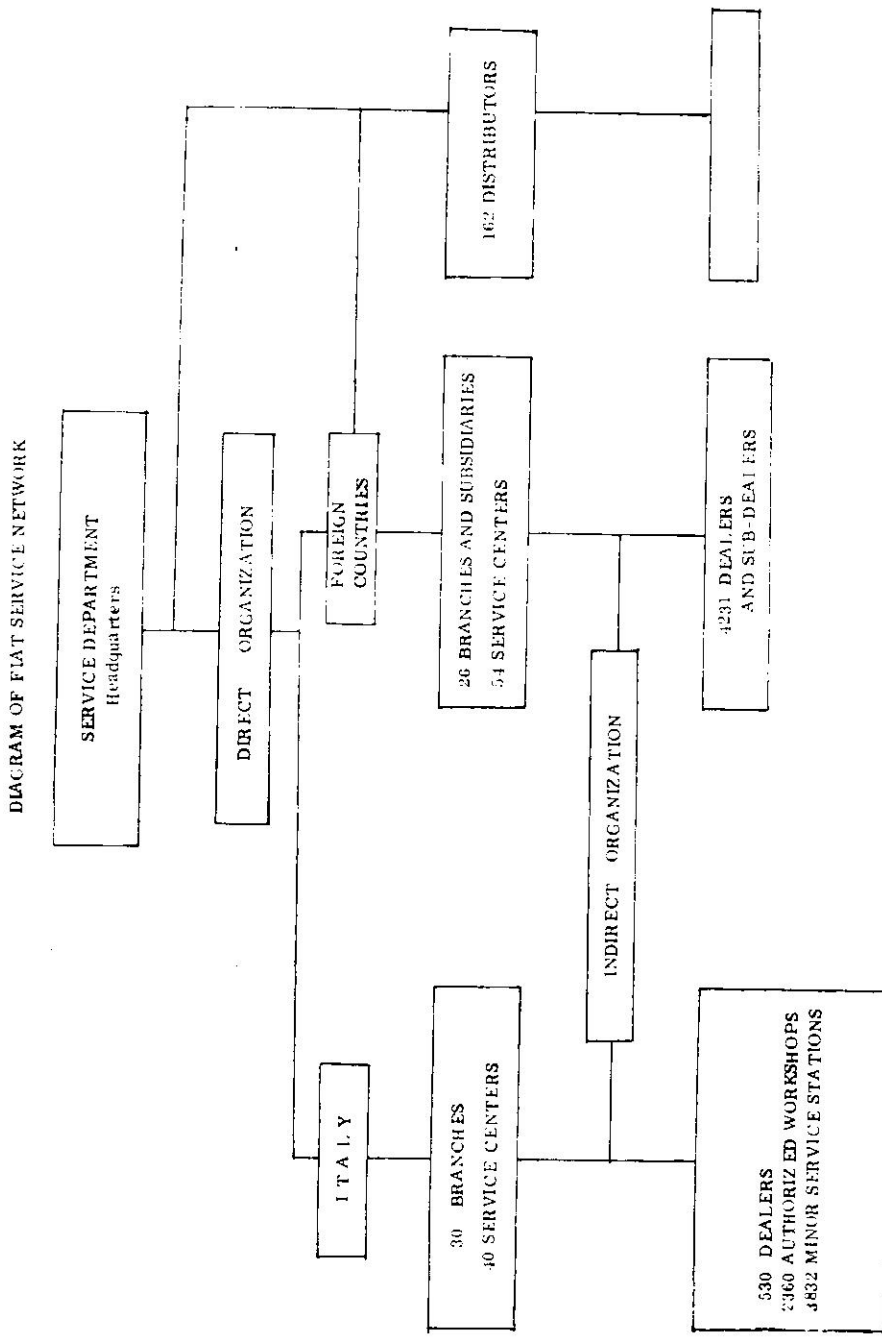

DIAGRAM OF FIAT SERVICE NETWORK
SERVICE DEPARTMENT
Headquarters
DIRECT ORGANIZATION
FOREIGN COUNTRIES
162 DISTRIBUTORS
26 BRANCHES AND SUBSIDIARIES
54 SERVICE CENTERS
4231 DEALERS
AND SUB-DEALERS
INDIRECT ORGANIZATION
ITALY
30 BRANCHES
40 SERVICE CENTERS
530 DEALERS
2360 AUTHORIZED WORKSHOPS
4832 MINOR SERVICE STATIONS

Fig. 2

an industrial structure comparable to the one in the more powerful but less numerous group of industrial nations.

Therefore, aside from the nations of North America and Western Europe, Japan, Australia, New Zealand and South Africa, the rest of the world can be defined as beng in a developing phase. An exception to be considered, though, is that of socialist economy countries, which by following a scheme of economic development basically different from the Western one, are typical cases on their own.

In general, the automotive situation in most of the developing countries can be summarized as follows:

— very low density of vehicles, in total and relative number;

— infrastructures not yet developed thus causing often the use of vehicles in totally different conditions from the ones foreseen by the manufacturers;

— excessive weight of auto import on the usually unfavourable balance of trade.

Therefore, by keeping in mind such difficulties and other different reasons of political and economic nature, the large companies and private enterprises have shown a tendency to invest locally rather than exporting the end product.

The major automotive industries appear to have anticipated this evolution by having already started since sometime to cooperate in the process of industrial development in the countries concerned by creating production factories and assembly lines, often in cooperation with local economic sources.

Since, however, the problem of relying upon an efficient after-sales service by establishing properly located service centers supplied with suitable equipment and staffed by trained personnel does not change in the case of vehicles locally assembled or exported, and because of the reasons outlined earlier there is an obvious necessity of backing up the afore-mentioned local enterprises through the concurrent creation of a direct service network or in close cooperation with local Distributors.

This line of action is followed by FIAT and to ensure that all service personnel have the knowledge and skills to successfully service the company products, FIAT has undertaken to train local personnal who, are managing the direct branches and who, in any case, are the back bone of serviee.

After-sales service contemplates the deployment of technicians of the central service department to the various countries, particularly those in a developing stage.

The training means, including general instruction programmes, educational material and mobile workshops, are basically employed to teaching methods and procedures for carrying out repairs and using properly the relatd machinery and tools. This with the purpose of reaching a satisfactory level of work efficiency demonstrated through the adherence to flat repair times. This system also provides standard yardstick against which the performance of service centers, as well as the validity of their economical management can be checked.

Service Staff in Developing Countries

As is well known, the after-sales service contemplates the displacement of technicians of the Central Service Department to the various countries—particularly those in a developing

CONTINENT	SALES 1969		SERVICE CENTERS	No.	SERVICE AREA m^2	TECHNICAL PERSONNEL No.	TOTAL PERSONNEL No.	TOTAL PERSONN A + B
EUROPE (Italy included)	1.373.400	A	Branches	71	615.000	1.370	8.800	
		B	Dealers - Sub-Dealers Aut.Workshops	7.060	3.500.000	13.700	71.800	80.600
AFRICA	28.077	A	Branches	15	44.000	90	978	
		B	Dealers- Sub-Dealers Aut.Workshops	370	110.000	380	4.200	5.178
AMERICA	58.563	A	Branches	7	23.000	95	560	
		B	Dealers - Sub-Dealers Aut.Workshops	970	300.000	950	5.500	6.060
ASIA	13.829	A	Branches	-	3.500	10	30	
		B	Dealers - Sub-Dealers Aut.Workshops	200	60.000	61	4.520	4.550
OCEANIA	7.999	A	Branches	1	1.200	3	20	
		B	Dealers - Sub-Dealers Aut.Workshops	180	55.000	330	1.150	1.170
T O T A L	1.481.958	A	Branches	94	686.700	1.568	10.388	
		B	Dealers - Sub-Dealers Aut.Workshops	8.780	4.025.000	15.970	87.170	97.558

stage in order to follow closely the existing organization.

FIAT technicians, among the duties described hereunder, organize and supervise local training courses either at the Service Schools located at every Branch or locally at the organization premises. Such courses, based on programmed schemes are, however, flexible enough to be adapted to the needs of the various levels of training. All educational material made available by FIAT specific and general shop manuals, slides, technical films, wall charts, exploded views, demonstration, cut-away assemblies, tools and machinery—is used to this effect.

In particular cases involving instruction at remote facilities, mobile workshops (the use of which was originally intended mainly for assistance purposes where service centers are not available) are employed, the van equipment being used as a means of demonstrating the repair techniques and the correct use of special tools in order that the trainees may give better results when on the job.

FIAT technicians, on the basis of their duties, can be classified as: resident technicians, technicians transferred abroad and engaged by Branches or Dealers and, depending upon special circumstances, technicians temporarily transferred abroad. Among these people, activities of the resident technicians, in particular, are described hereunder:

They operate mostly in areas such as Africa, Middle and Far East, Central and South America. These technicians make planned trips from their home base to inspect the local Organization. The results of such visits are reported in detail to the Central Service Department in Turin, so that it is kept abreast of local matters and is thus able to take whatever action is needed for a constant improvement of the service situation.

Every Dealer located in a developing country is periodically visited by said inspectors who spend one or more weeks (as required) supervising, in particular, workshop and warehouse activities and coping with the following main duties besides solving special problems:

— to study and counsel about the best layout of service centers and the proper use of tools and working procedures to achieve best results. A particular consulting care in this connection is given to dealerships being set-up as new and/or reorganized or transferred to new locations, by backing up the local management and personnel for a suitable period of time.

— to instruct the local staff by organizing training courses as mentioned previously, to cooperate with dealership management to choose the best local workers to be sent to Turin for specialization courses at the Central Service School.

— to control the technical performance of vehicles in relation to their use, the climate and road condition.

Conclusion

In conclusion, as it should materialize from the data as well as from the contents of this paper, it is evident that the "Service" commitment in general and in the developing countries in particular has to be great indeed. In fact, besides implementing its own scopes, "Service" engages to a large extent in activities like teaching and training the local staff, which major automakers carry out in a spirit of cooperation that always underlines their relationship to all countries in which they are present, including, of course, those in a developing stage.

It can be stated, therefore, that the commitments towrads these countries the industrial nations have in general, and thus also in the automotive service sector, go beyond the mutual benefit to transform itself into a tangible contribution of knowhow, techniques, systems etc., among which the technical development of local personnel is of primary importance from the younger generation, this being a normal and indispensable condition for the industrial growth of a developing country. ● ● ●


YOU MEAN THAT I WILL LOOSE ALL MY PROFITS EARNED DURING THE LAST TEN YEAR...
REPORT
MAINTENANCE EXPERT

Maintenance Considerations in Manufacture of Radio and TV. Receivers

GH Ebel*

Some basic ideas of reliability and maintainability concerning the manufacture of low-cost radio and television receivers have been covered in this article. Statistical approach to optimum spares inventory control has been adopted for explaining the cases cited.

THE developing countries are presently in a difficult position with regard to the reliability and maintainability of low cost radio and television receivers. This is primarily because of three facts:

1. Lack of trained people
2. Need to produce low cost receivers
3. Rapidly advancing technology.

The lack of sufficient trained personnel make it imperative that the receivers have long failure-free lives. This means that the design must be optimum, the craftsmanship flawless and the parts of high quality. These items tend to raise the cost of receivers and therefore must be carefully balanced against the necessity of producing low cost receivers that can be afforded by the market that this UNIDO programme is aimed at, namely the the general population of the developing nations.

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The problem is further compounded by the rapidly advancing technology from tubes and transistors through complex integrated circuits. Other parts are also changing but not as dramatically. Some changes are to reduce costs and some to improve quality, and some do both. However, in any case changes can affect reliability and maintainability by altering the basic failure machanisms for the devices.

The problem of selecting the lowest cost parts, design etc. that will do the job is a tough enough problem for developed countries, but for developing countries this task borders on the impossible. In order to succeed in producing the lowest cost radio and television receivers that will do the job, reliability and maintainability principles and practices must be employed.

BASIC RELIABILITY AND MAINTAINABILITY CONSIDERATIONS

Required Reliability

In order to make the proper "trade-off" between original cost of the receiver, the per-

formance that will satisfy most users and the maintenance resources available, certain basic calculations must be made.

Perhaps the best place to start is by predicting the reliability of a receiver or receivers that will meet the performance specifications set by UNIDO or some other acceptable source. This is done by obtaining a list of failure rates for the individual piece parts making up the receiver. Such a list is shown in Table 1. The failure rates given are expressed in the probable number of failures for a part type in one million hours of operation. The assumption for the data in Table 1 is that the parts are of a good commercial quality and the receivers operated in a climate about that of the south temperate or north torrid zones. Adjustments must be made in the failure rates for changes in operating environment and part quality. If no other data is available then predictions can be made with that data supplied in Table 1. As more experience is gained with parts and operating conditions more accurate failure rates can be generated. This is an iterative process of predicting, checking the prediction against the receiver performance and using the new failure rates for the next prediction.

An example of a prediction for a hypothetical 7-transistor receiver is shown in Table 2. All of the parts are listed along with the number of times each is used. Then using Table I—the expected number of failure for each part type for each million hours of operation is obtained and recorded in column 3. To determine the failure rate for each part type column 2 (the number of times a part is used) is multiplied by column 3 (the failure rate per part type) and the product listed in column 4. The failure rate for the receiver is determined by summing column 4. In this case the expected failure rate for the hypothitical receiver would be 62.55 failures in one million hours of operation.

The usual method of expressing the reliability of a receiver is in terms of 'mean time between failures' (MTBF). This is simply the reciprocal of the failure rate, that is, one million hours divided by 62.55 failures per million hours of operation or a 15,987 hour MTBF.

TABLE I

Failure Rates of Typical Parts Used for Radio and Television Receivers

Part Type	*Failure per* 10^6 *hours*
Capacitors	
Ceramic	1.10
Electrolytic	1.65
Foil, paper or plastic	.25
Mica	.83
Tantalum	1.10
Variable, air	1.63
Electron Tubes	
Cathode Ray (TV PICTURE)	20.00
Receiving	11.00
Inductors	.24
Lamps	
Incandescant	32.00
Neon	11.00
Resistors	
Film	.29
Composition	.17
Wire Wound	1.65
Variable	2.20
Diodes	
Germanium	3.30
Selenium	3.30
Silicon	1.20
Zener	1.65
Transistors	
Germanium	6.60
Silicon	2.80
Switches, per contact set	1.75
Transformers	.34
Speakers	1.72
Integrated Circuits	4.00

TABLE II

Reliability Prediction for a Hypothetical 7-Transistor Receiver

Part Type	Number used	Failure Rate	Failure Rate Part Type
Capacitors, Electrolytic	4	1.65	6.60
Capacitors, Foil	25	.25	6.25
Capacitors, Mica	4	.83	3.32
Capacitors, Variable Air	1	1.63	1.63
Resistors, Composition	24	.17	4.08
Resistors, Variable	3	2.20	6.60
Coils	3	.24	.72
Speakers	1	1.72	1.72
Diode, Silicon	8	1.20	9.60
Transistors, Silicon	7	2.80	19.60
Transformers	1	.34	.68
Switches (contact Sets)	1	1.75	1.75
		TOTAL	62.55

$$\text{MTBF} = \frac{109}{62.55} = 15{,}987 \text{ hrs.}$$

For most receivers this MTBF would be sufficient from the users' standpoint. The question of adequately servicing the failed receivers must be investigated. Figure 1 is a graph of expected failures per receiver per year for various MTBF's and various average daily usage. For the above example the average failure per year for an average usage of four hours per day would be 1 failure. If the area being serviced had 100,000 receivers then there would be 10,000 failures not counting receivers damaged by mishandling or accident. Making the further assumption that the average serviceman would be available 250 days a year, then 40 failures a day would be the service load for the area. An experienced man could service one receiver per day and therefore 40 servicemen would be required for the hypothetical case discussed above.

The foregoing illustration serves to show the general techniques used to determine the required reliability of a given receiver for a given set of conditions. Such an analysis serves to show if more servicemen or higher quality parts will be needed or if it is possible to lower the quality of some of the parts to decrease the cost and thus make the receiver available to more people.

Required Maintainability

The two major problems of maintainability for low cost radio and television receivers are:

1. Shortage of adequately trained servicemen
2. Adequate inventory of spare parts.

The shortage of trained servicemen was referred to in the previous section on reliability requirements. While good maintenance manuals do aid servicing, there appears to be no easy alternative to properly trained servicemen. At present it appears that the trade off of reliability *versus* servicing must be made in favour of reliability for developing countries in the immediate future.

Method of Economically Stocking Spare Part

A system has been developed whereby unskilled personnel, using simple charts and tables, can select the number of spare parts required to support a given product in a given location.

The detailed method of programming a digital computer to generate the charts and tables is presented below for general background material. Information is generated for various confidence limits, operating times and failure rates. Typical cases are presented for the use of these charts and tables. These include:

1. Selection of minimum spares requirements for a given programme.
2. Determination of critical spares after programme has been running for some time. Basically this operation is a check on original failure rate assumptions in time to take corrective action before a system is out of service due to the lack of a spare part.
3. Action to be taken if a spare part is determined to be critical.

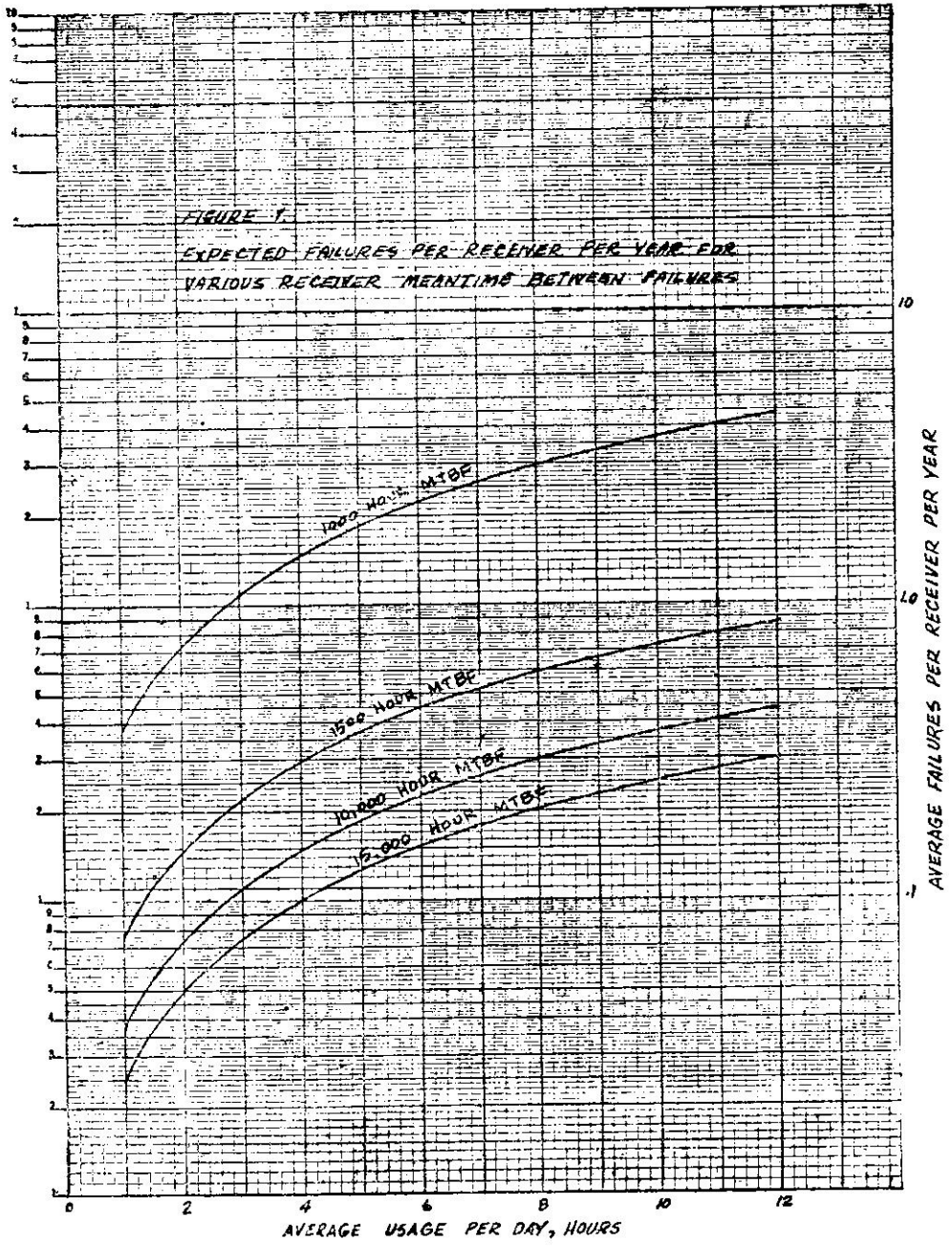

FIGURE 1.
EXPECTED FAILURES PER RECEIVER PER YEAR FOR VARIOUS RECEIVER MEANTIME BETWEEN FAILURES
1000 HOUR MTBF
1500 HOUR MTBF
10,000 HOUR MTBF
15,000 HOUR MTBF
AVERAGE FAILURES PER RECEIVER PER YEAR
AVERAGE USAGE PER DAY, HOURS
0
2
4
6
8
10
12
10
1.0
.1

Fig 1

In the last decade the method of predicting reliability using failure rates of individual piece parts has grown from an experimental toy to a standard tool in systems design and development. Since one step in the prediction of reliability results in establishing the expected failures for a system in a given time period, it would seem locgical to tie the spare parts requirements to the same basic method. Therefore, the method outlined below was originated which would make use of component failure-rate data to calculate spare parts list for any given receiver.

While good maintenance Manuals do aid servicing, there appears to be no easy alternative to properly trained servicemen.

In the process of developing the subroutines necessary for overall programme, a series of charts were produced which appeared to be useful tools in the solution of certain spare parts problems. These charts are useful, not because of any basically new material, but as a result of the form in which the material is presented. They allow unskilled personnel to prepare a spare parts list, and, after the programme has been running for a period of time, to determine which spares are critical.

Computer Programme

The charts were developed while generating a subroutine to find the minimum number of spares required to meet some pre-determined confidence level, given the operating time and failure rate of the item in question. The failure times for component parts of relatively complex systems are generally found to be exponentially distributed and, therefore, the Poisson Formula would apply.

$$Pn = \frac{\left(\frac{t}{\bar{T}}\right)^{n}}{n!} e^{-\left(\frac{t}{\bar{T}}\right)}$$

Where Pn = probability of having n failures in time t

$\bar{T}$ = mean-time-between-failures

t = operating time

Since failure rate, as opposed to mean-time-between-failures, is generally easier to handle, we can, by using the equation

$$\text{Failure rate} = \lambda = \frac{1}{\bar{T}}$$

redefine the expression for Pn as follows:

$$Pn = \frac{(\lambda \times t)^{n}}{n!} e^{(\lambda \times t)}$$

where as before

Pn = probability of having n failures in time t

t = operating time

and

λ = failure rate

Now define the comulative probability Pc (r) as the probability of having r or *less* failure in time t.

$$Pc(r) = \sum_{n=0}^{r} Pn$$

Since Pc (r) is the probability of having the number r or less failures of a particular item with a given failure rate during the time interval t, this also becomes the probability of having adequate replacement parts available if at the beginning of the period there were r replacement parts for this particular item in stock. In other words, if a desired cumulative probability is given for a particular item, the number

of pieces needed for spares can be dtetermined by summing the values of the individual probabilities of failures until this sum is equal to or greater than the desired cumulative probability. The current working value of n will then be the number of items which must appear as spares at the beginning of some time interval t to ensure the desired part availability. The flow chart shown in Figure 2 and described below was used to generate the data for the charts.

Box 1: Input data to programme is entered. is the failure rate per million hours λ is the operating time in months, p1 is the desired probability for confidence level for the chart being generated.

Box 2: The ratio $\frac{t}{T} = \lambda t$ is calculated.

The constant $730.x10^{-6}$ converts time in months to time in hours and adjusts failure rate per million hours to failure rate per hour.

Note: The number of hours per month is taken as 730.

Box 3: The exponential $e^{-(\lambda t)}$ is calculated.

Box 4: N, the number of spares required, is initialized to zero.

Box 5: P2, the probability of having N failures, and P3, the probability of having N or less failures, are initialized to the value of the exponential.

Box 6: If the cumulative probability P3 is greater than or equal to the desired probability, the results are printed. If not, the next iteration is executed.

Box 7: Increment N by one

Box 8: Compute a new value for P2, the probability of having N failures.

Box 9: Compute a new value for P3, the probability of having N or less failures.

Box 10: The probability of having N or less failures, P3, and N are printed.

The only subroutine needed to execute the programme is an exponential routine. Since the value of the exponential may fall into a large range, a subroutine, which will maintain sufficient accuracy throughout this range, is required. A suggestion for computing the antilogarithm is to use a Hastings Approximation for 10^x. The argument is initially multiplied by log e and then divided into an integral and a fractional part. The integral part becomes the characteristic of the result: the fractional portion is evaluated in the polynomial to produce the mantissa. When the argument of the function is positive, the error in the result for an eight digit mantissa does not exceed one in the last digit of the mantissa. When the argument is negative, e^x is evaluated as $\frac{1}{e^{|x|}}$ the limit of error is one in the next to last digit of the mantissa because of the additional truncation that may occur when taking the reciprocal.

The following example shows how one point for the 12-month curve of the 99% confidence level was obtained.

SAMPLE PROBLEM

Box 1 =30. Failures/million hours
t =12 months
P1 =.99 confidence level
Box 2 R =.262800
Box 3 E =.768896
Box 4 N =0
Box 5 P2 =.768896
P3(0)=.768896

Box 6 P3(0) is not greater than P1
Box 7 N—1
Box 8 .202066
Box 9 .970962

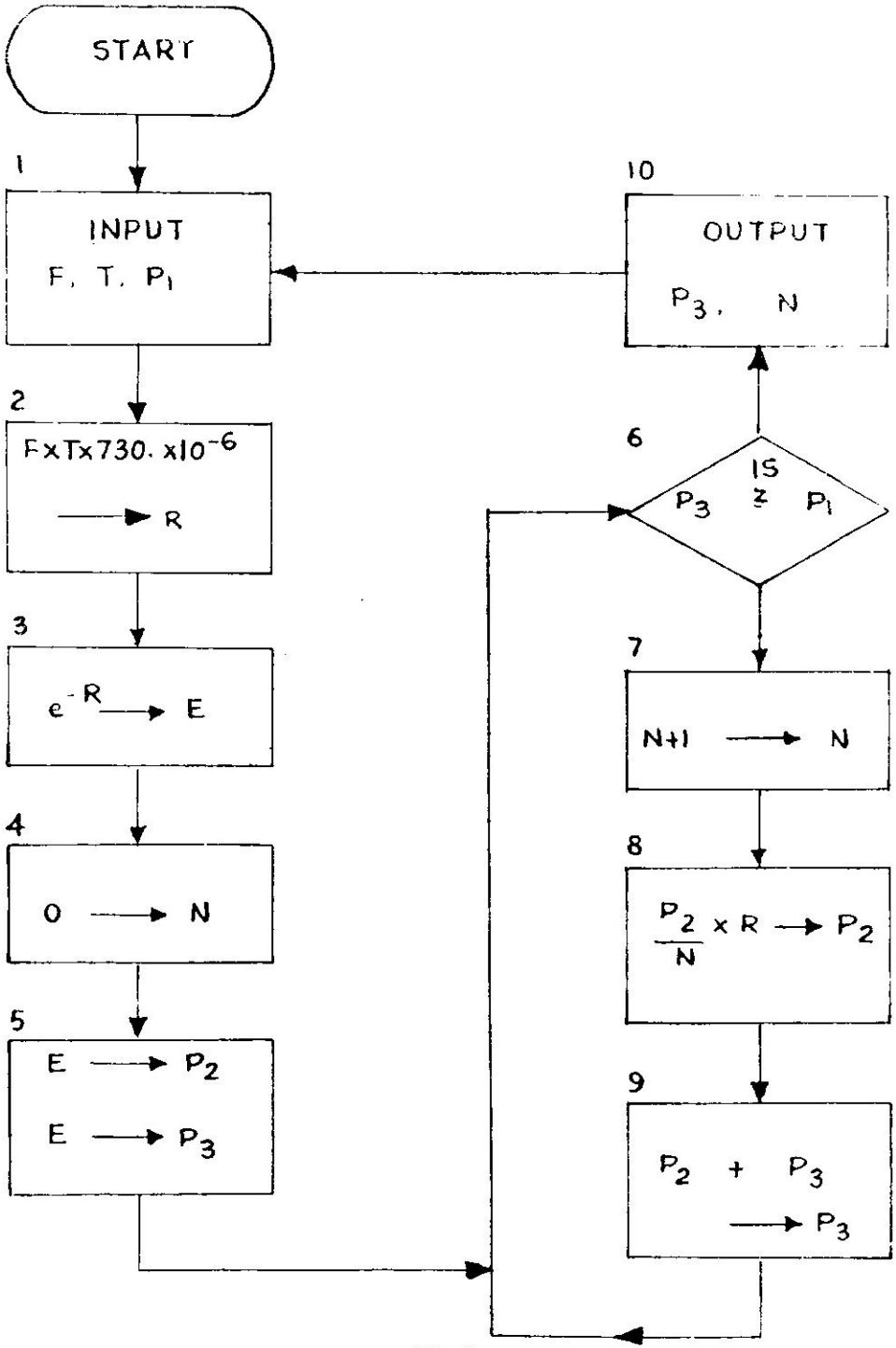


Fig. 2
Programme Flow Chart

Box 6 P3(1) is not greater than P1
Box 7 N=2
Box 8 .026551
Box 9 .997513

Box 6 P3 (2) is greater than P1
Box 10 P3 (2) =.997513
N=2

The charts for 50, 75, 90, 95 and 99% confidence levels were plotted and appear in Figures 3 through 7.

Use of Charts to Determine Spares

The charts presented in the preceding section were developed to allow unskilled personnel to perform two basic operations associated with spare parts control. The first operation is used to determine the number of spare parts required to support a programme for a specified period of time at a specified level of confidence. The confidence level is the probability that there will be adequate spares for the specified period of time. The second operation is used to determine the critical spares after the programme has been running for some time. Both of these operations make use of the failure rates of the parts making up the system.

Table I presents a set of failure rates that has given satisfactory results. However, any set of failure rates (based on constant failure rate assumption) that has proven satisfactory for predicting reliability could be used in conjunction with the spare parts charts.

Certain items may have predictable wearout life which is shorter than the expected operating time of the equipment under consideration. The replacement parts required due to normal wearout should be added to the spares complement determined by using the spare parts charts.

Requirements determined by these charts need not be confined to piece parts. Spares for any item (from piece part to complete system) which has a random failure pattern can be determined using the charts.

The basic procedure for determining the spares required is as follows:

Step I: Determine the applicable failure rate for the part, component, assembly, etc., under consideration (See Table I)

Step II: Determine the number of times the part (component, assembly, etc.) is used in equipment to be serviced by the supply point, i.e., the number of times the item is used in a system times the number of systems serviced by the supply point.

Step III: Enter the left-hand side of the chart at the value determined in Step 1.

Step IV: Move up the sloped line until it intersects the vertical line determined in Step II. This determines the total failure rate for the items for a particular supply point.

Step V: Move horizontally to the curve for operating time for the item. Operating time is determined by multiplying the length of the programme (calendar time) by the fraction of the time the equipment is turned on.

Step VI: Move down to the abscissa to determine the number of spares required.

The basic procedure for determining the critical spares after the programme has been running for some time is as follows:

Step I: Locate the point on the chart at which the original spare quota was determined, i.e., the intersection of the operating time curve and the spare parts initially required.

StepII: Move horizontally to the left until the curve of expected operating time remaining in the programme is reached.

Step III: Move down to the abscissa to determine the minimum spares which should still be in stock for the applicable confidence level.

Step IV: Compare the number in stock with that determined in Step III. If the number in stock is less than that determined in Step III, then the item is in a critical condition.

After a spare has been established as critical, the problem arises as to what action should be taken. For a spare to be in a critical condition, either the original estimate of failure rate was

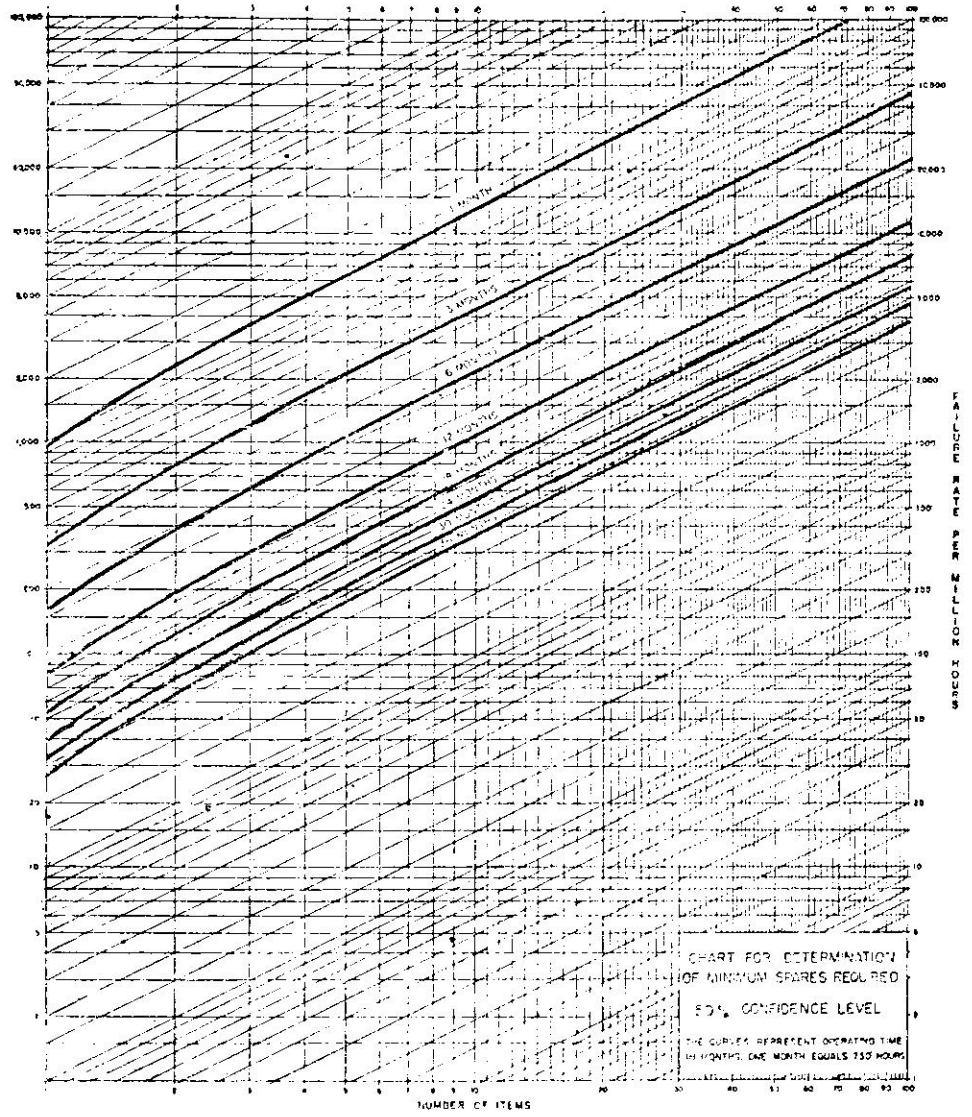


FIGURE 3

too low or the parts are being used up faster than expected due to statistical variations associated with the random failure process. The original failure rate assigned to the part is usually based on a considerable amount of past history and therefore the hypothesis that the original failure rate is correct should not be rejected unless there is substantial evidence to reject

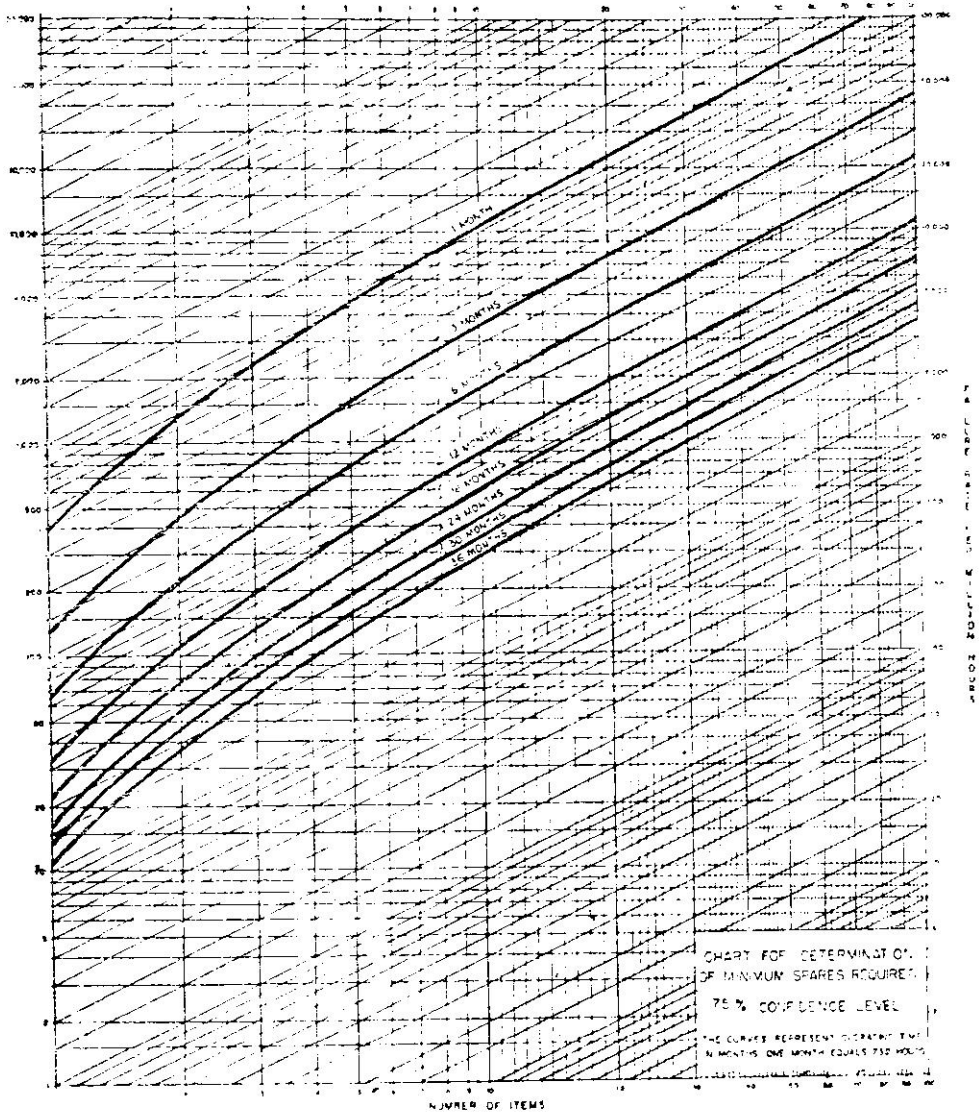


FIGURE 1

the hypothesis.

If the number of failures occurring in the time interval in question is such that there is less than a 10% chance that the true failure rate could be as low as estimated, then it would seem reasonable to recalculate a new failure rate for that part and increase the spares accordingly. This means that one time out of every ten we would be ordering more parts than necessary to support the programme at the original confidence level. Based on the foregoing discussion the following procedure can be established for

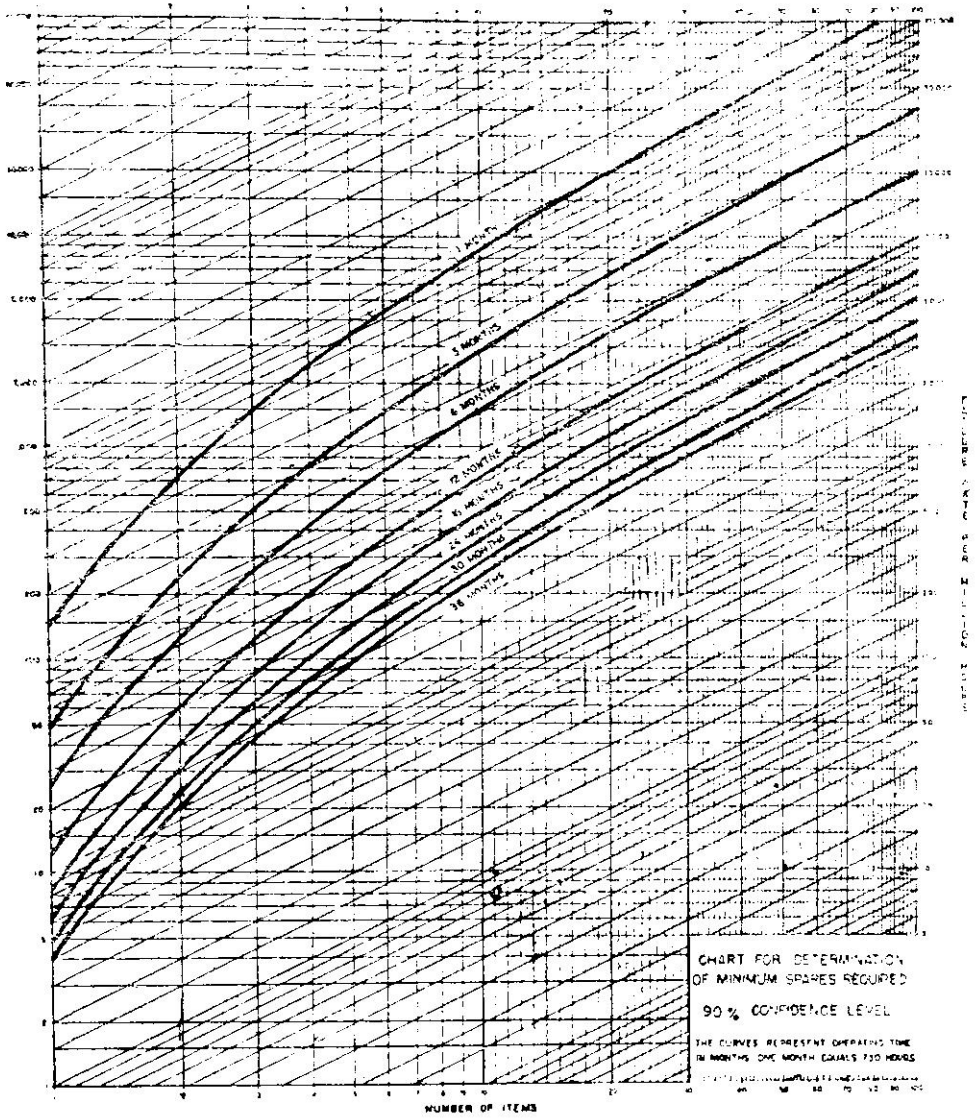


FIGURE 5

action to be taken if a spare is determined to be in a critical state:

1. Enter the 90% confidence level chart at the original failure rate and move up the sloped line to the intersection of the vertical line representing the number of times the item is used in equipment serviced by the supply point. Move horizontally to the operating curve determined by the operating time of the equipment from the beginning of the programme to the time of the

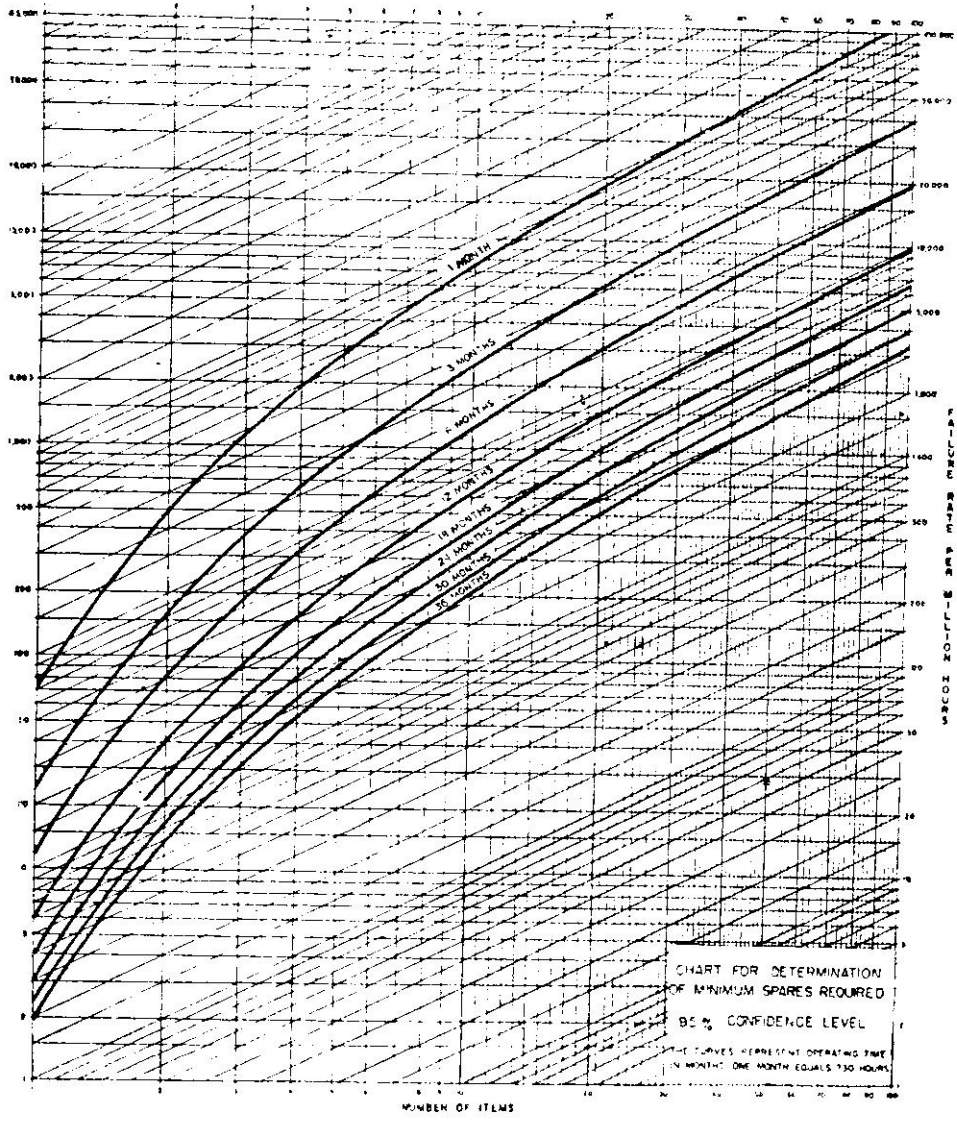


FIGURE 6

stock check.

2. Move down to the abscissa to determine maximum number of spares that could be used in the time interval before the failure rate for that part should be recalculated.

3. If the number actually used is less than the number determined in Step 2, then go back to Step III of "the basic procedure for deter-

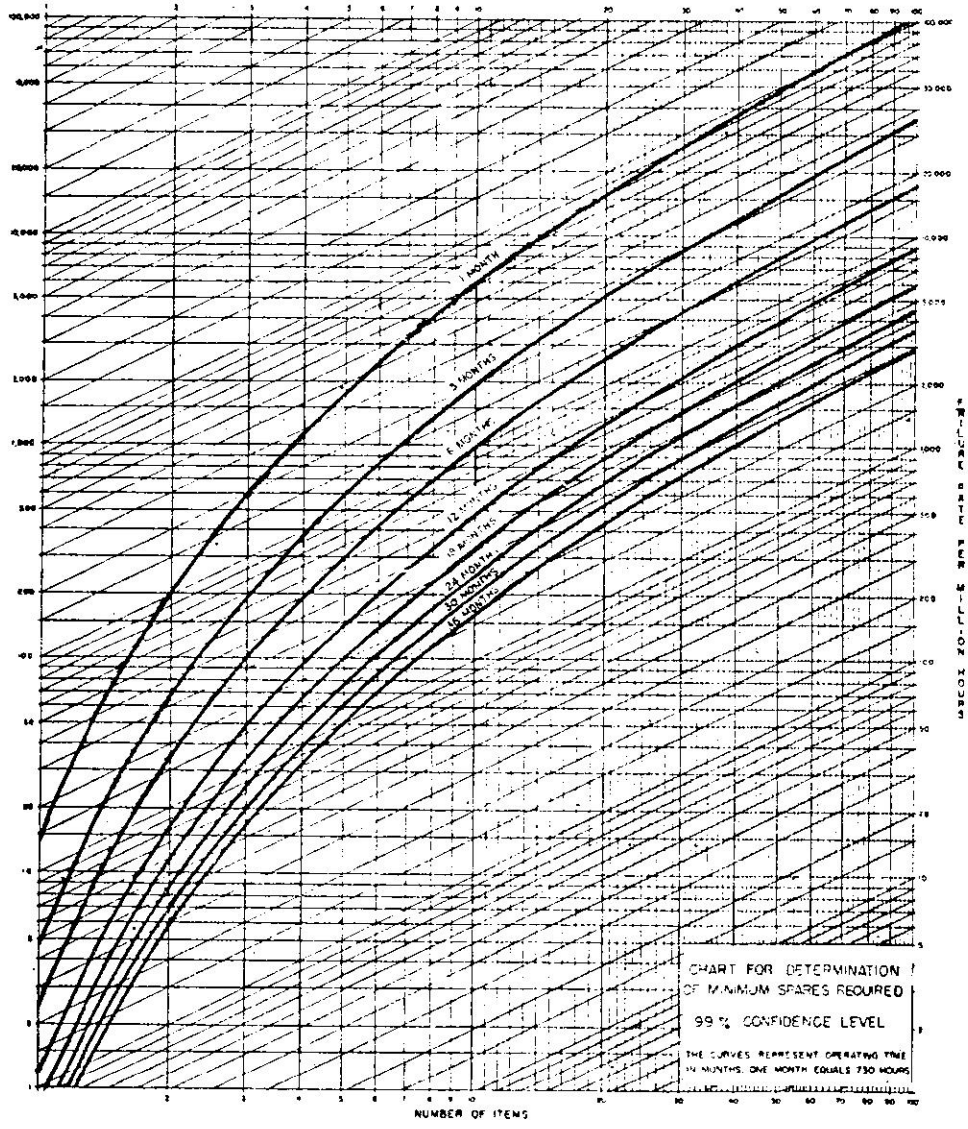


FIGURE 7

For a spare to be in a critical condition, either the original estimate of failure rate was too low or the parts are being used up faster than expected.

mining the critical spares after the programme has been running for some time" to determine the number of spares required to support the programme at the proper confidence level.

4. Order the difference between the number actually left in stock and the number determined in Step 3.

5. If the number actually used is *more* than the number determined in Step 2, then a new failure rate should be claculated using the following formula:

$$\lambda_n = \frac{N \times 10^6}{nt_0}$$

Where λ_n = new failure rate

N = number of spares used in the time interval from beginning of programme to time stock is checked

n = number of times the part is used in equipment serviced by the supply point

t_0 = time interval in hours (assume 730 hours in a month)

6. Using the new failure rate and the operating time left in the programme, determine the number of spares required to support the programme at the proper confidence level. (Use "the basic procedure for determining the spares required")

7. Order the difference between the number actually left in stock and the number determined in Step 6.

Examples of Spare Part Requiremet Calculations

The following three examples are presented to show several typical cases for the use of the spare parts charts.

1. Selection of minimum requirements for a given programme in which all spres are ordered at the start of the programme.

2. Determination of critical spares after the programme has been running for some time.

3. Action to be taken in the case of critical spares.

Example I

Assume a television receiver repair facility wanted to have enough spares on board to service 50 television receivers for a three-year period. The requirement was established that there be a 95% assurance that at least one spare of each part would be available, at the end of the three-year period. The operational duty cycle for the receivers was set at an average of 8 hours a day (or twelve months out of thirty-six) for each receiver.

For this example the problem is to determine the number of spare picture tubes required to satisfy the requirements stated above.

The first step is to locate the proper failure rate for picture tubes. Table I lists this as twenty. Next select the chart for 95% confidence level and enter the chart on the left hand side at a failure rate of twenty. Move up the slanted line until it intersects the vertical line marked 50 (the number of receivers to be serviced at the repair point). This will determine the total failure rate for the 50 picture tubes. Now move horizontally (in this case to the left) until the operation time curve for twelve months is reached and then down to the abscissa to determine the number of spares required. In this case the abscissa is intersected between seventeen and eighteen and so eighteen picture tubes are required.

Example II

The service manager in charge of supplies in the first example must know if any spare parts are in a critical situation in time to procure new spares before the supply is exhausted. In other words, he should have a method for reviewing his stock at any point in the programme and quickly selecting those items which are in a critical state. For this example let us assume that the programme in Example I has been running for eighteen months and as heighteen months left to run. This would mean that there is an average of six months of operation time left for each receiver. The problem is to determine if enough picture tubes are in stock to safely complete the three-year period without re-ordering. In this case we enter the chart at the intersection of the initial operating time curve (twelve months) and the spares in stock at the beginning of the programme (eighteen). Now move horizontally to the left until the six-month operation time curve is intersected. Then move down to the abscissa to determine the minimum number of spares which should be in stock for a given confidence level to complete the programme without re-order. In this case, there should be at least eleven picture tubes in stock. If there are more than eleven tubes in stock, then the spares situation is not critical. If there are less than eleven tubes in stock, the action to be taken would hinge on the number of spares used in the first eighteen months of claendar time, and six months of operating time.

Example III

Assume that 12 cathode ray tubes had been used in the first half of the programme described in examples I and II. This means that only 6 remained in stock, and the spares are in a critical condition.

To determine if the failure rate of 20 for the cathode ray tube should be recalculated, the 90% confidence chart is entered at 20. Move up the sloped line until the vertical line for 50 units is intersected. Next move horizontally to the operating time curve for 6 months (for actual calendar time for 18 months) and then down to the abscissa to dertermine the number which would not be exceeded more than 10% of the time if 20 were the true failure rate. In this case, the number is seven. Since twelve tubes were used, the failure rate should be recalculated as follows:

$$\lambda_n = \frac{N \times 10^6}{nt_o} = \frac{12 \times 10^6}{50 \times 6 \times 730} = 55$$

With a new failure rate of 55 for 6 months operating time left in the programme the spares required for a 95% confidence level is 23 (determined following basic procedure for determining the spares required as in example I). Since there are still 6 tubes in stock, 17 tubes will have to be ordered.

In order to make the proper 'trade-offs' between reliability, maintainability and cost of low cost receivers, the construction and predominant failure modes of the parts making up the receivers should be understood.

Component Construction and Prime Failure Modes

In order to make the proper "trade-offs" between reliability, maintainability and cost of low cost receivers the construction and predominant failure modes of the parts making up the receiver should be understood. It is beyond the scope of this paper to compile such a list for all or even most of the parts that would be used in low cost radio and television receivers. To point out some of the type of information that should be compiled, film resistors and semiconductors will be used as examples. Other information on component construction and failure modes is discussed in the next section on failure analysis.

Film Resistor Construction and Failure Modes:

The construction of metal-film resistors consists of metal or metal-oxide deposited on a refractory base. For high-resistance values, a spiral groove is grounded in the film to increase the effective path of resistance. The usual metal-film resistor involves metals such as platinum, paladium, rhodium and alloys such as nickel-chromium, etc. These films are deposited on a ceramic substrate by evaporation in a vacuum. Terminations are mede with conducting bands fired on the ends of the core. The specific resistance of the metal film may be much greater than the resistance of the bulk material.

The metal-oxide film resistors use a tin oxide film bonded fo a glass core at red heat. The expansion coefficients of the materials are matched. The films are rugged so these resistors are less susceptible to mechanical damage than carbon-film resistors.

Irreversible changes in film resistors result from overheating, humidity or mechanical damage. The increase in specific resistance of thin film of metal is thought to be due to the fact that conductivity is essentially determined by the mean free path of the electrons in the metal. A silver film, less than 400 angstroms thick, will not give consistent conductivity and a film less that 45 angstroms thick, will not give consistent conductivity and a film less than 45 angstroms thick does not conduct at all. Bulk characteristics are achieved only at a thickness of 3,000 angstroms. The temperature coefficient of resistance is very low for the metal-films.

Changes in resistance values occur over long periods of time and are not detected in the usual 1,000-hour life test. However, core defects and hot spots in the film due to uneven deposition or thin spot due to film chipping during spiraling are quickly found by using a short-term overload test.

Table III lists the major failures encountered in a testing programme on precision metal-film resistors.

The test results show that incoming inspection ranks high for these resistors as uncovering a number of defects. Difficulties are also noted for the type of encapsulation used, since 1.7 per cent fail the humidity test. Some manufacturing defects are also indicated by the 1.4 per cent failures in the overload test. Mechanical environments apparently are not a problem for these resistors. In addition to the resistance degradation failures at incoming inspection, test results also show 0.9 per cent of the specimens inspected failed the insulation resistance, 3.4 percent failed the noise test, and 0.25 per cent failed because of open circuits. Another major reported failure mode was 17 per cent of the specimens lacking acceptable insulation resistance after humidity exposure.

TABLE III

Metal-Film Precision Resistor Failures Ranked by Type of Test

(Per Cent of Sample Failing)

Quality Tests:	
Incoming Inspection	1.9
Humidity	1.7
Overload	1.4
Vibration	0.7
Acceleration	0
Shock	0
Soldering	0
Performance Tests:	
Tempeature Coefficient	14.4
125°C Life	5.2
Temperature Immersion	2.0
70°C Life	1.2
Thermal Shock	0
High Temperature	0
Low Temperature	0
60°C. 100°C, 175°C and 200°C Life	0

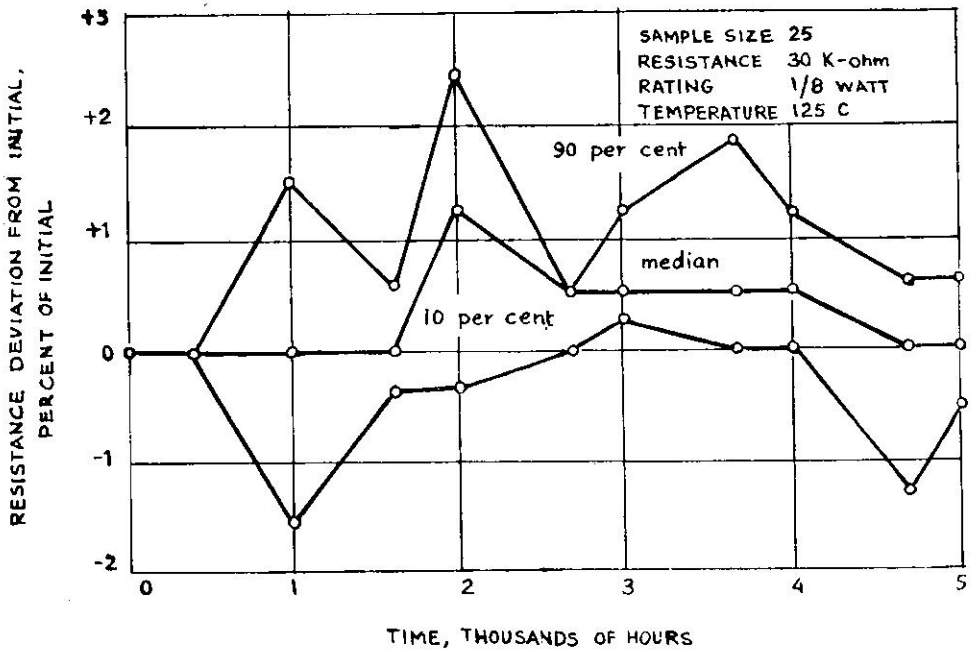


FIG 8. Life Characteristics of Metal-Film Resistors

By analysing the test results of Table III, it is found that these devices experienced the most failures during the temperature coefficient test (14.4%), followed by the failures occuring during 125°C life test (5.2%). The large number of failures for the temperature-coefficient tests may be due in part to the stringent specification requirements (0.005 per cent resistance change per degree centigrade in this particular instance). However, these requirements are reasonable since the metal-film resistor is often considered in applications requiring excellent temperature-coefficient properties. No additional failure modes were investigated.

Two examples of metal-film resistor characteristics are shown in Figures 8 and 9. Figure 8 represents the performance of 25 samples of 30K-ohm 1/8 watt metal-film resistors. They were stablized for 24 hours at 125°C before the initial data were taken. The conditions for the test were 125°C and full rated load. One failure was recorded which occurred because of a loose termination between the lead and the ceramic rod due to insufficient epoxy cement (talon construction described below).

During the test, the median deviation from initial was as much as 1.25 per cent, but for 5000 hours the median deviation was zero. The distribution range for 80 per cent of the sample, was ±0.5 per cent.

Figure 9 shows the end results of a 14,000 hour load-life on tinoxide metal-film resistors, but these particular samples were rated at 1/2 watt and 10K-ohm. The 75 samples were subjected to 100 per cent load at 60°C. It can be seen that 80 per cent of the sample had deviations from initial between +0.8 and —0.25 per cent at the end of 14,000 hours of exposure. The total excursion for the median was approximately ±0.15 per cent. Similar resistors of different ohmic values had a continued decrease

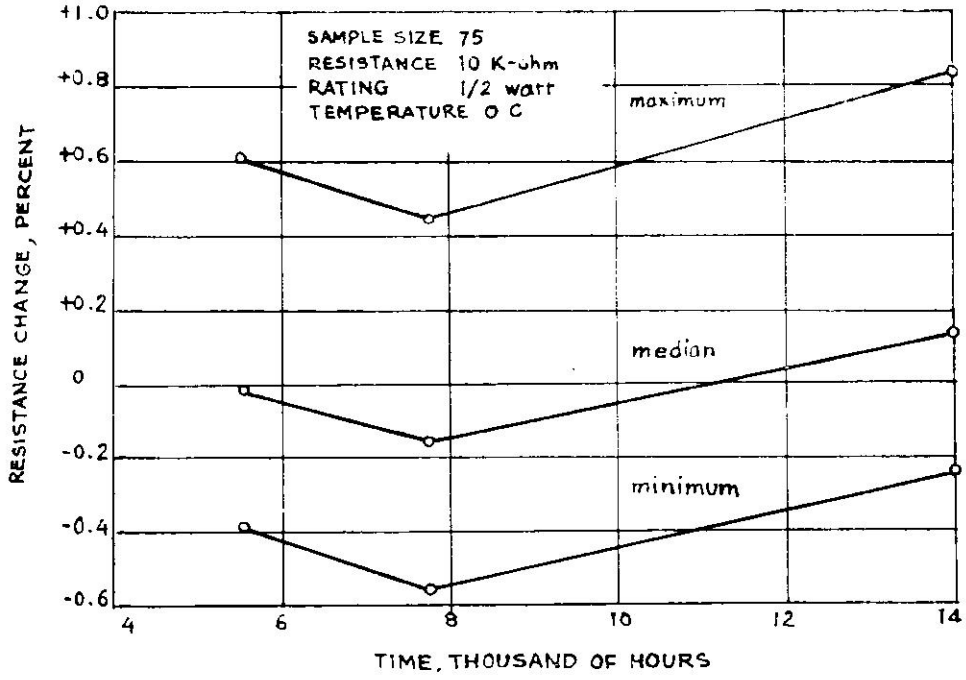


FIG 9. Life Characteristics of Metal-Film Resistors (tin oxide)

in resistance value by the end of the test in contrast to the upswing shown for the 10,000 ohm units.

Request for samples and data were made of several suppliers of metal-film resistors. Test data and samples were received from International Resistance Company for the talon and cap and lead type Metal-Film Resistors. These samples were opened and subjected to microscopic observations.

After examining both types of resistors (see Figures 10 and 11), it was determined that the cap and lead construction presently used by IRC is much more reliable than the talon type of construction. The talon assembly method holds the substrate loosey with an epoxy conductive cement and solder. Conductive expoxy cements are difficult to control during manufacturing and have a time-temperature degredation characteristic. This makes them unsuitable for high reliability applications. An attempt was made by the manufacturer to utilize screening tests to weed out defective talon units. Although screening did assist, they could not meet high reliability requirements. The cap and lead construction not only is held by solder and epoxy cement, but the end cap is press fitted to the outside diameter of the substrate. This type of construction has proven to be useful for high reliability applications and is only slightly higher in cost than talon type units.

Prime Failure Modes of Semiconductors

Table IV is a comprehensive table of failure modes in silicon transistors and integrated circuits. At first a list such as this leads one to believe that the only product coming off

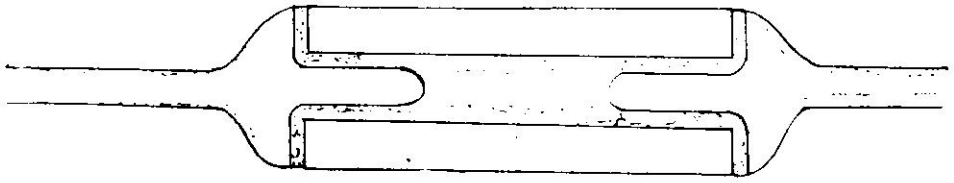


Fig 10

Cross Section of a Film Resistor Using Talon Construction

the lines are failures. In fact, most of these modes do not exist in any one device manufactured. The compilation serves two useful purposes: First to aid in failure analysis of malfunctioning devices and, second to develop economical and realistic screening tests.

FAILURE ANALYSIS, REPORTING AND FEEDBACK

For some unexplained reason, failures are rarely analyzed in depth and even more rarely systematically catalogued. It seems logical that if most of the product performs satisfactorily, then there should be reason for the piece of equipment, popularly referred to as "a lemon", to behave so differently. Most causes for the different behaviour fall into the following three general categories:

1. A marginal problem where parts coming from the tails of normal product distribution combine to cause malfunctions.
2. A "sport" problem where a part or parts fall well outside of normal product distribution.
3. An environmental problem where the equipment is stressed (intentionally or unintentionally) beyond the design limit.

The problem then, is to perform failure analysis adequate to determine the category of failure and allow feedback of corrective action on an economical basis. The key to the solution of this problem is that well-controlled processes result in homogeneous population of the product produced. This fact is useful in failure analysis

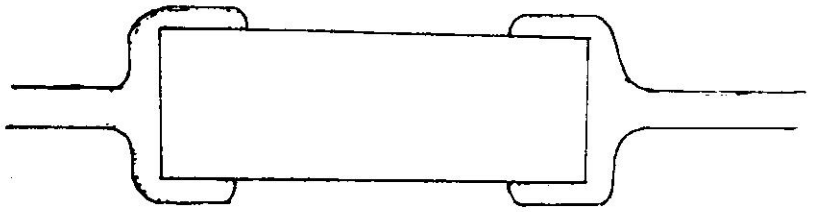


Fig 11

Cross Section of a Film Resistor Using Cap and Lead Constructiobn

Failures are rarely-analysed in depth and even more rarely, systematically catalogued.

techniques anywhere in the production cycle from early design to field use.

Specific Programme

Probably the most effective area in which failure analysis effort should be concentrated is in the manufacturing test area. This is because of the large number of equipments tested and the relatively accurate failure information obtainable at this point in the manufacturing cycle. This, in turn, allows for meaningful application of statistical techniques. Also, the early feedback to designers at this stage minimizes continuous "in-plant" repairs, reduces warranty problems and results in more staisfied customers.

The step-by-step method evolved for handling part removals during manufacturing test is briefly as follows:

Step 1: All parts removed from an equipment type are placed in a box. The high priority items discussed in Step 5 should be segregated by individual compartments for closer surveillance.

Step 2: The parts are checked daily to see if any patterns not previously noted are beginning. This simple check has greatly reduced the amount of rework by minimizing the number of units exhibiting a new symptom. The parts are collected from the manufacturing area once a week by taking the box with the week's removed parts and replacing it with an empty one. This allows for efficient handling of the parts using two boxes per manufacturing test location.

Step 3: Obtain the production records for the week the parts were collected. Using this and a parts list the total number of parts tested for that period can be established.

Step 4: Calculate the percent removal for each of the parts. This kind of an operation lends itself to computer operation.

Step 5: Determine the 12 parts that have the highest removal rate.

Step 6: Assign priorities to the 12 problem areas selected in Step 5. This priority assignment is based on many things such as, cost of part, cost of replacement, ease of solution of the problem, technical improvement of product, history of field complaints, etc., but the guiding rule is to give highest priority to that problem which, when solved, will result in the greatest overall economic gain.

The above six steps have resulted in a rather objective means of determining where to place the effort. Experience has led us to the conclusion that only the top three priorities should be worked on at a time, unless an inevitable delay is reached on any of the first three problems. Three seems to be enough to keep things moving at a brisk pace while still allowing enough time to really understand the problem so that it need be solved only once.

Once the three top priority problems are selected, the following process for investigating the problem has been evolved (this process is also useful for the investigation of parts removed for any reason, i.e., field removals, special test, etc.). First, all parts in the "top three" category that have been removed from equipment are put through incoming inspection. If the parts fail, an autopsy is performed on a few parts to determine general construction, the actual point of failure, and a possible cause. From this analysis a hypothesis as to the failure mechanism is formulated. Then several more failed parts are checked to see if the hypothesis still appears valid or should be modified.

Table IV

Failure Modes of Originally Good Silicon Transistors or Integrated Circuits

Which Might be Observed During Life and Environmental Testing

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most LikelyAs Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
1.0 Open No Continuity	1.1 Die off Header	Dynamic Testing, Thermal Fatigue	Die Lifting	Cleaning of header, die or preform; header plating, die down temp.	Microscope examination.
	1.2 Cracked Die	Dynamic Testing, Thermal Fatigue	Crack in die extending thru the isolation and or deposited leads	Header not flat, lead bond pressure or impact, ultrasonic cleaning, scribing, void under die	Microscopic examination, use of preferential etch; crack is visible
	1.3 Bonds				
	1.3.1 Off Clean				
	1.3.1.1 Intermetaic Phase Formation	Dynamic Testing, Thermal Fatigue, High Temperature Storage	Bond Lifting	Eutectic formation, metallization properties, bonding jig temperatures, wire properties.	Microscopic examination—bond comes off clean leaving traces of wire material on the bonding pad.
	1.3.1.2 Rad Metal Surface	Dynamic Testing, Thermal Fatigue—	Bond Lifting	Washing of subassemblies, wirep roperties, insufficient metal, eutectic formation.	Microscopic examination—bond comes off bonding pad clean. Pad metal under bond sometimes of a lighter colour than remaining pad material.
	1.3.2 Broken at Heel or Ball	Dynamic Testing, Thermal Fatigue	Work hardening of Lead Wire	Wire properties, mishanding of unit. Capillary condition.	Microscopic examination—wire is broken at heel of wedge bond or immediately above ball bond.

Table IV (*contd.*)

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
1.0 Open No Continuity (Cont)	1.3.3 Broken within the Bond	Dynamic Testing, Thermal Fatigue	Bond Lifting	Wire properties, capillary configuration, bonding jig temperatures, operator error, excess pressure on bonding jig.	Microscopic exam –wire broken within the bond leaving traces of wired material (wadge bond) or a donut-shaped wire material on the bonding pad (capillary bond).
	1.3.4 Off, Lifting Pad Material	Dynamic Testing, Thermal Fatigue	Bond Off	Metallizing, cleanliness, alloy time, alloying temperature.	Microscopic examination—pad material removed from under bond.
	1.3.5 Off, Lifting Silicon and Pad Material	Dynamic Testing, Thermal Fatigue	Bond Off	Excess pressure on lead bonding jig, header height variation, bonding jig temperatures, excessive capillary impact pressure.	Microscopic examination—Silicon is removed from the bonding area.
	1.3.6 Discontinuity of deposited metal				
	1.3.6.1 Lack of Metal	Operating/ Storage Life	Lack of Metal Deposition	Insufficient metal deposition, scratches caused by mishandling, operator error, metal properties.	Microscopic examination reveals a break in the metal, thereby resulting in the loss of continuity.
	1.3.6.2 Intermetallic Phase Formation	Operating/ Storage Life	Intermetallic—Phase Formation	Insufficient metal deposition, scratches due to mishandling Exposure to excessive temperature.	Microscopic examination –break in metal lead due to intermetallic phase formation.

1.0 Open No Continuity	1.3.6.3 Bad Metal	Operating/ Storage Life	Blistered Metal	Metal properties, Alloy Temperature, Alloy Time, Metallizing Cleanliness	Microscopic examination—break in metal due to blistering.
(Cont.)	1.4 Weld (s)				
	1.4.1 Off Clean	Dynamic Testing, Thermal Fatigue	Weld Off	Cleaning of sub-assemblies welding jig voltage, wire properties, welding jig pressures	Microscopic examination—weld comes off clean or leaves traces of wire material on the post.
	1.4.2 Broken at Heel	Dynamic Testing Thermal Fatigue	Work hardening of lead wire	Wire properties, mishandling of unit, welding electrode shape.	Microscopic examination –wire is broken at the heel of the weld.
	1.5 Wire Broken in Span	Dynamic Testing, Thermal Fatigue	Work hardening of lead wire	Wire properties, mishandling of unit.	Microscopic examination –wire is broken in that portion which is not associated with bonding and welding stresses.
	1.6 Electrical Overload	Excess Power or Current	Fused Lead, electrical path may be visible under the oxide.	Test equipment or misuse.	Microscopic examination—lead wire fused in span, Bond may be melted. Discontinuity of printed circuit material—material may be melted.
2.0 I L.	2.1 Excessive Current Leakage				
(Current leakage) and I LR	2.1.1 Surface Contamination	High Tempeture, Storage or Operating	Imperfect oxide protection, contamination on function.	Improper washing sub-assemblies, improper vacuum baking, improper, masking, scratches due to handling pinholes in oxide under metal.	Microscopic exam—look for contam. particles, if none visible, isolate defective area. Remove all metal, look for pinholes in oxide under metal. Light wash of die with HF, retest for improvement.

Table IV (*contd.*)

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Techniques
2.0 IL (Current leakage) ILR	2.1.2 Internal Contamination	High Temperature, Storage or Operating	Contamination internal to the device.	Unknown	Light wash of defective area of die with HF, retest indicates no improvement.
(Cont.)	2.1.3 Hermetic Seal	,,	Bad hermetic seal & imperfect Oxide protection.	Bad final seal, bad glass to metal seal, improper leak test, improper handling.	Radiflo test and further analysis as outlined in 2.1.1
	2.1.4 Crack	High Temperature, Storage or Operating Dynamic	Conduction thru a flaw in the silicon, usually a crack.	Header not flat, lead bond pressure or impact, ultrasonic cleaning, scribing, cracked die, void under die.	Diode may "switch" from high voltage low current to lower voltage high current. Microscopic examination, use of preferential etch, crack is visible.
	2.1.5 Break in Isolation	,,	Conduction thru a break in the isolation.	Masking defect, improper isolation diffusion	Microscopic examination—break in isolation visible. Section for verification.
	2.1.6 External Contamination	,,	Contamination external to device.	Washing of sub-assemblies, improper handling, dirty work area, poor workmanship.	External wash with HF improves the unit.
	2.1.6.1 Surface Contamination (Header)	,,	Contamination external to device but inside can.	Washing of sub-assemblies, improper handling, dirty work area, poor workmanship.	After uncapping the device, examine the glass around the posts (eyelets) for foreign material bridging from the header to the post. Remove the welds at the post and check the insulation resistance of the header. Leakage can be eliminated with HF wash of eyelets.

2.0 I_L (Current leakage) and I_{LR} (cont.)	2.1.6.2— Internal Contamination (Header)	High Temperature, Storage or Operating, Dynamic	Insulation Resistance of header too low	Header manufacturing problem, inadequate incoming inspection, faulty inspection limits, operator error.	No improvement after HF wash.
	2.2 Low Breakdown Reverse Biased Diode	High Temperature, Storage or Operating, Dynamic	Change in resistivity of junction.	Conductive particle on junction	Isolate defective area. Remove all metal. Retest for improvement. Removal of several layers of oxide may be necessary to remove the contaminant.
	2.3 Loose Foreign Material (Intermittent short)	High Temperature, Storage or Operating, Dynamic	Audible sound detected in device.	Improper cleaning, poor workmanship.	Audible sound detected in device. Uncap by grinding off the flange. Microscope examination of particle to determine if conductive or not. Retest device on curve-tracer; if no improvement, proceed as per 2.1.
	2.4 High Apparent Saturation Current				
	2.4.1 Inversion layer to Hard Breakdown	High Temperature Storage or Operating.	Surface state change	Surface ionisation, or change separation, other unknown.	Trace displays current conduction at low voltage, resistance and hard breakdown at higher voltage. Uncapping causes inversion layer to disappear.
	2.4.2 Inversion layer to Hard Breakdown	"	Surface state change	Unknown	Inversion layer remains after uncapping; can be eliminated by removal of metal and/or oxide.

Table IV (*Contd.*)

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Techniques
2.0 I_L (Current leakage) and I_{LR} (Cont.)	2.4.3 Inversion layer to Hard Breakdown	High Temperature Storage or Operating	Surface state change	Unknown	Inversion layer remains after uncapping and after metal and oxide removal.
	2.5 High Apparent Saturation Current				
	2.5.1 Inversion Layer to Soft Breakdown	High Temperature Storage or Operating	Surface state change	Unknown	Trace displays current conduction at low voltage, resistance, and soft breakdown at Higher voltage. Uncapping causes inversion layer to disappear.
	2.5.2 Inversion Layer to Soft Breakdown	,,	Surface state Change	Unknown	Inversion layer remains after uncapping; can be eliminated by removal of metal and/or oxide.
	2.5.3 ,,	,,	,,	,,	Inversion layer remains after uncapping and after metal and oxide removal.
	2.6 Shorted Diode				
	2.6.1 Shorted Diode	Test Equipment or Thermal Runaway	Excessive current or power causing melting of bond or metallized paths	Test equipment, thermal runaway, operation error.	Curve tracer indicates a short. Microscopic examination shows definite evidence of electrical overload.

2.0 Ic (Current reakage) and I_{LR} (Cont.)	2.6.2 Crack in Die	High Temperature Storage or Operating Dynamic	Conduction thru a flow in the silican, usually a crack.	Scribing pressures, header not flat, bonding pressure or impact, ultrasonic cleaning, void under die.	Microscopic, examination reveals cracked die; or use of preferential etch, crack is visible.
	2.6.3 Loose Foreign Material	High Temperature Storage, Operating, Dynamic	Intermittent short and audible sound detected in device.	Washing subassemblies, dirty work area, impure preform, poor header plating, poor workmanship	Curve trace displays intermittent short. Audible sound detected with Delcon particle detector. Uncap device at the flange—conductive particle visible.
	2.6.4 Holes in Oxide under metal	High Temperature Storage, Operating	Insufficient Oxide Protection.	Faulty masking, scratches, improper oxide removal, operator error.	Holes in oxide under the metal visible after removal of metal with NaOH. Verify by probing the transistors or resistors in question.
3.0 I_A (Current available) and/or V (Sat) Change to Higher Value	3.1 High Resistance				
	3.1.1 Surface	High Temperature Storage or Operating	Metal Surface	Metal properties, metallized cleanliness or thickness, alloy time, alloy temp., cleanliness alter scribing.	Sectioning reveals resistive area between bond and the metallized pad.
	3.1.2 Bond Attach	,,	Bond Attach	Lead bond temperature, tool pressure, tool configuration, dirty bonding surface, wire properties, operator error.	Sectioning reveals some separation between the bonding material and the pad material. Voids due to intermetallic phase formation will also be visible.
	3.1.3 Weld	,,	Resistive Weld	Cleaning of subassemblies welding jig temperatures, wire properties.	Rewelding of leads to posts increases I_A

Failure Modes of Originally Good Silicion Transistors or Integrated Circuits Which Might be Observed During Life and Environmental Testing

Table IV (*Contd.*)

3.0 I_A (Current available) and/or V(Sat) Change to Higher Value (Cont.)	3.1.4 Intermetallic Phase Formation	High Temperature Storage or Operating	Resistance due to Intermetallic Phase formation.	High temperature, metallize cleanliness, thickness, alloy time, alloy temperature, Insufficient metal deposition.	Microscopic examination reveals near break in metal due to excessive intermetallic phase formation near bonds. Probing of metal next to Intermetallic phase formation improves V(Sat).
	3.1.5 Lack of Metal	,,	Lack of metal deposition.	Metal thickness, scratches due to mishandling, excessive metal removal, operator error.	Microscopic examination reveals lack of metal. With probe contacts, probe for decrease in SAT around defective area.
	3.1.6 Change in Resistor value	,,	Value of resistor increased.	Insufficient oxide removal, masking, wrong type etchant, operator error.	Microscopic examination—after metal removal, resistor display little or no cutouts in the oxide for metal contact.
	3.1.7 Internal Crack	,,	Crack in Silicon	High temperature, bonding pressures or impact. Header not flat, ultrasonic cleaning, scribing, cracked die, void under die.	Sectioning reveals fracture is silicon.
	3.1.8 Butt Welded Lead to Header	,,	Butt Weld	Header manufacturing problem, inadequate incoming inspection, faulty inspection limits, operator error.	Use of another lead clipped on to header decreases SAT. Verify by sectioning through butt weld.
3.0 I_A (Current available) V_{BE} (Sat) Only	3.2 Base to Emitter Resistance Up				

3.0 I_A (Current available) VBE (Sat) Only	3.2.1 Surface	High Temperature Storage or Operating	Metal Surface	Metallize cleanliness or thickness, alloy time, alloy temp., cleanliness after scribing.	Probing of metallized path adjacent to the bond in question reveals a decrease in VBE (Sat). Section thru the bond followed by examination on a metallograph.
(Cont)	3.2.2 Bond Attach (Emitter and/or Base)	,,	Bond Attach	Bond jig temperature, tool pressure, tool configuration, misplaced bond, operator error.	Probing of metallized path adjacent to the bond in question improves VBE (Sat). Sectioning reveals separations between the bond material and pad material.
	3.2.3 Weld Attach (Emitter and/or Base)	,,	Weld Attach	Cleaning of subassemblies Welder malfunction (electrode configuration, wire properties, operator error.	Reweld welds and check for decrease in SAT. Further check as per 3.2.2 and 3.2.1
	3.2.4 Intermetallic Phase Formation	,,	Intermetallic Phase Formation	High temperature, insufficient metal, bonding pressure.	Microscopic examination reveals near break in metal due to intermetallic phase formation. Probing of metal near intermetallic phase formation decreases VBE (Sat).
	3.2.5 Lack of Metal	,,	Lack of Metal Deposition	Metal thickness, scratches due to mishandling, excessive metal removal, operator error.	Microscopic examination reveals lack of metal. Probing reduces VBE (Sat)
	3.2.6 Change in Resistor Value	,,	Value of Resistor Increased	Insufficient oxide removal, masking, wrong type etchant, operator	Microscopic examination—after metal removal resistor displays little or no cutouts in the oxide for metal contact

Table IV (*Contd.*)

Problem From Curve Tracer Anal. (External)	Defect Causing Failure (Internal)	Stress Most Likely As Cause	Phenomenon Involved	Possible Production Fault Causing Defect	Failure Analysis Technique
3.0 IA (Current available) VBE (Sat) Only (Cont.)	3.2.7 Internal Crack	High Temperature Storage or Operating, Dynamic.	Crack in Silicon	High temperature bonding pressure or impact; header not flat, ultrasonic cleaning, scribing, cracked die, void under die.	Sectioning reveals fracture in silicon.
	3.2.8 Butt Welded Lead to Header	,,	Butt Weld	Header manufacturing problem, inadequate incoming inspection, faulty inspection limits, operator	Use of another lead clipped on to header decreases SAT. Verify by sectioning thru butt weld.
4.0 hgg	4.1 Soft EB Diode (Surface)	,,	Contaminated Surface	Scratches, foreign material, insufficient oxide protection, operator error	Proceed as per Para. 2.1.1
	4.2 Increased V(Sa)	,,	Emitter/Collector resistance up	See "V (Sat)"	Examine the test data to determine the relationship between SAT readings and hgg. Proceed as per Section 3.1 and the appropriate failure made exhibited.
	4.3 Carrier Recombination Velocity	,,	Migration of metal atoms, charge in surface state. Other unknown.	Unknown	Curve tracer shows hard EB Breakdown Microscopic examination—no cause for failure visible after metal and-or oxide removal after locating defective, areas. Sectioning inconclusive.
	4.4 Short and/or Partial Shorted Diode	,,	See 2.6 "Shorted Diode"	See 2.6 "Shorted Diode"	Proceed according to the failure mode exhibited under Section 2.6 "Shorted Diode."

After a reasonable hypothesis has been established, a sample of new parts is drawn out of stores. Careful quantitative measurements are taken on the sample lot. This is useful in attempting to correlate specific parameter variations to the problem at hand. The measurements need not be confined to the purchase specification, but must not be destructive. If possible, they should be kept as simple as is feasible since these measurements may well form the basis of a screening test or a requirement on a purchase specification. When the parts have been measured, they should be tested in an attempt to reproduce the same failure experienced in the equipment.

If at this point the hypothesis appears to be wrong, a new one must be proposed and the process repeated. Once the hypothesis gains the status of an acceptable theory, then action is almost always quite clear. If the part is at fault, screening, followed by better vendor control or possibly a new vendor, is called for. If the theory points to a faulty manufacturing process, backtracking through the line until the offending process or operator is located is the action called for. Finally, if it appears that neither the part nor the manufacturing is at fault, the problem is referred back to engineering. When this is the case, it is surprising how often the solution results in a more reliable design at a lower overall cost.

If the parts still pass incoming inspection, the approach is slightly different. Engineering is usually called in immediately since they will almost invariably inherit a problem of this type. The first step for parts passing incoming inspection is to take quantitative data on various parameters to determine if any trend exists. In some cases the solution is as simple as picking a new center value for a parameter. Parts at or near one end of the limit condition do not necessarily call for a simple pulling in of one end of the specification. It is possible that overstressing the parts, either in manufacturing or normal operation of the equipment, could cause a shift or nominal value to either extreme. Parts requiring matching quite often show up in removal as parts on both ends of the distribution curve with very few parts in the middle of the distribution.

In general, if removals still pass incoming inspection, the problem is to find that paramter which was not properly specified in the inspection procedures. Care must be taken so that the cost of increased inspection is not more than the cost of locating and removing the defective part. Although I am sure that one could devise such a situation, I have never run into a case where, if the percent removals were greater than 1%, a suitable economical incoming test could not be devised.

Determination of Top Priority Items:

Figure 12 shows the form used for determining the priority of the top twelve problems. The first five columns (part, cost, number used, number removed and % removed) are self-explanatory. The sixth column, "total cost", is determined by adding the cost of isolating and correcting a malfunction (a conservative figure of $3.00 per part was used for this example) to the cost of the part (column 2) and multiplying by the number of parts removed (column 4). The total cost represents the maximum savings that can be realized for the quantity of equipment involved if that part were of a particular part to less than one percent, column seven (savings for 1% removal) indicates the minimum savings that could be realized for the quantity of equipment involved, if the 1% goal were attained. Practically, the actual saving lies between the dollar values shown in column six and column seven. The figures in column seven are determined by taking 1% of the number of parts used (1% of column 3) and multiplying the part cost plus the cost of isolating and correcting the malfunction and subtracting it from the dollars in column six. Column eight ("Break-Even" increased part cost) shows the increased cost that could be incurred, per part, if the removal rate were lowered to 1%. The "Break-Even" increased part cost is determined by dividing the savings for 1% removal (column 7) by the number of parts used (column 3).

For the example shown in Figure 12, the

Priority Evaluation Chart

Part	Cost	No. Used	No. Removed	% Removed	Total Cost*	Savings for 1% Removal	"Break-Even" Increased Part Cost
A	$ .38	286	127	44.0	$ 429.26	$ 419.61	$ 1.47
B	2.11	215	31	14.4	158.41	147.42	.68
C	1.23	1090	61	5.6	258.03	211.92	.19
D	1.96	1446	86	5.9	426.56	355.24	.24
E	2.95	1408	142	10.0	844.90	775.20	.55
F	.90	585	58	9.9	226.20	203.38	.34
G	.95	4569	194	4.2	766.30	585.82	.12
H	.65	1031	84	8.0	306.60	269.21	.26
I	1.25	3804	146	3.8	620.50	458.83	.12
J	1.11	1085	50	4.6	205.50	160.91	.14
K	1.50	1980	183	9.2	823.50	734.40	.37
L	1.75	560	53	9.4	251.75	225.15	.40
Total		(18,059)	(1215)	6.7	($5,317.51)	($4,547.09)	

*Total cost includes the cost of the part plus $3.00 labour per part

Fig. 12

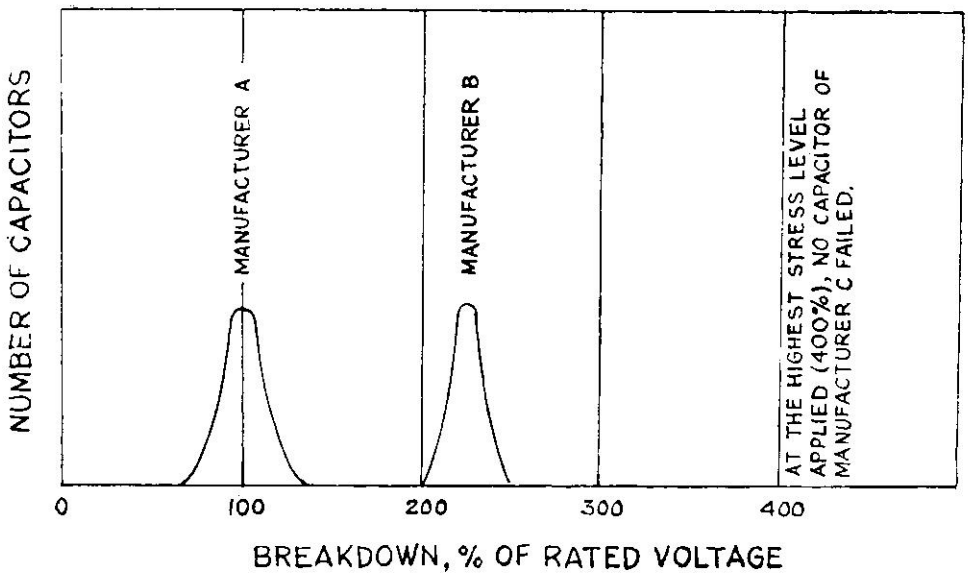


Fig. 13

top three priority items would probably be parts E, K and G in that order. However, when a "break-even" increased part cost is as high as item A, it is advisable to take a look at that item to see if a higher quality part could solve the high removal rate problem quickly.

Failure Analysis Case Histories

Once an item is isolated for further investigation a comprehensive evaluation programme should be initiated. Perhaps the best way to illustrate this is with some case histories.

Case I—High Voltage Capacitor Selection

The field has been narrowed down to three possible suppliers of a certain capacitor. All three were being sold to the same specification, and there was no price differential. It was decided to check breakdown voltage distribution for each of the three capacitors. Figure 13 shows the distribution for each supplier as a function of the specified breakdown voltage. It is obvious that, if the test were a valid one, supplier C would be the best. A sample of each type was assembled into equipments. The test, in fact, supported the contention that supplier C was superior. The equipment was run for 100 hours and supplier A had about 25% failures; supplier B had no failures in test but about a 3% failure rate on incoming inspection. Supplier C had no failures in incoming or during the test. Over 4000 of supplier C's capacitors have been assembled into equipment with no known failures to date.

An analysis of the three types of capacitors showed that supplier C had better winding techniques than either of the other suppliers. The failures could always be traced to a crease in the foil that caused excessive voltage gradients.

This is a simple example of differences between suppliers. The most significant thing about the investigation is that the decision was made, based on the data in Fig. 13, in one afternoon of testing.

Case II—Radio Noise Screening of Deposited Carbon Resistors

The technique of screening resistors by means of noise analysis 2,3 has progressed to the point where it is included in many purchase specifications. Before embraking on a programme of noise analysis of resistors it would be well to study the referenced material. Generally speaking, there are two types of noise—that expected due to such things as thermal noise, normal processing and fabrication, size, shape, and the bulk noise of the resistive material, and unexpected noise due to such things as high current density areas (see Fig. 14) or loose ends caps. The expected noise level on one type of resistor may well be above the unexpected noise level of an unreliable resitstor of another type.

In the case discussed below there was a removal rate of approximately 25% on a certain carbon film resistor. All resistors removed from the end product showed higher resistance values than the specification called for. The resistor had a conformal epoxy coating and therefore it was decided that a plastic sleeving was to be put over the resistor for protection. A review of the manufacturing process reveaaled that the lubricant used to slide the plastic sleeve on the resistor would also dissolve the epoxy coating. Therefore, the hypothesis was established that some of the lubricant was trapped under the plastic coating which in turn created hot spots in the resistors and caused the resistors to fail.

To check this hypothesis two sets of resistors were made up. One set used the epoxy dissolving lubricant to apply the protective sleeving and the other set used no lubricant at all. Sure enough, about 25% of the first set failed but, alas, so did about 25% of the second set.

A new hypothesis was required. About this time we were fortunate enough to have available a Quan Tech model 327 diode noise analyzer. Nineteen resistors were tested on the noise analyzer. It was noted that there were significant differences in the noise level of some of the resistors. Because of power supply limitation, only six resistors could be run under simulated circuit condition. The six resistors selected for test had the following noise readings:

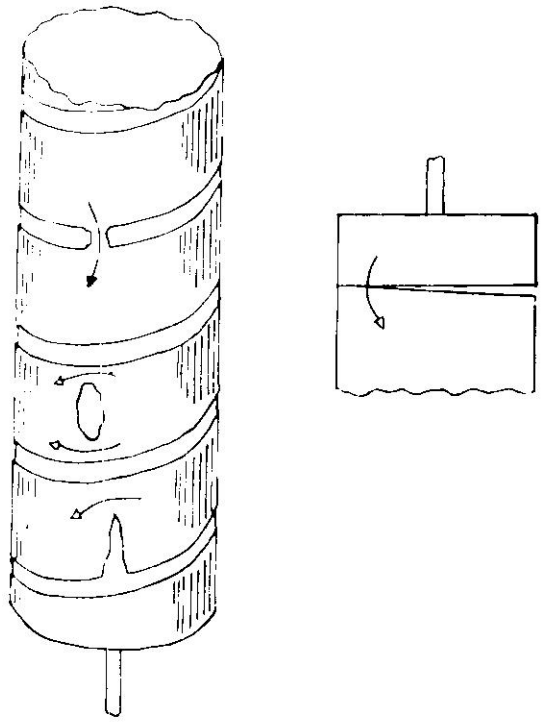


Fig. 14
High Current Density Areas of Film Resistors

Resistor Number	*Noise, mv.*	*Arbitrary Noise Magnitude*
6	0.8 erratic	8
11	0.13	1
13	1.2	>9
17	0.55	5
18	0.25	2
19	0.18	1

Figure 15 shows the percent change in resistance for the first 80 hours of operation. The

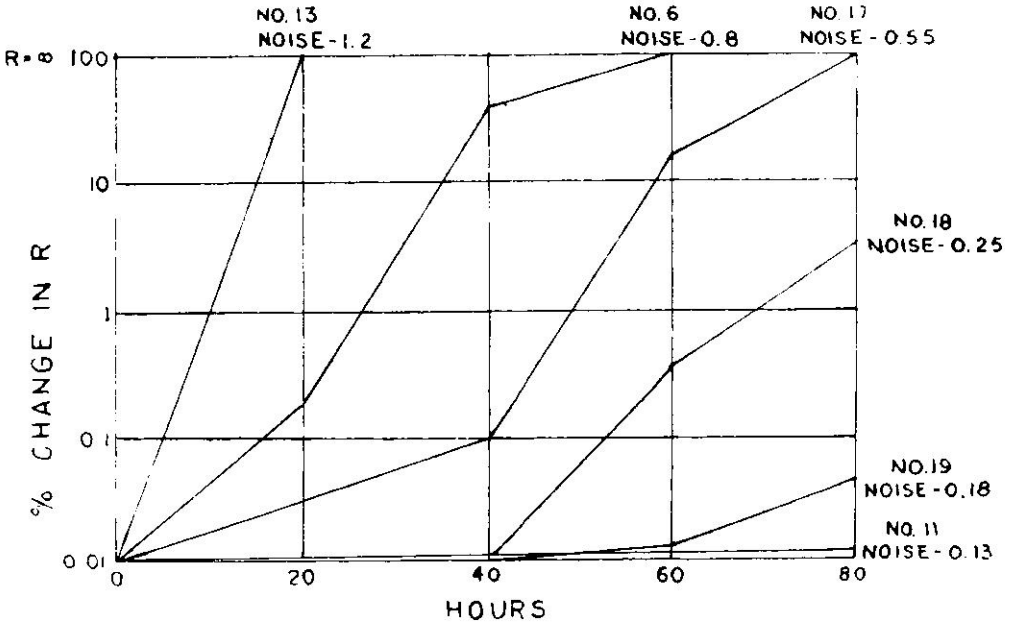


Fig. 15
Burn in of 6 Selected Samples

correlation between noise measurements and resistor performance was 100%. What is also significant is that no difference could be detected (even using careful microscopic inspection) between those resistors that failed in equipment and those that failed as prt of the controlled test.

As a result of this small sample testing, a radio noise screening test for these resistors was instituted. A lot of 375 resistors was screened to determine the nose distribution of the resistors. This distribution is shown in Fig. 16. The resistors were grouped into arbitrary noise magnitude levels. Each level as 0.1 mv wide. Based on the test results illustrated in Fig. 15, all resistors having a noise magnitude of 2 or more were rejected. As a final control, three resistors in the lowest rejectable noise level (noise magnitude 2) were colour coded and deliberately put into equipment. All three failed during manufacturing test. Fig. 17 shows that the screening test reduced the removal rate from about 25% down to about 1%. Subsequent investigations tend to show that the removal rate could be further reduced by subjecting the resistors to elevated humidity prior to testing.

The final outcome of this problem was a vendor study of similar resistors. The study resulted in obtaining a better resistor at a lower cost. Also, the new resistor selected was the same size but the rating was such that in the circuit the resistor was only operating at about 25% of its rating instead of 67%.

CASE III—NOISE ANALYSIS OF ZENER DIODES:

The removal rate of IN721A diodes in two equipments was excessively high. One case (manufacturer A) was for excessive noise in

the circuit and the other case (manufacturer B) was because of erratic behaviour of a precision oscillator. All of these diodes that were removed passed incoming inspection and, indeed, met all the requirements of IN721A zener diodes.

One group of diodes was obtained from manufacturer A and a second group from manufacturer B. Also, a third manufacturer, C was investigated at the same time. The black painted coating was scraped off one diode from each manufacturer. The differences in physical construction between the three diodes were obvious even without a microscope. The diodes were potted in clear epoxy and sectioned. Then the samples were etched to bring out the diode junctions and a picture of the junction area was taken at 100X magnification. Drawings made from these pictures for diode manufacturers A, B and C are shown in Figure 18. The arrows denote the junction.

The differences between the diodes were not limited to physical construction alone. There were also significant differences in the basic processes in making the diodes. Manufacturer A used a diffused junction with boron as the P dopant, and phosphorous as the N+ dopant. Manufacturer B used an etched alloy technique for making the junction with aluminum silicon eutectic as the P dopant. Manufacturer C, as did Manufacturer A, used boron as the P dopant and phosphorous as the N+ dopant, but used a planar method for producing the junction. Manufacturer C also used a process which caused the zener breakdown to occur in the internal portion of the junction rather than at the surface.

The differences mentioned above also resulted in electrical differences not covered in the IN721A specification but, nevertheless, important to the two circuit applications under investigation.

Five diodes from each manufacturer were selected at random. The noise levels for about the first 250 m.a. of conduction were viewed on an oscilloscope. The standard diffused silicon wafers' characteristics (manufacturer A) exhibited high noise, multistate breakdown (resulting in junction hot spots) and a large dissimilarity

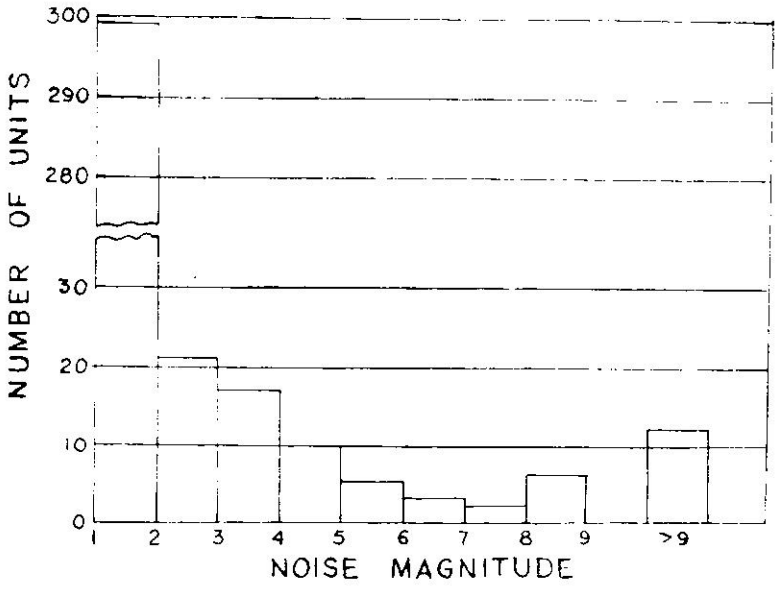


Fig. 16
Noise Histogram of Carbon Film Resistors

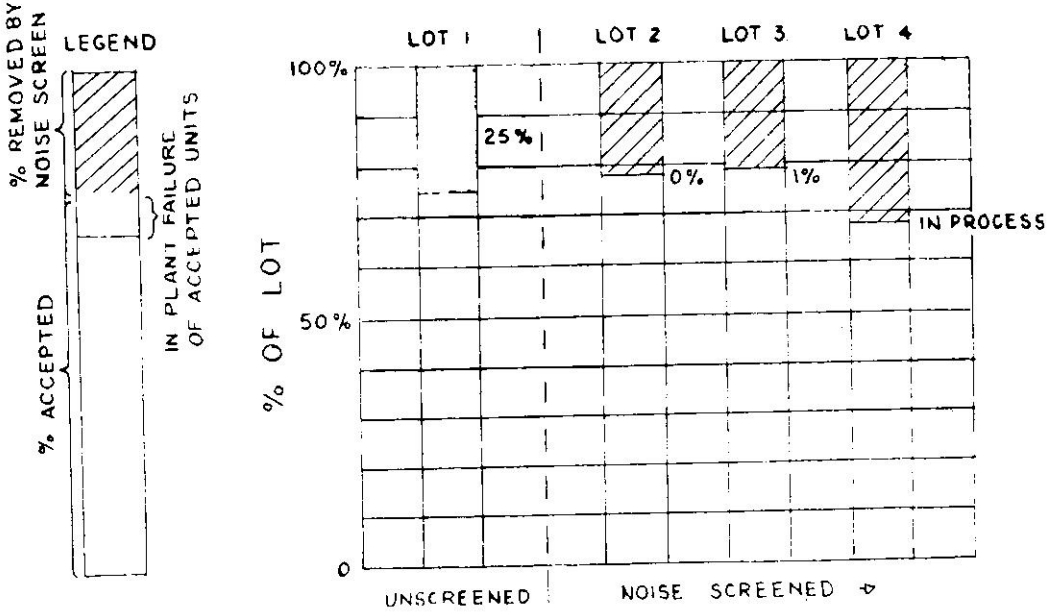


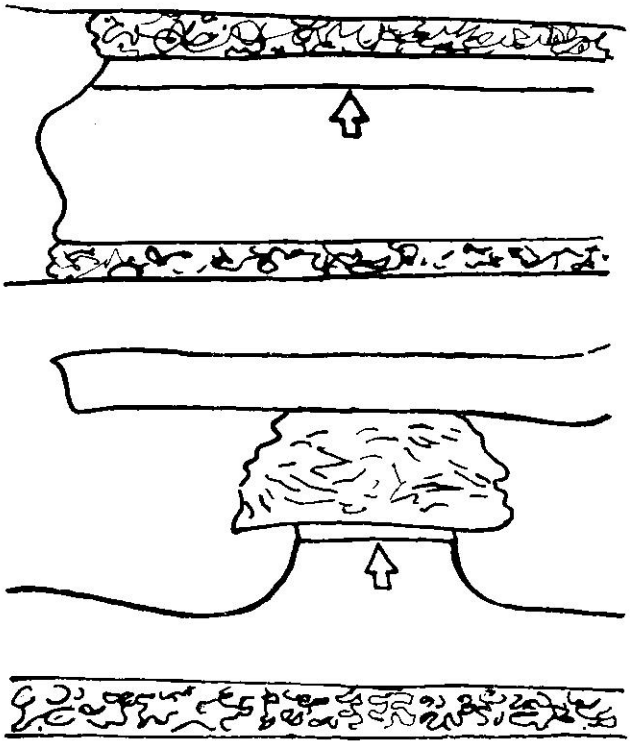
Fig. 17
In-Plant History of Carbon Film Resistors

between the 5 diodes. The alloy-type junction (manufacturer B) produces the following characteristics: a high noise level in two diodes, multistating, and non-uniformity of the diode noise characteristics. The characteristic of a planar zener diode (manufacturer C) were designed for bulk breakdown. These diodes have low noise, no multistating and relatively good uniformity.

Figure 19 shows the E-I characteristics and the noise voltages generated at diode breakdown for a representative sample from each manufacturer out to 2.4 milliamps of conduction. From this series of pictures it is obvious that supplier C had the least noisy diodes for operation in the malfunctioning circuit where the current range was from 0.5 mils to 1.5 mils. The present theory for this phenomenon is that the junction designed for internal breakdown did not have surface problems which would cause multiple breakdowns of the junction.

The noise characteristics alone did not solve the second diode problem of unstable oscillator performance. Four diodes were selected at random from each of the C suppliers. The zener current *vs* the dynamic impedance was plotted using the diode noise analyzer and an oscilloscose. Fig. 20 shows these plots for the 12 diodes. Here again the differences can be traced to the lack of surface problems with supplier C.

Both diode problems were solved by using diodes made by manufactuerer C. The cost per diode for manufacturer C was slightly higher than A and B. However, the cost per useful diode after incoming inspection was considerably lower for manufacturer C since about a third of the other diodes would not have been usable in finished equipment.



(a)

IN721A Zener Diode—Diffused Junction (boron for P dopant)

(b)

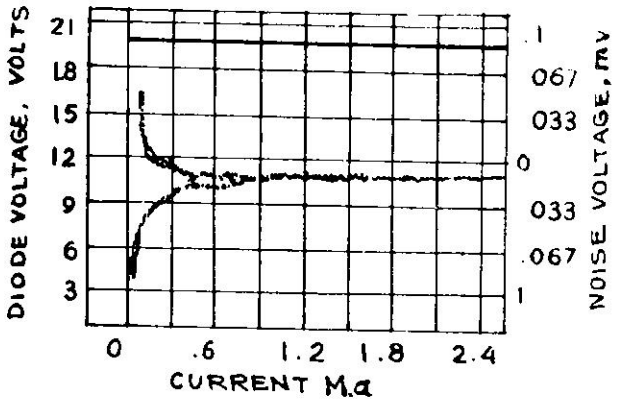
IN721A Zener Diode—Etched Alloy Junction (aluminium silicon eutectic as the P dopant)

(c)

IN721A Zener Diode—Planar Diffused (doped for internal breakdown)

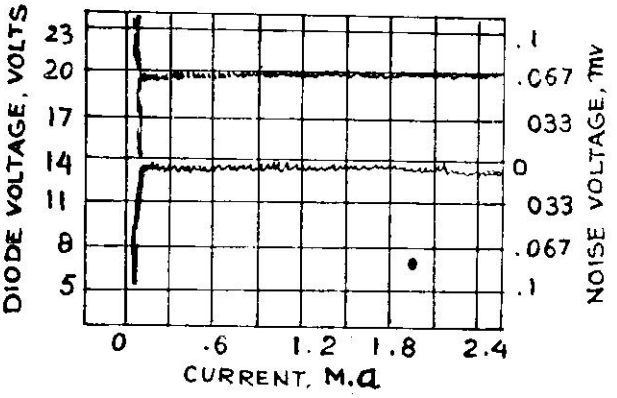
Fig. 18

Etched Diode Sections Showing Junctions 100X Magnification



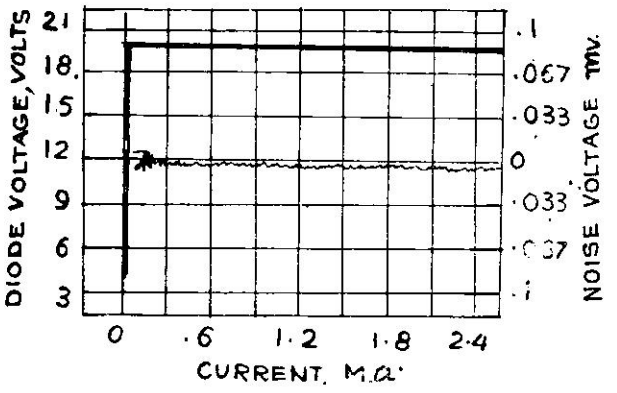
(a)

Diffused Junction E-I Characteristics and Noise *vs* Current



(b)

Alloy Junction E-I Characteristics and Noise *vs* Current



(c)

Planar Junction E-I Characteristics and Noise *vs* Current

Fig. 19
Medium Conduction
E-I and Noise Characteristics of IN721A Diodes from Three Different Manufacturers

Commercial Physics of Failure Laboratory

The first step into the world of failed-part analysis is usually taken with apprehension. Most people lack the knowledge of component construction and, therefore, there is great reluctance to look inside a component. However, those who have entered the field would urge every apprehensive person to start dissecting components for a useful education. It isn't until knowledge gained of possible failure modes caused by various construction techniques that real gains are made in commercial reliability programmes. The understanding of components is equally useful whether the problem is one of vendor selection, devising a screening test, or studying a failed component.

The purpose of a commercial physics of failure laboratory is *not* for basic research on components, but primarily to gather enough information to make intelligent decision. The component manufacturer probably knows more about his product than anyone else. Therefore, if enough detailed information is gathered on a specific problem to carry on an intelligent conversation with the manufacturer, he will usually meet you more than half way in arriving at a sensible solution. However, before a supplier can help, he must be given more to work on than "Your components aren't any good—they keep failing".

Summing up, the main functions of the commercial physics of a failure laboratory are:

1. vendor selection and liaison
2. rapid isolation of design, manufacturing, or field problems
3. design of economical screening tests to allow orderly production to continue.

The gamut of problems that could arise is exceedingly large. In addition to the three cases cited above, ten more representative problems are outlined in Table V.

From the ten foregoing examples it is obvious that detailed failure analysis can lead down many trails. It does not, however, require an elaborate laboratory to produce cost savings and increase equipment reliability. For example, periodic testing of liquid solder fluxes, cleaning solutions, etc., by using litmus and silver chromate paper to detect acidity and chlorine problems can be carried out for pennies. Example ten above was solved in about two hours using less than one cent's worth of silver chromate paper. If this problem had not been detected and corrected rapidly, thousands of dollars of rework could have been wasted on this item.

Along with simple, rapid, low cost chemical testing equipment, a basic laboratory consists of:

Metallurgical microscope

Two eyepieces—4X and 10X

Four objectives—1.5X, 5X, 10X, 40X

Leitz IPSO microscope-to-camera adaptor

35mm camera back

Vertical illuminator

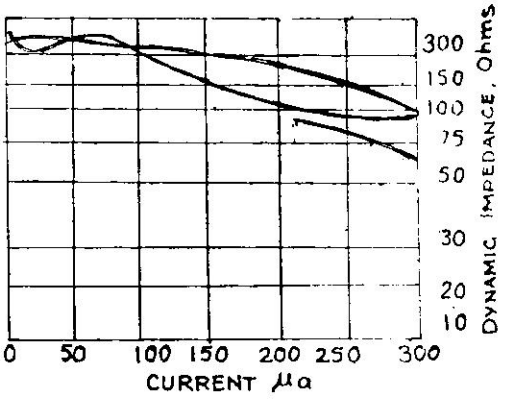
Microscope lamp

Quan-Tech Model 327 Diode Noise Analyzer

Sears lapidary kit (for preparing samples)

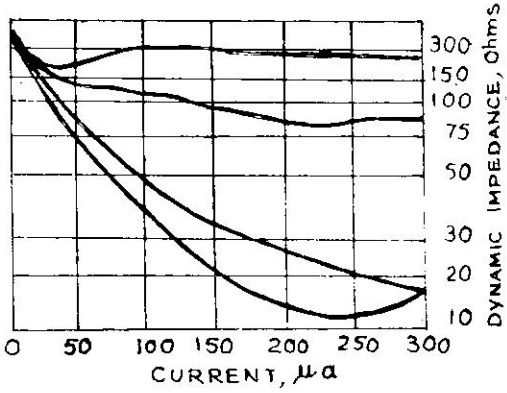
Small oven.

In conjuction with normal incoming inspection facilities, the above equipment is all that has been necessary to solve every problem encountered to date. The only major piece (over $200) of equipment purchasesd for the failure analysis laboratory has been the diode noise analyzer mentioned before. The usefulness of the noise analyzer has not been fully explored as yet, but the amount saved to date has already paid for the equipment several times over. By



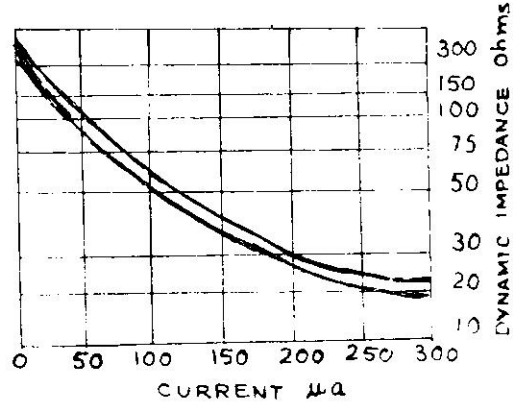
(a)

Diffused Junction Dynamic Impedance *vs* Current



(b)

Alloy Junction Dynamic Impedance *vs* Current



(c)

Planar Junction Dynamic Impedance *vs* Current

Fig. 20
Dynamic Impedance Characteristics of IN721A Diodes from Three Different Manufacturers

Table V

Ten Representative Problems Solved by Commerical Physics of Failure Laboratory

PROBLEM	CAUSE	CURE
1. Corrosion on coax delay line.	Excess catalyst in foam epoxy reacted with copper braid.	Changed to foam using a catalyst that did not affect delay line.
2. Sticking of tuning slug in polystyrene body of a variable capacitor.	Soldering temperature caused polystyrene to deform when tuning slug was not entirely within body of capacitor.	Tuning slugs were turned into body before soldering.
3. Shorting of ceramic disc capacitors.	Silver migration.	Changed to better capacitor.
4. Ceramic trimmer capacitors would not turn.	Improper curing process of epoxy moisture proofing—epoxy only hardened after capacitor had passed incoming inspection.	Capacitors were returned to supplier for replacement parts.
5. Shorted wrap and fill capacitors.	Damaged by soldering aids and irons.	Cautioned workers and added fiber glass tape wrap on capacitors.
6. Shorted zener diodes (glass envelope)	Flaking of gold epoxy paste in diode.	Changed to manufacturers not using epoxy paste in diode construction.
7. Shorted zener diodes (metal stud).	Excessive torque used in lightening diodes to chasis caused piercing of mica insuating washers.	Used torque wrench to install diodes.
8. Arcing of high voltage transformer.	Removal special coating during a cleaning process.	Chnged cleaning process.
9. Shorting of some vacuum diodes in a power supply	Occasional motorboating of an amplifier in another package.	Eliminated an unnecessary capacitor in the amplifier.
10. Low resistance in switch assembly.	Use of unauthorized flux cotaining chlorde.	Continuous education and surveillance is required to minimze this type of problem. Total elimination appears impossible as long as there are people soldering.

making only minor modifications in the diode analyzer it has been possible to investigate not only diodes but also transistors and field effect transistors. Of course, resistors and certain types of capacitors can be investigated without modifying the analyzer. It is not intended to leave the impression that all problems can be solved through the use of the noise analyzer, but our experience has been that, when carefully used to determine statistically significant differences between parts made by the same process, and the reasons for these differences determined, the noise analyzer can aid significantly in improving a product in the areas of reliability and over-all cost. Probably the biggest advantage of the noise analysis approach is that it offers a good, rapid, non-destructive method of screening out defective components.

Donot understimate the value of the camera. At first Polaroid was tried, but since then, all pictures have been taken on 35mm Kodacolor X. The cost per print—Polaroid black and white vs Kodacolor X—is about the same. The advantages of using Kodacolor are: :

1. Good reproducible colour prints are available for reports
2. High-quality slides can be made from the colour negative
3. The film appears to have a wide latitude.

The major disadvantage of Kodacolor is the time required for processing. At first it was thought that this would be a serious limitation. Because of the wide range of exposures which will yield useful pictures, the number of retakes required has been insignificant.

Component Screening

The subject of screening parts is a complex and controversial subject. The amount of part screening should be based on the results of the failure modes and effects analysis and the results of analysis on all failed parts. In this manner the screening tests, if required, can be done in the most efficient manner. The screening of integrated circuits no doubt affords the most topical example for detailed discussion.

Integrated circuits are today in about the same situation that transistors were a decade ago. The glamour has worn off, corners are being cut, marginal suppliers have moved into the filed to fill the large demands, and even reputable suppliers have several grades of circuits using the same chip design. The pendulum has begun to swing away from the perfection aura that integrated circuits had. People now are beginning to realize that it takes more than the name "integrated circuit" to build highly reliable equipment.

The amount of part screening should be based on the results of the failure modes and effects analysis and the results of analysis on all failed parts.

Every time a new device appears on the market the pendulum swings back and forth until all the myths and philosophies are tested and the device is an established item. One of the most common attitudes leading to unreliable parts is, "These parts are just as good as the top grade parts; they probably come off the same production line, and they save me about 25%". The parts probably did come off the same procuction line, as rejects, perhaps, or they could have been made by a supplier, much like the equipment manufacturer, who bought his raw material on the basis of a trade name and a 25% discount.

Integrated circuits, properly specified, screened, and handled do, in fact, produce equipment that far surpasses the reliability of equipment built using discrete components.

There has been much evidence that integrated circuits, properly specified, screened, and handled do, in fact, produce equipments that far surpasses the reliability of equipment built using discrete components. There also has been much evidence that equipment built using integrated circuits without screening, plastic encapsulated, and using "commercial grade" have had lower reliability than the electromechanical devices they were supposed to replace.

The question then becomes how does a prospective buyer or manufacturer of equipment find his way through the maze of conflicting reports. A good way of starting is to understand the basic failure modes of integrated circuits. The comprehensive Table IV shows possible failure modes for integrated circuits.

By sampling a few circuits from various manufacturers and using such techniques as step-stress testing, it is possible to find which failure modes are most prevalent from a given manufacturer. With this information available, economical screening methods can be developed to keep bad parts from being assembled into the receivers.

The previous example has been devoted to integrated circuit screening. This is not the only area where efficient screening procedures are useful. The following example concerning the screening of solid tantalum capacitors is a good illustration of an efficient approach to parts screening.

A study of the failure modes of solid tantalum capacitors revealed that more than 90% of the failures were due to breakdown of the tantalum pentoxide dielectric. The next step was to screen the capacitors using some form of power "burn-in". This was effective in removing the weaker capacitors from the lot. However, the process was relatively time consuming and costly. A detailed study of the failure mechanisms revealed that thin spots in the dielectric caused the capacitors to short. Further investigation showed that a simple dissipation measurement at a low (less than 1 volt) DC bias and 60 cps was as effective as the long time power burn-in. Now effective screening can be done in minutes for pennies instead of in hours for dollars.

In general, screening of parts is at a higher level earlier in the programme. However, if the results of the screening tests are not closely followed the testing will become inefficient. By carefully analyzing the parts failing the screening tests, more and more efficient testing can be used. Of even greater importance than the better screening techniques, is the information that is available to institute corrective action so that the total product reliability is significantly improved.

Specification for Purchase Items

The foregoing sections discussed many of the pieces of information required to write a good specification in terms of quality and reliability. For example, if the predicted reliability of a receiver has plenty of margin for a particular requirement, then items specified for that receiver can be purchased from reputable suppliers without any extra screening or testing. Also, the prediction indicates what purchased components or subassemblies contribute the most toward unreliability. Then by knowing the construction and failure modes for a particular item, economical and efficient screening or aging procedures can be added to the general part specification.

Assembled Subassemblies

The more complex subassemblies should probably have an MTBF specified together with a means for determining if the requirement is

met, the environment in which the MTBF applies, and the penalties for not meeting the specification. The mean-time-to-repair (MTTR) should also be specified along with the skill level and equipment required to meet the specified MTTR.

The use of 100 hour failure free operation before an assembled item can be accepted is generally a sound investment. Other relatively low-cost acceptance testing that has proven effective is thermal cycling, low amplitude single frequency vibration, and simple low level mechanical shock. The thermal cycling usually consists of several cycles moving equipment from a chamber at elevated temperature to one at low temperature. The low frequency vibration is usually done at a nonresonant frequency between 20 and 60 cycles per second at about a 2g. level. The mechanical shock is done at a level low enough not to cause damage to a good piece of equipment but high enough to cause weak equipment to fail. The purpose of all of these tests on assembled items is to remove early failures caused by substandard parts and poor workmanship.

Component Parts

The underlying basis to writing cost effective specifications is that parts made by the same process should have smooth, rather tight, continuous distributions of any measurable characteristic. Another important item to keep in mind is that in order to stay in business a product must be made today with existing components. The problem then is to select the best component from about half a dozen available manufacturers. The solution of this problem is attained by finding differences in component characteristics, both between manufacturers and within a sample from a given manufacturer, and then determining the reasons for the differences.

Once the technical problem of what causes the differences between components is determined, the choice of what part to use becomes one of economics. Some of the costs which must be considered in making a final selection are:

Once the technical problem of what causes the differences between components is determined, the choice of what part to use becomes one of economics.

initial cost of part;

replacement costs (both) in plant and in warranty);

cost of screening;

salvage costs for parts not passing screening;

gain or loss in sales due to improved or degraded performance.

By understanding the failure mechanisms and devising simple, low-cost acceptance criteria using physics-of-failure studies, reduction in the overall cost can be attained while improving performance. The technique of writing tougher specification often does not solve the problem while it almost always increases the cost. This situation is compounded by an apparent law which does not allow for the removal of a requirement once it has been established. There are cases where expensive screening tests were continued for over a year after a design change eliminated the need for such screening.

The reason usually given for not removing an obsolete requirement is that, "the person who established it must have thought it was necessary so why take a chance ?" Therefore, before any requirement is added to a specification, a report giving the specific need for the requirement should be referenced in the specification.

A handbook for the use of developing countries in connection with production of low-cost radio and TV Receivers should concentrate on information that would allow the manufacture of the lowest cost item that will do the job.

The International Electrotechnical Commission whose headquarters are located at 1 Varembre Street, Geneva, Switzerland has a technical committee (TG-56) that is charged with the responsibility of handling international reliability problems. Two publications that would be of interest to developing countries are:

1. Publication 319, First Edition 1969, "Presentation of Reliability Data on Electronic Components (or Parts)"

2. Publication 300, First Edition 1969, "Managerial Aspects of Reliability"

Possible Areas for UNIDO Assistance

The following discussion covers various areas where UNIDO's assistance could be useful. No attempt is made to list the items in order of importance.

Compile Publish and Distribute Reliability and Maintainability Handbook

Although there are many books on reliability and maintainability, most of these are compiled for use in highly complex military or space exploration programme where reliability is generally more important than cost. A handbook for the use by developing countries in connection with the production of low-cost radio and television receivers should concentrate on information that would allow the manufacture of the lowest cost item that will do the job.

With UNIDO's aid a useful handbook featuring such items, various part construction and the reasons for these differences, failure modes, and hints on writing efficient, economical specifications, could be compiled. Once such a handbook is compiled it should be published through the auspices of UNIDO and then distributed to the developing countries cooperating with UNIDO in producing low-cost radio and television receivers.

Interchange of Information

UNIDO could provide the much needed and important communication information channel between developed and developing countries. One method of accomplishing this is to compile a list of specialists from developed countries in the field of reliability and maintainability who could aid developing countries with their particular problem. Also a clearing house could be set up to which developing countries would apply for help in certain chronic problem areas. Through UNIDO at least a first contact with a specialist could be established.

Problems from various developing countries could be catalogued and progress on these problems could be disseminated to all the developing countries on a quarterly or semi-annual basis. This could help each of the countries from having to solve the same problems over and over again.

Regional Testing and Analysis Facilities

It would be most beneficial for each country to do as much of their own testing and analysis as possible. However, for economical reasons and lack of trained personnel, start up problems do present difficulties for developing countries. Therefore, if UNIDO could establish some

Regional testing and analysis facilities the result could prove extremely rewarding. Such a facility would train people from the developing countries in the basics of failure analysis and aid in establishing rudimentary failure analysis laboratories in each country.

Another important function that could be performed by a regional facility would be to act as a clearing house for mutual problems. It is not unlikely that many of the countries in a given region would have similar failure patterns of components due to environments peculiar to a region. By having regional facilities, the inefficiencies of solving the same problem many times could be avoided.

A regional facility could also perform testing and evaluation of new parts in a more economical fashion than each individual country.

Summary and Recommendation for Future Action

This paper has outlined many of the items that should be considered in order to produce reliable, low-cost radio and television receivers. The items discussed include:

1. Reliability Requirements
2. Reliability Prediction
3. Maintainability Consideration
4. Spare Parts Stocking
5. Component Construction
6. Failure Analysis
7. Component Screening
8. Specifications for Purchased Items.

It is recommended that under UNIDO direction, the programme outlined in this paper be expanded into a useful handbook on reliability and maintainability for developing countries. This could be accomplished by an "Ad Hoc" group slected by UNIDO from both developed and developing countries.

Other items that should be covered by an "Ad Hoc" group would be:

1. Study the feasibility of having regional test and analysis facilities.
2. Cooperate with the reliability group (TC-56) of the Electrotechnical Commission.
3. Compile a list of specialists in the field that could aid developing countries.
4. Recommend that best method of establishing two-way communications between developed and developing countries concerning reliability and maintainability.

In order to maximize the success of the UNIDO programme on the manufacture of low-cost radio and television receivers, modern reliability and maintainability disciplines must be adequately considered. The same discipline that assured a safe trip to the moon and back should aid substantially in maximizing the number of properly functioning receivers in developing countries.

REFERENCES

1. Hastings, Jr., C.: "Approximations for Digital Computers" Princeton, New Jersey; Princeton University Press, 1955, Page 144
2. G.T. Conrad, Jr., N. Newman, and A.P. Stansbury: "A Recommended Standard Resistor-Noise Tests System", Reprinted from the IRE Transactions of the Professional Group on Component Parts, Volume CP-7, Number, 3, pages 1-18, September 1960.
3. N. Newman and G.T. Conrad, Jr., "Discussion of Errors of a Recommended Standard Registor-Noise Test System", Reprinted from the IRE Transactions of the Professional Group on Component Parts, Volume CP-9, Number 4, page 180-192, December 1962.


BOSS, OUR MAINTENANCE WORK LOAD HAS INCREASED; WHAT ABOUT OUR RAISE...
VOHRA

Preventive Maintenance Schedules and Practices

HA Kress*

The increasing significance of maintenance as a cost-factor due to the increase of construction-intensity on account of rising automation in the field of machine fabrication makes a systematic and careful planning of maintenance absolutely necessary today. This planning must include both the moment of maintenance as well as the completion of the maintenance planning since its objective is the minimization of the total maintenance costs.

Unexpected failures usually occurring at the most unsuitable moments can be anticipated by preventive actions. By stating this, it is not suggested that downtime is eliminated but in certain cases it may cause less damages or costs than an accidental breakdown. The preventive actions have to be planned in advance and here the time-series of application and the size of actions have to be arranged according to the ratio of the single cost factors to the failure distribution of the aggregate. Such a layout defining time-series and size of preventive actions is called "strategy". The strategy essentially depends on the kind of the objective which is to be applied, i.e. whether

(a) the attainable profit is to be maximized by the actions

(b) the appearing costs are to be minimized or

(c) the reliability of the aggregate at fixed budget is to be maximized.

OBJECTIVES OF APPLICATION OF STRATEGIES

Maximization of Profit

The maximization of profit is the most essential objective of every entrepreneur. Therefore, the insertion of this objective function would also be desirable for the optimization of the maintenance strategies. As the profit is strongly influenced by the trade condition on the one hand, and as distribution of profits on the single machines is endangered if bottlenecks are amongst them on the other hand, the objective function of profit maximization for maintenance

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problems is not very suitable[1]. It is very seldom used in literature on maintenance[2] and shall not be discussed here either.

Minimization of Costs

With the reduction of costs of maintenance actions an indirect maximization of Profit is pursued and therefore this objective is specially suitable for the exact calculation of costs.

According to the structure of maintenance problems[3] simple cost-estimations with average costs are chosen, e.g.

$$K = Xa\ Ca + X_p\ C_p \qquad (II.1)$$

Xa or Xp gives the number of failure or the planned actions while Ca or Cp gives the average costs per failure[4], or else, all single costs per failure or preventive action are considered and summed up for the total costs.[5] Among these extremes there are, of course, many combined opinions operating more or less with average or single costs.[6]

In any case the maintenance costs will have to be divided into 3 groups in order to be able to calculate all parts and then decide whether an average account is sufficient or not.[7]

(a) downtime costs

(b) material costs

(c) personal costs.

(a) The downtime costs of a machine contain all costs which can be asigned to this machine for the period of its downtime and the increased production which could have been attained with the manufactured product from this machine. Additionally lost profits have to be considered, too. By the additional application of expediency costs, the significance of the machine may be expressed in regard to the manufactures (e.g. bottleneck machines) and thus a long waiting period for maintenance may be avoided by planning the maintenance-completion according to cost-selection.

(b) Material costs include spare-part costs or reparations of the respective spare-parts as well as costs arising from defective goods caused by machine failure.

(c) Personal costs include all costs concerning the maintenance department, directly applicable costs as well as general costs of maintenance.

The sum of all these cost-shares must be minimized. The policy essentially influences the downtime costs as well as the material costs. A suitable policy causes more downtimes, however, but less downtime expenses, because the waiting periods for service are reduced, if the standstill of an aggregate is planned in advance. The material costs for spare-parts

1. See KreB H., Untersuchungen zur Bestimmung der optimalen organisation von instandhaltungsarbeiten an Fertigungs—maschinen bei Werkstat tenfertigung anhend eines Simulations—models, Diss. TH Munchen 1968, page 87, McCall J.J., Maintenance Policies for Stochastically railing Equipment A. Sterbey, Management Science 11 (1965) page 493-513.

2. Compare Drenick R.F., Mathematical Aspects of the Reliability Problem, Journal of the Society of Industrial and Applied Mathematics 9 (1960) page 125 ff.

3. Often a simple cost-estimation is chosen in order to allow an analytic treatment of the problem.

4. Compare McCall J.J., a.a.0. page 490

5. Compare KreB H., a.a.0. page 88 ff.

6. Compare Bovaird R.L. , Characteristics of Optimal Maintenance Policies, Management Science 7(1961), page 238 ff., Kettelle J.D., Least Cost Allocation of Reliability Investment, Operations Research 10(1962), page 249 ff., McNeill J.G., Forecasting of Equpipment Maintenance, Diss. with Cambridge 1955, Lindsay G.F., Bishop A.B., Allocation of Screening Inspection Effort—a Dynamic Programming Approach; Management Science 10(1964), page 342 ff., Parson J.A., Preventive Maintenance Policy Selection, Industrial Engineering 16(1965), page 321 ff.,; Welker E.R., Relationship between Equipment Reliability, Preventive Maintenance Policy and Operating Costs, ARING Research Report No. 7, Washington 1957

7. Compare KreB. H., a.a.0., page 88 ff.

may rise; on the other hand, the occurence of defective goods is abolished, and no other parts of the machine will be damaged by the failure.[8]

Maximization of Reliability

In certain cases—especially aviation or military projects the reliability of the function of an aggregate is most important. Here no estimation in the sense of cost-consideration can be emphasised because the operational readiness of an aggregate which might determine the end of a war (e.g. use of rockets) or even human lives (transport aircraft) cannot be calculated. With very complex aggregates e.g. systems of news transmission, computers or complicated methods of fabrication, the reliability of the various aggregates is of special importance because a failure might cause extremely high costs; important informations might be lost or catastrophes caused. (Atomic reactor, chemical works, pipe-lines)

It may be convenient to manufacture the less accessible parts of even the smaller fabrication aggregates very carefully (e.g. by redundancy in order to avoid expensive repair).

The objective of maximization of reliability essentially differs from the minimization of costs. The policy in the first case does not consider a series of cost-shares, because a fundamental calculation is lacking and it endeavours to improve condition with given measures.[9] In the second case a failure of the system is purposely accepted since it is calculable, whereby only the sum of all cost-shares is minimized, i.e. the policy considers only valueable aggregates worthy of receiving careful treatment. It is, therefore, necessary to strictly distinguish between these objective functions and these models.

In order to be able to formulate the objective function the word "reliability" must still be defined. The definitions given in literature are very different.[10] The scale varies from very general definitions, like e.g. "The Reliability of a System is the probability that it can satisfactorily fulfil the required duties under certain work-conditions for a certain period of time,"[11] to exact mathematical definitions which must unconditionally be preferred. Some of the most important of these shall be described here in this context. The following concepts have to be distinguished:

(a) reliability

(b) efficiency

(c) operational readiness

(d) interval reliability.

(a) If you look at single conditions of a system at time t and they are described by a probability size X(t) with the values X_1 (t), X_2 (t)....., X_n (t) and the distribution function F (X_1, X_2,.... X_n, t), these conditions may receive a certain profit function G(x). Hereby we think of a technical rather than an

8. The following literature gives information on the composition of maintenance costs: Cziner R.M., *How to control Maintenance Costs*, Petroleum Refiner 33 (1954) page 106ff., Althoff P., Muller K.D., *Das Problem der Reparaturkosten in den USA-Chemie Ingenieur* 8(1956) page 296ff., o.V., *What should Maintenance Cost*, Factory Management —and Maintenance III (1953) page 113; o.V. *Refinery Maintenance: what it costs*, The Oil and Gas Journal 58(1960) page 100; Clapham 7 C.R., *Economic Life oj Equipment,, Operational, Research Quarterly* 8(1957) page 181ff; Kolbel H., Schulze J., Wirtschaftlichkeits *kontrolle der Instandhaltung in Chemiebetrieben.*, Zeitschrift fur Betriebswirtschaft 35 (1965) page 29ff., (Erganzungsheft); Margo B.A., *A New System for Maintenance Control.* Petroleum Refiner 36 (1957) page 235 and 6 page 171; Lude W.S., *Six Steps to Equipment Cost*, Petroleum Refiner 38 (1959) page 139; Pretzger A.A.B., *The Setting of Maintenance Tolerance Limits*, Industrial Engineering 14(1963) page 80ff; Rachal E.A., Dougher W.E., *Reports for Maintenance Cost Control* Petroleum Refiner 40(1961) 7, page 165; Teel H.L., Use *Data Processing to Control Maintenance Costs*, Petroleum Refiner 42(1963) 1, page 115.

9. Compare Barlow R.E., Proschen F., Hunter C.L., Mathematical Theory of Reliability, New York 1965—page V.

10. Compare Barlow R.E., Proschan F., Hunter C.L. a.a.O page 5; Drenick R.F., a.a.O. page 125.

11. compare Barlow R.E., a.a.O. page 6

economic profit; e.g. the probability that the aggregate does not fail. The reliability R(t) is then given by the expected value of this profit-function at moment.[12]

$$R(t)=E\{g[X(t)]\} = \int_{x_i=x_n}^{X_n} g\,[X(t)]dF(X_i) \qquad (II.2)$$

(b) The efficiency Eff_t[13] is, contrary to the reliability R(t), independent of the time. It has the value

$$Eff_t=\frac{1}{T}\int_0^T R(t)dF(t) \qquad (II.3)$$

and here F(t) represents the probability that the system is ready to operate at a certain time. Eff_t being the main value of the reliability, represnts the expected time of operation in the interval T, allowing maintenance actions as they can easily be considered by changing R(t) and F(t).

(c) The operational readiness[14] expresses the probability that a system is ready to operate at any time. This value is influenced by the realiability and possible maintenance actions. It is calculated out of the efficiency of a system in case that the time interval T increases infinitely. The simple conception that probability is expressable by the number of favourable cases to the number of possible cases (Application of the counting rule[15] easily makes this diversion clear.

$$P_{t,p}=\lim_{t\to\infty}\frac{\Lambda}{t}\int_0^t R(t)\,dF(t) \qquad (II.4)$$

(d) The reliability of intervals[16] is the probability of the readiness of a system within an interval beginning at moment T and lasting at least t_o time units. Until T maintenance actions are allowed. Let it be X (t)=1 or o, if the system works or has failed at moment t. Then it has the value

$$R(t_o,T)=W[X(t)=1,T\leqslant t\leqslant T+t_o] \qquad (II.5)$$

This value cannot be explicitly calculated as it depends very much on the events within interval O to T and hereby reflects the policy.

Besides these values there are of course a number of other definitions which, however, may be diverted mostly from these concepts. So we find e.g. the strategic reliability[17], i.e. the probability of using a machine at any interval[18] from the interval reliability with the threshold crossing $T\to\infty$. No further special definitions[19] shall be given here.

12. compare Barlow R.E., Hunter L.C., *Mathematical Models for System Reliability*, Sylvania Technologist 13(1960) page 16ff., especially page 17.

13. compare Barlow R.E., u.a., a.a.O. page 7

14 see Bhashyam N., Jaiswal N.K.' *Operational Readiness of a Complex System*, Opsearch 1 (1964), page 13ff.; Colemann J. J., Abrams I.J., *Mathematical Model for Operational Readiness*. Operations Research 10 (1962), page126ff.

15. see Heinhold J., Gaede K.K., page 21

16. see Barlow R.E., Hunter L.C., *Reliability Analysis of a one unit System*, Operations Research 9 (1961) page 200; Flehinger B.J., *A General Model for the Reliability Analysis Under Various Preventive Maintenance Policies*, Annals of Mathematical Statistics 33 (1962), page 137 ff.; Pugh E.L., *The Best Estimation of Reliability in the Exponential Case*, Operations Research 11(1963) page 57ff.

17. see Truelove A.J., Strategic Reliability and Preventive Maintenance Operations Research 9(1961) page 22ff.

18. Barlow and Hunter call this function a Limiting Interval Reliability; compare Barlow R.E.-page 8

19. see Weiss G.H., On the Theory of Replacement of Machinery with a Random Failure Time, U.S. Naval Ordnance Laboratory Report, White Oaks, 0. J.; Corcoran W.J., Weingarten H., Zelma P.W., Estimating Reliability After Corrective Action, Management Science 10(1964) page 786ff.

These measured numbers may be influenced by the separate preventive actions. It is the objective to choose the strategy in such a way that the given costs maximize the measured values or that the costs are minimized by the given limits (minimum demand).

STRATEGIES AND MODELS OF PREVENTIVE MAINTENANCE

Suppositions for Intelligent Application of Preventive Actions

The maintenance costs can be reduced, if either the expenses per action or the number of actions or both are reduced. Smaller savings are achieved, if the influence of the one factor is strongly reduced by raising the other one. In maintenance, these factors are mainly represented by downtime costs[20] which strongly vary between preventive action and *reparation* of failure, and by the number of downtimes which is essentially determined by the failure distribution. It is impossible to reduce both factors simultaneously. Only redundancy could influence failure distribution. The redundancy costs, however, would strongly raise the cost-balance, even if only insignificant improvements are desired. Therefore the rebundancy is reserved for those special cases where rather the reliability should be maximized than costs minimized, because downtime—or failure costs are incomparably higher than the total costs of an aggregate, or because failure costs are not at all or not easily calculable. To begin with, it may be attempted thus to reduce downtime costs without preventive actions. This is achieved by shortening the reparation periods or reducing downtime costs per time unit.

The second value cannot be influenced as it is preceded by the production; the first effect could be attained by an increase of personnel. But this action again raises the expenses. It is possible, however, to reduce the downtime costs per time unit by means of optimum deployment

Maintenance costs can be reduced if either the expenses per action or the number of actions or both are reduced.

of the maintenance crew to such an extent that a minimum of total costs arises which depends on the ratio of downtime costs to personal costs. The next step, screening these problems covers the material expense. High material costs arise from breakdowns of single machine parts which involve complex mechanical systems. Often such involvements are unnecessary—an objective construction[21] considering the failure conditions, too, may help to avoid high material costs and also high downtime costs due to unnecessarily high periods of repair of the affected series of parts. Starting from one of such best constructed aggregates the cost may be further reduced under certain conditions by raising the amount of downtimes—i.e. by preventive actions—simply because thereby the downtime costs are reduced. The time when this occurs will be discussed as follows.

To begin with, a table shall be given here, shortly stating the result of the following commentary.

First of all this model shows the rate of failure r(t) in its periodic development as a substitute of the failure distribution. As already shown, the periodic development of the failure rate is a measure of the change of the failure probability over a period of time. Therefore,

20 The personnel—and material costs are usually very low in comparison to the downtime costs. Although they shall still be considered in the later exposition, they shall be neglected for the time being.

21 The value-analysis as a strongly growing division in our days complies with this demand with regard to every possible objective.

Failure rate	Cost ratio $C_p/C_a = A$	$C_p/C_a < 1$
$\frac{d_r(t)}{dt} \leqslant 0$	no PH	no PH
$\frac{d_r(t)}{dt} > 0$	no PH	Proventive Maintenance

Fig. 1
Determinant Table for the execution of Preventive Maintenance

it is easily conceivable that a preventive action, i.e. a periodic pre-shift of a failure, is put on only if this failure can thereby be avoided or stated more precisely and if the probability of failure is decreased by the preventive actions.[22]

The second criterion of the ratio of average costs for a planned action (or preventive action) C_p to the average costs of a failure reparation C_a still needs examination. If more downtimes are caused by preventive actions[23] one should be sure that then the costs per downtime are essentially less in order to reach a minimum. It is, therefore, necessary in each case to examine how the costs of a preventive action in relation to a failure reparation can be reduced. Generally the following reasons are the determinants:

(a) The waiting time of the machine for reparation in cases of preventive maintenance is not important as the actions can be planned while the failure usually happens when the maintenance personnel is engaged elsewhere.

(b) The period of repair is shorter, too, as the replaceable parts are exactly known while the defects of a failure have to be searched for first. Other parts are usually involved, too, and these are also replaceable.

(c) For the same reason the material costs are usually higher.

(d) The personal costs rise too, because there is more work and more workers are required during failures.

In special cases however, it may by all means happen that the costs C_p are higher than C_a, perhaps because the downtime costs are very high so that with less technical complexity of the machine parts there are no essential cost differences per time unit between prevention and failure, whereby the greater amount of downtimes may have a negative result, if they are prevented. In majority of the cases, however, especially those with technical equipment, the application of planned prevention actions brings the expected cost advantage. It is important, however, to find the suitable strategy which is to be optimized in order to totally scoop the cost advantage.

This strategy is then applied to an object of which the structure still has to be screened in the respective cases as it will surely be of great importance whether the strategy is used per part of machine, per part-set per machine or per machine-set. In order to describe this object more precisely the concept "maintenance unit" was formed, which is to determine the application area of the strategy. It cannot be described here in details as this maintenance unit very much varies in literature and it is more appropriate to leave a specially favourable choice of this maintenance unit to the specific problem of practice.

Criteria for Division of Maintenance

As described before, the maintenance policies can be divided according to several viewpoints. Fundamentally we here find the same criteria for cost-and reliability-models, even if the problems with regard to the executed main

22 Preventive actions seldom pay with electronic parts which often at first show failing—and when rising failure rates due to cauterization processes, because the prevention causes costs only, without changing the failure situation, or even aggravating it.

23 As preventive actions are applied before the failure the mean operations interval of the machine is shortened and thus the amount of downtimes per time unit increases.

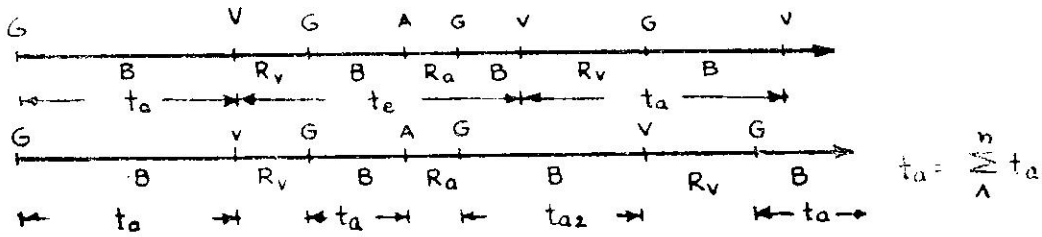


Fig. 2

Periodic Strategies

ınce actions (e.g. inspection, reparation, ıcement) are partly considered differently:

(a) time lapse

(b) knowledge of condition

(c) distribution

(d) complexity of machine

(e) reliability of information.

These criteria are explained more precisely in the following:

Time –Series of Actions

Preventive measures may be applied periodically or sequentially with regard to their succession of time. A periodic strategy is based on the fact that specific moments of preventive ons during the life time of a machine must e repeated in rgular time intervals. On the ıtrary a sequential strategy gives sequences differing periods or calculates these during he utilization time of the machine.

The period between the preventive actions of machine may be based on various moments what the periodic strategy is concerned. Prin- ly a machine is maintained preventively the period has passed or if it has previously ailed.

Figure 2, shows a time-axis which is to demonstrate a sector of the durability of a machine. This machine is in use (B), fails (A), is repaired (R_a), is set going again (G), is closed down for prevention (V), and this is carried out. The difference between the time-axes ($_a$) and ($_b$) is that by ($_a$) we mean the period t_p between the initial points of the respective preventive measures, while ($_b$) is the period determined by the sole operation time of the machine between two downtimes. Thus one discerns two strategies:

(a) exact periodic strategy

(b) periodic strategy after operation time.

The exact periodic strategy is optimum only, if the downtime periods of the machine in relation to the periods are short, because only then it can be guaranteed that the carrying capacity and durability of the machine parts are uniformly utilized. If one allows big oscillations of the duration time of the parts, or if one forces them by an exact periodic strategy, material reserves will not be fully utilized which naturally increases the maintenance costs. The periodic strategy, however, allows a possibility to fully utilize the operation pauses for the maintenance which is particularly advantageous, if

(a) the optimum period is not to be essentially changed in order to fall into the operation pauses,

(b) the optimum above the period runs flat (see fig. 3)

(c) the fabrication capacity is fully utilized.

The optimum period may then be changed within the limits which arise due to the avoidance of downtime costs $\triangle$Ks during the operation pause. If one succeeds thus to change the period within $t_u \ldots\ldots t_o$, s_o that it coincides with the period of operation pause, the total costs may still be reduced.

This is not possible with the periodic strategy after operation time, as the interval between two planned downtimes is obtained as a sum of reparation times, waiting times for reparation and operation time. The interval is a contingent value because only the operation period can be given. Yet this strategy is normally to be preferred to the exact periodic strategy, although it causes slightly greater planning expenses because a registration of operation hours has to be kept for every aggregate. As, however, the waiting—and reparation times are usually not to be neglected and additionally only few plants will carry out reparation during night shifts, if they operate on a one-shift production basis (operation pauses!) thus also causing increased personal costs, the slight extra costs of management will be acceptable and the exact periodic strategy will be limited to special cases (e.g. at very high downtime costs).

The sequential strategies also carry out preventive measures after certain time intervals and immediately repair failures, if they occur. The difference in relation to the periodic strategy consists of the shaping of the interval for the prevention. For the sequential strategy a sequence of time intervals is supposed or calculated in the course of utilization. One hereby assumes that with increase of age a machine changes its failure condition because the general idea of a repaired machine being as good as new proves to be an approximation in practice. Accordingly the time interval will be again calculated after every failure or after each preventive action. Here one considers the experiences

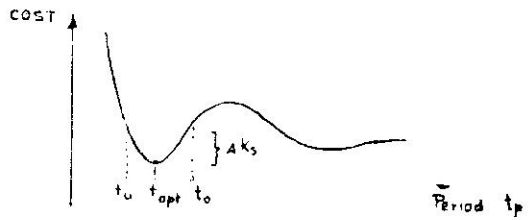


Fig. 3

Cost Pattern above the period of a Periodic Strategy

of known data and the remaining interval utilization of the machine. The objective is th minimization of the total costs over the remaining period of utilization. The method shall not described in details here[24] as it is very costl and has little significance on the other hand It can be shown that the sequential strate alone is indeed optimum for final utiliza periods of machine, that the deviation, however of an optimum periodic strategy from this genera optimum is only very slight.[25]

The series of interval, however, may also accidental. In he first instance there is th possibility to use Monte Carlo methods to generate a given failure distribution. They a lixed after a corresponding diminution by means of a factor smaller than 1 as preventive interval-series. As, however, the contingency of such number series between contingent numbers and effective failure moments may cause great differences, this method seems to be unsuitable in practice. The contingency of such interv however, may be a result of the fact that originally periodic pre-planned preventi measure cannot be carried out because at preventive moment there is no available worke so that the machine, of course, continues tion until it fails or until it may be controlled.

24 see Barlow R.E., Froschan F., *Planned ment*, page 68

25 see KreB H., page 38

26 see KreB H., page 43ff., Kre B speaks of a periodic operating time strategy; in the strict sense of classification this strategy has to be defined as sequential strategy with incidental periods.

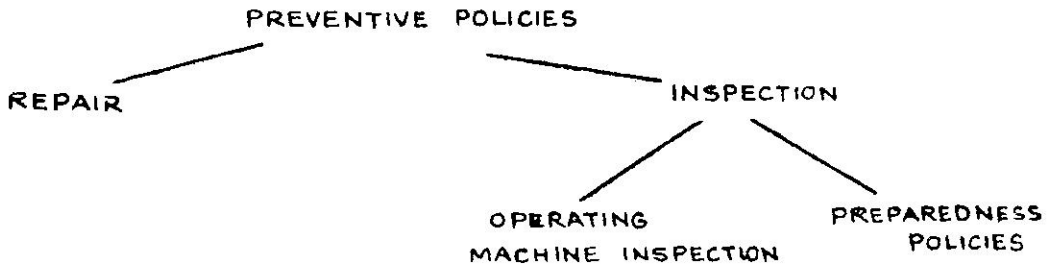


Fig. 4

Division of Preventive Stategies in view of variable known degree of the condition of a machine

this case the series of the preventive intervals 'omatically results in the contingent sequence, ı though the measures were planned periodi-/. Similarly various other application orien- sequential strategies may be suggested which certainly preferable to pure periodic stra- gies when specific cases are concerned.

ıown Degree of Condition of a Machine

Thus far we have always regarded the condi- ɔn of a machine as "good" or "failed". This not always the case, however, as many parts a machine do not cause the breakdown of a ne, if they are defective, even though they ve a negative influence of the production ıtcome. Thus it may happen that one part the machine breaks down unnoticed, with consequence of a gradual-neither noticeable- vation or even unnoticed defective goods. example is the only occasionally controlled belt, where a tap inside a workpiece ght break off and the defective result will be noticed at final control. Every work- following this one is to be regarded defec- ve, sometimes causing high damages of recon- oning afterwards. Such examples and many ıers may surely be avoided by a suitable rategy. As the determination of the condition s always connected with an inspection, such rategies may also be called "inspection strate- " Contrary to this are the reparation stra- not requiring any inspection as the condi- is known. These inspection strategies can gain be divided into strategies for operating ggregates and into those applying to aggregates ready for insertion at a certain moment—the readiness strategies.[27]

The division of the criterion already shows that the choice of a strategy according to this view point depends on a specific problem, i.e. one has no possibility of free judgement whether this or that kind of strategy would prove more appropriate. Given problems will always easily show, whether the condition is recognizable or not.

Number of Possible Conditions of an Aggregate

If we expand the case mentioned in the previous paragraph into another direction, we have aggregates which, besides the two extremes "good" and "failed", show up various steps or a continuous course of the quality of a condition. In a strict sense this will almost always be the case as, in most of the practical examples, a failure is caused by wear, whatever the nature of wear may be, and such appearances of wear seldom develop by leaps. (e.g. overburdening leading to breakdown, overcharging electric apparatus). Such pure contingent failures may, however, be avoided by means of preventive strategies, too. Inspite of the frequent existence of a continuous course of a condition one finds that there will be no affect of the contingent diminution on the output of an aggregate—this aggregate is to be called "good"—until a certain limit is passed below whereby the aggregate

27 see KreB H., page 35

fails and receives the condition "failed". A typical example is an incandescent bulb of which the glowing filament is continuously thinned due to evaporation without affecting the function until it breaks and the lamp has to be replaced. Most of the technical aggregates react in this way so that in many instances two conditions are sufficient. With other examples it is more favourable, however, to distinguish among several conditions if different demands are to be expected of various aggregates.[23]

Here one speaks of multi-staged strategies contrary to single-staged strategies which only allow two conditions. The multi-staged strategies usually apply the theory of Markov Chains in order to be able to describe the various steps.[29] The transition from one quality-step to the next is here described by probabilities. The strategy itself is multi-staged because for all the condition grades rules of optimum proceeding must be found which, however, have a reciProcal influence.

The problem-setting strongly influences the application of a single or multi-staged strategy so that here, too, a judgement of strategies is impossible. It may be stated, however, that in the first instance one should always try to get along with a simple strategy as multi-staged strategies are expensive in their administration and thus increase the management costs which again might absorb the advantage of their application.

Reciprocal Dependence of Aggregates

If one speaks of the dependence of aggregates or machines, a distinction must be made between:

(a) the statistical dependence

(b) economic dependence.

(a) The statistical technical or stochasti dependence of aggregates proves i mutual technical and complex li by the injurious effect of a failure of machine or of a machine part on t operating efficiency of another aggre or aggregate part. As then the fai distributions of both aggregates statistically dependent, these interdepe dent situation must be considered w determining the strategies of such a gates or rather while choosing the mai tenance unit. The problem may simplified by choosing the total comple of such dependent parts as the nance unit.[30]

(b) The economic dependence must strictly discerned from the above menti ned paragraph. It is limited to tho cases proving to have a cheaper r nance of a part set as a whole, than separate maintenance of parts belo ging to this set.[31] This happens if pair costs in times of refurnish are rel tively high and it would pay to carryo maintenance by exchanging or repairin a single part together with other pa in order to prevent higher downtim costs.[32]

With the increasing reciprocal depende of machines it will be necessary to consi whether the experienced downtime of a machin or another preventive action does suggest

28 e.g. tyres for tractors may be classified in condition grades according to profile depth. New tyres are only for agricultural work and worn tyres for transport.

29 compare e.g. Kolesar P., Minimum Cost Replacement under Markovian Deterioration, Management Science 12 (1966), pp. 694

30 This thought underlines the more recent and wing tendency towards the exchange of whole construcuo groups of machine parts (e.g. exchange engine at a bile repair) which more and more substitutes the of single parts. Hereby the repair of the failed part all other affected parts can be brought to a degree "as good as new" as all damages can be done calmly.

31 see McCall J. J., page 501

32 Typical examples are general overhauls of veyor belts, chemical plants etc.

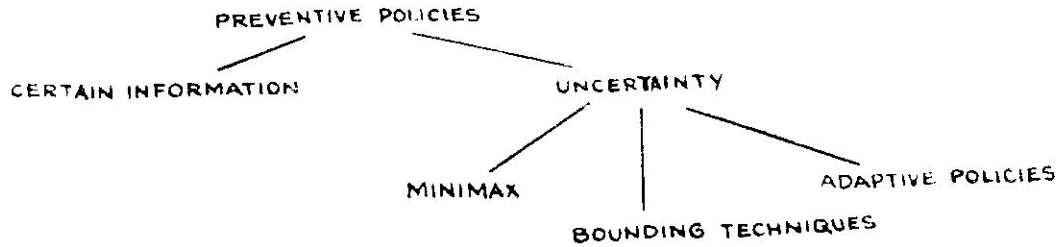


Fig. 5

Division of Strategies according to degree of reliability of information on failure distribution

preventive maintenance of other machines in order to avoid further downtimes or even failures. Here one speaks of opportunistic strategies in opposition to simple strategies. An important problem must here be considered. It is not at all easy to determine such "opportunistic" parts. A cost optimum exists here, but due to the many possibilities of combinations with several machines an attainable calculation would be very costly.

Only a particular case can determine the application of an opportunistic or a simple strategy. Opportunistic strategies are very different. It is hard to find such a normed or typical strategy. Consequently, the next step has to be determind by a simple cost comparison of optimum strategies of both cases.

The Reliability of Information on Failure Distribution

Thus far we supposed that the failure distribution was known. Only few practical cases submit this. Reality provides very few dates necessary to generate the failure distribution. Correspondingly various strategies have been developed in literature which, according to the degree of uncertainty (i.e. according to the value of existing dates) shall guarantee optimum ways of proceedings. A more precise inspection of these strategies and models at uncertainty shows, that in a strict sense no new kinds of strategies are revealed here rather than methods of calculation of how to obtain estimation values for the failure distributions from unreliable information. Of course these proceedings are usually so closely connected with the applied strategies that we prefer to only touch the proceedings here briefly, while the comments together whith the corresponding models will be added in a later chapter.[33] If one wishes to agree with the concept given in literature, the result will be the structure of Fig. 5.

The following is a brief description of the processes:

(*a*) *Minimax Strategies*

It attempts to minimize the expected maximum costs by proposing any strategy. As there is no report on experiences concerning the failure distribution, we come to the trivial conclusion to do nothing in the case of reparation policies, i.e. to only repair failures. This strategy has significance only with problems of readiness when seeking the optimum inspection strategy in order to prevent failed parts from blocking the part-stock thus causing unnecessary expenses.

(*b*) *Bounding Techniques*

Based on spot-checks of failure moments (sporadic measurements) this procedure endavours to find limits for the failure distribution since the kind of distribution is unknown. Estimates of the expected value and extent of scatter of such distributions are

33 see paragraph 'Cost Models'

With the increasing reciprocal dependence of machines it will be necessay to consider whether the experienced downtime or another preventive action does suggest the preventive maintenance of other machines.

formed from measurement results of the spot-check and by means of laws of statistics, of the evaluations of the upper and lower bounds of failure distribution are proposed. Very evidently the procedure only aims at the development of the failure distribution based on existing dates.

(c) *Adaptive Strategies*

Starting from the kind of failure distribution provided that it is known the parameters are estimated from few values. As new dates and experiences can be collected in the course of machine application, it is obvious to immediately use every date for the improvement of the parameters thus very quickly achieving an adaption of the original roughly estimated parameters to the values of the actual distribution. This procedure guarantees the best success at uncertainty of information, because it continually works out available information, thus reflecting the actual dates and conditions with low expenses—better than every estimation.

Models in Particular

It has already been mentioned that the particular strategies are strongly interwoven among themselves. Many authors have forced developments, compared strategies and unrolled entire maintenance models with built-in and often hardly separable strategies. As the particular criteria are often all or sometimes only separately applicable to the strategies, we here attempt to present these models of literature in a simplified total structure[34] in order to define the actual position in the field of strategy research.

Cost Models

The most suitable division criterion is given by the objective function. Minimum costs are distinguished so clearly from maximum reliability that a covering of the problems will not be achieved. The reliability models, however, also deal with costs but these costs are independent variables or dates. The costs here are dependent variables and objectives in regard to their minimisation.

Although a certain inconsequence cannot be avoided, the division pattern of Fig. 6 is to be applied to these cost models. It shows a compromise between the total number of possibilities of all criteria and the merely incomplete existence of strategies touching these criteria.

Cost Models at Reliable Information on Failure Distribution

Reparation Models—In the case of repair strategies there is a difference above all between preventive reparation and reparation at failure. A machine failure, will of course be required as quick as possible and according to the organized maintenance (that is a question of availability of personnel and equipment). As we shall realize later it is the size of the operations here which is of importance and not the moment. In this connection the concept "preventive repair" is not to be applied only to reparation processes. The action comprises maintenance proceedures as well as replacements of parts. Here the problem is determined once by optimum planning of moments and also by the size of actions of course.

34 Logically only the essential and fundamental models of maintenance strategies can be discussed here. Many application-oriented strategies which often developed from slight changes of these basical strategies are not mentioned here unless by data of literature.

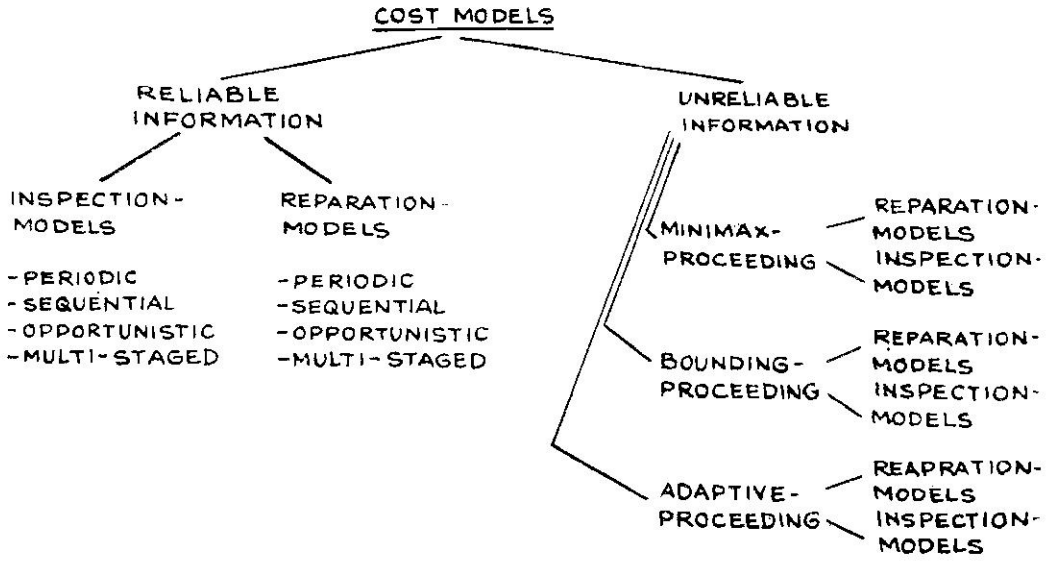


Fig. 6
Division of Cost Models

Periodic Strategies—Periodic strategies are found very often. A great deal of models could be mentioned here. The strategy which suggests a preventive measure at fixed moments, thereby removing failures appearing in the meantime, is the simplest strategy and therefore particularly suitable for practical objectives of application, above all with workshops using simple machines. Some typical examples shall here be quoted from rich sources of literature.[35]

(a) Cox Model with Exact Periods of Time—A unit is repaired in constant periods t_b, $2t_b$, ...independent of the duration of service in this time. Should it fail during the period, it will also be repaired. The average costs C_b are calculated per time unit.

$$C_b = \frac{c_p + c_a H_o(t_b)}{t_b} \qquad (11.6)$$

C_p respectively C_a represent the costs per planned or else per failure dependent reparation. $H_o(t_b)$ is the expected amount of failures in the interval o .....t_b and is termed "Renewal function". This function is given by a multistaged extremely complicated integral as function of t_b and is calculated from the failure distribution of the unit.

35 see Barlow R E., Proschan F., page 63ff., Brender D.M. *The Statistical Dynamics of Preventive Replacement,* WESCOB Convention Record 1959 Cox D.R. Smith W.L. *On the Super position of Processes,* Biometrica 40 (1953) page 1ff. Kamins W. *Determining Checkout Intervals for Ssytems to Random Failures* Rand Corp. 1960 RM—2578 McCall J.J., *Solution of a Simple Overhaul Model,* Rand Corp. 1962, RM-2989 PR., McCall J.J., *Maintenance Policies..,* page 493ff., Morse P.M., Queiles, *Inventories add Maintenance,* New York 1958, Savage F.R., *Cycling,* Naval Research Logistics Quarterly 3 (1956) page 163ff., Weller E.L., Bradley O.E., *A Model for Scheduling Maintenance Utilizing Measures of Equipment Performance,* ARING Corp. Washington 1959 No. 8, White D.J., *Optimum Revision Periods* International Journal of Production Research 1 (1961) page 44ff. These data are by no means complete as the amount of such models is incalculably big.

The objective of the model is to define an optimum period t_{popt} which is derived from $dC_b/dt_b = 0$.

(b) THE COX[36] MODEL WITH RUNNING TIME PERIODS—An aggregate is always repaired at the moment it fails or if since the last reparation (immaterial whether prevention or failure) a certain operation time t_e has passed without a failure. The mean costs per time unit which are to be minimized are given from

$$C_e = \frac{c_p\,(c_p - c_a) \mp (t_e)}{t_e \int_0 [A \cdots \mp(t)]\,dt} \qquad (11.7)$$

with F (t) representing the failure distribution of the aggregate. The optimum period t_e may be derived from $dC_e/dt_e - t_e O$.

(c) THE MODEL OF BARLOW AND HUNTER 37—By briefly applying the same strategies of constant running-time periods like in paragraph(b) this model shows that the optimum period t_o justifies the division.

$$q(to) \int_0^{to} \left[1 - F(t) \right] dt - F(to) = Cp/(Ca - Cp) \qquad (II.8)$$

q(to) is the degree of failure of the distribution; Ca Cp respectively are the reparation costs at failure or at prevention. This result corresponds with that of Cox even though it was first found by using a different time function, namely the determination of maximum availability $Eff T \to \infty$ (compare equation II.3). Therefore this model is also useful for reliability inspections and is thus superior to the model of Cox.

(d) THE COX MODEL WITH IDLE TIMES OF THE MACHINE—In model (a) it may occur that a part which has just been replaced after failure and which is still new will again be replaced due to consideration of a preventive reparation which is to consist of a replacement of parts in our case. In such cases it may be of advantage not to repair the machine at breakdown, if a preventive action will be performed soon.[38] Thus the part will be replaced at moments tb, 2tb .....Should it fail within the r—period in an interval td before the termination of this period, that is in the interval r tb—td to rtb, the part will not be replaced. The mean costs may here be determined as:

$$C_d = \frac{1}{t_b} \left\{ C_p + C_a \mu_a\,(t_p - t_d) + \int_0^{t_d} (C_i - C_i\,t) \right.$$
$$\left. h_a(t_b - t) \left[1 - F(t) \right] dt \right\} \qquad (II.9)$$

Hereby C_r respectively C_i is the share of the fixed or variable costs for the failure period of length t, $h_a\,(t_b\text{-}t)$ is the coefficient of the renewal function $H_a(t_b - t)$ according to $t_a t$ retained tb. Equation (II.9) shows at a certain value t_b an optimum value t_d from $dC_d/dt_d = o$. If one realizes the procedure from model a) and model b) for various values t_b, it is possible to obtain the best combination (t_b, t_d).

(e) OTHER MODELS—Some other models are still to be mentioned here which treat the key sectors of periodic strategies. To begin with we refer to another model of Cox who tries to make use of the wear of parts for their replacement criterion. This proceeding, however, is unreal, because it

36 Compare Cox R., Renewal Theory, London—New York 1961

37 See Barlow R., Hunter L., Optimum Preventive Maintenance Policies, Operations Research 8 (1960), page 90 ff.

38 When closing transistor tubes consisting of two glass tubes a melting process is applied in a machine with 20 parallel incandescent spirals. Should a spiral fail it will be replaced only, if there will be no preventive replacement of all spirals in the near future because otherwise a higher charge of the other spirals is caused. If a prevention is planned within a short time however, the process will be continued with 19 spirals in order to prevent unnecessary downtime costs, material costs and times of refurnish.

might be very difficult in practice to estimate probabilities describing the change-over of the condition "good" to another condition. Only few cases allow experiments on account of which such probabilities may be fundamentally defined. At the same time Terborgh, Rifas and Eisen/Leibowitz developed models optimizing the renewal of entire aggregates depending on the appearing maintenance costs and other costs (Return on Investment etc.). Such models are, therefore, of mere secondary interest, because the replacement of entire aggregate is less decided by viewpoint of replacement theory than by those of investment theory.

Sequential Reparation Strategies—In practice and literature sequential maintenance strategies have shown little significance. In relation to the periodic strategy it requires much administration expenses. Barlow and Proschan worked out a comparison of these strategies. Although they established that the sequential strategy is superior to the periodic strategy with regard to final durability of machines, these improvements would cause maximum 1% of the maintenance costs. The calculation procedures of such a programme alone would affect its improvements.

The procedure of Barlow and Proschan is very complicated and because of its unimportance it shall not be mentioned here.

Opportunistic Strategies—Opportunistic strategies are of great importance for multi-furnished aggregates. The intention to decrease downtime costs by saving refurnishing-time is striking inspite of great difficulty of realization and higher material costs. The difficulty consists in the lack of an impartial actual limit, prescribing the planned size of the preventively treated parts. The only answer here would be a definition of a limit of the failure-probability beyond which a part shall be treated along with the *reparation* of another. In a complex aggregate (machine, conveyor-belt) all such endangered parts are now to be processed. The cause requires certain pondering, too. Several possibilities are relevant:

(a) Failure of a part
(b) Amount of endangered parts
(c) Particularly high degree of endangering of parts.

To utilize the failure of one part by preventively maintaining others is very evident, and this is the basis of opportunistic strategies. Of course an optimum defined amount of parts exceeding an optimum defined limit of failure-probability may also lead to downtimes. In this case the costs may be less than in the previous case, because the damage costs caused by this failure are to be estimated very high. The third case is somewhere between these extremes—but it also proves that such damages may often be higher than additional downtimes.

Even if the reason for the application of an opportunistic strategy is known, it is necessary to define the optimum proceeding regarding several parts, i.e. the optimum number of the parts to be maintained preventively and the optimum limit of failure possibility. It is very obvious that this procedure is a very complex problem. Therefore, literature only deals with models of very special assumptions (like the joint maintenance of two parts.).

(a) A Model with Two Units and Two Conditions—The aggregate is to consist of two machines 1 and 2, with the possible conditions "good" and "failed". A failed unit is repaired. Failures of each machine cause the breakdown of the specific aggregate. Every machine may be repaired separately. A strategy is pursued which minimizes the expected value represents

$$E\left(\sum_{o}^{\infty} a^{t}\ \varphi_{i}\right)_{i} \qquad 0 < a < 1 \tag{II.10}$$

whereby

$$\varphi_{i} = (C_1, C_2, C_{12}, C_1 + C_p, C_2 + C_p \text{ or } C_{12} + C_p) \tag{II.11}$$

a contingent value which can take up the values in equation (II.11) at moment t. Here C_1, C_2 or C_{12} are the the costs of the preventive actions for machines 1, 2 or for a joint prevention, and C_p are the costs arising on account of the failure of a machine. The anticipation-value in equation (II.10.) then gives the expected discounted costs at the actual moment. The moments t depend on the failure distribution of the machine. The minimization of E from equation (II.10) is solvable in two cases:

a_1) If one of the failure rates e.g. r2 is constant, the machine 2 will only be repaired at failure.[39] Thus a strategy has to be developed only for machine 1. It can be shown that the following strategies are optimum here:[40]

—if $t<n$, repair machine 1 at failure

—if $n \leqslant t < N$, repair machine 1 at failure and at failure of machine 2

—if $N \leqslant t$, repair machine 1 without delay—preventively.

This strategy has value only if C_1+C_2 C_{12} at border-line case $C_1+C_{12}=C_{12}$ is $n=N$, i.e. the result is a periodic strategy. The parameters n,N are non-negative whole numbers (whereby $n \leqslant N$), which are obtained by mini-mization of equation (II.10) as E represents $E=f_1$ (n,N, r_1, r_2). This procedure of calculation is rather spaceous and will therefore be skipped.

a_2) If the failure costs are given with $C_p=O$, the problem is also solvable with r_1 ; $r_2=$ const.[41] Although no failure costs are saveable on account of prevention, it will pay here to replace both machines together in order to prevent refurnish costs, because $C_1+C_2>C_{12}$. The following strategy proves to be optimum:

—if 1 fails, it will only be repaired, if the age of 2 is $t_2 \angle n_2$, and both, if the age is $t_2 \geqq n_2$.

—The procedure is analogous at failure of machine 2, whereby t_1 is compared with n_1.

The calculation of n_1 and n_2 is again derived from equation (II.10) the value again being $E=f_2$ $(n_1, n_2 r_1, r_2)$.

An expansion of the model with M machines at constant failure rate and 1 machine with increasing failure rate has been developed by Jorgenson and Radner.[42] Here a strategy is formed with M+1 parameters which are calculated by means of dynamic programming. This model, however, is very costly already.

(*b*) *The Reparation of Whole Machine-Groups*

If the failure rates of several mechine-parts are all known, and if the costs of individual and groupwise reaprations of such machines are calculable, a model of Rifas may be applied. This model was developed for the case of reparation consisting of a replacement of parts. The strategy advises to change all parts separately, should they fail within a certain period, and to preventively replace all parts at the end of a period. This sirategy is based on the opinion that group replacement may avoid refurnish costs. An optimum interval is calculated. The given costs at the end of interim periods-determine the necessity of a group replace ment. In this way the replacement interval is built up stepwise. The criterion consists of the mean costs per time unit.

$$K(t)/_t=(NC_1+C_2 \sum_{1}^{t-1} X_a(i))/t \qquad \text{(II.12)}$$

39 see paragraph 2.1

40 see McCall J. J. page 493 ff.

41 see Noonan G. Optimum Preventive Maintenance Policies when Immediate Detection of Failure is Uncertain Operations Research 10(1962)—page 70 ff.

42 Radner R., Jorgenson D.W. Opportunistic Replacement of a Single Part in the Presence of Several Monitored Parts Management Science 10(1963)—page 70ff.

It is to be with C_1 or C_2 costs per part at group replacement or at individual replacement, X_a (i) as the number of anticipated failures in the i—interim period, N as the number of parts and t as the number of the considered interim periods. In the optimum point, i.e. t=to, the difference of the mean costs of the previous interval must be negative while it must be positive to the following interval. i.e.

$$\frac{K(t_o)}{t_o} - \frac{K(t_o-\Lambda)}{t_o-\Lambda} < 0 < \frac{K(t_o+\Lambda)}{t_o+\Lambda} - \frac{K(t_o)}{t_o} \qquad \text{(II.13)}$$

with equation (II.12) it thus gives

$$C_2X_a(t_n) > \frac{NC\Lambda + C_2\Sigma\Lambda X_a(i)}{t_o} \qquad \text{(II.14)}$$

and

$$C_2X_a(t_o-1) < \frac{NC_1 + C_2\Sigma X(i)}{t_o-\Lambda} \qquad \text{(II.15)}$$

If hence the costs of individual replacement during a running period are higher than the average costs according to equation (II.12), the group replacement will be carried out at the end of an interim period.[43] Otherwise the next period will be started without replacement.

MULTI-STAGE STRATEGIES[44]—The consception "multi-stage" may be used in different ways. On the one hand an aggregate may pass several stages of quality and for the different degrees of demand in these stages it is of course useful to carry out the replacement with old parts of the pre-stage,[45] in order to save material costs. On the other hand expensive parts can be replaced less frequently than inexpensive ones as far as opportunistic strategies are concerned. Therefore the strategy itself is to make a multi-staged decision, e.g. testing successivesively

(a) Which of the parts are to be preventively maintained according to limit of failure—probability?

(b) Which of the parts are to be removed because of too high material costs?

This last conception of "multi-stage" shall not be dealt with here. There is no corresponding model in literature either.[46]

Inspection Models—The objective of inspection models is not only the optimum planning of reparation, maintenance or replacement but above all the determination of the unknown condition of an aggregate by means of inspection. This inspection has to be planned optimum, immaterial of the fact that an aggregate is in operation or held in readiness for a certain moment, as too many inspections cause high costs, while too few inspections entail damages with running aggregates (conveyor-belts without continual control) or depot costs for failed aggregates which are kept in readiness.

An optimum inspection strategy does not only treat inspection itself, it also considers the consequent decisions with regard to reparation. It may by all means be appropriate to inspect recently repaired parts only after a long time, as their immediate failure is very unlikely, and to test them more frequently at increasing age. This already hints at what is determinable in pracice or in literature, namely that a sequential strategy has a greater significance for inspections than for reparations.

Cost Models at Unreliable Information

Unreliable information usually means that

43 e.g. The interim period is to last one week. In the 6th week the costs of individual replacement (i.e. caused by failure) appear to be higher than the average costs during the past 5 weeks. Then group replacement will be carried out at the end of the 6th week.

44 Naik M.D. Nair K.P.K. Multi-stage Replacement with Finite Duration of Transfer Operations Research 13 (1965)—page 828ff.

45 compare example of tractors on page 21

46 This problem is a typical opportunistic strategy which is to be solved in the special case of practice by simulation.

there are only few spot-checks concerning a frequently statistic distribution, and dates based on statistic laws of a procedure are totally or partly missing. In our case the unreliability refers to the failure distribution of the concerned aggregates or to their single parts.

Type and parameter must be absolutely known at failure distribution in order to be able to strictly apply them as basis for optimum maintenance strategies.

According to the degree of knowledge of these symptoms, however, several procedures may be applied in order to develop good estimations of the missing criterion or significant strategies. Fig 7 shows which procedures are to be applied for the relative cases.

There are only few such models in literature, as one usually starts from failure distributions which, according to existing experiences, appear appropriate and reliable. (Partly due to other research). In many instances this procedure is more practical than the development of lengthy models, because the minimax—and bounding procedures only allow rough estimations. The adaptive procedure appears to be very promising, because by means of few dates it estimates the parameters of a distribution and improves this continually with dates of practice, also allowing repeated checking of the original assumption on the kind of failure. This procedure will be superior to the usual method of proceeding as it was initially described, because it derives its information from actual dates and continually adjusts them.[47]

Redundancy systems and Optimum Redundancy

The most effective way to increase reliability is not preventive maintenance—it is the redundancy control of aggregate parts. The grouping of redundancy controls, however, is duty of the construction and not of the maintenance and has thus little in common with the upholding of value—the actual problem of this analysis. We briefly deal with redundancy models here, because it has some significance

47 see KreB H. a.a. O.

Failure Distribution			procedure
kind	prameter		
	expected value	deviation	
unknown	unknown	unknown	minimax-procedure
constantly rising rate of failure	known	known or unknown	bounding-procedure
known	unknown	unknown	adaptive-procedure

Fig. 7

Division of procedures for determination of failure distribution according to fields of application

for the maintenance whether parts are maintained which are directly engaged in the process of operation or those which are redundant. The maintenance strategy for redundant aggregates can often restrict itself to firstly testing the size of danger of failure by means of inspection, i.e. how many redundant parts have already failed. For the future such inspections will not be repeated too often, thereby, avoiding downtimes and in the end only actually failed parts will be replaced to reduce material costs. The advantage of such redundant systems is the full utilization of the material until failure, while prevention obviates possible utilization of material. The price of redundant systems consists of the additional expenditure on space and the costs of additional investment. The reliability is generally higher with redundant systems. If we think of redundancy controls, the question immediately arises how such controls are to be set up, how the reliability is thereby influenced, how the redundancy is to be distributed along with restricting secondary conditions (weight of rockets), whether advantages of redundancy may be combined with those of preventive maintenance and others—in short, the question for an optimum redundancy.

The literature on the calculation of reliability of multiple systems is copious.[48] Beyond that there is a series of research of optimum redundancy in view of the most diverse optimizing criteria.[49]

III. FUTURE RESEARCH TENDENCIES

Inspite of the large number of the developed strategies it was established that an isolated research of maintenance is favourable only in few instances. If one considers literature, the boom of maintenance researches has considerally declined. At present one attempts to attribute the assistant function of maintenance because it only serves to uphold the operation condition to the right position in the process of manufacture. Especially aviation industry which requires maintenance on a large scale has realized this necessity and has been a signpost in this development.

For the fabrication management it has the following significance:

(a) In a workshop with simple machines nothing is won by applying complicated strategies, as the cost assets of improved prevention are again consumed by administration costs. Here the objective of maintenance is to guarantee a most inexpensive completion of the maintenance orders. (With simple strategy).

48 See Barlow R.E., Proschan F., Hunter C.L., Mathematical Models, Birnbaum Z.W., Esary J.D., Saunders S.C., *Multicomponent Systems and Structures and their Reliability*, Technometrics 3 (1961) page 55 ff.; Esary J. D., Proschan F., *Coherent Structures of Non-Identical Components*, Technometrics 5 (1963), page 191 ff.; Esary J.D., Proschan F., *The Realiability of Coherent Structures*, in: Wilcox, Mann, *Redundancy Techniques for Computing Systems*, Washington 1962 page 47ff.; Hees R.N., Meesendonk H.W., *ptimum Reliability of Parallel Multicomponent Ssystems*, Operation-Research Quarterly 12 (1961) page 16ff.; Lipp J.P., *Topology of Switching Elements v.s. Reliability*, IRE *Trasactions on Reliability and Quality Control*, o. J.; Moore E.F., Shannon C.E., *Reliable Circuits Using Lee Reliable*, Journal of the Franklin Institute 262, page 191ff. (Part 1) and page 281ff. (Part 2); Moskowitz F., Mclean, *Some Reliability Aspects of System Design* IRE Transaction on Reliability and Quality Control 8 (1956), page 7ff.; Weiss G.H., *The Reliability*. .Walter R.M., Dickinson W.E., *Reliability Improvement by the Use of Multiple Element Circuits*, IBM Journal of Research and Development (1958) page 142ff.

49 See Barlow R.E., Proschaw F., Hunter C·L Moskowitz F., McLean, page 7ff., Weiss G.H., On the Theory. .Boer J., *Some Mathematical Aspects of Reliability Problems*, Statistica Neelandica 18 (1964) page 453 ff.; Halperin M., *Some Waiting Time Distributions for Redundant Systems*, Technometrics 6 (1964) 1, page 27 ff.; Gordon R., Optimum Component Redundancy for Maximum System Reliability, Operations Research 5 (1967), page 229ff.; Flehinger B.J., *Reliability Improvement Through Rebundancy at Various System Levels*, IBM Journal of Research and Development 2 (1958), page 148ff.; Proschan F., Bray T.A., *Optimum Redundancy Under Multiple Constraints*, Operations Research 13 (1965), page 800ff.; Masatunii S., *A Simplified Method of Obtaining Highest System Reliability*, Journal of the Inst. of Electrical Comm. Eng. (Japan) 45 (1962), page 144ff.

(b) In line production, the discovery of a very favourable strategy is certainly advantageous. Being an oppotunistic strategy it is usually of a some what complex structure. It pays here, however, as one will always have personnel in readiness for completion. (Downtime costs outweight.

In both cases, however, research in the field of maintenance will have to deal with the problems of manufacture. A real, totally optimum planning of fabrication-completion will also have to be considered as also vice versa—a maintenance research must also be adjusted to a greater extent to the problems of fabrication. The only and almost independent research on the sector of maintenance can be achieved by developing opportunistic strategies—the optimization of which, however, again requires dates of the manufacture —a development which gradually begins to stand out in the literature of maintenance.

IV. ASPECTS OF PREVENTIVE MAINTENANCE IN DEVELOPING COUNTRIES

Optimum Policies

The problems of developing countries differ to some extent from those of highly developed, industrial countries. This also has an influence on the parameters of a preventive maintenance.

The essential cost shares are

—downtime costs
—personnel costs
—material costs

The downtime costs are obtained from the lost covering dues, i.e. the possible turnover minus the variable costs for those products which could have been manufactured during the downtime period.

It is to be expected that the downtime costs in development countries are not as dominant as in highly developed industrial countries, because on the one side the automation with its high, fixed cost-shares does not yet outweigh, and on the other hand the machines are usually not fully utilized, so that the failure period does not carry great weight.

The personnel costs are incomparably lower influencing the preventive strategy to a great extent. Due to low personnel costs and the existence of sufficient labour resources it is possible to interchange whole aggregates and repair them very calmly. This shortens downtime periods, operation procedures are simplified and less skilled workers are required. It also solves the problem of insufficient training of professionals who would have to be put into action very office in case of emergent reparations, because it is simple to teach plain procedures of aggregate-replacements even to unskilled workers.

The material costs in development countries are usually high, because often the rawmaterials and semi-finished products are not available and have to be imported. The reparation of failed parts, therefore, plays a more important part than in industrial countries, where after wear such parts are simply replaced by new parts, because it would be too costly to repair these parts on account of the high personnel costs.

All these reasons speak in favour of a periodic replacement strategy, repairing the failed parts afterwards. This strategy is of simple application and causes the least costs, especially for medium size and small enterprises where the costs of administrative execution have relatively big influence. Apart from this there will of course be cases where one of the other strategies opportunistic or multi-staged or readiness strategies—must be applied. These strategies are very complicated, however, and too expensive for medium size and small companies.

Spare Part Problems

The question of stocking of spare parts is important for the maintenance. In many cases one would have to consider, whether it pays to

keep up a totally secure spare part depot because of the high depot costs. We do not have this problem, however, in development countries. Here the time of delivery for imported spare parts is so long, that a sufficient stocking must be guaranteed in order to satisfy the demand for spare parts at all times. On the other hand the stoking may be reduced, as the old parts will mostly be reused after reparation.

Thus it is commendable to install at least one reserve equipment beside the basic equipment, and to provide for another location where the failed parts may be repaired after their removal.

The maintenance problem of the spare part depot is not generally solvable. It will strongly depend on the conditioning factors of the specific country, on the regional conditions with regard to the supply of rawmaterial, on the industry of semi-finished products and on the special economic conditions and Government Regulations on import of spare parts.

DESCRIPTION OF CONCRETE SCHEDULES IN SPECIFIC INDUSTRIES

Preventive Maintenance in Aviation Industry—Preface to Maintenance Systems of Aircraft Mechanisms

The necessity of preventive maintenance of aircraft in airtransport is based on the gravitation of absolute security, underlined by the demand for "safety first". The maintenance system—we wish to apply this general conception for the sum of all necessary measures executed to maintain operating conditions of the aircraft—will usually be carried out by the airline company in 3 different levels.

Level 1: Controls carried out on the way to destination (e.g.: Start control before every take-off)

Level 2: Smaller maintenance measures executed in certain periodic intervals (e.g.: aircraft basic control after 250 flight hrs.)

Level 3: Maintenance measures carried out regularly after longer periodic intervals in the technical basis of the airline company (e.g.: Overhaul of engine after 4.000 flight hrs. or overhaul of cells after 5.000 flight hrs.)

These maintenance measures are partly or totally carried out by the airline company itself.

The mechanical workshops in the technical basis have to execute the maintenance works of level 2 and 3 for the mechanism and mechanism systems.

It is their duty to supply aircraft operation with ready mechanisms at any time.

We wish to briefly deal with their function and their problems.

Objectives of a Simulative Circulation of Mechanism.

The objectives which are attainable by means of a circulation of the mechanism are multilevelled and shall be briefly patterned as follows:

(a) Time-planning—long range and medium range—for the mechanical workshops by pre-defining planned and unplanned replacements of mechanisms.

(b) Prediction of the required man-hour capacity and operation capital derived from the predefined number of replacements.

(c) Determination of expected need of material.

(d) Prediction of capacity reserves for the maintenance of mechanisms of foreign companies or failure capacities by pre-

50 Greger H., EROS 'Engine Repair and Overhaul Simulation')— ein Planungsinstrument fur Triebwerkinstandhaltungs werkstatten von Luftvarkehrsgesslschaften in Bussmann K.F., Mertens P. (ed.) Operations Research und Datenverarbeitung bei der Instandhaltungsplanung Stuttgart 1968—pp. 137-154

diction of removals and workshop supplies.

(e) Listing the development of the stock of spare mechanisms.

(f) Quantitative determination of the risk level when no spare engine is ready for x-days at given initial value.

(g) Listing of consequences at change of parameters, (e.g. reliability of mechanism or rate of passage through workshop).

Maintenance Completion

Maintenance uses a strictly periodic strategy in each of the mentioned levels which is supplemented by actions at unpredicatable moments of failures of machine parts. The maintenance system is simulated in order to determine the optimum paramenters of the maintenance strategy.

A certain key-date is chosen as the starting date of the simulation period. Starting from this moment as a basis of all static parameters, a continous industry carlender is kept. Every day all incidents of the total system of circulation will be acted sequentially, just as they might occur in reality under the co-operation of all factors of influence. An incident in a program-branch may cause a chain of reactions in another branch. As the contingent- dependent incidents are determined by means of the Monte-Carlo-Method, the results of each test-run contingently differ, even at equal initial parameters. Thus several simulation-runs are excecuted and concentrated in a final programme into arithmetical mean values in order to obtain the most probable value.

The result of simulation provides the most important record of a short-ranged workshop scheduling with weekly and monthly concentrated workshop inputs and outputs, as well as workshop, and reserve-stock of engines.

Preventive Replacement of Aggregates with the Manufacture of Transistors.[51]

A machine, welding the glass coat of transistors, has a particularly failure-inclined single part; a heating spiral which has multi-parallel arrangement. Should one spiral fail, we have the foilowing maintenance alternatives:

—replacement of all spirals
—replacement of the failed spiral

The alternatives are only determinable by the examination of the arising costs.

The following strategies have been examined in detail: One strategy deals with the single reparation or replacement of the respective part at failure; the other strategy proposes the collective reparation or replacement of equal single parts after a certain operation interval which is shorter than the expected durability, or at failure,—according to necessity. By variation of the operation interval the optimum cost-moment of reparation or replacement may be established. The situation of total cost minimum will shift according to the ratio or costs arising firstly from the single reparation or replacement of parts and secondly from total reparation or total replacement.

As the single heating spirals consist of absolutely equal parts, we assume they are of equal durability.

Furthermore the maintenance strategy was varied to that point that single parts which, due to early contingent failure, had to be repaired on replaced just before a total replacement and were not considered again at actual total replacement or total reparation. This might avoid possible additional costs.

Both alternatives were simulated, whereby the model was constructed in such a way that it could be used for all statistial distributions for the failure periods of the heating spirals.

It was found that the strategy of collective

51 Schwarz F., Die Ermittlung der optimalen Reparatur—oder Ersatzstrategie mit Hilfe der Simulation, Thesis 1967-TH—Munchen

replacement was by all means the superior one. An additional examination[52] proved that the cost-optimum did not occur with strict time-periods (e.g. replacement after 2 weeks) but with running time-periods (i.e. replacement after 10 hrs. of continuous running time).

In the discussed case all heating spirals are thus replaced after having run through a certain operation time, or single spirals are replaced at failure, if this does not occur just before total replacement.

Maintenance Scheduling of Workshops

For the optimum maintenance of workshop machines the following model was developed:

By means of preventive actions and completion of the maintenance orders with the aid of priority rules a cost-optimum is to be obtained. The variable values here are the parameters of the strategy which determine the processing series of the orders, the kind of rule and the number of workers.

Supposition of Models

The examinations were based on the following supposition:

The Machine Park—The dependency of the machines in the working process is described by the organisation-type of the workshop fabrication which means that the machines are technically as well as economically independent of each other. There is no grouping of similar machines for the purpose of simultaneous maintenance. In practice the separate machines have only few parts which may really cause a failure. As, on the other hand, the failure distribution as a pure durability distribution is only determinable with machine parts, and moreover a precise calculation of material costs and reparation time is possible only for single parts, those parts were chosen for a maintenance unit which might be determinant for the failure of a machine.

The total utilization time of the machines is without significance, as it shall be assumed that at final shutdown of a machine it will be replaced by a simular new unit.

Maintenance Strategy—A periodic preventive strategy is chosen according to operation hours, and shall be applied to the failure inclined independent single parts or part groups of a machine.

When applying preventive actions, the machines are only shut down, if workers are available for the execution. Filed into the already existing orders of the waiting queue the preventive action is planned, however, for the scheduled moment.

Should the machine fail, however, its downtime is inevitable, and it must wait for maintenance according to its scheduling into the waiting queue.

If there have been maintenance measures for several parts of a specific machine during an operation time, the machine will be classified according to the highest priority of all its parts. All existing measures are considered at the service of maintenance orders.

Preparation of Maintenance—The time for technical management required for the planning of failures and preventive actions, and the listing of the individual maintenance orders is not considered in the model. Neither is the time of preparation of the works at change of orders.

Furthermore, it is assumed that there are no time losses due to insufficient material and tool preparations.

Priority Rules—The model assists to investigate the effects of priority rules on the maintenance completion planning. Ten rules were given for the model which were developed from rules of the fabrication completion planning

52 Pelz P., Ein Vergleich von praventiven Instandhaltungsstrategien, in Bussmann K.F., Mertens P., page 51-63

with consideration of particular data during maintenance.

The Maintenance Personnel—The maintenance personnel consists of universal workers with an equal degree of performance. This causes only a waiting queue of orders from which ready workers obtain new work. The necessary working course should be altogether carried out by the same worker.

Duration of Works—The duration of single maintenance actions is presupposed as known—it is always of similar length with preventive actions for the single part. It is different, however, for the various parts. The time consumption for the settlement of a failure is derived from the time for the preventive maintenance of the failed part plus an inspection time which varies as a machine constance for the single machines according to technical complexity.

Optimal Costing—Material costs of single parts, costs of maintenance organization and downtime costs are considered. Hereby it is assumed, that the costs of maintenance organization are proportional to the number of maintenance workers. The downtime costs reveal the upset sensitivity of the fabrication process.

Optimization Criterion of Minimum Total Costs—The quality of an organization system of maintenance works for fabrication aggregates can be judged best from the arising costs. The costs consist of:

(a) personnel costs for the execution of the maintenance works.
(b) the material costs of maintenance,
(c) the lost profit and the covering share of the fixed production costs for the production fall-out during the period of maintenance (downtime costs).
(d) the costs for the solitary set up of an organization system and
(e) the running management costs for the planning, guidance and supervision of the maintenance.

The total sum of these cost shares should give a minimum for an optimal maintenance organization. For the planning of the organization only the quantitative cost shares—personnel costs, material costs and downtime costs—can be used in one model. The cost shares for the set up and continuous control of the system must be considered in the basic concept of the organization according to quality.

It may easily be estimated that a minimum of total costs arises, because the downtime costs and the working costs have a bearing on the number of maintenance workers.

The material costs on the other hand are largely neutral—they only grow with increasing prevention thereby decreasing the downtime costs which has, however, only secondary importance, because by means of repeated preventive maintenance the inspection times of the machine fall, in fact, though this effect is weakened by the frequency of downtimes.

Results of Investigations

The result of investigations consists of the optimum determination—i.e. of the cost minimum—of the following system-parameters:

(a) Type of priority rule for completion planning of maintenance.
(b) Preventive period for time planning of maintenance.
(c) Number of maintenance workers.

And the calculation of minimum total costs of maintenance.

The underlying data very precisely proved that a cost minimum can be attained only, if preventive measures are applied. Considering all costs—even the costs of maintenance execution—that periodic strategy is most appropriated of which the period is only slightly below the average failure time of the single parts. The best windup of orders is obtained, if the machines wish the highest downtime costs are treated first. ●●●

Maintenance and Repair Organisation in Industrial Enterprises

JD Edwards*

The purpose of this paper is to outline the basic requirements of maintenance and repair organisations. The actual requirements to suit any situation, whether in developed or underdeveloped countries, will vary with the type and size of industry, the local surroundings, the normal weather conditions, the degree of local industrialisation, labour availability and many other factors. However, these requirements can be established in relation to the basic features outlined.

BEFORE any effective maintenance and repair organisation can be established, there must be a recognition at top management level of the vital need for such an organisation, and an understanding of its aims and objectives.

It should be recognised that such an organisation is an integral part of the process of production. The costs of a maintenance and repair organisation must be seen as an operating cost which can have a significant effect on the ultimate product cost.

It is a gross mistake to aim to reduce maintenance and repair costs without reference to the effect on other factors such as plant availability and production rate.

Reduction of maintenance and repair costs by reduction of maintenance and repair activity, will result in reduction of plant availability. Equally, reduction of expenditure on equipment replacement will result in reduction of production rate or efficiency by continuation of use of worn out or patched up machinery.

Understanding of the impact of such factors on overall production costs is necessary at top management level and all levels in production and maintenance management.

Terminology in current use to describe maintenance and repair activities varies from place to place. In order to avoid misunderstandings with regard to the ideas presented in this paper, the meanings ascribed to terms used are listed in Appendix I.

STRUCTURE OF MAINTENANCE AND REPAIR ORGANISATIONS

Before we can consider the structure of the organisation needed to undertake maintenance and repair of an industrial enterprise, we must first examine the enterprise.

Dependent on the circumstances of the enterprise, it is often convenient to include

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various functions within the responsibilities of the maintenance and repair organisation.

Such a situation is an acceptable one provided the separate functions are recognised and the strength of the organisation is determined accordingly. Non-recognition of the various functions and responsibilities can lead to neglect of one or other of them, to the overall detriment of the enterprise.

Primary Functions

The primary functions of any maintenance and repair organisation will include the following:

1. Provision of adequate and suitable manpower and facilities to maintain production plant at the desired level of operational availability, efficiency and appearance.

2. Provision of manpower and facilities to maintain service plant, buildings, and roadways at the desired level of availability, efficiency and appearance.

3. Provision of facilities for the progressive self improvement of the performance of the organisation in terms either of production plant availability or production cost or both.

Secondary activities which may be included in the responsibilities of a maintenance organisation as circumstances dictate could include:

1. Provision of facilities for the progressive development of the production facilities in terms of either improved throughput, improved economics, modernisation for expansion.

2. Provision of the factory services. This could involve operation of power generation facilities, steam raising plant, water supply and treatment facilities and effluent treatment and disposal facilities.

3. Provision of facilities for procurement storage of items of equipment either for maintenance and repair use or for general use.

4. Provision and operation of transport and facilities either for internal factory use or even for transport of raw materials and finished products ouside the factory.

Secondary Activities

The secondary functions listed above are possible extra responsibilities for a maintenance and repair organisation, as the background and training of the personnel of the organisation often make it the most capable group to deal with them. Generally, these sort of additional responsibilities are added in smaller enterprises where setting up of separate organisations to handle them cannot be justified.

It is desirable, whenever possible, to separate such functions entirely from the maintenance and repair organisation. When it is not economically justifiable to set them apart in a separate organisation, it is necessary to separate them within the maintenance and repair organisation. This separation must be made in terms of the personal responsibilities of members of the managerial or supervisory staff. If this is not done there is a real danger that either one function or the other will suffer neglect.

With larger enterprises where such additional functions achieve sizable proportions, the temptation to incorporate them must be avoided. Equally, as enterprises grow, it is necessary to re-assess the needs and separate out such additional functions as soon as possible.

Responsibilities of Maintenance and Repair Organisation

Having clarified the true functions of the maintenance and repair organisation, we can now look at the separate reponsibilities which go into meeting the three primary functions. The work of the organisation will include the ability to undertake:

1. Emergency maintenance and repair work.

2. Planned maintenance and repair work—this will probably include a mixture of breakdown, shutdown, scheduled and preventative maintenance work.

3. Operation of engineering workshop facilities.

4. Provision of diagnostic service to determine causes of malfunction of production or service equipment.

5. Operation of a planning service to provide for control of the overall use of the manpower and facilities.

6. Operation of a plant inspection and records system.

7. Establishment and review of levels of spare parts stock.

8. Installation of minor plant modifications and extensions.

9. Provision of technical service to improve performance or working life of plant or reduce the maintenance costs.

Distribution of Work Force

Let us now examine each of these aspects of the responsibilities. Emergency maintenance and repair work can vary between minor jobs requiring no more than one or two manhours of effort and major work involving the sustained effort of a large section of the workforce. Similarly planned work may vary greatly in the amount of effort necessary to complete it.

When considering the structure of the organisation necessary to handle the different calls for maintenance work, it is usually of more value to separate work in terms of the manhour requirements and priority. This distinction can lead to a separation of the workforce into two or more teams or groups with different primary responsibilities.

Emergency maintenance and Repair work can vary between minor jobs requiring no more than one or two manhours of effort and major work involving sustained effort of a large section of the workforce.

Other separate responsibilities can also be established either grouped in terms of specific plant needs or work function. These would inlude such groups as say, machine shop, welder's shop, sheet metal workshop, joiners or carpenters, vehicle maintenance, etc.

Again dependent on the size of an organisation, it may be decided to carry out all these operations by separate teams. Alternatively all or groups of these operations may be carried out by one team having the necessary skills and training for the jobs to be covered. The decisions on how to group such teams should be influenced by the following factors:

1. The convenience of separating production facilities into areas grouped geographically or in terms of similar maintenance and repair requirements.

2. The base level of work requirements in each area.

3. The requirement for specialist services of any sort in one or all areas.

Area Maintenance Teams

Generally it will be found possible to identify groups of production facilities which can provide

a steady workload for a number of men. This work would consist of small emergency jobs and routine scheduled maintenance work such as oiling, greasing, and machine adjusments. Such jobs would not normally require much in the way of special equipment or specialist work.

It is often convenient to establish small teams operating in such localised areas. Each team may have its own supervision or share a supervisor with a number of other teams. Advantages to be gained from area teams include:

1. The team develops an intimate knowledge of the plant in their area

2. They are readily available to deal with minor emergencies which, if given prompt attention, can avoid major plant down-time

3. They have direct reponsibility for scheduled maintenance work in their own area. Without this area separation, one section of the plant may claim excessive attention due to perhaps the agressiveness of the production supervision in that section, or a more agreeable working environment.

The area team arrangement has a number of potential disadvantages which can be avoided with careful control. They are:

1. Unless sized correctly to suit the base workload, they can overmaintain plant and become an expensive way to do maintenance. A continuous cross checking of the work they tackle and their manpower is necessary.

2. Such teams tend to accept present practices as essential for evermore. Often they will not challenge the need for a job which is part of their routine. Situation which may be major maintenance cost items may not be identified because dealing with them has become a routine job.

3. Seldom, when there is a reduction of workload in an area, whether short or long term, will it become apparent to management. The potential to use underemployed labour elsewhere will then be lost.

The main disadvantages can usually be avoided by undermanning such groups to the point where they regularly need to request additional assistance. This will tend to focus attention on their operation from a higher level on a regular basis.

Some sort of routine feedback of information on how their time is spent can also prove of use in identifying high cost operations. It is advisable to resist the temptation to place such teams under the control of the production supervision in the area. This supervision will stubbornly resist any attempt to reduce the size of the team. In addition, the necessary control of engineering standard of work performed will be lost, with possible catastrophic results.

Centralised Maintenance Teams

With small enterprises, the question of whether to organise into area or centralised teams seldom arises. In these circumstances usually a single centralised team best suits the situation. The decision to operate with a centralised team in a larger enterprise will be influenced by the following factors:

1. Whether workload requirements for specialist skills are concentrated in a section of the production facilities or spread generally over the whole factory.

2. Whether there is a need for high capital investment for fixed facilities for any particular maintenance or repair operation. For example, the need for machine tools and workshop space, heavy fixed welding or pipe fabrication facilities or similar facilities.

3. Whether the general workload is steady in all sections of the factory or fluctuates from section to section.

In almost every case it will be found that there is need to concentrate the machine tool facilities and some if not all of the welding, sheetmetal working and woodworking facilities in centralised workshop. In general also, with the larger enterprises, centralisation of part of the mechanical, electrical and instrument trades is desirable. These groups can be used as a workforce which can range over the factory, carrying out the bigger jobs where they occur.

It is unusual to find a situation in the larger enterprises where complete centralisation of the workforce is a practical proposition.

A combination of the Area and Centralised will usually be found to be the most workable arrangements.

As with area teams, centralistion of the maintenance teams has its advantages and disadvantages. The advantages include:

1. The ability to ensure an even loading of the workforce.

2. The centralised workforce lends itself more readily to work planning.

3. It avoids the necessity of uprooting men from one area to tackle a heavy workload in another, as is necessary with a completely area-organised force.

4. It permits men to gain wider experience over the whole of the factory giving the workforce greater flexibility.

5. Supervision is more readily arranged to cover major work, with regular teams used to one another and their supervisor.

The drawbacks largely centre around the wider field than the centralised groups cover. Principally they are the opposites to the advantages of area teams, that is:

1. The groups lack the intimate knowledge of the plant. Also they lack an attachment to any particular section of the plant around which to build a team spirit.

2. If work quality is not strictly controlled there is a danger of lack of care and attention to detail. The area man generally is aware that poor performance by him will result in a return to the same job. Lack of attention by the centralised man generally means trouble.

Combined Area and Centralised Maintenance Teams

Other than with small enterprises, it is most likely that a combination of both area and centralised maintenance teams is preferable. Determination of the optimum manpower split between a combination area and centralised organisation is a difficult problem. It will depend on the incidence of emergency work together with the steady load of routine scheduled maintenance.

The scheduled workload is readily determined. The incidence of emergency work is quite another matter. Without some control system, all maintenance and repair work will be emergency work. It is only when manpower becomes difficult to obtain that production men start to order their priorities for service from the maintenance and repair organisation. By steadily reducing the strength of area teams and requiring production people to be realistic about their service requirements, it is possible finally to arrive at a workable situation. It is necessary, however, that this be done with the co-operation of the more senior production management. This co-operation, also, will only be forthcoming if the production management fully appreciate the effect of maintenance and repair costs on their operation.

Other groups such as rigging teams have to be considered in the light of the workload distribution for them. Services of a less urgent

Sizing of the maintenance and repair workforce must take account of the known periods of peak workload.

nature provided by civil craftsmen such as painting, bricklaying, carpentry, glazing and the like can usually be completely centralised with advantage.

Installation of Minor Plant Modifications and Extensions

Of the additional responsibilities which a maintenance and repair organisation may be required to undertake, new construction work of this sort can be undertaken with advantage. It would be most unusual if the incidence of maintenance and repair work constituted a steady workload.

Sizing of the maintenance and repair workforce must take account of the known periods of peak workload. While it may be possible to hire additional labour for short periods to cover these peaks, this is not always desirable. For instance, successful execution of the work may require some level of specific training not available on the labour market. It may be also found difficult to get the calibre of men required when needed. One alternative, to hire a maintenance contracting firm to cover peak work loads, will be discussed later. The third alternative is to employ a total workforce capable of handling the workload peaks, and provide them with other work in times of lower maintenance and repair workloading. Construction of plant modifications and extensions provides a ready means of occupying these men. It also has the advantage of providing a team which can be more readily controlled to give a good quality job than most contractors.

It would be a mistake, however, to have more men than is necessary to do more than cover peak maintenance and repair workloading. New construction work itself can include wide fluctuation in workloading, particularly where significant seasonal weather fluctuations occur.

It is usually advisable when such a construction team is formed to retain it strictly under the control of the maintenance and repair organisation, preferably with the centralised team if it exists. In this way, maximum flexibility in use of the men can be retained and the best possible service to production maintained.

Use of Contractors

Mention was made earlier of the possible use of contractors to deal with some aspects of the workload of the maintenance and repair organisation. There are a number of circumstances where the use of contracting firms clearly can be advantageous. Other circumstances exist where the decision whether to use contractors or not is not so simply resolved. While taking the first circumstances, use of contractors will be advantageous to deal with specialist problems such as infrequent overhauls of propriety equipment. For instance, a major boiler overhaul will be a job which does not arise frequently. The attention it requires demands certain skills which would not necessarily be found amongst a general maintenance crew.

If a specialist contracting firm is available within reasonable distance, use of them will avoid the need to train men for skills for which there will be infrequent call. Other overhauls which may fall into the same category would include turbine or diesel prime movers, generating equipment, and maybe items such as compressors, motor transport and other forms of mobile plant, also specialised packaging or conveying equipment.

Use of contractors is also often advantageous for non-urgent maintenance and repair work when there is time to organise contractors to submit a quotation for the work. The sort of work which most readily falls into this category is realted to the civil engineering trades. Building maintenance and repair work, building

and plant painting and decorating, maintenance and repair of yards, roadways, drainage systems and so on.

Use of contractors in other circumstances will depend on a number of factors such as workloading, type of plant, location and availability of contractors. There is an increasing tendancy in a number of countries nowadays for almost complete use of contract labour for maintenance and repair.

General engineering firms are tending to offer this sort of a service to help them over the peaks and troughs of their workload without resort to hiring and firing of employees.

These sort of services can be extremely valuable on occasion to help over workload peaks, particularly when these can be predicted in advance. It is as well, however, to organise the work so that the contract men have a specific part of the job to undertake rather than to mix them with Company employees. Often there is a tendency toward friction between the groups. Contractors of this sort tend to have special pay structures which, when engaged in work away from their base, gives them a high level of takehome pay. Also their discipline may not match the factory standards both in terms of work control and safety standards. The factory employees will tend to compare the contractor's results unfavourably with their own to the extent where industrial relations may become strained.

Plants where maintenance and repair is principally undertaken by contractors tend to be rather specialised continuous process plants. On these plants, maintenance and repair needs are very small during normal operation, and very high during plant shutdown periods. To successfully operate with total contract maintenance under these circumstances it is necessary to have a major engineering company within easy reach which is able to plan its workload to include the plant shutdown demand.

Factories which operate such a system successfully usually are situated in developed industrial areas, usually on or near the coast where there are major ship repair or ship building facilities. Shipyards are usually ideally organised for such undertakings, as the labour force is used to moving from job to job and appreciate the urgencies of shutdown or turnaround work.

Use of contractors is often advantageous for non-urgent maintenance and repair work.

It is generally necessary with this sort of system to make long-term arrangements with the contractor so that the labour force gets used to the plant and its needs. At the same time, the plant must retain a minimum number of maintenance and repair staff to plan, direct and supervise the work, develop preventative maintenance routines and carry out plant inspection and so forth. To meet the small continuous demand for maintenance and repair service during normal plant operation use of contract labour again is preferable, although it may be more expensive than employing men direct. Use of contractors exclusively, avoids the possibility of labour relations problems at shutdown time. Working practices and remuneration are governed by one set of rules only and continuity of contact with the contracting force is maintained.

Maintenance Staff Duties

We have considered up to now, those responsibilities of a maintenance and repair organisation which involve the provision, organisation and control of the artisan manpower. The remainder of the maintenance and repair organisation's responsibilities are those that involve the staff members of the organisation.

The Supervisor

Any discussion of organisation of the workforce necessarily includes the supervision of this

manpower. This first line of management has the specific responsibility of putting these men to work and controlling their efforts.

The surpervisory force also has other responsibilities. Being the section of the management team most directly involved with the production and service plant, they have a more intimate knowledge of its shortcomings than most. This knowledge is valuable. It is, therefore, the supervisor's responsibility to record and feed back any such information to the appropriate section for action.

The supervisor also has a responsibility to ensure that expenditure on maintenance and repair activities is correctly recorded against the section of plant or equipment concerned.

Without these two information feedbacks, maintenance improvement activities would have no foundation. A more detailed outline of maintenance and repair costing will be given later.

Technical Service—The Plant Engineer

The next function of the maintenance and repair organisation staff is the provision of a technical service. This service takes the form of diagnosis of the causes of equipment failure and establishing corrective action. With equipment failure resulting from normal wear and tear, causes and corrective action can be determined by the workforce themselves or by the supervisor. With unexpected failure, or in circumstances where the cause of failure is apparnt, but the best way to tackle the corrective action is not, a more qualified opinion is required. It may not always be that the decision required is based on technical grounds. It may be a question of which possible solution is the best on an economic basis. These are the sort of decisions and technical service which must be supplied by the next level of maintenance and repair management.

This function is carried out by the maintenance or plant engineer. A man with a sound practical background and adequate technical training. In addition to this he also requires a working knowledge of the principles of management. The plant engineer is part of the line team. He has control of a number of supervisors and so carries responsibility for maintenance and repair of some part of the factory.

It is necessary for the plant engineer to be aware of the production situation at any time. His decisions must be based on production needs. However, this must be an overall view. "Production at all costs" must not be his motto. The correct decision may be at times to incur an extended period of downtime in order to effect a better or more long-lasting-repair. This would be with the aim of securing the production situation at a later date.

The decisions again must not be made in isolation. He must consult with the production management and with his superior when necessary. Neither must his supervisors be neglected. He has to consider the overall management of his resources. His supervisors have responsibilities and must be allowed to make their own decisions. If they are not consulted, or made aware of situations they will become merely shepherds of their workforce. They will not act with initiative and the plant engineer will have to direct their every move. This level of management of the maintenance and repair organisation is the one at which there is the greatest input of technology into the day to day work. It is essential that the plant engineer organises his group to give himself the maximum time to supply this input where it is required. Inability to delegate responsibility to supervisors means his involvement in every decision and a consequent diminution of the time he can spend on considerations that warrant his attention.

Maintenance Planning

This staff function of any maintenance and repair organisation is probably the one which is most misunderstood and misrepresented of all. At best a planning group can be the cornerstone of the whole organisation. At worst it can be an encumberance and unjusti-

fiable overhead. Which category it falls into depends chiefly on how well its function is defined and what authority it commands.

Perhaps use of the word planning itself is wrong. When a planning group exists in a maintenance and repair organisation. there is a tendency for all outside it to assume they have no planning responsibilities. Use of the term Maintenance Preparation Group or Works Services Group can help to get around this problem.

First let us decide what we mean by planning. Planning is the process of preparing in advance for some activity which is to occur. Accepting this definition we can see that planning is something which goes on all the time, with just about everyone, in any situation. Formation of a planning group is a means in a maintenance and repair organisation of formalising the process for a specific part of the organisation's operations. How much of the operations of the organisation to be dealt with by the planning group will depend on the size of the organisation and the staff strength it can support.

However, assuming that a full-scale planning operation can be mounted, the following responsibilities would come within the scope of the group:

a. Preparation and organisation of operation of long-term maintenance and inspection schedules.

b. Provision of a plant inspection and records service.

c. Preparation and organisation of operation of long-term plant shutdown maintenance and reapair programmes.

d. Preparation and organisation of operation of major repair work.

e. Co-ordination of work loading of a section of the maintenance and repair workforce (including operation of maintenance measurement systems).

Let us see each responsibility separately.

LONG-TERM MAINTENANCE AND INSPECTION SCHEDULES—It is most often convenient to organise the preparation and operation of schedules of this sort on an overall basis for the factory. When this is so, the planning group, as a factory-wide service group, is the logical place to invest the responsibility. Short term routine schedules as discussed earlier are best handled on an area basis. Longer term schedules which involve inspection or maintenance work at a frequency of say six months or more require a reminder system if they are to operate at all.

The sort of schedules usually considered are those where statutory legislation requires formal inspection of particular types of equipment on a fixed frequency basis. Similarly, insurance companies may require similar programmes for equipment risks which they underwrite.

Other schedules might include inspection of pressure relief devices, electrical interlock systems and switchgear, and critical items of equipment, failure of which in operation may constitute a major hazard to safety of production.

In addition, this service could also include inspections required to plant, the need for which has been identified at previous inspections. Generally the job of this part of the planning group would be to operate a reminder system to that part of the organisation charged with carrying out the inspection or maintenance operation for the particular item of plant concerned. They would also be responsible for either recording completion of the operation or reporting to higher authority on non-completion. The establishment of inspection frequencies would not necessarily be their responsibility. However, they should be responsible for ensuring that frequencies are established and reviewed periodically.

PLANT INSPECTION AND RECORDS SERVICE—Here again, it is usually more efficient to operate such a service on a factory-wide basis and hence the planning group becomes the logical place

for it. This service involves the provision of suitably trained personnel, equipped with the necessary tools and equipment, to determine the period over which items of plant can continue to operate. The description of the service is deliberately phrased as the determination of the period over which operation can continue. The major job of any inspection service of this nature is to provide information which allows decisions to be made, in time to safeguard contunuity of production.

Dependent on the size of the enterprise and complexity of the operations conducted, the techniques used by the inspection team can vary.

They can include the most sophisticated non-destructive testing techniques such as:

Radiography

Ultrasonic testing

Eddy current testing

Vibration analysis

Television monitoring

or be simpler but nonetheless effective techniques such as:

Dye penetrant testing

Magnetic detection

Measurement by gauging, calipering or drill test

Use of test coupons

Hammer or other physical testing

Pheumatic or hydraulic testing

Visual inspection.

An essential feature of all such inspection programmes is the need for meticulous recording of test results. This should then be followed up by comparison with previous tests to determine deterioration rate. By this means future life of plant may be estimated. The final stage in the operation is to inform those responsible of the conclusions reached so that decisions on need for replacement can be taken. It is also necessary to ensure that the inspection frequency is reviewed in the light of findings of successive inspections.

Dependent on the size of the enterprise and complexity of the operations conducted, the techniques used by the inspection team can vary.

LONG-TERM PLANT SHUTDOWN PROGRAMMES—The planning group can provide an overall factory programme service for major plant shutdown maintenance and repair work. It is necessary with most production plant at some time or other to arrange for a complete shutdown for major overhaul. Usually experience will determine the frequency at which these shutdowns should take place, although sometimes the frequency will be determined by the statutory inspection frequency of some major item of equipment. These shutdowns usually represent a major peak workload for the maintenance and repair organisaion, and as such need careful planning if they are to be carried out efficiently.

The aim of the overall factory programme should be to include all major plant shutdowns in such a way as to spread the maintenance and repair workload evenly throughout the year. The planning group must of necessity take the initiative in organising the shutdown programme. There are a number of different considerations which will affect the build up of the programme which will be given different stress by the various sections of the enterprise organisation. It is necessary therefore that a central organisation collect and co-ordinate all

the relevant data, resolve conflicting viewpoints where possible and refer them for senior management decision where not possible. The various factors which may have to be considered in formulating the programme might include:

1. Frequency of statutory insurance or safety inspections
2. Production programme, that is, production capacity *versus* market demand, seasonal variations, finished stock levels, etc.
3. Effect of seasonal weather variations on working conditions in the plant.
4. Availability of in-plant labour and outside services.
5. Availability of spare parts.
6. Programmes for plant modification or expansion and equipment delivery position.
7. Findings of previous plant inspections.
8. Experience of the plant engineer.
9. Experience of the plant operational staff with regard to deterioration of production rate, and so on.

As the major aim of the programme must be to give the best overall factory service with the available labour force, it is essential that careful attention be paid to exactly what work is done during the plant shutdown. Firstly, all work that needs to be done to return the plant to full operational efficiency or to safeguard operation between shutdowns must be listed. This list will be compiled from all available sources. The plant engineer, the plant operations staff, the inspection schedules, records and previous plant shutdown records. Secondly, all work to progress plant modifications, improvements or expansion which requires shutdown of the existing plant must be determined. Finally, each item of work requested should be examined critically to determine whether it can possibly be undertaken at any other time than the major shutdown. For instance, some items of equipment can be released for short periods during normal operation, or by short-term build up of buffer stocks of materials. Sometimes, slight changes to the means of tying in proposed plant modification can eliminate the need for shutdown or at least greatly reduce the time or work required. By means of this examination, the work to be carried out during the plant shutdown can be reduced to the minimum necessary. Detailed determination of material, manpower and services requirement for each shutdown can then proceed.

MAJOR REPAIR WORK—All major repair work which is predictable on a long-term basis will automatically be included in the major plant shutdown programme. Other major repair work will develop without very much notice. This can result from premature equipment failure, mal-operation of equipment or perhaps due to heavy loading from a change in production programme. Some of these requirements will develop suddenly and require immediate attention. These we will refer to later. The rest are those which were referred to earlier as the likely responsibility of a centralised workforce. Such work will often require the organisation of various services, provision of special machinery or procurement of special equipment or spares.

This sort of work requires more detailed or specialised attention than can be supplied by a local area maintenance group. Again the planning group is the logical collecting centre for such detailed specialist attention to be provided on a factorywide basis.

CO-ORDINATION OF WORKLOADING OF A SECTION OF THE MAINTENANCE AND REPAIR WORKFORCE—This co-ordination service is really the end product of the activities of the various activities of a planning group. By organisation of long term schedules, plant shutdown work and major repair work, the group is in the position of being able to provide a steady work

Major emengency work is the greatest enemy of any maintenance and repair organisation; such work demands immediate attention and major workforce effort.

programme for a significant proportion of the maintenance and repair workforce. Whether the workforce is divided into area and centralised groups, operated as a series of area forces or maintained as one plantwide group does not basically alter the situation.

It has been etablished that all maintenance and repair work can be divided into plannable and non plannable work. The term non-plannable work is not restricted to work which it is not possible to predict in advance and make preparation for. Some predictable work consists of minor jobs or local regular routine work. It is usually uneconomical to consider expending planning effort on jobs of this sort. As a general rule, work which can be completed by a supervisor and his workforce without other than routine reference to other parts of the organisation, can be considered to be non-plannable within this definition.

What proportion of the total workload this represents will vary from one type of enterprise to another. However it is unlikely that more than 75% of the workload can be considered plannable. At the other limit, it should be possible to effectively plan at least 60% of the workload. There are two possibilities in considering how the planned and non-planned work should be distributed to the workforce.

The first alternative is to engage all the workforce on a mixture of planned and unplanned work. That is to give them sufficient planned work to fill part of their time. The second is to engage part of the workforce totaliy on planned work and leave the remainder to deal with the unplanned. While both schemes are used, the second approach is the one most often applied. The planning group in the second case would have a fixed number of men to schedule work for on a day to day basis.

Their purpose would be to supply to each supervisor, sufficiently detailed information each day on what jobs he is required to undertake. The supervisor must also provide a daily report on progress of planned work to enable the next day's work plan to be adjusted where necessary. The reporting and readjusting process is often best arranged on an informal basis between the supervisor and planner concerned. The daily programme can then be produced jointly between them. It is necessary that the programme is jointly agreed. Without such agreement, relationships between planners and supervisors are likely to become strained with both refusing to accept responsibility for any failure to meet work schedules.

Minor emergency work will normally be contained by the workforce not committed to a planned programme of work. Major emergency work is the greatest enemy of any maintenance and repair organisation. Such work demands immediate attention and major workforce effort. It will interrupt and delay planned work, interfere with scheduled programmes and generally lead to inefficient utilisation of manpower and equipment.

The planning group can make a major contribution in reducing the incidence of major emergency work through its inspection programme. However, allowing that even in the best regulated situations, emergencies will still occur, the planning group again contributes to the amelioration of the worst effects. By definition, planning is the process of preparing in advance for what may occur. By being aware of the work situation at any time, a well organised planning group can rapidly decide how best to deal with emergencies with the least effect

on the overall situation. The least important jobs can be stopped, facilities can be diverted with minimum interruption to other situations and on completion of the emergency the threads of interrupted work can be picked up.

Planning organisations are often severely criticised on the basis of the number of times planned work is not finished on time. While this must remain a measure of their achievement, it smust be viewed against the background of the re ponsibility and authority they are permitted to exercise over potential emergency work. If no attmept is made to reduce the occurrance of emergency work or to question the demands for such work, dislocation of planned effort is inevitable. Perhaps under these circumstances the only value of planning is the ability to reduce the effects of emergency work. Most planning operations are a compromise, depending on the views of senior management. None of them can operate with any real degree of usefulness unless they have the authority equal to that of any group whose operations they seek to influence.

Staffing of the planning group will consist of a number of levels. The senior man should be of a status equivalent to the plant engineer. Like them he should have a sound practical background, adequate technical training, and a working knowledge of the principles of management.

The planning staff themselves should be of similar status to the maintenance superivisors and have had an extensive experience of maintenance and repair work on the plant. It is probably a useful exercise to recruit planning staff from experienced supervisors. Interchangeability of supervisory and planning staff can be a useful asset to the organisation. Inspection personnel again should be equivalent in status to supervisory staff, with perhaps, if the size of the group warrants it, a specialist engineer in charge. Special training will be necessary to familiarise the staff with specialist equipment, but experience of operation and maintenance of the plant concerned is of value. The remaining duties can be adequately handled by clerical staff.

By being aware of the work situation, a well-organised planning group can rapidly decide how best to deal with emergencies with the least effect on overall situation.

Maintenance Improvement

If any industrial enterprise is to flourish it has to make progress in the face of competition. In addition, the continuous demand for upward progression in living standards requires an increase in per capita productivity. Consequently it is not acceptable for any part of the enterprise to remain static. There should be a continuous and purposeful effort towards self-improvement. This is equally true for the maintenance and repair organisation. The effort towards self-improvement is so essential to the future of the enterprise that it is insufficient to leave it to chance or individual inspiration.

It has been the practice over many years to invest the responsibility for improvement of the maintenance and repair organisation with the plant engineer. The success achieved in this way will vary considerably with the personality and temperament of the individual engineer.

The major drawback to this method of approach is the tendency for the plant engineer to be drawn into the pressing considerations of the day to day problems. It takes a good deal of self discipline for him to put aside his immediate problems and set his mind to next year's problems. Additionally, his line responsibilities demand some part of his attention, even under the most favourable circumstances, at frequent intervals throughout his working

day. His efforts towards self improvement then will be punctuated by these demands. The difficulties of producing satisfactory results in a reasonable period of time will be appreciated.

There is an increasing tendency nowadays to make the major effort towards self-improvement of the maintenance and repair organisation the responsibility of a separate staff group. The group will be referred to as the Maintenance Improvement Group. It is the responsibility of this group to formulate a programme for improvement of the performance of the organisation.

Input to this programme must be derived from all available sources. The most obvious source is the experience of the plant engineers themselves. While perhaps they cannot give the undivided attention necessary to develop improvement programmes, they are well able to identify areas where improvement is desirable. Very often, as they are technically trained men, they can offer a number of possible avenues of approach towards achieving an improvement. In addition to highlighting the problem areas, the plant engineer is well qualified to advise on the feasability or acceptability of the improvement proposals developed by the Maintenance Improvement Group. It is necessary therefore that the group keeps in regular contact with the plant engineer at all stages of the development of any proposals. Sometimes this can be continued on an informal basis. However, it is often found desirable to set up a formal means of stage approval of development proposals as a background against which to work.

An outline of such a formal procedure is contained in Appendix II together with a suggested means of formally initiating improvement proposals. A means for formally initiating work is necessary if the group efforts are not to be dissipated on following unprofitable lines of investigation. As can be seen in the Appendix, the initiator is required to state what objective is to be achieved and what value the solution will render to the organisation.

Circulation of the proposal within the organisation can avoid the possibility of following up lines which have previously proved unfruitful. it can also draw on the previous experience of others in suggesting likely avenues for investigation. The formality of filling in the initiation document, at least, forces the initiator to discipline his thoughts and think through his problem.

Supervisors can also be relied upon to provide input into the improvement programme. Their contribution is likely to be less disciplined than their plant engineer might make but is valuable, nevertheless. By cultivation of ideas from this section of the organisation, potential major problems can be identified in their early stages. There is a side benefit from a morale point of view. The supervisor feels able to make a contribution towards improving his own situation and the standing of the enterprise. In addition there will be no more enthusiastic protagonist for the installation and operation of the improved plant or procedure.

Certain pitfalls can be avoided by the formation of a Maintenance Improvement Group. Such pitfalls may exist in proposals for improvement based on impressions from supervisors and plant engineers, not substantiated by real evidence. When involved in day to day work, the immediate problems are the ones which fill the mind. The difficulties in dealing with them are more real than the problems themselves.

It is possible to find supervisors or plant engineers concentrating their efforts on eliminating a problem which, because it occurs infrequently, causes, them a lot of bother. At the same time, a regularly recurring problem which occupies a lot of the time of the manpower at their disposal causes them little concern, because it has become routine procedure.

The writer can recall a major pumping problem which was only highlighted when a particular craftsman left the firm. Until that time, this man had an almost continuous job tending three pumps. He knew them so

well that he was able to keep them in operation without any trouble to his supervisor or the plant engineer. When he left, the pumps suddenly constituted a major production bottleneck and were the subject of frequent major emergency work. On investigation it was discovered that the pumps were operating at 150% of their design conditions, that they were of obsolete design and that cheaper, more efficient and reliable pumps were available on the market.

Another avoidable danger is the temptation for a plant engineer to deal with problems which take his interest rather than those which merit most attention. Identification of which problems merit first attention can be made the responsibility of the Maintenance Improvement Group.

Of necessity, the major criterion for determining the relative merits of a number of proposals will be cost. Maintenance or repair costs incurred in the present situation and what reduction can be achieved by successful solution of the problem, need to be determined.

The maintenance and repair cost records are the source of the required information. If properly organised for the purpose, these records can also supply a valuable service to the Maintenance Improvement Group as source information for their improvement programme. The major cost components of the maintenance and repair bill can be identified and examined to determine the potential for cost reduction. Means of organising the maintenance and repair cost records will be discussed later. Cost of maintenance and repair alone will not be the only criterion which determines the priorities of improvement work.

It was stated initially that the maintenance and repair organisation must be recognised as an integral part of the process of production. It is equally important that the organisation itself recognises this and align the efforts to give optimum service to production needs. In many cases this will be achieved by maintenance and repair cost reduction. In other cases the optimum service will result from attention to production problems. Plant availability must be considered in relation to the market situation. With parts of the plant, the major problems may result from the amount of time the plant is not available for production rather than maintenance and repair cost. The Maintenance Improvement Group then must also inspect plant downtime records to isolate improvement work. A further source of material for the improvement programme is from technical literature, trade exhibitions, proceedings and meetings of professional societies, conferences and all the other communications media which exist in the fields of technology.

The Maintenance Improvement Group should operate a moinitoring service on all these sources. In addition they should act as a collecting centre or library for information of this type. It is valuable to ensure that information of value obtained during visits to conferences or manufacturers is formally reported by whichever of the technical staff attending.

Not only should the information be collected, it should be reviewed and potentially valuable ideas isolated. It is then necessary to ensure that the information is brought to the attention of those it will interest and is adequately discussed.

The efforts of the Maintenance Improvement Group should not be restricted to consideration of means of ameliorating maintenance or repair problems alone. Other subjects worthy of their attention will include:

(1) Organisation of the workforce.

(2) Distribution of the workforce throughout the factory.

(3) Maintenance workshop facilities.

(4) Maintenance equipment tools and techniques.

(5) Organisation of maintenance and repair staff.

Standardisation of plant and materials can lead to considerable savings to the enterprise.

(6) Staff and workforce manning strengths.

Maintenance Improvement Group duties can conveniently be extended to cover other activities by virtue of their role as a technical centre for the maintenance and repair organisation.

Standardisation of plant and materials is a subject which can lead to considerable savings to the enterprise. Selection of plant and materials besides being a matter of cost and availability, must also be based on technical aspects of its suitability for purpose. In collaboration with the purchasing function for the enterprise the Maintenance Improvement Group can contribute to standardisation programmes aimed at reducing procurement costs or improving material availability.

Formulation of standards for plant and materials will also assist whoever has the responsibility for plant improvement and extension work. In addition to providing standards for use for plant improvement an advisory service can also be provided to ensure that maintenance and repair needs are considered in new plant design. Manning of the Maintenance Improvement Group will, of course, be principal with technically qualified personnel. If they are to providea nd successfully conclude a sufficiently authoritative programme for improvement and cost reduction, at least some of the staff must be experienced in the work of the organisation. On the other hand the group is a good starting point for younger members of the organisation to come in contact with the problems and fit themselves for further responsibilities.

The Group will not have any line responsibilities but must be in a position to influence the activities of the line team. The manager of the group should then be responsible directly to the maintenance and repair organisation manager.

TRAINING

Artisans

It is unlikely that any industrial enterprise will find itself situated where there is unlimited labour available for its purposes, suitably trained and experienced in its particular line of business. If the location of the industrial enterprise is in an already industrialised area, labour experienced in the various disciplines required to make up a maintenance and repair workforce should be available.

Nevertheless, even in this situation the maintenance and repair organisation will find it necessary to carry out some form of training for its workforce. As with all the subjects discussed up to this point, the extent to which these procedures will be necessary will depend on the size of the enterprise. With training procedures, the formality of the training will also vary with the size of the enterprise.

With the smaller organisations as a very minimum there will be some form of induction training. This may only consist of a half hour talk between the employee and his supervisor. Following this, the employee will receive training in particular aspects of his work, in one form or another. He will come across plant with which he is not familiar. Particular hazards of materials being used in the process or manufacture will need to be explained to him and so on.

It is of far more benefit to the enterprise and to the employee if an attempt is made to give him this sort of information, rather than let him train himself through his mistakes. As

the size and complexity of the enterprise increases, so does the training need.

Although an enterprise may be fortunately placed so that sufficiently trained maintenance artisans are available to them, it will not be long before training needs arise. Training needs of maintenance and repair artisans can arise from a number of sources :

1. Induction training of new employees.
2. Training of new employees inexperienced in the particular circumstances, plant or process hazards of the enterprise.
3. Training in basic engineering skills for non-skilled employees or for youths entering industry for the first time.
4. Training the existing workforce to extend their skills.
5. Training the existing workforce to meet the needs of new plant or new techniques.

Induction Training

Induction Training is normally a fairly straightforward business of introducing the employee to his workplace. He needs to know where his workplace is, who his supervisor is, what his hours of work are, where toilet and canteen facilities are located, what his job and the purpose of his work group are and how it fits into the general operation of the organisation.

Other information he requires to know includes the rules he must obey, and what the consequences of failure to observe them might be. He will be interested in knowing what pay he is entitled to, what bonuses or premium payments he may qualify for, what additional benefits he derives from his employment, etc; if there is any form of pension scheme, what arrangements exist when he is unable to work through sickness. The ambitious employee will also be interested in what chances there are for his advancement through the organisation or the enterprise generally. An important aspect of his induction training should be to introduce him to the safety practices and rules which are observed in the enterprise. Safety at work will be discussed in more detail in a later section of the paper. The timing of the various aspects of this induction training is worth considering.

It is of far more benefit to an enterprise and the employee to give him proper training rather than let him train himself through his mistakes.

Some aspects are obviously necessary to deal with before the employee is actually set to work. This should be held to a minimum, he will have enough on his mind starting a new job without overloading him with too much information. The remainder of the subjects can be dealt with after he has had a few days to settle down and become familiar with his surroundings.

The best person to present the induction training to an employee is his supervisor. This gives both the opportunity of getting to know one another and gives the supervisor the opportunity of gaining the employee's confidence. However, it may be more convenient to organise some parts such as factory safety rules, welfare benefits and so on as group sessions with a number of new employees, the information being presented by the safety and personnel organisations respectively. These group sessions, however, must only supplement and not replace the supervisor's induction training.

Plant Training of New Employees

This training refers to the familiarisation of already competent new maintence and repair artisans with features of their new workplace they have not previously encountered.

This sort of training should be carried out on a strictly 'need to know' basis. The supervisor again has a responsibility here. It is the supervisor's job to discover exactly to what extent the new employee or employee new to his area of responsibility is familiar with the plant or situations he will meet in his new job. He is aware of the needs in his area and can, with experience, produce a check-list against which he can compare the new employee's experience.

Depending on the work needs it may be necessary for the supervisor to set about the training right away in some aspects. This training may consist of some instruction from the supervisor himself. He may put the employee to work with an already experienced employee (the "sitting next to Nellie" approach), or he may use a combination of these or other more sophisticated techniques, depending on the requirements. However, whichever method he adopts, it is always necessary for him to be aware of what instruction has been given and, more important, to test out the employee concerned to discover whether the training was effective.

Some of the training needs identified may be general needs applying to a number of employees. If this is so, a group session can be organised. It is probable that these needs will become well recognised after a while and a standardised programme or series of training sessions can be drawn up.

There is one thing these and other programmes aimed at imparting skills must have in common. All such training must first instruct, then be followed by demonstration and finally should be completed by the person to be trained practising the exercise to be learned. This enables the instructor to measure the effectiveness of his instruction and to reinstruct where the trainee has not absorbed the instruction first time.

Basic Engineering Skill Training

The need for training of this sort will vary considerably with the situation of the enterprise. Where skilled men are in extreme short supply, a major training programme may be necessary. Even otherwise it will probably still be advisable to undertake some training of this sort, particularly with youths with a view to providing skilled men for the future.

The needs of such a training programme will depend on the locally accepted application or division of skills between trade groups. Consideration of these factors is beyond the scope of this paper. However, Appendix III contains an example of a listing of skills required by a mechanical fitter prepared as a starting point for a training programme.

Training of this sort can involve a fairly substantial capital outlay in provision of training facilities and full-time training staff will be required. Every advantage should be taken of national or local schemes or facilities -or such training. Once the basic skills have been learned, a period of familiarisation and practice in the skills will then be necessary under suitable supervision on the factory. A programme for training youths, based on the listing of required skills is exampled in Appendix IV.

Training for Extension of Skills

A common feature of the workload of all maintenance and repair organisations is its variability and continued change. If the organisation were to be set up to deal with every possible eventuality in the best possible manner, the organisation would become a complete engineering enterprise in its own right.

Obviously this situation would be ridiculous. The aim should be to produce a flexible organisation which can tackle a wide variety of work. Machine tools and equipment should be general-purpose rather than specialised. Similarly,

artisans generally should have a wide variety of skills and not be restricted to single specialist disciplines. Industry in countries where development took place many years ago have suffered and in many cases are still suffering considerably from this sort of situation. Engineering crafts developed in a specialised manner and were adopted into industry.

There is a good opportunity for developing countries to avoid the worst effects by learning from others' mistakes. Every effort should be made to avoid building up artificial barriers between groups of workpeople based on the jobs they usually perform. Understandings must be reached with the workpeople that jobs will be performed by people suitably trained to do them. Additionally, these understandings must include the premise that training can be made available to whoever can benefit from it when the need arises.

In this way, flexibility of use and mobility of the maintanance and repair workforce can be retained. Depending on the sophistication of the equipment employed in the production process, it may be necessary to build up certain specialist skill groups. Though even here some flexibility in the arrangements for recruiting additional personnel to the section should be carefully considered. Training for extension of skills assumes some importance in this context of flexibility and mobility of the maintenance and repair workforce. Techniques employed in such training, again, will depend on the number of people requiring training at any one time and the complexity of the skill to be acquired. Training can vary from shopfloor instruction by the supervisor or a nominated artisan to classroom or training workshop sessions. The important feature of instruction, demonstration and practice must remian a common factor whichever means of training is adopted.

Training for New Plant and Techniques

This training need is self-explanatory and most of the foregoing remarks on means of training are equally applicable to this case.

Depending on the sophistication of the equipment employed in the production process, it maybe necessary to build up certain specialist skill groups.

Staff

The various sections which go towards making up the staff side of a maintenance and repair organisation will have various needs in terms of basic training and experience. Again it is not possible within the scope of a paper of this nature to go into detail of all aspects of training requirements. It is possible, however, to outline the background from which the various staff grades can be drawn and to indicate what further training needs may be required.

Induction Training

As with artisan employees, some form of induction training will be necessary. Because of the wider scope of duties encompassed by staff personnel, particularly as one passes up to the higher levels, the induction training programme will assume a much wider scope.

All the features of the simpler programme will remain—workplace, working conditions, rules, pay structure, additional benefits and so on. Additional information on the structure of the organisation and the enterprise and the interdependance of the various sections will be necessary. Administrative procedures, data collection and processing methods and general management policy and operation will also

feature to a greater or lesser degree at some time during the induction period.

Supervisor Training

In this context the background and training of the supervisor and any planning staff follow th same pattern as the author believes in interchangeability as far as is possible between these groups. Eeven where the personality of a member of one or other of these team precludes interchangeability, a thorough grounding in the oher's responsibilities is essential for adequate performance of his own duties.

The most satisfactory and successful means of recruiting supervisory personnel is from the workforce. One of the major demands in terms of background and training of the supervisor, the first line of management, is familiarity with skill requirements of the maintenance and repair workforce. Another almost equally valuable asset is familiarity with the plant.

Experienced members of the workforce fill this specification most admirably. As the major requirement for a supervisor is his ability to put the workforce to work, and to produce the necessary results, it is obvious that this background is not all that is necessary to produce the complete supervisor. In this context the author can do no better than refer to a paper presented to The Institution of Plant Engineers with the title "The Supervisor". See Appendix V.

Technical Staff Training

The background and training requirements for the plant engineers must be carefully considered. It is this staff group which besides carrying out an essential function, also provides the basis for the future of the organisation. It is perhaps well to consider not only the plant engineer in this context. The term as used up to this point has been restricted to one who performs a line function and to whom the supervisors report.

In the broader understanding of the term, a plant engineer is one who has responsibility for design development operation, maintenance and repair of plant. Within this definition one can include the majority of the technical staff that have been discussed previously. They are:

The plant engineer
The maintenance improvement engineer
The specialist engineers
The senior maintenance and repair management.

The background and basic training required for personnel to perform all these functions has the same or similar basis. The basic essentials consist of a combination of teennical education and practical experience.

The level of technical education required varies with duties required to be performed. Obviously someone engaged in design work will require a fairly high level of technical education.

Generally a minimum level of attainment will be sufficient for most duties. This level of attainment is specified by the entry requirements to professional bodies which cater for plant and various other specialist engineering disciplines. The technical education levels may be achieved through university or full or part time technical college education. This fact makes it possiole for advancement of personnel from the workforce as well as entry from university or technical college. The practical experience referred to is also considered an essential requirement. This is again clearly indicated by the entry requirements for the professional bodies referred to.

As far as personnel who have advanced from the shop floor are concerned, they are fully qualified in this respect. Most university courses which cater for engineering students nowadays also generally provide for a period of training in industry. On this foundation, as the young engineer progresses through the industrial environment, he will build experience and fit himself for jobs of increasing responsi-

bility. If he is fortunate he will join a progressive company with a policy of training for its potential senior managers.

The very least that the enterprise should provide is training in the essentials of management, and modern management techniques. This training should be planned and should be relatable to the management policy of the enterprise. It is a very discouraging experience for a young engineer, to attend a management course and on return to the factory to discover that his immediate superior is unaware of, or disinterested in, applying the concepts presented at the course. There is often a good case for sending the senior managers on the course first, following up with the same training for successively lower levels.

MANNING OF STAFF FUNCTIONS

If the maintenance and repair organisation is to be well equipped in terms of personnel to carry out its function adequately, the need must be recognised and action taken to meet it. Background and training of staff personnel has been discussed. Training must, however, be carried out on a planned and purposeful basis.

The first stage in the process is to decide what sort of an organisation is required, and what positions are required to be filled. At this stage it may be helpful to write job descriptions for the various posts. These descriptions must describe the responsibilities which the job carries and also the duties which are required to be performed. Some typical job descriptions for maintenance and repair staff functions are attached in Appendix IX. They relate to an organisation concerned with maintenance and repair of chemical process plant. Care must be taken in producing job descriptions that the key responsibilities are identified.

A satisfactory method of producing these within an existing organisation is to get the existing staff to write their own. They should be supplied with a questionnaire designed to encourage them to view their jobs critically. This exercise will make the incumbents think about what they do and at the same time will provide valuable information to senior management. The answers to the questionnaire will reveal any discrepancy between what senior management thinks their staff is doing and what they are actually doing. It should also help to identify where re-instruction with regard to responsibilities might be necessary.

Writing of the job description can then be completed by summarising the answers to the questionnaire. It is advisable at this stage for discussion of the questionnaire to be carried out between the man concerned and his immediate superior.

The aim here is to resolve what differences there may be in their view of the job. Though it is generally accepted that job descriptions should exist for every staff function within an industrial enterprise, there are certain hazards that must be guarded against. Indeed it is felt by some organisations that the hazards are so great that they write descriptions and keep them away from the person performing the jobs concerned. This, however, is an extremist attitude and provided the situation is kept under control, the author believes that well written job descriptions are of great value.

The major hazard referred to is, of course, that the job description is viewed by the incumbent of a post as the limit of what is required of him. This sort of person is not an asset to any organisation. This approach tends to destroy morale and team spirit, particularly if the person concerned is in a position in control of others.

A job description must be seen as the minimum that is required of the incumbent if he is doing his job adequately. Reward for good performance should be based on achievement in excess of the job description requirements. Armed with an understanding of the sort of organisation required to undertake maintenance and repair in our enterprise and also with the job descriptions, we can now consider how we are to man the organisation. It is not often

that the situation arises where a complete new organisation is required. More often the situation is one of re-shaping an existing organisation. Whichever is the situation, the problems remain somewhat the same. A man must be found with the required background and training to fill the post. If the man is not available within the organisation he must be recruited from outside. It is seldom that anyone will fill the specification fully in every detail. The important thing is that anyone selected, with perhaps suitable training, can develop to the stage where he can perform the job required of him. The requirement that a man can develop to fill a post adequately, leads on to a most important factor to be considered in selecting personnel. That the person selected has the personality and physical qualities to suit the job requirements.

With regard to physical qualities, good health is, of course, always desirable. Dependent on the industry and the duties to be performed various other physical characteristics may be desirable. For instance defective vision can be a serious hazard in any job where the person is expected to spend time in areas with moving machinery, hearing defects where mobile equipment is in abundance, fear of heights or tendency to dizziness in jobs requiring the climbing of scaffolding, claustrophobia where entry to confined spaces is required and so on.

Personality is a much more difficult thing to judge but nevertheless an attempt must be made to match the personality of a candidate to the job required of him. With maintenance and repair work, two particular personality characteristics are necessary, because of its role in an enterprise. These characteristics are a sense of responsibility and the ability to recover quickly from disappointment or adversity. The incidence, particularly of repair work, cannot easily be regulated. The demands of production also generally tend to require attention to trouble whenever it occurs.

Maintenance and repair management must often depend on the sense of responsibility of its engineers to apply themselves to the job whenever it occurs and to follow the job through to completion, whatever this requires in terms of time. The engineer, of course, must be adequately compensated for his efforts, but money cannot buy this sort of service if a sense of responsibility is absent. Maintenance and repair work has other features, which doom the personnel in the organisation to frequent disappointment. Neither can they expect much recognition of their efforts from outside the organisation. Maintenance and repair is a constant battle with deterioration. The deterioration the organisation fights is a continuous process resulting from age, fair wear and tear, misuse, deliberate abuse and weather conditions, to name a few circumstances that readily come to mind. This is a battle which is never won. At best, the organisation can derive satisfaction from the effectiveness of its delaying actions.

That plant will ultimately fail is the inevitable fact which the maintenance and repair organisation faces. When the failure occurs, more often than not, the production staff view this as a failure by the maintenance and repair organisation. In their anxiety to resume production they will seldom recognise even outstanding effort to return plant to service. Because of the exigencies of production, often a job cannot be completed in the best "engineering" manner. Compromise between what the maintenance engineer wants and what he must do is often necessary. He will often see his best efforts reduced to nothing by the use to which the plant is put and he will then be expected to pick up the pieces and start again. With a man of the wrong temperament or personality these circumstances can quickly result in frustration, dissatisfaction and in the ultimate even to mental or physical illness.

The maintenance engineer then must be imaginative but confident in his own ability. He must be able to derive satisfaction from carrying out his duties in a responsible manner. He must be able to accept criticism without worry but at the same time he must not completely ignore the fact that criticism has been made. He should use this as a basis for a critical appraisal of his own performance with a view to improvements. As stated previously,

such characteristics are difficult to determine. However, tell-tale signs of the effects of the job strains can often be detected before serious harm to either the person or the organisation occurs. If this happens, the person can be transferred to other functions within the organisation where these strains are not so great.

Generally it is the plant engineer who carries the brunt of this effect. The Maintenance improvement engineer will not be subject to the same pressures. The job characteristics described do not have any ill effect at all on someone suited to them. In practice a plant engineer who is temperamentally suited to the job derives great satisfaction from it, and will not readily change to other responsibilities. In manning the organisation one must take all these factors into account, making the best compromise possible. Training needs to develop personnel better to carry out their duties must be identified and the necessary training organised. This is the first part of the manning operation. The second part is to consider the future needs of the organisation. The future plans for the enterprise may require an increasing maintenance and repair service.

Some members of the organisation may be due to retire. Certainly some members of the organisation will be looking for the opportunity to take on increased responsibility. Apart from these predictable or visible circumstances, allowance must also be made for the unexpected. Personnel may resign, become ill or be involved in accidents. At any time there may be a need to fill a key post in the organisation. Plans must be laid in advance to deal with such situations. Possible successors to the key posts must be identified. Training and development of such people must then be organised to fit them for these posts.

If suitable people are not available, recruitment of people with the necessary future potential must be the policy when the opportunity arises of engaging new staff.

MAINTENANCE AND REPAIR FACILITIES

Having considered the organisation, manning and training of the maintenance and repair personnel we can now consider the facilities they require to do their work effectively.

Workshop Facilities

Workshop needs will vary considerably with the size and disposition of the maintenance and repair organisation and also with the type of enterprise it serves. It is possible, however, to discuss guidelines which should help in deciding what the needs are for any particular enterprise. Discussion of the possibility of organising the workforce into centralised or area groups touched on the subject of workshop facilities and gives us our starting point.

Maintenance and repair work can be divided into two main groups : Firstly that work which is carried out on the plant which doesn't require the equipment to be transported from its operating situation. The second goup is that which requires the work to be carried out on plant removed from its normal operating position.

Most maintenance and repair jobs require a combination of both on and off-site work. The first group, the on site work, will be discussed under the heading "On site facilities". The second group of work, that conducted away from the plant operating situation will normally best be carried out in a workshop.

Area Workshops

If the maintenance and repair workshops are divided into area and centralised goups, area workshops will almost certainly be desirable. Even in the circumstances where the total workforce is concentrated into a centralised group, area workshops may be desirable.

The primary requirement here is for a designated place where maintenance man can do benchwork jobs. Such a workshop then must be provided with suitable workbenches equipped with vices, suitable for the type of work to be undertaken.

Other facilities will also be found necessary. These may include:

Fixed floor or benchmounted grinding wheels
Pipebending facilities.
Powered screwing machine.
Turning facilities.
Fixed floor or bench mounted drilling machines.
Portable powered tools.
Hand tools.
Lifting equipment.
Spare parts stocks
Engineering material stocks
Special clothing stocks
Storage and drying facilities for clothing
Drawing storage facilities
Office facilities—desks, files and telephones.
Washing facilities
Men's room facilities

Not all area shops will require all the facilities referred to and the sophistication of the facilities will vary considerably. Appendix VI contains lists of typical facilities contained in area workshops in a fairly large chemical processing factory. Some explanation of the purpose of the facilities listed is perhaps relevant.

Grinding wheels are probably the most commonly used powered engineering tools and are probably used equally by most trades. In general they will be used for the rough removal of metal and for sharpening tools. Whenever it can be justified a fixed floor or bench mounted unit should be provided. It is more readily available for use than portable equipment and generally safer to use for most purposes. The hazards associated with use of grindstones are well known and well documented.

When area maintenance and repair work is likely to include pipework, normally a hand powered hydraulic pipe bending rig with a capability of bending up to 3" bore piping is suitable. Powered bending equipment would not normally be justifiable for the small scale needs usual to a small area group. If pressure testing is required a small hand operated hydraulic test pump may be justified.

It is often the practice to use screwed pipework on small bore low pressure systems. If this is the case and work load warrants it a small powered pipe screwing machine can be a useful asset.

If there is a frequent need for turning small parts for skimming seatings and so on in a particular area a small lathe may be justified. This should be for general use rather than being manned full time by one man. Normally it is unlikely that area workload needs would keep the lathe in sufficient demand to justify its installation.

Drilling facilities are almost certainly necessary in any area maintenance workshop. Fixed floor or bench mounted units fitted with a suitable work vice and with a capacity of up to $\frac{1}{2}$" diameter are usually most suitable.

A range of portable power tools can probably be justified for area workshops, particularly if "on plant" power supply facilities exist. Suitable power supplies in the workshop will also be necessary to gain most advantage from the tools.

Compressed air powered tools generally have a greater power to weight ratio than electric tools. They also have distinct safety advantages both in their absence of electrocution hazard and the capability of their use in areas where fire or explosion risks exist. Because of the capital cost of supply of compressed air for tool puposes it is more likely that electric power will be available. Use of portable transformers and low voltage tools will reduce electrocution hazards or alternatively portable monitored earth systems can be used with higher voltage and consequently more powerful tools. Most usual tools found suitable for this sort of use include drilling machines, grinding and sanding machines, hammers and impact wrenches. If neither electric or pneumatic power are available on the plant, battery powered tools can often be useful.

The effectiveness of the maintenance workforce will be greatly influenced by how well they are equipped. Hand tools should be good quality and suited to workload needs. Where justifiable, personal sets of tools for the workforce have the advantage that the men concerned will look after them. With tools in less frequent use, a shop tool stock will be necessary. For example for special spanners, heavy hammers, stocks and dies, long tape rules and so on.

Lifting equipment will be required for many operations. It is often useful to have the more frequently used items available in the area workshop. A light hand powered hydraulic crane can be very valuable and possibly also a hydraulic scissors platform, capacity of both about 1 ton. Lifting blocks say up to ½ ton capacity and pull lifts up to 1½ ton capacity are inexpensive and useful site tools. A variety of suitable slings, eyebolts, cleats and any special lifting strongbacks will complete the requirements.

A stock of spare parts which are in frequent demand can usefully be retained in area shops to avoid delivery delays from the main stores. Stocks should be the very minimum necessary, certainly no more than would be required during an average week. Anything more than this will result in taking up valuable working space and increasing spares inventory by duplicating the function of the main stores.

Effectiveness of the maintenance workforce will be greatly influenced by how well they are equipped.

As with spare parts, a stock of general engineering items in regular demand can be a useful asset to an area workshop. Again stocks should be limited to about one week's supply.

Certain maintenance and repair operations may require the wearing of special clothing. For example, gas or dust masks, eye protection, gloves, acid-proof suits, rainwear or perhaps clean room clothing for dust-free operations. A minimum stock of such items should also be considered.

It will be necessary for the workforce to have facilities for storage of their street clothing while at work. This storage can also be used for storage of work clothing during off duty hours if suitably adapted. Dependent on climatic conditions it is often useful for the storage area to be adapted to drying this clothing should it become wet. If central facilities are not provided it will be necessary to supply them in or adjacent to the workshop.

Facilities for storage of plant detail drawings and for spreading them out for examination are necessary. Use of a workbench for examining drawings is not usually suitable. Drawing stocks should be restricted severely to those likely to be required regularly or in an emergency. Original drawings should not be retained in any workshops. Copies only should be used.

Operation of an area workshop will usually require some basic office equipment for the supervisor to use. He will need a desk top and a chair to use for his administration and reporting work. A file for instructions, notices and report forms of various types will also be necessary. A telephone for factory internal communication is necessary. A noticeboard for general workshop reference will also be necessary. Often a blackboard and chalk will be found to be useful for discussion purposes.

If central facilities are not provided, washing facilities will be required in or adjacent to the workshops. Provision of a suitable hand cleaning material for use with cold water can be useful. However, the additional provision of

hot water supplies is preferable. Disposable paper towels will avoid the considerable problem of laundering. They can also serve the dual purpose of being available for general use in the workshop.

Again in the absence of central facilities, provision of mess room facilities at or adjacent to the workshop may be necessary.

For the purposes of effective control it is usually preferable to have the clothing, washing and mess room facilities visible from the workshop. Either a segregated area of the shop or a partition with sufficient windows will meet this need.

Central Workshops

As mentioned during discussion of organisation of the workforce it is usually convenient to concentrate high capital equipment in centralised areas where maximum use of them can be made. Due to the frequent needs of major work to involve the services of a number of work groups, it is preferable to group all the centralised workshops together.

For example, a job may involve fitting, turning, welding, sheetmental working, brickwork and painting. Grouping the shops together will limit the amount of transporting and walking involved. Grouping of the engineering stores and spares stocks and also welfare and mess room facilities in the same area is also desirable. The location of this central complex should also be considered in terms of its accessability from the plant. In addition, positioning and size of entrances in relation to roadways, size of plant likely to be transported and transport facilities likely to be used should be considered. Provision of storage facilities for plant awaiting repair, delivery of spares or reinstallation should also be taken into account.

Let us now look in a little more detail at the sort of workshops we might need. Appendix VI contains details of the facilities in the central workshops complex at a chemical factory.

MACHINE SHOP—It is unlikely, except in a very large works covering a large area, that it would be justifiable to have anything other than small or special-purpose machine tools in area workshops.

In most circumstances it is advantageous to concentrate the machine tool facilities in a central shop. In this way maximum use can be made of the tools and in most cases it is possible to keep men fully employed on operation of individual machine tools. Use of specialist tradesmen in this way has advantages in raising the quality of work produced from the machine tools and also extending their useful life. The machine shop will be principally engaged in the manufacture of spare parts from stock material. In addition there will be work involved in the repair of existing equipment. boring out parts for bushing, preparing ends for welding and so on. Generally the workload will be varied and unpredictable.

Because of the variability and wide range of machining operations likely to be required to satisfy all the needs of maintenance and repair, the machine tools should be capable of a wide range of use. Lathes certainly will be necessary. In all probability two ranges of size will cover most needs unless there is a particular piece of plant to be maintained. The aim in selection of lathes should be maximum flexibility in speed range covered and screw cutting facility, maximum length between head and tailstock and maximum swing over the bed. A pillar drilling machine again will almost certainly be necessary. The maximum size of drill required will be governed by the work requirements. For instance, the maximum diameter of heat exchanger tube in use may be the criterion. Generally 1½ inches diameter should meet most cases. Again speed range should be as wide as possible to cover a wide range of materials to be worked on.

Siting of the drill should give maximum access with maybe a pit included within the arc the drilling head will cover. The pit would

normally be boarded over and only uncovered when required.

Metal planing or shaping machines are usually a useful attribute and also milling machines. With all these tools the aim should be to obtain a machine with a wide range of use and adaptability. Other equipment which will be necessary include floor or bench-mounted grindstones, both for general use and one especially for tool grinding purposes. An attachment for drill grinding is also useful.

A means for cutting off bar stock will also be necessary. Depending on the size of the shop, either a powered hacksaw or a circular cold cut off saw will be most useful. Abrasive cut off machines, hand saws and fusion saws generally will not produce a sufficiently square cut for workshop use.

Depending on the sort of work required it may also be found useful to use vertical or horizontal borers, surface grinders or other specialised tools.

If these sort of tools are not in frequent demand and there are local machine shop facilities outside the factory, it may be more economical to contract the work out. A thorough examination of the likely range of work required and local facilities should be made before equipping the workshop. Equipping the workshops complex with power supplies greatly increases the flexibility of their use.

Provision of welding power sockets, monitored earth electrical supplies or low voltage supplies, compressed air and possibly fuel gas can be used to advantage. Lifting facilities in the form of either a gantry crane serving the full length of the shop or jib cranes sited over particular machines will almost certainly be necessary. The choice of crane, capacity and whether power or hand operated will depend on the workload to be handled.

If a gantry crane is to be made use of, it may be advantageous to site shops in line and allow for passage of the crane from one shop to the next. An extension through an end door onto an open unloading area will also be of great advantage.

It is often convenient to combine the machine shop with a fitting shop.

FITTING SHOP—It is often convenient to combine the machine shop with a fitting shop. This shop will principally be engaged on the dismantling and reassembly of items of plant. The dismantling reveals what spares are required to return the unit to working condition. Often machining work will be necessary to manufacture special spares or to bore out housings and make bushes. With the machining and fitting work under the same supervision, planning of throughput and machine loading becomes a simpler operation. The main features of the fitting section of the shop will be sturdy benches with suitable vices. Equipment will be required for degreasing and cleaning parts and possibly sandblasting.

If equipment is likely to be very dirty externally on leaving the plant, special facilities will be necessary for cleaning before delivery to the workshop. Gas freeing can also be crarried out in the same location. The requirements here are an open area, with good road access, steam and water supplies, good drainage facilities with the means of trapping solids to avoid drain blockage. If oils or chemicals are likely to be contained in the run off to drains, consideration must be given to the means of its safe disposal.

Within the shop itself there is a need for an open floor area in which to carry out dismantling operations on larger items which cannot be

mounted on a bench. This area should be served by lifting facilities. A small power or hand operated hydraulic press is an exteremely useful tool for this workshop both to aid in dismantling and re-assembly of parts.

In maintenance and repair work, good use can be made of thermospray systems for building up worn parts. It is often useful to put aside an old lathe for this work. If possible it should be located away from the other machine tools. If this is not done, the sprayed material may find its way onto machine beds and so on, producing accelerated wear.

FABRICATION OR WELDING SHOP— If it is possible to site shops in line to take advantage of a gantry crane, the welding shop should be sited next to the machine fitting shop.

It is usually convenient to combine facilities for fabrication of equipment with the general welding shop. As the fabrication will often include sheet metal work, facilities and craftsmen for his purpose should also be included. It will be found that the major part of the welding work required can be dealt with by electric arc stick welding methods. However, some use will be made of oxy-acetylene welding particularly for sheet metal work. In addition gas shielded arc welding such as argon arc will be useful for non ferrous applications. Other techniques which it is usually necessary to have available will include soldering, brazing, leadburning and almost certainly hot gas welding for thermoplastic materials. Oxy-acetylene burning facilities will also be necessary for plate and bar cutting and preparation for welding. If a significant amount of vessel fabrication is carried out arc gouging equipment will also be useful. Usually the maintenance and repair welding workload seldom consists of jobs of such magnitude that the speed of applying weld metal plays any appreciable part in the cost. Although CO_2 or argon shielded M.I.G. welding techniques can result in appreciably reduced times in completing a welded seam as compared to stick electrode welding, for general use it is seldom advantageous. With short run and anything other than easy to get at seams, the time lost in setting up outweighs its other advantages. However, if there is likely to be a regular workload such as frequent vessel fabrication or large bore pipework fabrication this type of equipment will prove advantageous.

In addition to shop welding, there will be a need for on-site welding work. The ideal arrangement would be to have welding power outlet sockets installed throughout the factory. Mobile welding transformers can then be plugged into these as required. If this is not feasible a number of self powered portable or mobile sets will be necessary. The ventilation system in the welding shop must be given particular attention in order to reduce fume nuisance. Apart from the normal fume production from welding and burning poperations, with equipment for repair, there is often oil and chemical contamination to be dealt with. For 'on site' welding work there will also be a need for ventilation or exhausting equipment in some cases. Electric or compressed air powered fans or compressed air powered air movers will meet this need. Sheetmetal working equipment should include a guillotine, hand or power operated dependent on workload, folding, rolling and shearing machines. Space will be necessary for material storage, a marking out area, a fabrication area, workbenches for welding and sheetmetal working. The welding workbenches should be suitably screened to prevent arc flash injuries. Prortable screens will also be necessary for general use in the workshop.

A useful asset might be small furnace which can be used for hardening tools and small components. It is usually most convenient to site this in the welding shop where the ventilation system can cope with the heat load. A properly organised tool and material store will also be required to serve the needs of both the machine and welding shops. If the shops are of any size, a full time storekeeper who can service and carry out minor repairs can usually be justified. As the sort of equipment contained in a store of this kind is easily carried and can usually realily be sold, good security is essential. Besides easily accessible, dry, clean racking, the store should contain heated facili-

ties for storage of the conated stick electrodes required for welding.

WOODWORKING SHOP—The need for woodworking facilities will vary considerably with nature of the factory to be served. As a minimum there will be a need for a workbench and timber store and a circular saw. If there is an appreciable workload, a bandsaw and planing machine may be required. Whichever is the case, a selection of portable tools will be useful. The shop should-then be supplied with the appropriate, suitably protected power supplies. In this shop also, an extraction system will be necessary, in this case to remove sawdust.

FIELD WORKSHOP—If the maintenance and repair organisation includes a centralised workforce to be used on factory-wide work, it will be necessary to provide workshop facilities for them. While on site they will be able to utilise facilities available in the area workshop nearest to the worksite for minor work. However, as the centralised force will be engaged on the more major repair work, they will require rather more sophisticated workshop facilities than are provided in area workshops: For pipework fabrication, a powered pipe bender, powered screwing machine and a cut off device. Again, either a powered hacksaw or cold cutting circular saw is preferable. Additionale quipment may be required dependent on the size of the workforce.

A cold flanging machine is a most useful tool for pipework fabrication. With this, flanging of pipework can be carried out without the need for welding services. To use this machine effectively pipework material must be of consistent outside diameter; it should be cut off with square ends and be rag free. Provided these conditions are met, sound flanged ends can be produced in a few seconds for most services up to 150 psig. Steelwork fabrication is another likely service required from this workforce. The requirements here are less exacting. An abrasive cut off machine or a band saw will usually be sufficiently accurate for this work. Of course an additional machine would only be necessary if the workload justified it.

With steelwork fabrication a pillar drill with a capacity of up to 1" diameter may well be found necessary. Steelwork requires a good level surface with preferably a lifting jib with capacity of approximately $\frac{1}{2}$ ton. It is often useful to include welding facilities in this shop with perhaps one or two welders employed full time. Despite the value of a flanging machine, there will still be a constant need for welding for pipework. Pipe brackets and steelwork will also provide a regular welding workload. The welder should be allotted a section of the workshop with a bench, some floorspace and provided with suitable screening.

Associated with the workshop there should be storage space. This space is needed for holding stocks of tube and steel sections for immediate use. Stocks should be replenished on a weekly basis to avoid the need of journeys to the stockyard whenever a job comes up. Space is also required to store completed work awaiting installation. This storage area does not necessarily need to be in the workshop. All that is necessary is that it is within easy reach of the shop doorway and is readily accessible by road.

Preferably the area should have a good concrete surface. The necessity of providing cover would depend on the nature of equipment likely to be stored, the prevailing weather and the periods of time of storage likely to be involved.

ELECTRICAL WORKSHOP—Specialist groups such as the electrical workforce, because of the relatively small numbers of men involved are usually best organised on a centralised basis. Occasionally where particular circumstances make it worthwhile small area workshops may be justified. Equipping of such area shops will be basically the same as for the general maintenance workshops. Additional items related to the specialist activity will, of course, be necessary. A conduit vice and bender may be necessary and also crimping tools. Solder-

ing facilities and means of melting sealing compound will almost certainly be required as also will be portable continuity testing devices. Spare parts and supplies again will be related to needs of the area served by the workshop.

As with the other centralised shops, the central electrical workshop will contain the more sophisticated items of equipment. This will include fixed facilities for continuity and earth testing; lifting equipment for electric motor handling and possibly facilities for motor rewinding if this service cannot be obtained locally.

INSTRUMENT WORKSHOP—Only under very special circumstances would it be justifiable to establish an area workshop for instrument work. Generally instrument maintenance requires fairly sophisticated and expensive testing equipment. In addition clean working conditions are essential if maintenance is to be effective. The types of equipment required will depend very much on the instrument systems which it is required to maintain.

With increasing use of electronic control the training needs of instrument maintenance men are increasing, and also the sophistication of the testing and calibrating equipment. However, the difficulties can be eased enormously if standardised maintenance procedures are developed and employed.

Despite the increasing use of electronics, pneumatic controls still represent the major part of the systems in use. Even with these systems, use of standardised maintenance procedures will reduce the training and maintenance problems appreciably.

RIGGING STORES—Rigging work, that is, the more specialised operations concerned with the moving of equipment, will all be carried on around the factory site. There will consequently be no need as such for a workshop for riggers. However, if a special team of lifting specialists is necessary they will need a base from which to operate. More important, a recognised storage area will be required for their rigging equipment.

This area should be dry and racking should be provided so that equipment can be stored off the floor and readily accessible both for use and for inspection and cleaning. It is important that the job of inspection of rigging equipment be the first priority responsibility of one man suitably trained for the job. The consequences of lifting gear failure in use can be extremely serious both in terms of property loss as well as life and limb. A register of all items of lifting equipment must be kept and all the items should be identifiable against the register. A regular schedule for inspection of all equipment should be operated and unserviceable items withdrawn from use for repair or replacement. Such a register and inspection routine are mandatory in the U.K. and other countries. The statutory regulations in these countries form a useful reference for instituting a procedure where no legislation exists.

It is often useful to include scaffolding and access equipment within the responsibility of this group. Many suitable systems of quick erect scaffolding are now available besides the more conventional tube and clip system. Whichever system suits the situation best, adequate storage space will be required and inspection of the equipment whenever it is returned from a job. Together with the scaffolding framework, timbers will be required to form walkways and toe boards on the finished structure and also ladders for access. As many maintenance or repair jobs are necessary in confined or inaccessible places, scaffolding timbers and even ladders get cut up into short lengths and are mutilated in other ways. Often through handling operations with heavy equipment, boards might be split or cracked and ladders damaged. Spillage of oil or chemicals can similarly have a deleterious effect on the timber. For all these reasons it is also essential to carry out regular inspection of equipment in use.

The provision of a central storage area with a responsible person in charge makes it possible

for these inspections to be carried out. It also provides for control of the inventory of all lifting or access equipment. Missing items can be noted and searches can be initiated. With items in constant use on the factory or with scaffolding structures in use over a long period, the inspections must be carried out in *situ* at the predetermined regular intervals.

TRANSPORT WORKSHOP—An essential feature of any maintenance and repair organisation is transport. In its most simple form it may consist of perhaps a sack truck or handcart. The possibilities range wide from this starting point depending on the size of the organisation and the work to be done.

The purposes for which the transport or mobile equipment may be used are simpler to enumerate than the variety of vehicles available to fill the need. The main aim in selecting the vehicle is maximum flexibility of purpose so as to ensure maximum utilisation with minimum capital expenditure.

For example, personnel carrying, carriage of small items, carriage of heavy equipment and say snow clearing could require the provision of a mini bus, a van, a lorry and a tractor. All the same duties could be carried out by use of a utility vehicle suitable for towing and provided with power take off, together with a suitable trailer. Besides the duties mentioned in the foregoing paragraph, mobile equipment may be required for lifting, access, earthmoving, bulk material tarnsport and material handling. In addition to the maintenance and repair organisation, other functions within the enterprise will have transport needs. These will include personnel carriers, mechanical handling equipment both in plant and in the warehouse, fire tenders, factory internal goods transport and possibly even an external goods fleet. If the factory is served by rail, shunting locomotives for the factory sidings may be necessary.

The first aim with regard to maintenance of factory transport should be to contract out as much as possible to specialists in the field.

The first aim with regard to maintenance of factory transport should be to contract out as much as possible to specialists in the field.

Owing to local circumstances this may not always be possible. Even when it is possible, routine maintenance servicing jobs are better carried out on site and some facility is necessary for immediate repairs when time cannot readily be made available to fit the contractors' programme.

The transport maintenance workshop should then be provided with facilities in line with the needs. Essentials will include the general engineering accessories common to all maintenance workshops, that is, grinding and drilling machines, power tool facilities, lifting facilities and so on.

In addition at least one inspection pit will be necessary, provided with a suitable means of covering when not in use. Other features should include a ready means of removing road dirt and accumulated grease, a degreasing tank for disassembled parts, well ventilated battery charging facilities and distilled water supplies, tyre changing and testing equipment, high pressure greasing equipment, spark plug cleaning and testing equipment and wheel alignment checking gear.

Oxy-acetylene welding equipment should be available for bodywork repairs and extension handlamps suitably protected against damage and short circuit. The hazards of using both these items and power tools in the vicinity of gasoline should be clearly understood by all concerned and adequate precautions taken.

The inspection pit is an extremely hazardous area in this respect. Steaming facilities for gas freeing of fuel tanks before any repairs are undertaken should be provided outside the workshop itself. Another serious hazard to be guarded against is the carbon monoxide generated when running vehicle engines. Within the workshop, engine operation should be prohibited except for driving in and out when the doors should be open.

If it is necessary to test run engines in the workshop, and exhaust extract system should be provided which can be connected to the vehicle exhaust and discharged outside the workshop.

Finally some means of collecting and disposing of waste sump oil is required. Depending on the quantities involved it is possible, with a suitably designed boiler, to make use of it for space heating purposes.

Storage facilities will be required for spare parts, engineering goods and supplies and for tyres, oils and greases. Generally a good deal of both convered and open parking areas are usually found necessary. This would be for vehicles awaiting spares and for those whose size or shape make it difficult to fit into the workshop when requiring servicing or maintenance.

"On Site" Facilities: Much "on site" work will be of a minor nature. This minor work will include true maintenance work, lubrication adjustment of wearing parts and so on. In the repair category, the minor work will be that which can be carried out on the plant with a minimum of facilities.

Facilities in these circumstances will only be what the maintenance and repair crew can conveniently carry with them.

More complex work which is best dealt with in a workshop will need "on site" facilities for removal of the plant from the operating situation.

Major plant shutdown work also generally involves extensive "on site" work. Because the plant is out of service, working conditions are favourable and with major items of plant removal to a workshop is expensive. Finally, work on certain major items of plant, for example, boilers, would always be "on site" work. Some facilities for major "on site" work will be installed in the plant location. Other facilities will be transportable from one operating unit to another.

Fixed equipment will include lifting beams. Depending on the frequency of use they may be fitted with lifting trolleys, blocks or hoists. Other fixed facilities might include pipework to supply compressed air, water, gas or steam or to vent equipment or provide drainage. Provision of such facilities would depend on the frequency of the work and the possible savings.

Portable facilities would include portable tools as described in the workshop discussion. Portable benches with vices and tool box trolleys can be provided. Scaffolding, ladders, stepladders and possibly hydraulic access equipment will be necessary. Lifting equipment might include jacks, winches, hoists and lifting blocks. The workshop equipment lists in Appendix VI details such equipment.

A mobile materials and tools stores which can be parked at the plant will be useful in reducing stores trips on major jobs.

Office Facilities

The office facilities required by the maintenance and repair organisation will depend both on the size and type of organisation which is set up. The office facilities required by supervisors in the workshops have already been mentioned.

The remainder of the maintenance staff should be housed together wherever this is possible. The siting of the central office facilities probably is most suitable adjacent to the central workshops complex. By siting here,

communication between the major part of the organisation will be simplified. The staff functions which are to be housed in the central office will include the senior management, the maintenance improvement group and the planning group, the secretariat and maintenance files.

By grouping in one building, the identity of the organisation as a single team with a common aim can be best preserved. Secretarial facilities can be shared to ensure maximum utilisation and duplication of files can be avoided. An "open plan" office system can be adopted with value for both the maintenance improvement and planning groups. By this means maximum contact between the members of the teams can be encouraged to avoid duplication of effort. The planning group will be encouraging frequent and regular contact with the supervision and workforce. For this reason it should be readily available from the workshops, without the need for people to pass through other sections. In addition, soundproofing between this section and the rest of the office should be adequate.

Apart from sufficient desks and filing cabinets the office facilities should include storage for drawings, table space for studying them in each office area, and sufficient drawing boards and equipment to meet the casual needs of the groups.

If facilities are not available elsewhere in the enterprise and are not locally available it may be necessary to install facilities for dyeline reproduction of drawings and reproduction of documents within the planning group, wall area will be necessary for display of charts and programmes. Great use is made in some planning offices of wall displays of maintenance schedules and programmes. Use of such things while looking most impressive are of questionable value unless they are carefully designed to achieve a particular objective. They are only justifiable if they carry out a necessary function which cannot be achieved better in any other way. All too often they are merely toys which are the pride and joy and sole preoccupation of one man and duplicate a job which is being done initially on paper. A document which can be reproduced and distributed for ready reference is often of far more use.

Planners generally need to make sketches. Provision of sketch pads printed with a squared or isometric pattern can be very useful. Another useful tool is a polaroid camera which can often be used to eliminate the need of sketching altogether. Little in the way of special facilities will be necessary elsewhere in the central office, apart from perhaps a desk calculator or two in the maintenance improvement section.

The subject of communications can perhaps be briefly discussed in this section. Telephonic communication between the centre and the various branches of the organisation and with the operations they serve will be necessary. A recording device to receive non-urgent messages can be a useful asset for use of work requests and instructions. External telephone links will be required also, particularly for the maintenance improvement group and senior management.

A radio link between the planning group or the transport supervisor and the maintenance transport fleet can pay dividends on a large site. Similarly a personnel radio call system used in conjunction with the internal telephone system can greatly reduce the frustrations of difficulties in contacting key personnel quickly. It also frees them from the discipline of leaving frequent clues to their likely future location.

These systems, however, do represent a fairly high investment and require fairly sophisticated maintenance techniques in themselves if they are to remain serviceable.

MAINTENANCE AND REPAIR TECHNIQUES & POLICY

The policy of any maintenance and repair organisation must be to aim to maintain opera-

When malfunctioning is detected of sufficient seriousness to affect production, action to correct the situation should be instituted.

tional plant at the required level of availability at the lowest cost. This is a very wide ranging statement and is of little value in determining action to be taken in any given set of circumstances which may arise during a day's work.

It is necessary, therefore, to determine certain lines of action or strategy to be applied as general guides in everyday decision-making, which in themselves will guide the organisation towards the general objective.

Maintenance, Repair and Replacement

Gernerally with any item of plant it is possible to adopt one of three courses of action or a blend of the three, to ensure availability as required. Whichever policy is to be used with a particular type or item of plant must be determined in relation to a number of factors.

Maintenance

It is possible to apply maintenance to almost every item of plant in the form of routine servicing, that is lubrication, adjustment and so on. However, in this context we are considering the broader meaning of the term.

With major items of plant which have a critical role in the production sequence, a scheduled maintenance approach is necessary. Other factors which qualify plant for scheduled maintenance treatment will include:

(a) Items whose failure in service could lead to extensive damage and property loss. For example, high speed rotating machinery such as steam turbines, vessels operating under high presssure of lifting equipment.

(b) Items whose failure in service could lead to serious hazard to life and limb apart from those hazards in (a). For example, critical process control instruments, pressure relieving devices, interlock systems, fire detection or control systems.

(c) Items in continuous process lines whose failure in service can result in serious process interruption.

(d) Items whose complete failure can present a major rapair or replacement problem. For example items for which a complete replacement spare cannot be justified as cost and delivery times are excessive. This could include turbines, generating sets, compressors, blowers or any major item of plant.

Application of scheduled maintenance routines to anything other than such items, apart from servicing can lead to excessive maintenance and repair costs. Scheduled maintenance tends to be expensive because of the organisation necessary to ensure its effective application and because, by definition, plant is overhauled before its working life is fully exploited.

Repair and Replacement

The remaining work will be carried out on a breakdown basis. This is not to say that plant should be allowed to cease work completely before attention is given to it. Reporting of malfunctioning of plant should be encouraged from the process operators and supervision. Additionally, the maintenance and repair supervision should devote part of their attention to inspection of operating plant during their visits to their areas of responsibility on the factory. When malfunctioning is detected of sufficient seriousness to affect production, action to correct the situation should be instituted. With practice and familiarity with the

plant, often corrective action can be determined by the responsible maintenance supervision.

Determination of Corrective Action—For the sake of completeness the sequence of factors which will determine the corrective action are listed as follows:

1) An estimate of the seriousness of the malfunction and the probable progress of further deterioration.

2) The method to be adopted to return the plant to operating efficiency.

3) The effect of shutting down the plant on production. Whether an immediate shutdown is necessary or if a convenient time can be arranged in the near future.

4) The availability of manpower and repair facilities and spares and the extent of preparations necessary.

5) The relative importance of the plant under consideration compared to other plant undergoing or requiring attention.

Whatsoever the importance of the plant or the magnitude of the problem, these questions must be answered. The level of responsibility at which the answers are given and the decision made will vary with the magnitude of the implications of the problem. However, training and development of the maintenance and repair staff should be aimed at encouraging the major part of this work to be carried out at the first level of supervision. This level should, however, be able to differentiate clearly between decisions within their scope and those with sufficiently far-reaching implications to require reference to higher authority. Understanding is best reached on these matters if some sort of regular but informal reporting system is encouraged. The more senior level of management is then able to recognise where decisions have been passed to too high a level or otherwise and can encourage acceptance of the desirable level of responsibility by their subordinates. Correct operation in this sphere is vital if each level of management is to perform its proper function.

A most important factor which is all too often neglected in making these sort of decisions at all levels is the effect on production.

Because the maintenance and repair staff are specialists in their way, their main concern tends to revolve around condition of equipment and engineering standards of performance of work. All too easily they can forget their prime function to provide the plant in a suitable condition for production when it is needed. Decisions on when to do a job and what standards of performance are necessary should always be guided primarily by production requirements. That is, the effect of their decision on production either in the short or long term. The person making the decision, therefore, has the responsibility of consulting the appropriate level of production management in the process of arriving at his conclusions.

ALTERNATIVE ACTIONS—Of the questions to be answered listed previously the one relating to the method to be adopted is the one which exercises the professional competance of the maintenance and repair man to the fullest degree. In fact, the answer to this question is one which must have been answered in advance of any failure. It is the responsibility of the maintenance and repair organisation to examine each item of plant to determine the possible causes of ultimate failure. From this, decisions as to whether to attempt to repair the plant when it fails or to replace it should be made. Possible actions which may be taken could include:

1. Scrap the item and instal a new one with a spare to be held in stock.

2. Dismantle the item and replace those parts of it which have failed with spares to be held in stock and then reinstall.

3. Dismantle the item and repair those parts of it which have failed and then reinstall.

4. Remove the item and install a replacement which is to be held in stock, then overhaul the failed item using either of the two previous methods. The overhauled item has to be held in stock against future failure.

5. Arrange for a duplicate item of plant to be installed in the process line which can readily be brought into service so that failed item can be removed for overhaul.

Preplanning of this form is one of the strategies referred to at the start of this section. Commenting on each possibility separately:

Items should be scrapped and replaced where the total cost of repair exceeds the cost of replacement. In estimating the total cost of repair, the cost of production loss, the cost of stocking or preparing spare parts and the need to maintain facilities or specialist skills for carrying out the repairs should be considered in addition to the direct material and labour cost of the work. This should be balanced against the cost of stocking the spare item of plant, the anticipated replacement frequency and availability of replacements.

The effect of the non-availability of the plant during repair will determine whether time can be allowed for dismantling for parts replacement or repair. Whether to stock spares, make spare, or repair worn parts will again depend on the cost of stocking availability of spares, cost of making or repairing items, balanced against the time available and so on.

Replacement with a spare is a compromise between the foregoing. It is a useful way of dealing economically with fairly critical items of plant. By reducing the urgent part of the work to a minimum it permits better planning of use of repair facilities. This system can be used to excellent effect when there are a number of identical items of plant in use. The ability to use this system of maintenance economically is one of the strongest arguments in favour of standardisation of the smallest possible range of proprietory items of plant in use on the factory.

Installation of standby spare items of plant can only be justified by critical production requirements. For instance, in continuous production units where failure of the item concerned will immediately cause shutdown of the unit and where the anticipated operational life of the unit is less than the required period of operation of the total production unit.

If an installed spare must be included in the unit, precautions must be taken to ensure that when required it is capable of operating effectively for its normal anticipated life span. It is a fact of life that operations personnel will use the item of plant which gives them least trouble. As soon as the line item shows any sign of wear, the operator will use the standby in preference. He will continue to use whichever is the better of the two items until one of them fails completely. At this stage it is not unusual to discover that the standby spare is in little better conditions.

Control of the situation is therefore necessary. Use of the standby must be prohibited until the line unit reaches an agreed condition, except for specified periods of test running to check its condition and retain it in working order. Changeover to the standby must be accompanied by a reporting system which ensures maintenance attention to the line unit at the earliest possible time.

Human nature being what it is, physical means of restricting use of the standby is preferable to rules and instructions. If changeover time permits, installation of blanks in pipelines or perhaps the need to remove a section of pipework from the line unit to couple up the standby can be useful devices. Locking

out of electrical supplies, together with a procedure for obtaining the key is another means. This tends to be less effective due to the ease with which locks can be opened, or damaged.

Review of Strategy

Whichever strategy is adopted with each type of plant, initially it will be necessary to review the procedure from time to time. Initial estimates of failure frequency will need modification in the light of experience. Causes of failure will vary from what was anticipated and spare part requirements also.

Possibly the most difficult factor to determine is the relationship the various items of plant bear to production efficiency. The production staff will tend to overestimate the effect of failure on production and will underestimate their ability to continue production in the absence of any item of plant. Experience will eventually show the true situation, usually as a result of a premature failure or other unexpected circumstance. The initiative in determining these factors accurately must come from the maintenance and repair organisation if excessive costs due to high spare stock levels, unnecessary emergency and overtime work, or overmaintaining of plant is to be avoided. If a maintenance and repair organisation operates without complaints from production or service departments, this is a sure sign that the organisation is overstaffed and it is costing more than it should. Without the check and balance of difficulties and complaints there will be no searching for better ways and means ensuring an efficient service.

SAFETY AND WELFARE

It is well recognised that safety at work is a matter for concern simply from an economic standpoint apart from any human consideration.

Because of the nature of maintenance and repair work and the tools which are used, maintenance men are probably exposed to more accident risk than any other group in a factory. Also, they have most influence on the safety of others through their responsibility to ensure that the plant is safe to operate. Every man in the maintenance and repair organisation must be aware of this responsibility for himself and others. He must be trained to work safely, not to take shortcuts, to be sure of the consequences of his actions, to keep his workplace tidy and his tools in good, safe condition.

Hazards cannot be eliminated from maintenance and repair work. However, accidents can be eliminated by recognition of the hazards and selection of the most practical means of controlling them.

Safety must always be uppermost in his mind so that his reaction to a job is not "how can I do this job" but "how can I do this job safely". Hazards cannot be eliminated from maintenance and repair work. However, accidents can be eliminated by recognition of the hazards and selection of the most practical means of controlling them.

To obtain a consistent approach to safe working by maintenance and repair men is a long and difficult process. The process will be impossible however if the management does not show by action as well as words that they too are committed to such an approach. Men will not keep their workplaces tidy if their workplace is tumbledown and uncared for. Guidance is necessary to establish means of tackling particularly hazardous operations, and facilities must be supplied to match the instructions or guidance given. For example, pro-

Provision of adequate welfare facilities is another means of demonstrating the organisation's concern for the well-being of its employees.

cedures should be established to cover the following:

Guarding of moving machinery
Isolation of machinery for maintenance or repair
Entry to vessels
Flame permits (for fire risk areas)
Access to and safe working on roofs
Opening of pipelines.

Provision of adequate welfare facilities is another means of demonstrating the organisation's concern for the well being of its employees. Such facilities will include adequate toilet and washing facilities, facilities for the storage and, if necessary, drying of clothing and a means of storing food and a suitable place for eating it.

Dependent on the industry concerned there will be specific problems with regard to industrial diseases. For example, numerous hazards associated with toxicity in the chemical industry, dust and pneumocosis problems in many industries and skin cancers from exposure to mineral oils in engineering industries. Each of these problems require their own precautions in the way of instructions procedure, washing facilities and provision of protective equipment. Attention to these problems by the organisation will set the minimum standard for employee welfare on which to build a healthy approach to safe working.

ADMINISTRATION

As the size of an organisation increases, it becomes necessary to establish rules or procedure for its operation. The aim should be to keep such rules and procedures to the absolute minimum necessary to permit effective operation of the organisation. Every procedure or rule must be established on the basis of a recognised need and must have a specific objective. Some rules will be mandatory, generally for safety or property protection purposes or may be for financial reasons. For example, no smoking in the fuel store, or levels of authorisation of expenditure. Non-mandatory procedures and rules will generally apply to operation of the organisation to avoid the possibility of duplication of effort. The aim with these will be to ensure that others concerned are consulted when particular sections are being taken. The essential need for rules of this kind is to ensure that they leave the maximum scope for the exercise of individual initiative. Too strict a rule book will inhibit initiative and provide reasons why people should not get involved in particular tasks. For the maintenance and repair organisations procedures are desirable apart from those previously mentioned under safety and those necessary to specify the functions of the various groups forming the organisation. These will include procedures governing:

Work Requests
Allocation and reporting of costs
Budgetting and budget control.

Discussing each in turn.

Work Requests

A properly organised written work request system can serve three purposes:

i. Provide a visual record of work backlog and supply the basis for planning maintenance work.

ii. Provide information for use in determining where maintenance improvement effort must be applied.

iii. Provide the basis for a maintenance costing system.

There are many ways of going about organising a work request system but the basic essentials of all of them are similar. Details of a system in current use is included in Appendix VIII. A workable work request system must comprise a written record of the work requested. Without this. completion of maintenance and repair work depends on the memory of the supervision. Excellent as these may be. inevitably essential work will be forgotten sooner or later, with serious consequences in terms of production loss, property damage and maybe even injury to persons. The written work request must be arranged for minimum effort and time to compile and will contain certain key information as follows:

Location of job

Item of plant concerned

Description of defect or name of person to contact for details.

An indication of urgency or time by which completion of work is required.

Cost centre to which charge is to be made

Date when work request was placed

Name of initiator of work request.

Subsequently the work request must be given a reference number for indentity purposes.

A carefully designed work request form can ensure that the initiator is reminded of these needs when placing his request.

Allocation and Reporting of Costs

Correct allocation and reporting of maintenance and repair costs is necessary with any enterprise producing more than a single product, if the true production cost of each product is to be established. Apart from this objective, the maintenance and repair organisation itself has need of a breakdown of their costs. This cost breakdown provides the necessary information to enable future expenditure budgets to be drawn up. They also provide information for cost control by indicating areas of high expenditure or trends in expenditure in any particular area. Further applications include use of the information provided to form the basis of estimating costs of work so that decision on repair or replacement or economic feasibility of proposed modifications can be made. The costs also form the major source of information for the maintenance improvement group.

As with most, things compromise is necesary in determining the form that the cost reporting system will take. The compromise will lie between what information is desirable and the effort necessary to allocate and report it. Allocation of costs to the correct cost centre has to be done at source. The supervisor is the only person who is aware of exactly which jobs his men are occupied with, for how long, and what materials they use during the course of it. He therefore, must spend some of his time in reporting this information to the accounts department. The more information he is required to report the greater inroads it makes into his supervisory time.

For the purposes of product costing it is obviously necessary to separate charges on this basis. If there are a number of plants producing the same product, differentiation between these plants is useful to determine which of them is the most efficient.

The sort of information most useful to the maintenance and repair organisation is the cost of maintaining particular items of plant or types of plant. For instance, cost centres could include: pipework, pumps, heat exchangers, centrifuges etc. In some plants, particularly significant items of equipment may be worthy

of special attention, perhaps a waste heat boiler or an autoclave of a packaging machine.

A typical cost reporting system would consist of a series of numbers, each representing some aspect against which costs are required to be collected.

For instance:

2 digits — represent the plant or product

1 digit — represents the class of work, for example, routine, shutdown, emergency, expense associated with capital work or work to assist operations.

1 digit — represents the group undertaking the work: area or centralised force, electricians, instrument mechanics, civil trades.

2 digits — represents the type or item of plant on which the work is carried out.

As an example:

01 — could be one of up to 99 product cost centres.

2 — could be routine work

3 — could be work carried out by the area work force associated with the particular product

04 — could be work carried out on pumps

The time spent and any materials used would be reported against 012304. The variations that can be applied to a basic system of this sort are limitless and can be applied to isolate whichever source of expenditure is required. The extent and detail to which it can be applied must, of course, depend on what detail it is practical to expect supervision to supply as input.

If further information is required when investigating causes of maintenance costs, copies of work requests can be retained for future reference. Another system is exampled in Appendix VIII.

Budgetting and Budget Control

In order that reliable forecasting of product costs can be made, it is necessary for the maintenance and repair organisation to forecast the further cost of maintenance. The budget thus produced will then serve as the cost objective for the period concerned. The budget also serves as a yardstick against which to measure the performance of the organisation. By its use, abnormal occurrances or trends of cost can be observed and corrective actions determined.

It will be realised that it is not possible to forecast accurately, exactly what the future will bring, but it is possible to foresee the likely trend of the immediate future. By doing so, it is possible to forecast future costs, assuming nothing extraordinary will occur. When such occurrances do inevitably happen, they can be recognised and their impact can be isolated. Preparation of budgets is an exercise that improves with practice. Budget preparation must initially be based on previous experience. The more often budgets have been prepared previously and compared with subsequent performance, the more apparent will normal trends become. A typical budgetting exercise might be organised as follows: The prelude to budget preparation would be the formal presentation of costs incurred over the immediate past. As budgets, of necessity, must be prepared in advance of the period concerned, the complete costs for the current period will not be available. The performance against budget for the previous period then will be the best comparison available. Thus we would have:

Budget for previous period

Actual costs for previous period

Budget for current period

Actual costs to date for current period.

An estimate can now be made of the likely outcome of actual costs for the current period. This information then represents the best guide to future performance. Next it is necessary to isolate major cost items from the actual performance. These should fall into two categories, those which were anticipated and those which were not. Further, items which were anticipated by the budget which did not occur should also be identified.

Once this sort of information has been isolated, one is left with a background of cost which is made up of small cost jobs. These generally will be routine maintenance or adjustments and so on. One can assume, providing no extraordinary change in plant is anticipated, that costs will continue to be generated at the same rate.

Inspection of all the other major items is now required to determine the likelihood of a repetition in the next budget period. Inspection of these and indeed the routine or background costs must be made in the light of information available from Production on the budgetted production rates for the forthcoming period, any plant extensions or modifications proposed and any maintenance improvement work anticipated. Having determined the likely workload in terms of current costs, it is then necessary to vary these with reference to trends of material and wages costs. By this means the budget for the forthcoming period can be built up.

However, before it is finalised it is often useful to make a few checks. For instance, over a few years, ratios between labour and materials costs can be established and also the normal relationship between contract maintenance costs and costs of maintenance by company employees. A check between these ratios and the proposed budget can avoid the possibility of budgetting for far more work than the maintenance team could possibly handle, or alternatively predicting costs which are lower than will be generated simply by continuing to employ the current workforce.

The more comprehensive the cost reporting system, the simpler identification of extraordinary costs will be and the more realistic the budget forecast.

Dependent on the circumstances, other factors may have to be borne in mind. For instance, anticipated overtime levels and premium payments involved. Also the amount of non-maintenance work to be carried out by the workforce. This could be minor capital work or plant modifications or improvements.

Obviously, the more comprehensive the cost reporting system, the simpler the identification of extraordinary costs will be and the more realistic the budget forecast. Another important point to remember is the need to fully document the considerations affecting the build up of the current budget. Without these reasons, it will not be possible to make much sense of it in twelve months, time when the next budgetting exercise is due.

Good documentation is also necessary if the budget is to be of use during the budgetted period. By organisation of the budget into monthly expenditure, control of maintenance expenditure can be exercised throughout the year. As far as possible, the monthly predic-

Use of the work study questioning procedure by maintenance supervision when deciding how to organise their work, can result in well-organised working procedures.

tions should be realistic. Anticipated major expenditures should be included in the month's budget they are expected to occur, if use of the budgets for control is to be useful. If the timing of a job is not exactly predictable, the anticipated cost can be extracted from the annual figure and injected into the budget for the month at the time it occurs.

WORK CONTROL AND WORK MEASUREMENT

Many techniques exist which can be used to determine the efficiency of the workforce. They are generally based on the principle of determining the work content contained in the tasks to be carried out and comparing the actual performance of the workforce with them. These techniques in themselves do not provide any control of work. Control of the maintenance work will always remain the prime function of the maintenance supervision. The techniques of work measurement, however do provide the necessary information for the supervision to determine how many men they need, and whether efficiency of work is at an acceptable level.

It is suggested that initially the less sophisticated techniques are all that are required. The more specific and sophisticated techniques are costly to apply and require a good deal of understanding by supervision and the workforce if the cost of installation is to be recovered by increased efficiency. Briefly the more generally used techniques are outlined together with some idea of where and how they can be utilised. However, most of the techniques cannot be fully developed in a paper of this scope. Much has been written on these subjects and expert guidance is available if it is decided to proceed along any particular line.

Work Study

While work study in itself is not a technique for measuring work, it is the background to most techniques. In addition, it is an invaluable tool in all aspects of maintenance and repair work, ranging through the administration, supervisory and work execution fields. Certainly all the Maintenance Improvement Group staff should be familiar with work study techniques and also the Planning Group staff. Preferably all the supervisory staff should have a working knowledge of the subject, with perhaps one member of the staff who is a trained work study practitioner.

Use of the work study questioning procedure by maintenance supervision when deciding how to organise their work, can result in well organised working procedures. Major overhauls or repair procedures of critical items of equipment are in the province of the work study engineer. Organisation of the workforce, administrative procedures, costing systems, layout of workshops and types of tools and equipment are also suitable subjects for his trained approach.

Estimating

The most basic form of work measurement is contained in the various practices of estimating. In its simplest form estimating will consist of deciding how long a job may take and how many men are required, based on the estimator's previous experience. The procedure can be refined by collecting the knowledge of experienced men, by comparing actual performances against estimates and by collecting simple data on the quantity of work contained in jobs whose performance time is known.

For example, simple factors can be determined for the installation of pipework based on the length and bore of pipe, with modifying factors depending on accessibility of the piperun, number of bends, and so on.

Work Sampling

Work sampling is a useful procedure for comparing performance from time to time, to determine trends of performance and activity. For instance, measurements before and after a change in organisation can indicate whether the effects are beneficial or not. The technique is based on statistical probability and consists of sampling a number of preselected factors on a random basis. The number of samples required can be determined to give the required probability of error.

Work sampling is a useful procedure for comparing performance from time to time to determine trends of performance and activity.

The technique is simple and requires a minimum of instruction to apply. The results it produces, however, are only as specific as the factors selected. The procedure is better used to compare change in the factors over a period, rather than to quantify the factors themselves. A typical application of the technique was its use to determine change in workforce activity over a number of years. The factors selected for study consisted of three activities: Working, Travelling and Standing. These factors were then defined in some detail for the observers so that the possibility of different interpretations of activity by different observers could be minimised. In this way, successive surveys could confidently be compared.

As a simple example, a rigger standing waiting for a load suspended from a crane to come to him, might be classified "Working" by one observer and "Standing" by another. A predetermined approach to these sort of situations is necessary.

The method of observing must also be defined. For example, an observer sampling continuously as he walks will get different results to one who proceeds to a particular position, say the centre of a workshop, before sampling. In the latter case for instance, the knowledge of his presence will result in change of activity of the men under observation. An essential factor in any of these techniques which involve observation of the workforce is that of participation.

The workforce must be fully aware in advance of what is being undertaken, and what its purpose is. If this is not attended to, any results obtained will be questionable. It is a simple matter for a worker to spoil the results by reacting to the presence of the observer with a spurt of activity, or by complete inactivity. At the very worst, application of observation techniques without workforce participation will result in poor industrial relations and even strike action.

The workforce must be fully aware in advance of what is being undertaken, and what its purpose is.

There is no single solution to the problems of maintenance and repair, Any organisation is shaped by local circumstances and the job it is called upon to do.

Analytical and Synthetic Work Measurement

These descriptions are applied to the more sophisticated methods referred to earlier. In effect they are an extension of the techniques of estimating combined with work study. In essence they involve the reduction of any job to minute detail, the determination of the time required to perform each element and reassembly of the elements, together with suitable allowances, to give performance times for complete jobs. Again much information is available from consultants who specialise in variations on the basic idea and who have already collected or produced data for building up, or synthesising, job times.

Introduction of any system of this sort must only be undertaken after a careful study of the maintenance and repair situation to determine the needs for improvement. The technique to be applied must also be carefully studied and its fitness for the results required determined.

Again, full information must be made available to the workforce who must themselves be convinced of the need for the system, and see some benefit in it for themselves. Often these techniques are applied as the basis of an incentive scheme for payment of the workforce. Neglect of any of the aspects mentioned can result in complete negation of any benefits which might be expected from the project. Poor results recorded in a number of organisations have ranged from complete rejection of the system after a period, or continuation of the system, operated at shopfloor level purely with the purpose of guaranteeing an acceptable level of take-home pay.

In either case the system has merely become an expensive exercise. Poor application of such schemes can and usually are accompanied by deterioration of industrial relations based on lack of confidence in management. If the scheme is installed as the basis of incentives, it is very difficult to get rid of, if it doesn't work. At best it would involve an expensive "buying out" situation.

The author is convinced that it is necessary first to explore fully the less sophisticated methods of improving efficiency. When efficiency can be improved no further by these means, then is the time to explore the more advanced means. By this time both the staff and the workforce themselves will have advanced to the stage where they accept and understand the procedures.

CONCLUSION

The foregoing discussion, together with its appendices, is intended to direct the reader towards an understanding of the factors which must be considered in the setting up and operation of a maintenance and repair organisation in any industrial enterprise.

The factors which will affect selection of one form of organisation or another, or adoption of one technique or another are indicated. It will be apparent from the discussion that there is no single solution to the problems of maintenance and repair. Any organisation is shaped by the local circumstances and the job it is called upon to do. It is hoped that the information provided will at least assist in setting up organisations which meet initial basic needs. Alternatively, where organisations already exist, perhaps the discussion will aid in planning future development or strengthening such organisations.

APPENDIX I

TERMINOLOGY

Plant —Refers to all mobile or fixed machinery, pipework, switchgear, cabling etc. which forms a part of any production or service facility, or any group of items equipment which comprises a production or service facility.

Maintenance —Is used as a general term to describe overall activities of a maintenance and repair organisation. When used in a specific sense it refers to the servicing of plant which is in operable condition, to ensure continued operation at the required level of efficiency. This would include lubrication, cleaning, adjustments to clearances, glands etc., resetting of cutting edges and replacement of parts or units which, by design, wear or are consumed in operation i.e. grindstones, cutting fluid, filter elements and so on.

Repair —Refers to the operations required to return plant which has ceased to function effectively back to operating efficiency.

Replacement —Refers to substitution of an item of plant with a new item of similar design in preference to repair.

Unit Replacement —Refers to the replacing of defective parts of an item of plant with new parts, in preference to repair of the defective items.

Installed spares —Refers to the installation of additional items of plant not required for normal production which can be put into service immediately another becomes non-operational. These items are installed in the production flowline and do not require more than switching on power, or services, by production personnel, to put them into service.

Non-installed spares —Refers to complete items of plant, duplicating specific items of production plant. These may be held in a storage area or installed adjacent to the production flowline. These items require installation work by other than production people before they can be made operational. Normally the installation will be arranged for the work to be minimal. Nevertheless, an essential feature is the need for a service from other than production personnel.

Planned maintenance —Is a general term that refers to any work carried out to maintain or repair plant which has been pre-arranged.

Preventative maintenance —Refers to work carried out on plant with the objective of forestalling equipment breakdown or deterioration. Such work may or may not be planned.

Scheduled maintenance —Refers to any work carried out on plant on a regular basis in accordance with a pre-arranged programme.

Shutdown maintenance —Refers to any work carried out on major items of plant or sections of production plant, on a planned basis which requires the complete shutdown of the item or section of the plant.

Breakdown maintenance —Refers to work on plant which is not initiated until after it has ceased to function. Breakdown maintenance may be planned, to the extent that contingency action in the event of breakdown has been prepared.

Emergency maintenance —Refers to breakdown maintenance work which, because of the relationship of the failed item to the production situation or for safety reasons, must be started immediately. Such work will, by definition, take priority over other work already in hand.

Artisan —Is a general term referring to personnel who are engaged in physical or manual operations. For example, craftsmen, labourers, operators.

Staff —Is a general term referring to personnel engaged in administrative, supervisory, technical or managerial operations. For example, clerks, foremen, draughtmen, engineering specialists, managers.

Supervisor —Is a general term referring to anyone engaged in directly overseeing the work of others to ensure performance to the

required standard. This term is used in preference to the term foreman.

Manager —Is a general term referring to anyone engaged in organisation and control of the work of others. In these terms a supervisor is also a manager. However, the term supervisor is reserved for the first line of management, where the control is of persons who themselves have no management.

Line Function —A line function is defined as one in the direct chain of command controlling the efforts of the workforce. Line responsibilities are then responsibilities for control of the workforce and execution of work.

APPENDIX II

MAINTENANCE IMPROVEMENT GROUP

REQUEST SYSTEM FOR MAINTENANCE IMPROVEMENT WORK

I. Purpose

To define the methods to be used in requesting the services of Maintenance Improvement Group and the responsibilities of the various persons involved.

II. Policy

It is the intention of Management that Maintenance Engineering problems should be handled by a Group free from line responsibilities. It is considered that this service should be freely available to all, via a formal request system designed to ensure:—

(a) that a clear statement of the problem and objective is received by the Maintenance Improvement Group.

(b) that appropriate line supervision are kept informed of requests emanating from other departments.

(c) that all requests irrespective of origin are approved by appropriate line supervision at initiation stage.

(d) that effective communications and relationships are maintained between staff and line organisations.

(e) that the improvement programme is effectively organised and controlled.

III. Scope

The service of the Maintenance Improvement Group should be used for the solution of engineering proolems associated with excessive maintenance cost or mechanical downtime.

IV. Procedure

Initiation of Service Request

Any member of the Supervisory staff may submit a problem to the Maintenance Improvement Group. The request should be presented on a Service Request Form (copy attached).

Requests raised within Maintenance Department

The request form will be routed through the appropriate Maintenance Superintendent and the General Superintendent of Maintenance for signature approval and onward transmittal to the Superintendent of the Maintenance Improvement Group.

Requests raised outside Maintenance Department

The request form will be routed through the General Superintendent of the initiating department, the Superintendent of area Maintenance and the General Superintendent of Maintenance for signature, approval and onward transmittal to the Superintendent of the Maintenance Improvement Group. Receipt of each authorised request will be acknowledged by the Superintendent of the Maintenance Improvement Group and a rough estimate given of the date that the investigation will be put in hand. The request will be allocated a request number and registered by the Maintenance Improvement Group secretarial staff.

Preparation of Service Request

The Service Request will include the following information.

Job Title

The job title should provide a brief reference to the equipment or system needing attention and as concise a description as possible of the problem itself , e.g. Reboiler Pump—Recommendations for improved bearing life, or Building Maintenance—Evaluation of roofing materials.

Statement of Problem and Objective

This should provide a clear adefinition of the problem indicating scope of study and a review of the objectives to be gained by its solution.

Estimated Savings or other benefits

This section should provide an indication of the estimated gross savings to be realised and any other benefits which may be derived from the solution of the problem. Where practicable, this information is to be provided by the originator, but where not, it will be provided by the Staff Engineer assigned to the job.

Suggested approach, references, etc.

This should include any ideas the originator or other persons involved may have, for attacking the problem. References to background information or to files or publications which may be helpful, should also be listed to provide as comprehensive a picture of the problem as possible.

Other information

The department number, location, name of initiator and date of initiation, should be entered by the originator in the spaces provided.

Manpower requirements, etc.

This portion of the form will be completed by the Maintenance Improvement Group. If other staff or line groups are involved, the scope of their participation is to be defined under special instructions. The relative priority of the job must also be determined and an appropriate statement included. The Superintendent of the Maintenance Improvement Group will insert the estimated completion date of the project.

Initiation of Staff investigation

When the investigation is put in hand, the Staff engineer assigned to the job will, if necessary, re-draft the Service Request and submit it to the Superintendent of the Maintenance Improvement Group.

On approval, the request will be passed to the Maintenance Improvement Group Secretarial Staff who will prepare the required number of copies of the request for distribution. Issue of these copies will indicate that work has started on the investigation.

Distribution

All Service Request forms will have the following distribution:—

Works Manager/General Superintendent, Maintenance.
General Superintendent, Project Group.
General Superintendent of Production or other Group concerned.
Superintendent of Maintenance Group concerned.
Originator of request.
Superintendent of Maintenance Improvement Group/Staff Engineer concerned.
Foreman of Maintenance Group concerned.

Reports

A Monthly Report in summary form will be issued covering all major activities of the Maintenance Improvement Group. In addition, if a request involves a lengthy study, then a Progress Report will be issued to all recipients of the Service Request at significant phases during the investigation or at six monthly intervals where there is little progress to report.

The progress report will show the form the study is taking together with an outline of future work and any new ideas which are considered to be worth following up.

Recommendations

Recommendations resulting from an investigation will be submitted in report form to the General Superintendent of Maintenance, the Superintendent of the Maintenance Group concerned and all other recipients of the original Service Request.

An approval slip is to be attached to the reports sent to the General Superintendent/s who approved the original request and the Maintenance Superintendent/s concerned, requesting approval or comments.

Recommendations

The completed approval slips are to be returned to the Superintendent of the Maintenance Improvement Group within the period specified (usually 7 days). Where approval is withheld, supporting reasons must be given for follow-up by Staff Engineer concerned.

Following approval, the Staff Engineer concerned will be responsible for developing the recommendations to such a degree that they can be readily administered by line supervision. If necessary, this will include the provision of detailed procedures, craft schedules and instructions, materials and spares lists and any other information which may be required to facilitate effective work scheduling and execution.

TO	SERVICE REQUEST MAINTENANCE IMPROVEMENT GROUP	REQUEST NO.
		DEPT. NO.
		LOCATION
INITIATED BY	DATE	CATEGORY
APPROVED SUPT.	GEN. SUPT.	
ASSIGNED TO	DATE REQUIRED	DATE COMPLETED
TITLE		

TO BE COMPLETED BY M. I. GROUP

SPECIAL INSTRUCTIONS

PRELIMINARY EVALUATION	MAN HRS.	SUPT. M. I. GROUP
TOTAL ESTIMATED MANPOWER	MAN HRS.	
ACTUAL MANPOWER	MAN HRS.	

Stanaara Design Instructions

Before closing a job the Staff Engineer will be responsible for informing appropriate staff of any improved materials, equipment and methods which it is intended will be adopted as local or Company Standards and incorporated in future equipment and project designs.

The information will be prepared as a Works Design Instruction. After signature approval by the Works Manager, copies will be issued in accordance with agreed distribution for Works Design Instructions.

Follow-up

After 12 months maintenance operation and earlier if practicable, the Staff Engineer will be responsible for reviewing each improvement study and reporting whether the original objective has been obtained or if further improvement is needed.

APPENDIX III

OUTLINE OF BASIC SKILLS REQUIRED FOR A MAINTENANCE FITTER

1. Introduction

In the preparation of this training programme, the intention has been to provide a master outline covering all aspects of the craft, in order that the apprentice will receive a thorough training. It will be necessary to compile a detailed programme against each section of the master outline, detailing the departments where the particular experience may be gained. This could well involve a sub-division of the time allotted and short term training transfers to other companies or training centres. An induction period in the company of two weeks' minimum duration should precede basic training, carried out, where possible, at an approved training centre. During the third year of training, the apprentice should be given increasing responsibility. During the fifth year, the apprentice should work on his own responsibility, with the minimum of supervision.

Throughout the full duration of the apprenticeship, persistent attention to the detailed requirements for safe working should be stressed and correct procedures demonstrated, especially those relating to machinery in motion and artificial respiration.

2. General Outline

A.	Basic Training (including initial induction programme)	12 months
B.	Fitting Shop	6 ,,
C.	Machine Shop	6 ,,
D.	Plant Services and Inspection	15 ,,
E.	Plant Erection and Testing	6 ,,
F.	Technical Services	3 ,,
G.	Advanced Work	12 ,,

3. Programme of Practical Training

A. Basic Training—12 *months*

The main aim during this period should be to impart to the apprentice a good working knowledge of basic engineering principles. Persistent attention to the detailed requirements for safe working should be stressed, and correct procedures demonstrated, especially those relating to machinery in motion. The work covered should be of a useful and interesting nature embodying simple basic exercises,which should be incorpareted simple basic assemblies during the latter part of thecourse. Stress should be placed on the interpretation of the workshop drawing, with ample attention being given to idimensional and quality inspection. An appreciation of costs and method analysis forms an important part of the basic period.

Instruction should be given in:

(a) Bench fitting, leading to precision handwork.

(b) General fitting, including metal joining processes, pipefitting and simple sheetmetal work.

(c) Machine tool practice, to include centre lathe, vertical and horizontal milling, shaping and grinding.

(d) Section 1 should be included in the basic training and induction period:

(1) Workshop rules and routine; cleanliness and hygiene; Factory Acts as they apply to employees; safety appliances and procedures in case of accidents; explanations of products and services of company.

(2) Bench-work instruction and practice in the use and care of tools, spanners, torque wrenches, hand scrapers, files, hacksaws, screw drivers, calipers and dividers, taps and dies, reamers, cold chisels, hand and electric drills.

The special conditions necessary for satisfactory service. Importance of alignment. Lining up and checking alignment of connecting equipment.

(2) Drives—
Chain, vee-rope, belt, friction and all gear drives, care and maintenance. Electric motors, mounting and coupling. Shaft couplings, advantages and disadvantages of various designs.

(3) Lubrication—
First principles and their applications. Grooving of bearings, Installing lubrication systems.

(4) Use of Portable Power Tools—
Instruction in the use of pneumatic hammers, impact wrenches, grinders and drills and electric grinders and drills.

(5) Hydraulics—
Systems, making joints and packing glands. Removing air locks. Pressure relief valves and their function.

(6) Steam and Air—
Services,boilers and pipe lines. General pipe fitting, flanges, valves etc. Safety devices—valves, bursting discs, pressure switches etc. to include maintenance and overhauls of boilers and auxiliaries. Familiarisation with special purpose flanging machinery.

(7) Transport—
Routine maintenance of transport including fork lift trucks.

(8) Electrical Safety—
Recognition of dangers and precautions necessary for safe working. Linking of electrical load to mechanical should be explained and demonstrated. A short appreciation of instrumentation as available should be included.

(9) Press and Tool Setting—
Operation of presses. Assembly of dies, tools and maintenance checking and adjustments.

(10) Company Processes—
The extent to which sections (1-9) above can be covered will depend upon company facilities and will of necessity be the subject of a separate detailed study, into which, where possible, the listed sections can be phased. There may arise, however, the need for outside experience. In arranging coverage of the company processes, both the Training Officer, and Supervisory Engineers should ensure that the following points are well developed in the apprentice.

Intimate knowledge of plant geography—know where all maintenance spares and equipment are kept. Functions of plant in relation to production processes. Know sources, pressures and flow of gas, steam, cooling water, fuel oil, oxygen, compressed air, hydraulic oil or water. Isolation of plant. Special equipment. British standard and other appropriate coding systems for pipeline indentification. Location of safety equipment and operation of safety rules and procedures.

B. Plant Erection and Testing—6 months

(1) Installation of new equipment working from plant layout drawings, and piping flow sheets. Importance of alignment, foundations, securing and grouting in. Special precautions to avoid distortion. Machine guarding of new equipment. Testing and commissioning.

(2) Advanced fitting, maintenance and repair in situ. Installation and removal of large components.

(3) Lifting tackle and slinging—Safe practice in the use of chains, wire rope, hemp slings and pulley blocks. Signals to crane drivers. Screw and hydraulic jacks. General principles of rigging. Demands of the Factories Act.

(4) Project development work under general guidance of engineer or foreman.

C. Technical Services—3 months

Towards the latter part of the apprenticeship, apprentices making good practical and academic progress should be given the opportunity of experience in a Technical Department, such as Drawing Office, Planned Maintenance Office, Factory Planning and Layout, Plant Engineering.

D. Advanced Work—12 months

During this period, the apprentice should work with the minimum of supervision in that department to which he has proved most suitable.

4. Technical and Theoretical Training

(1) City and Guilds of London Institute Mechanical Engineering Craft Practice

(2) City and Guilds of London Institute Mechanical Engineering Technicians
(3) City and Guilds of London Institute Plant Engineering
(4) Ordinary and Higher National Certificates.

APPENDIX IV

CRAFT APPRENTICE TRAINING PROGRAMMES & GENERAL PROCEDURES

1. The master outlines can be taken as summaries of the overall experience to be gained.

2. The programme indicates chronological order of experience as it should be gained. This is the basis of an apprentice loading/movement chart.

3. Check lists, where appropriate, containing the details of training and experience to be gained in a given location will assist supervision to identify quickly and control the part of the programme to be covered in his department.

   The Supervisor should have a copy of the Master Outline and Programme. This will assist in determining the previous experience gain by the apprentice. The Work Book will be of considerable assistance.

4. Reporting procedures and general control:

   (1) The apprentice to maintain a record of training by means of Work Book.

   (2) In the Work Book the Supervisor to complete a 4 weekly report also interim report if a movement from one location to another occurs within a 4 week period. These reports are made in the workbook.

   (3) The Training Officer will interview each apprentice every 4 weeks and maintain a master record. Vet the work Book, discuss progress with apprentice and supervisor, arrange outside transfers ect.

   (4) Every 3/4 months an assessment be made—copies to management, apprentice informed. The Training Officer would act in conjunction with Supervision. Every 12 months annual assessment to be made taking into account academic progress.

   (5) The overall assessment at completion date should give indication of practical and technical proficiency also comments on personal qualities which could serve as a useful guide to company on future potential of apprentice.

TRAINING PROGRAMME FOR APPRENTICE MECHANICAL MAINTENANCE FITTER

Year of App.	Location	Training Period	Practical Training-for details see Master Outline attached	Remarks
1	Basic Training Centre	36 to 48 weeks variable, see note	*SECTION 3A* Section A. (1) Induction (2) Acquisition of basic skills (3) Specialised mechanical section	To Engineering Industry Training Board approved scheme. To include company induction to approved induction programme both before and after basic training. *NOTE* Vacations in works and/or under Group Training Officers e.g. Industrial visits etc. Period variable until establishment of full 48 week year at Training Centre
Remainder of Programme based upon 48 weeks basic course. 2 weeks annual leave. Should the Basic Training period be less than 48 weeks the number of weeks less should be spread over the period allocated to Central Maintenance Dept. e.g. for the 1966 intake. 20 weeks Fitting Shop. 20 weeks Machine Shop. 12 weeks Fabrication Shop.				
2	*Central Maint. Dept.* 1. Fitting Shop	15 weeks	*SECTION B.* 1. *a.b.* SECTION B. 3. (6) Safety devices, valves. *SECTION E.2.* Advanced fitting only *SECTION E.4.*	During this period the following to be covered by talks and demonstrations. (i) Ref. Section D.1. Advantage and disadvantage of various bearings in various applications. (ii) Ref. Section D.2. Shaft couplings, advantages and disadantages of various designs. (iii) Ref. Section D.3. (iii) Ref. Section D.3. Lubrication. First principles and their applications. Grooving of bearings. A short period of outside experience may be necessary. See attached note.

TRAINING PROGRAMME FOR APPRENTICE MECHANICAL MAINTENANCE FITTER

Year of App.	Location	Training Period	Practical Training-for details see Master Outline attached	Remarks
2	Machine Shop	15 weeks	*Section* C.1. C.2. a.b.c.d C.3. C.4.	Certain aspects may require outside experience. See attached notes.
2	Fabrication Shop	10 weeks	*SECTION* B.2 also pneumatic and electric grinders	

FOLLOW ON SAFETY PROCEDURES AND PRACTICE APPLIED FOR PLANT MAINTENANCE (Prior to experience of area maintenance Units)

2	Riggers Dept.	4 weeks to include ½ day ½ day ½ day	*SECTION* B.3. *SECTION* D.8. *SECTION* D.8. vessel entry and pipe breaking	attached to Electrical Dept. „ „ „ Instrument Dept. „ „ „ Area Mechanical Supt. The importance of the above cannot be overstressed.
	Area Maintenance Units 1:3:4:2	* * * * * *	*SECTION* 3. A (8) as applied on Company plant. include flanges, valves. *SECTION* D.(1) Shafts, alignment, bearings. *SECTION* D.(2) Drives *SECTION* D.(3) Lubrication systems *SECTION* D (5) Hydraulics *SECTION* D.(6) Bursting discs. Pressure switches.	*Area Maintenance Units-General Note* In addition to acquiring experience of the listed sections, the aim should be to develop an intimate knowledge of plant geography - know where all maintenance spares and equipment are kept. Functions of plant in relation to production processes. Know sources, pressures and flow of gas, steam, cooling water, fuel oil, oxygen, compressed air, hydraulic oil or water. Insulation of plant. Special equipment. British standard and other appropriate coding systems for pipeline indentification. Location of safety equipment and operation of safety rules and procedures.

The above may be dealt with either separately or upon a combined basis whilst attached to Units 1,3,4,2 given below. This will be dependent upon Unit policy adopted from time to time. Sections marked thus will be the subject of more advanced work whilst attached to Field Force Unit.

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TRAINING PROGRAMME FOR APPRENTICE MECHANICAL MAINTENANCE FITTER

Year of App.	Location	Training Period	Practical Training - for details see Master Outline attached	Remarks
2 3	Area Unit No. 1	8 weeks		
3	Area Unit No. 3	8 weeks		
3	Area Unit No. 4	8 weeks		
3	Area Unit No. 2	8 weeks		
3	Area Unit No. 5	12 weeks	*SECTION* D.6 Steam and Air. Services, boilers, pipelines. General pipe fitting, flanges, valves etc. To include maintenance overhauls of boilers and auxiliaries.	See general note-area maintenance unit. - Boiler inspections. Since these may not fall within the period allocated, special arrangements should be made for the apprentices to be present when they take place.
3	Motor Transport Section	4 weeks	*SECTION* D.(7)	
3	Construction Department	8 weeks	*SECTION* E. (1)	Testing as carried out to be included.
4	*Central Maint. Dept.* Field Force Unit	38 weeks	See Area Maintenance Units. Sections marked* plus *SECTION* D. (4) pneumatic hammers, impact wrenches and drills. Electric drills. *SECTION* D. (6) Special purpose flanging-machinery. *SECTION* E. (2) Maintenance and repair in situ instation and removal of large components.	More advanced work than that previously under taken- Outside experience may be necessary.

Year of App.	Loction	Training Period	Practical Training - for details see Master Outline attached	Remarks
4	Planning and/or Drawing office	6 weeks 6 weeks	*SECTION* F. Technical Services	To be arranged provided good practical and academic progress has been maintained. It will be necessary to consider the detailed nature of the technical training for each trainee as it arises. It may be desirable for the apprentice to gain further practical experience during this period.
5	To be arranged in the company	50 weeks	*SECTION* G. Advanced Work	During this period the apprentice should work with the minimum of supervision on that section of the company in which he has proved most suitable. The work should be varied as much as possible to give broad experience. During this period special attention could be paid to manufacturers courses, short course in instructional techniques, etc.

Outside experience notes

Although it is expected that the majority of the programme can be met by "in works" training, continuous attention should be paid to aspects that may not be covered due to circumstances prevailing. In particular outside experience should be considered for the following:

(1) Section B.3.

(2) Section C. (1) Multi-spindle drills. Band saws, straighteners, presses.
C. (3) Universal milling.
C. (4) Surface grinding. Cultter grinding.

(3) Section D. (6) Special purpose flanging machinery.
D. (9) Press and Tool setting.

Arrangements for outside experience to be actioned by the Training Officer.

JD EDWARDS

APPENDIX V

THE SUPERVISOR*

Introduction:

My talk will be principally obout foremen engaged in supervision of maintenance personnel. However, as the term "supervisor" is more descriptive of the job I use this title for the paper rather than the traditional title foreman.

Most of my experience in this respect is related to process industry, specifically the chemical industry. However, these circumstances probably involve more severe man management problems than in other industry.

With the engineering and production industries, the supervisors technical knowhow is more important than in the process industries. This technical knowhow is chiefly a matter of training and must be allowed for in selection and training of supervisors. Even so, I suspect that even in these industries the man management aspect is the one which proves the most difficult to resolve.

Why talk about supervisors at all? Surely they have been around long enough for us to know all the answers.

I have found since getting involved in maintenance management that, sooner or later, whatever I am doing the supervisor comes into the reckoning. Ultimately success or failure of any plans laid by more senior management depends on the supervisor. He holds a vital and unique position in any organisation. It is only through him that the organisation can produce any results. The most sophisticated and technically reasible enterprises can come to nought if the supervisor is incapable of dealing with his part of it. He is the vital link between planning and execution.

It is rather like having the most expertly designed racing car with the most powerful engine in the class and no transmission shaft to translate all the technical brilliance into the end product—speed.

Increasing competitive pressure and rising labour costs put more and more stress on the need for effective man management. Yesterdays answers no longer meet the problem.

I have never been a foreman, so what then are my qualifications for talking to you on this subject?

During the whole of my working life, except perhaps for the time spent in a Drawing office, I have been in constant contact with foreman Working for them, learning from them, advising them technically, obtaining information from them and, in latter years, working with and controlling them. My experience covers the engineering industry, construction work and the chemical industry.

At a rough count I discover I have had direct working contact with somewhere in the region of 40 to 50 foremen.

The Foreman's Job

Let us now get down to the subject at last by asking ourselves what a supervisor's job really is.

Simply stated, the supervisor's job is to make the most efficient use of manpower.

Like most simplifications it is more easily said than done. Perhaps I can start with a lighthearted interpretation. This is a little piece entitled "The Supervisor's Prayer".

"Dear Lord, help me to become the kind of supervisor my Management would have me be. Give me that mysterious something which wi'l enable me to, at times, satisfactorily explain policies, rules, regulations and procedures to my workers even when they have never been explained to me.

Help me to train the uninterested and dimwitte without ever losing my patience and my temper, give me that love for my fellow men so that I may lead the obstinate, nogood worker into the path of right-eousness by my own example, by soft persuading remonstrance instead of punching him on the nose.

Teach me to smile if it kills me. Make me a better leader of men by helping me to develop larger and greater qualities of understanding, tolerance, sympathy, wisdom, perspective, equanimity, mind-reading and second sight.

And when, dear Lord, thou has helped me to achieve the high pinnacle my Management has prescribed for me and when I shall have become the paragon of all supervisory virtues in this mortal world—Dear Lord, move over."

*Paper presented by J.D. Edwards, C. Eng., M.I. Mech E., F.I. Plant E., General Superintendent of Maintenance, Monsanto Chemicals Ltd, Ruabon, to Merseyside & North Wales Branch of The Institution of Plant Engineers on 19th September, 1968.

Communication

A bit of a smile, but when you think about it, it is not so silly after all. Let us look at the first part about explaining policies and rules. Keeping his men informed is a very necessary part of the supervisor's job.

A man who knows the rules, and perhaps what is more important understands what the rules are in aid of, is half way to keeping them.

The next point, policies. Company policy is never a static thing. Even less so when it gets down to day to day operating policy. Product requirements can change at short notice such as when a salesman land a long angled catch, when a competitors new plant fails to take off in time, or as happened to us when the Welsh Nationalist Army blows up a water pipeline. A foreman must explain these things to his men. A man must know why he has to leave the job which was urgent yestereday. He must understand why he is asked to work overtime on a job which he knows has been untouched for weeks. If he does not understand these things, he has no confidence in management, he does'nt care about the job. When he does'nt care, he does'nt work well.

To explain, the foreman must understand himself. He must also understand why his men must be informed. He should see this as a means of easing his own job.

The foreman, of course, must depend on his next in line to receive the information. Let us hope there are not many foremen in the state of the man who wrote the prayer—with the reasons not explained to him.

These conversations with his men are also the foremans opportunity for gauging the men's reactions. It is all too easy for management to fail to appreciate causes of unrest. The foreman can find out what needs to be explained.

So then we see that the foreman has an important role in communications —two way communications. To the men he is the voice and representative of management. To more senior management he must be the voice of the men.

Welfare

Communication of course is involved in most aspects of the foremans duties. One of these duties, which he must not neglect, concerns the welfare of his men.

Holiday entitlements, sick leave, time off, restricted, duties and similar questions must be dealt with promptly fairly and humanely. This is the big opportunity for the foreman to develop the team spirt within his group Men respond more effectively to a little human consideration than to any other form of motivation, and I would include pay.

The foreman's boss must be eareful here that he does not put his foot in it. The foreman's decision must be supported in the eyes of his men. If a decision must be reversed the reversal must be seen to be the foreman's decision, if at all possible.

The foreman must be allowed some discretion in bending the rules. He must be allowed to decide for instance that a man can take time out for a smoke or rest, secure in the knowledge that his boss will consult him on the subject before tackling a man for an apparent misdemeanour.

Discipline

Discipline is equally a foreman's responsibility. But again, he must be supported in his decisions as far as possible.

It is very necessary here to make sure the foreman fully understands the extent and limitations of his authority. Equally, he must understand that he has the responsibility of weighing the facts carefully before reaching his decision. Obviously, no unjust decision can be backed by his superiors.

Most young, inexperienced managers, myself included in my time, get into troble in the communications field between foreman and man at some time or other.

In my case, I was fortunate in working with a very experienced foreman He told me in no uncertain terms where I was out of line, and I added one more experience to my storehouse.

Training

The next point in the prayer is a plea for help to train his men.

Most of the larger organisations nowadays have some sort of training organisation. You might say that these are the people whose job it is to do the training—not the foreman. This may be so to some extent. Even so, the foreman has some very definite training responsibilities.

Firstly, he above all is in the best position to assess what training is required. He can see the weakneasses in job performance. He can see the use, or otherwise, that is made of new tools and techniques. He is best placed to advise where his mens knowledge of the function and operation, or maintenance needs, of production equipment is deficient.

So the foreman then can be invaluable in assessing training needs—but does his responsibility end there ?

I don't think so—Not only is the foreman best placed to advise on training, he is the best man to carry out

at least some of the training. He is the man who knows the men best and the one they will talk to most readily. The foreman is the one who will be assisted most directly from the results of effective training. He then has a vested interest in making sure the training is done properly and is understood by his men.

Another advantage to be gained is the consolidation of the foreman in control of his men, as their rightful leader, as a man they can respect.

If the foreman does so much training, what then is the purpose of the training department?

The foreman is a busy man, he cannot spend the time preparing the training information or the training programme. He must receive the necessary training or instruction himself. The information and props must be put in his hands. He must learn some of the techniques of training. The training facilities must be organised.

The foreman is the man in the front line, the training department is one of his support groups behind the line.

Safety

In talking about training I have dealt principally with training to improve job performance. There is, however, an ever more important training function—Safety training. I have deliberately separated this from job training. Not because it can be separated from job performance but because it is essential to be specific about safety.

I have seen it stated recently that one of the greatest diservices done to the cause of safety was the coining of the phase "Safety First".

If we really meant safety first, no-one would ever leave his home. and they are dangerous places by all accounts. What we really mean is proper attention to our endeavours to make sure that known hazards are guarded against. At Monsanto we use the term "Safe Production".

How best to achieve this is a matter that we have not solved yet. One thing we are certain of though, is that the foreman's part is a vital one. It is proper that the safety theme should colour every aspect of the foreman's duties.

In training he munst carry out safety training personally. The safety and training departments have a joint responsibility for safety training. They can deal with specific aspects of the subject, can deal with general topics and teach safety philosophy. But when it gets down to doing the job on the shop floor, or on the plants, once more the key man is the foreman.

As part of the job instruction he must make sure that the man is fully aware of potential hazards on the job and what precautions are necessary. A major difficulty he may encounter here is the mans own familiarity with the job. Unless the foreman is careful in his approach the man may resent being told what he already is aware of. The less wise may even be tempted to take unnecessary chances to prove they know better.

Perhaps questioning the man on what precautions he intends to take may be the answer here. It is an approach we are trying. As I said, we don't know all the answers but we do feel sure that it is essential for safety to be discussed at the job instruction phase.

It is also essential that the foreman follow through with the safety philosophy. Unsafe practices must be stopped, unsafe tools must be barred, proper equipment for protection, access etc. must be supplied before the job is allowed to proceed. These factors must be observed even if this means job delays. Anything less than this will leave the foreman open to criticism of preaching safety only when it suits him.

The philosophy of "Safe Production" requires the common sense application of practical precautions which the men can appreciate and see the sense of themselves. If the foreman can get the men to commit themselves beforehand to taking the necessary precautions, so much the better.

Regular formal meetings between a foreman and his men to discuss accidents, potential hazards and current safety precautions can also be useful in establishing the foremans genuine concern with safe working.

Job Instruction

Safety instruction is only a part of job instruction. Job instruction is an art in itself. I never caese to be surprised by the number of different interpretations which people can apply to the simplest instruction. My secretary, with a little thought, can produce a document which basically can be interpreted to be what I asked for. At the same time, it can be different from what I had in mind when I gave the instructions. Not infrequently, it is a better layout than I had in mind.

How much more difficult it can be then to put across instructions on a complex maintenance job.

Very often job instruction must include a good deal of description of why the job is necessary and what the objective is.

The job must be described, pointed out, discussed and finally the foreman must obtain reassurance from the man that he has correctly interpreted the instruction.

The wise foreman will draw on the mans accumulated experience in the instruction process and guide the man to

arrive at the right or required method by his thought processes. This may sound to be a rather unnecessary procedure. Some foreman would say "A man is there to do as he's told".

In my experience, this type of foreman never becomes the "star" man. All too soon he gets frustrated by lack of results and falls back on blaming lack of energy on the part of his men.

Another foreman by getting results can develop a team spirit with this crew. Because they secceed they believe in their superiority and will work to retain their reputation.

Every good foreman develops his own way of dealing with this sort of thing. I don't really know whether it is a thing that can be taught.

One successful foreman I know uses a brand of outrageous flattery at times. I have heard him say to a man "As soon as I saw this job I thought of you right away, you're the very man we need" these jobs, incidently, often tend to be the dirtiest or most awkward. The man did'nt really believe the flattery and was well aware of what it was all in aid of. However, he appeared to enjoy the charade and was prepared to play along to the extent of putting that little extra into the job. Obviously this is'nt an approach that can be recommended as a standard procedure. It requires first establishment of understanding and respect between the two parties.

The same foreman would, of course, very his approach different men and with different circumstances. This type of foreman can make giants of the meekest, and can make the unreasonable reasonable. This is how he leads the obstinate into the paths of righteousness.

He knows the man who needs persuading, the one who needs driving, the one who must be encouraged and the one who can be stung into action by criticism. He realizes that to succeed in his own job he must be prepared to play the game according to its rules. This is an approach which I have seen applied unconsciously by some foremen who have a natural flair for it. In other cases, the foreman is consciously applying these principles.

This is the reason that I feel there is scope for passing on these skills to those not naturally endowed. However, it is only possible to pass on the idea. The Individual foreman must develop his own technique with practice.

Job Supervision

After job instruction comes job supervision. Despite the clarity of job instruction and the strength of job motivation applied to the man at the start of job, follow up is necessary.

Here again, the foreman must rely on his judgment of his men to decide how frequently they must be visited on the job. Who can be relied upon to overcome problems, and who will need help. Talk of supervision of work always raises the question of how many men can a foreman effectively supervise. I do not think there can be a straightforward answer to this question. There must be a series of answer related to different circumstances. For instance, in a workshop such as a welding welding or machine shop upwards of twenty men can be effectively supervised.

On a single major maintenance job perhaps fifteen to twenty men can be supervised. On a collection of small scattered jobs, each involving two or three men, it is doubtful if really effective supervision can be given to ten men. I would imagine also that the ratio of manpower to supervision on production work where each man has a set task can be a good deal higher than with a maintenance situation.

If the foreman is to supervise effectively then, he must also be an active one who prefers to be out rather than sitting in an office. This requirement in itself presents a problem. Every foreman has some paperwork to handle, which I will referring to shortly. The active Outdoor foreman is inclined to be averse to paperwork. In selection then compromise is necessary. We must be prepared to submerge some of our desires in favour of this.

Administrative Responsibilities

We have dealt up to now principally with the man management aspects of a Foreman's job. I think that most people will agree that this represents at least some of his responsibilities. Deficiencies in these areas are too serious to be outweighed by other qualities. By the same token, deficiencies in application to the other 25% of his duties can be well outweighed by strengths in his man management capabilities.

Because of the pressing need of effective man management, the reminder of a foreman's duties, the administrative work must be reduced to a minimum. It would be very nice if we could eliminate it altogether.

Unfortunately, this is not possible. There are some jobs which only the foreman can do. Others it is more convenient for him to do, or it is not economically justifiable to get someone else to do it. If you can justify employing a clerk to do some of the foreman's bookwork, you could better justify an extra foreman to spread the load both of the man management and the administrative work.

Job Preparation

To take the first case of the work only the foreman can do. This can be generally grouped under the heading of job preparation. The Planning or work preparation

group can be left to deal with the major part of this work. From receipt of work orders, right through to issue of the job to the execution group.

In the job preparation stage it is necessary to be thinking of who, how, where, when and what with. As the man who ultimately will be responsible for the job, the foreman is, or should be, vitally interested in the planning stage. He is best placed to appreciate the physical problems involved. His first hand knowledge of his resources and capabilities of his men demand that he should be consulted. Problems of job maning strength and services required are in his province. An experienced planner can probably deal quite effectively with most of these problems. Nevertheless, the foreman must take an interest and have a say in apporving or rejecting the plan. This may take care of the who, how, where and what with. The when still would have to be settled.

Scheduling of the job is again of vital interest to him. He must know where the priorities are and what is expected of his group, and must object loudly if he doesnot agree. He must endorse the plan if he is to take the responsibility.

The planner/foreman relationship is one fraught with problems of split responsibility. These are problems which can only be resolved at a personal level between the two of them.

The complaint, "who does he think he is, telling me what to do, on the one side an "Why doesn't he do the job as planned instead of going his own way" on the other shows a lack of realisation of both sides of their joint responsibilities. This sort of relationship can produce worse results than the foreman working entirely on his own.

This sort of problem can develop very quickly between quite reasonable people but fortunately doesn't last very long with the more intelligent of them.—When the pressure is on they soon realize the need to work as a team.—Interorchange of duties between them often produces a quick change of mind in the less adaptable as they come to realize one anothers problems.

When we look at the jobs it is more convenient for a foreman to do we arrive at a stage where it is necessary to look into the economics. This is an easy thing to say but not so easy to do. Generally, what is meant when people use that phrase is to have a look to see whether a convincing enough case can be made to get top management approval. Some assistance can be obtained use of work sampling techniques to determine activity levels and highlight the problem areas. If one for instance, a low activity level and high proportion of standing time coupled with a high backing and unsatisfactory plant availability, it is fair to assume that more supervision is necessary.

How then can we get more supervision ?

More supervisory time can be made available either by increasing the number of foremen of reducing the non-supervisory duties of the existing foremen.

It is in this area that the jobs that the foreman does for convenience must be studied. These jobs can range from plant inspection duties right through to cheeking time cards and cost allocations.

Plant Inspection

Plant inspection is a very necessary part of any maintenance planning especially in the absence of a person or group specifically allocated to such duties, the foreman must carry some of the load. Indeed, even with an inspection group the foreman, as the man on the spot, can often provide valuable information. This must then be recorded and put into the record system. I have never found many foremen reluctant to carry out inspection work but they often have a different attitude to recording the information, and generally this is the most time-consuming part of it.

Time Booking

Time booking duties are duties which cannot be neglected and again, as the man on the spot the foreman almost inevitably is involved.

Cost Allocation

Necessary to a maintenance organisation for cost control and maintenance investigation purposes, also usually comes the foreman's way. We have tried different methods of handling this chore without any real success. These methods included getting the men to make them on completion of jobs and also using a clerk. Both methods led to such serious inaccuracies that they were abandoned. We have now settled for a simple system of tear off cards, which reduces the writing duty to a minimum. Another chore which can consume a good deal of a foreman's time is requisitioning of materials. This again, we have attemtped to reduce to a minimum. Initially, the planning group can organize the main items required.

General engineering goods, bolts, joints, small valves, fittings, piping etc. are held in open accesx stores at strategic points throughout the works. These stocks are replenished automatically to a predetermind level by a stores delivery service. This works together with a regular delivery service and an electro writer system of placing requistions on the stores from transmit/ttina stations located in different parts of the Works.

The temptation for a foreman to supply a personal delivery service is therefore reduced, but as yet not altogether eliminated.

A good foreman is, by definition, a concientious and energetic man. It is his very impatience with delay and his energetic nature with all too often leads him

into inefficient ways. If he has not develored the habit of planning ahead, his materials and equipment requirements are always urgent and the best delivery service too slow.

It is only by letting a foreman see that his time is valuable and that it is most usefully spent on supervision that he can be led to do his best job. This leads us naturally then to foreman training.

Foreman Training

As with all training, catching them young is likely to yield the best results. This is not to say that training of the older established foreman should be ignored. However, it is by training of the younger men that we have achieved some of our most promising results and it is about this aspect I wanted to talk principally.

A word first about foreman selection.

Selection

I suppose the most common method of foreman selection is via promotion from the shop floor to changehand and thence to foreman when a vacancy occurs.

Some years ago, it was decided to abolish the changehand system at Ruabon. The number of foremen was increased, mostly from the changehand group, and changehands disappeared. For a number of years thereafter due to our low staff turnover and the ages of the foremen there was little demand for new foremen. Holiday and absence cover was dealt with by temporary appointments from the work force.

Increasing economic pressure and passage of years gradually changed the situation and a need for a planned approach became evident. As a result, a Potential Forman Training Scheme was developed and put into effect. Applications were invited from the workforce and selections made of suitable candidates after intelligence tests, mathematical and written exercises and interviews. In the interview we looked for a number of things. The major ones being the personality and character of the man himself.

If one tried to write the ideal specification for the man it would sound too good to be true. A reasonable compromise is necessary in selection, providing the essential qualities required are present.

For instance, the man would need to be:-

Fit and active.
Ambitious.
Determined, self reliant and strong willed but ready to listen to and appreciate a reasonable argument.
Not influenced by mass opinion or reaction.
Have a logical mind and be capable of innovation.
Be interested in people.

Training Programme

A training programme was developed with classroom sessions at roughly monthly intervals. Thes were generally conducted by maintenance staff personnel. They included talks on maintenance and works organisation and systems, maintenance philosophy, policy and objectives, job instruction techniques, formenship and so on. Some use of outside courses was also made All absence cover was carried out by potential foremen and they were allocated to special assignments in planning and the maintenance improvement group.

In this way, over a period of a year or two, they became familiar with the ways of the department and its objectives. In addition, a feature which I personally feel is most important, they came to know maintenance staff in a different sort of relationship than had been possible before. This is necessary if the man is to divorce himself from His shop floor thinking ties and allegiances, it is a process which cannot be accomplished overnight.

From a financial point of view the job was attractive. While performing temporary and special duties they received an increased hourly rate.—In addition, they were still able to take advantage of their share of available overtime in their work group. Progress was reported after every spell of duty and an annual review carried out. Any candidate who proved unacceptable was dropped from the group and the remainder retained. When foreman or planner vacancies occurred, applications were invited and selections made after interview by the department head concerned.

The need to study training requirement for these potential foremen had beneficial side effects in strengthening the training programme for existing foremen. In addition, there was a general increase in awareness and understanding of foreman needs throughout the maintenance management them.

This scheme has proved a most useful source of young talent to restock our first line supervisory and planning group. So much so, that it awakened interest in the Production Departments who were also begining to face an ageing foreman situation. The Maintenance Department scheme has now been adopted as a basis for a factory wide scheme. The new scheme will incorporote all the best features of the original programme but will be conducted as a full time training programme over two years.

It is aimed to staff the scheme to meet the factory's future need and to give candidates reasonable expectation of achieving staff grade at the end of the training period. More use will be made of outside courses but there will still be ample room for instruction by work staff and for periods of acting duty. In recent selection of candidates for the scheme, a new problem has started to show itself. Having raked over the available talent though the years we are running short. Our source of new talent from within the work is most likely to come from the ranks of time served apprentices.

With the present trends in education, potential foreman material will possibly get better educational opportunities and are more likely to end up in the technical category rather than in craft ranks. This suggests that there will be less potential foreman talent coming into craft ranks in future. In apprentice selection we are now looking for our future talent. It's a difficult, long range forecasting job but one we feel is necessary.

Summary

Summarising then, we can say that a foreman's main responsibility is man management.

Factors included in this aspect are:-

Communication with his men and to his boss-conveying company policy, general information, rules and regulations, job status reports, problems and shop floor opinion.

other duties nclude:-

Welfare
Discipline
Training of his men
Safety
Job Instruction
Union Relations

His other responsibilities can include:-

Job Preparation
Plant Inspection
Time booking and cost allocation
Materials requisitioning

What qualities then do we have to look for in selecting a foreman?

He must be intelligent and must have the necessary technical knowledge of the job. This does not necessarily mean that he must be the best craftsman in the shop.

He must possess that indefineable quality "leadership".

I have deliberately avoided fusing that word up until now. I have tried to show what results a good leader will achieve, as I feel this is of more pratical value than trying to define leadership.

Selection of foremen then must be aimed at identifying these qualities in the candidates. Necessary compromises of course must be made, providing essential qualities are present. Subsequent training can then be directed at developing the latent talents and passing on the necessary information on organisation and procedures. A planned approach to supervision and its problems is necessary nowadays. The old chance methods are no longer sufficient to meet the more demanding requirements of competative industry.

APPENDIX VI

EXAMPLE OF MAINTENANCE WORKSHOPS FOR CHEMICALS MANUFACTURING ORGANISATION EMPLOYING APPROXIMATELY 500 PRODUCTION WORKERS

Workshop Facilities: 1. Three Area Workshops. 2. Field workshop, 3. Machine and Fitting Shop, 4. Welding Shop, 5. Civil Trades Workshop, 6. Rigging Shop, 7. Garage Workshop, 8. Electrical Workshop, and 9. Instrument Workshop.

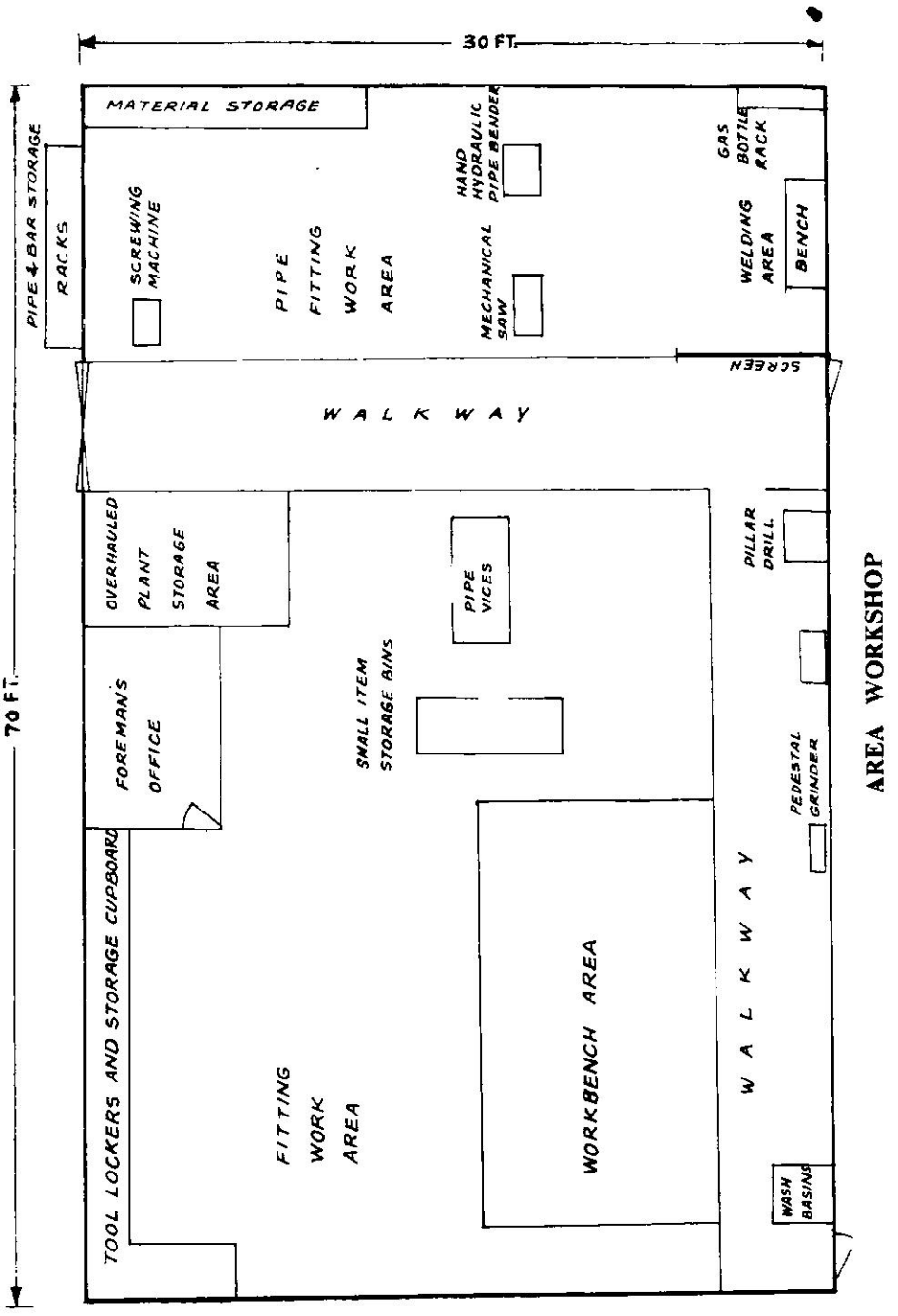
1. AREA WORKSHOP

Personnel

2 Foreman	—daywork
8 Mechanical Fitters	—daywork
8 Pipefitters	—daywork
3 Non craft men	—daywork
2 Greasers	—daywork
1 Mechanical Fitter	—Shiftwork (1 per shift)
1 Pipefitter	—Shiftwork (1 per shift)

Workshop Equipment

14" Rough Grinding Stone
6" Tool Grind Stone
Tubular Hydraulic Pipe Benders up to 3"
"Rapidor" Mechanical Saw with Angle Vice for Sawing up to 6"
Bench Drill with Morse Taper Chuck to spare Chuck for straight Shank Drills to us
"Rigid" 300 pipe threader to 50m with Dies for Screw Cutting



AREA WORKSHOP

Workshop Tools

Set Socket Wrenches with extension Bars and Ratchet A/F sizes
Set Metric Socket Wrenches 5mm—20 mm.
Torque Wrench
7lb. Lump Hammer
10lb. Sledge Hammer
Electric Pistol Drill ½" Chuck
2 Electric Portable Drills ?" Chuck
Electric Portable Drill ½" Chuck
Morse taper Shank Drills to ?"
Straight Shank Drills to ⅛"
2 Electric Extension Leads
2 Electric Transformer 25÷50 Volt
Internal Circlip Piers
External Circlip Pliers
Hacksaw Frames and Blades
Set Wad Punches
24" Stillson Wrench
18" Stillson Wrench
Dexion Iron Angle Cutting Tool
B.S.W. Taps to ¼"
B.S.P. Taps to 2"
2—1" Ring Slogging Spanners
Set open ended Metric Spanners 5 mm—20 mm.
Flame Proof Hand Torch
50 Volt Trailing Lamp

Mechanical Fitter Tool Kit

1½ lb. Ball Pien Hand Hammer
Centre Punch
½" Flat Chisel
Round Nose Chisel
Diamond Point Chisel
Cross Out chisel
Set Allen Keys
Stillson Wrench 10"
Screw Derivers 6"
Hose Clip Screw Driver
Off Set Pinch Far 16"×½"
2 Fox Wedges –2"
Pair Combination Pliers
Scraper ½" Round×6"
Scraper Flat 8"
Scraper 3 Square 6"
Spanners –Open Jaw Double Ended
Precision Hexagon Bolts, Screws and Nuts—BSW & BSF Threads 3/16"—½"
5/16"—⅜", ½"—¾", ⅞"—1"
U.N.F. 3/16"—¼", ¼"—5/16", ⅜"—7/16", ½"—9/16", ½"—⅝", ⅝"—¾"
Double Ended Cranked Ring Spanners
Precision Hexagon Bolts, Screws and Nuts—BSW & BSF Threads ½"—⅝", ¾"—7/9"
U.N.F. ¾"—5/16" ⅝"—7/16", ½"—9/16", ½"—⅝"
U.N.C. ½"—⅝", ⅝"—¾"

Pipefitter Tool Kit

1½ lb. Ball Pien Hand Hammer
½" Flat Chisel
Stillson Wrench 24"
1 Pair Stillson Wrench 14"
Fox Weages 2"
Pinch Bar 16"×⅝" Off Set
Combination Pair Pliers
Hose Clip Screw Driver
Spanners as Mech. Fitter

2. FIELD WORKSHOP

Personnel

4 Foremen	
16 Mechanical Fitters	—daywork
29 Pipefitters	—daywork
1 Welder	—daywork
11 Non-Craft Men	—daywork

Workshop Equipment

"Leonard" Flanging M/C

Flanges MS and SS Tube up to and including 4" N.B. by cold rolling flange on pipe end.

Bench Drill

Uses twist drills up to and including ⅝".

Standard Drill

Uses twist drills up to and including 1¼".

Pedestal Grinding Wheels

Large and small

Tube Bender Electro-hydraulic

½" to 4"

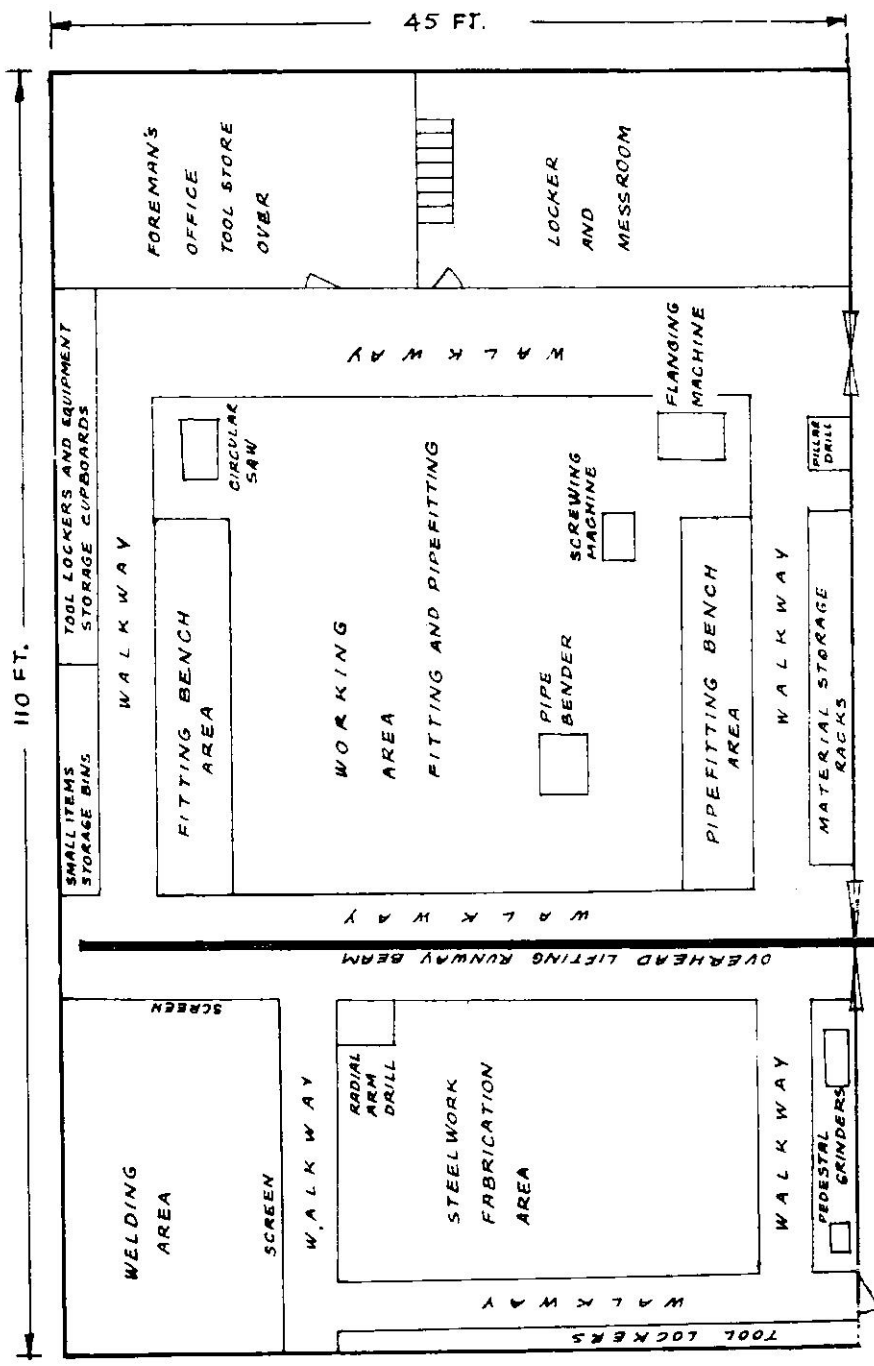
Machine Hack Saw

Cuts MS and SS Tube up to and including 6" N.B. Cuts stealwork up to 6"×4".

Abrasive Cut-off Machine

Cut all pipe and steelwork up to 4½".

For use with 18" diameter abrasive wheels



FIELD WORKSHOP

Circular Block Saw

Used for cutting tube to be used in Flanging M/C. Cuts up to 4″ N.B.

Screwing M/C

Used for cutting threads up to 6″ N.B.

Workshop Tools

2 Portable Sanding Machines
2 "Box" Magnetic Drilling Machines
"Bandit" Banding Tool
1 Battery Drill
4 Ermeto Spanners
"Bicep"Hand Truck with Hand Hydraulic Lift Platform

Mechanical Fitter Tool Kit

Ball Pein Hand Hammer, 1¼ lbs. weight
Chisel—1″ width—8″ long
Chisel Cross Cut—¼″ width—6″ long
Chisel Round Nose—¼″ width—6″ long
Chisel Diamond Point—¼″ width—6″ long
Set Double Ended—open jawed Spanner for Whit Nuts
3/16″×¼″: 5/16th″×⅜″: ½″×⅝″: ¾″×⅞″.

Double Ended—open jawed Spanner for Unified Fine Threads UNF

½″×7/16th″ A.F. 9/16″×11/16th″.

Set Double Ended open jawed Spanner for Unified Thread UNC

½″×⅝″ AF ⅞″×1 1/16″

¾″×⅞ AF 1⅛″×1 7/16″

Set Double Offset—double ended Chrome-vanadium-ring spanners—Unified

½″—⅜″ U.N.C. (AF ⅞″—1 1/16″)

⅜″×¾″ U.N.C. (AF 1 1/16″—1¼″)

¾″×⅞″ U.N.C. (AF 1⅛″—1 7/16″)

1 Set Double Offset—double ended Chrome-vanadium ring spanners—Whitworth ½″×⅝″×¾″—⅞″

Set Allan Keys ⅛″ to ½″
Stillson Wrench—10″
Screw Driver—6″ (Wood Handle)
Hose Clip Screwdriver—T. Handle
Pair Tin Snips—10″
Pinch Bar 16″—⅝″ diameter
Files and Handles as required
Fox Wedges—1″×3½″
Pair Pliers 7″
Key drawer
Hacksaw
Spirit Level
Square
Feeler gauges
6 ft. Tape Rule

Pipefitter Tool kit

Ball Pein Hand Hammer 1¼ lbs. weight
Chisel Flat ½″×8″ long
Cross Cut Chisel—½″×8″ long
Set Double ended—open jawed Spanners for whit Nuts
3/16″×¼″: 5/16″×⅜″: ½″×⅝″: ¾″—⅞″

Set Double ended—open jawed Spanners for UNF
⅜″—7/16″ AF 9/16″×11/16″

Set—Double—ended—open jawed Spanners for UNC
⅜″×⅝″ AF ⅞″×1 1/16″
¾″×⅞″ AF 1⅛″×1 7/16″

Set—Double Offset—Double ended Chrome-vanadium Ring Spanners
½″×⅝″ UNC (A/F ⅞″×1 1/16″)
⅝″—¾″ UNC (A/F 1 1/16″—1⅛″)

Set—Double Offset—Double ended Chrome-vanadium Ring Spanners—whitworth
½″×⅝″ & ¼″×⅜″
14″ Stillson Wrench
24″ Stillson Wrench
Files and Handles as required
Fox Wedges 1″—3½″

Pair Tin Snips—10″
Pair Pliers—7″
Screwdriver—6″
Hose Clip Screwdriver T Handle
Hacksaw
Spirit Level
Square
Feeler gauges
6 ft. Tape Rule

3. MACHINE AND FITTING SHOP

Personnel

1 Foreman
4 Turners
4 Mechanical Fitters
2 Non-Craft Men
1 Storekeeper

Workshop Equipment

Centre Lathes

Machine No.	Swing Over Bed	Swing Over Gap	Speed Range R.P.M.	Length Between Centres	Screw Cutting Capacity
No. 1	18"	26"	20 RPM—1600	6' 6"	2 TPI—72 TPI + Metric
No. 2	16"	32"	13 RPM—404	4' 6"	2 TPI—28 TPI + Metric
No. 3	22"	39"	13 RPM—400	5' 0"	2 TPI—28 TPI
No. 4	22"	36"	13 RPM—500	9' 0"	1 TPI—36 TPI + Metric
No. 5	12"	No Gap	54 RPM—1200	3' 0"	4 TPI—52 TPI + Metric
No. 6	16"	No Gap	42 RPM—375	2' 6"	Metal Spray Only

Mechanical Fitter Tool Kit (Shop Work)

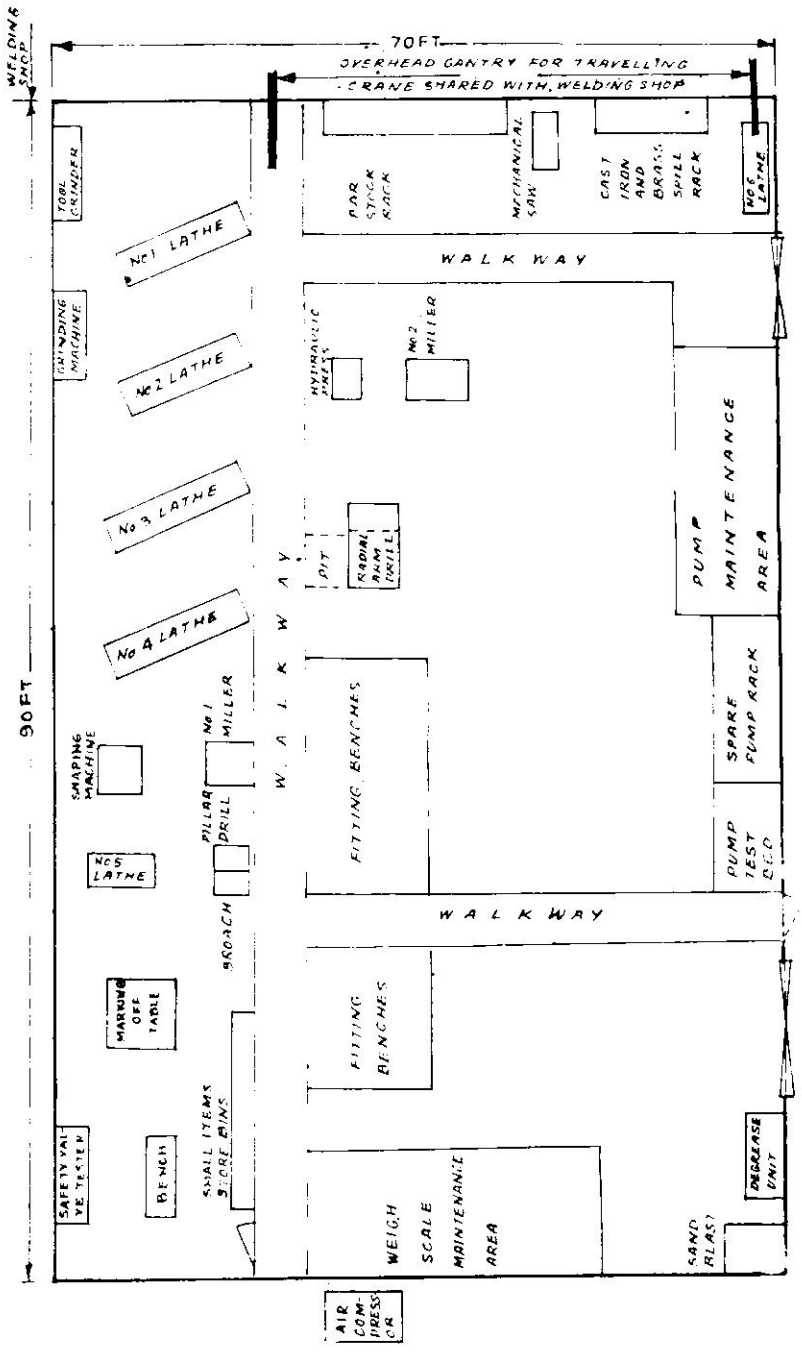
Sets of Spanners

Whitworth	*A/F*	*Metric*
$\frac{1}{8}$"—1"	$\frac{1}{4}$—1 1/6	6 mm.—12 mm.

Screwdrivers	—	4" and 8"
Pliers	—	6"
Allen Keys (Sets)	—	British Standard and Metric
Scrapers	—	Half Round—flat—three square
Hammers	—	1 lb.—1$\frac{1}{2}$ lb.—4 lb.
Chisels	—	Flat—cross cut—diamond point—round nose
Stillson Wrench		14"
Clamps	—	Tool makers and "G"
Centre Punches	—	2" and 4"
Rules	—	6"—12"—24"—B. Standard and metric readings
Calipers	—	Inside—outside—Dividers—Tramells—Odd legs in various sizes
Hack Saws	—	Junior and standard
Spirit Level	—	6"
Squares	—	6" and 12"
Podger Bars	—	8" and 14"
Tin Snips	—	8"
Scriber		

Workshop Tools (Toolstore also serves as central store for total maintenance workforce)

Hydraulic Drawing Equipment	—	20 and 50 ton
Small Screw Drawing Equipment	—	4"—12"
Broaching Equipment (Hand Operated)	—	$\frac{1}{8}$—9/16 Keyways



MACHINE AND FITTING SHOP

Electric and air hand drilling machines	—	$\frac{1}{4}$—$\frac{1}{2}$—$\frac{3}{4}$
Ratchet Drills	—	$\frac{1}{4}$″—1″
High Speed Steel Drills	—	1/64—2$\frac{1}{2}$″ Dia
High Speed Steel Taps	—	Whit—BSP—BSF—UNC—UNF BSF—Metric
High Speed Steel Dies	—	Whit—BSP—BSF—UNC—UNF BSF—Metric
Tube Expanders	—	$\frac{3}{8}$″—2″
Socket Sets	—	Whit—A/F—Metric
Portable Sanders (Electric)		
Portable Grinders (Electric)		
Milling Cutters —various	—	Rotary—end mills—slot drills Woodruff
Non Spark Tools	—	Hammers—chisels—spanners
Pressure Gauges	—	0—1000 p.s.i.
Vacuum Gauges		
Tube Bending Equipment	—	$\frac{1}{2}$—3″ N.B.
Wad and Bell Punches	—	$\frac{1}{8}$—2″
Stillson Wrenches	—	18″—24″—36″—48″
Impact Tools	—	$\frac{3}{4}$Drive
Tube Cutters	—	$\frac{1}{2}$—2″
Oil—Grease—Degreasing Fluid		
Cotton Waste		

Milling Machines	No. 1	No. 2
Table Length	3/4″	60″
Table Height from Spindle Centre	12″	19″
Speed Range	31-1010 RPM	28-1400 RPM

Shaping Machine

Length of Stroke	—	12″
Table Dimensions	—	17″×11″
Table Height from Tool	—	12″
Feed Traverse	—	30″

Grinding Machines

Tool Grinding Machine	—	12″ dia—2″ wide Stone Size
Centre Grinder	—	3′ 0″ between centres 12″ over bed.

Drilling Machines

4′ 6″	—	Radial Arm—Drill Capacity —$\frac{1}{8}$″—3$\frac{1}{2}$″ dia
Pillar Type Drill	—	1/64—$\frac{3}{4}$ Capacity

Mechanical Saw

10″ Dia. Vice Capacity
12″ Stroke

4. WELDING SHOP

Personnel

1 Foreman
14 Welders/Sheet metal Workers
4 Burners
3 Non Craft men

Workshop Equipment

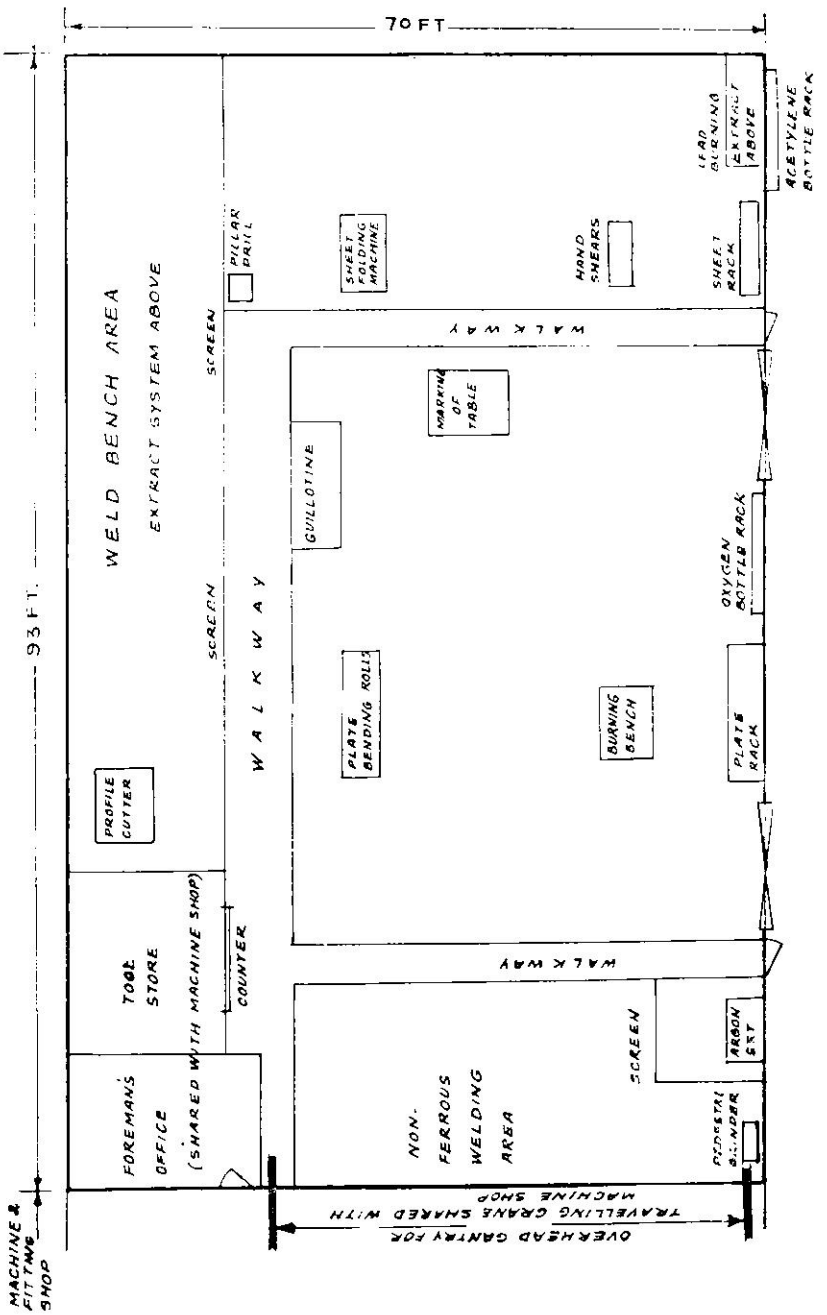
8 ft. Plate Guillotine Capacity $\frac{3}{8}$″ M.S. $\frac{1}{4}$″ S/S Plate
6 ft. Plate Bending Rolls. Capacity $\frac{1}{2}$ M.S. Plate
6 ft. Sheet Bending M/C. Capacity $\frac{1}{8}$″ M.S. Plate
Pedestal Grinder 14″ Abrassive Wheels. Spindle Speed 1440 r.p.m.
3 ft. Tinsmiths Rolls. Capacity 24 S.W.G.
3 ft. Tinsmiths Guillotine Capacity 24 S.W.G.
2 Banks of 8 Oxygen Cyls. Pipe all around the Shop
2 Banks of 3 Acetylene Cyls. Pipe all around the Shop
Oxy. Acety. Ring Main around W/Shop covering all benches
1 Fixed Welding Transformer with 3 pots Range 30—280 amps
1 Argon Welding Set Range 24—330 amps
2 DC Welding Sets 20—300 amps
1 AC/DC Welding Set Range DC 92—520 amps. AC Range 116—624 amps
1 Dual AC Welding Set Range 2 Operators 20—250 amps
Range 1 Operator 20—480 amps
1 Dual AC Welding Set Range 2 Operators 45—185 amps
Range 1 Operator 45—350 amps
11 Singe Operator Portable AC Sets Range—20—300 amps
1 Petrol Driven DC Welding Set Range 40—170 amps
4 Oxy. acety. Burning and Welding Sets—Portable
All Welding Sets with the exception of the 1 Fixed transformer and 3 Pots are portable
1 "Air Products Quickly" Oxy. Acety. Cutting M/C
1 Oxy. Profile cutting M/C with powder cutting attachment for S/S
A single phase 50 v. ring main supplies the shop with points accessible to all benches
An air ring main of 80 p.s.i. supplies the shop with points accessible to all benches
A travelling gantry crane operates over $\frac{1}{4}$ of the length of the Shop and is fitted with an Air Operated 1 ton Block and a Manually Operated 3 ton Block.

Workshop Tools and Stores

Compressed air "Trumph" Bevelling M/C TKF 100

Chamfers 45° Angle on plate or pipe edges from thickness $\frac{1}{4}$″—$\frac{5}{8}$″

3″—7″ Portable "Black-Decker" Sanders Electrically Operated



WELDING SHOP

1—4″ Portable "Black-Decker" Grinderette Electrically Operated
Battery Operated Pistol Drills
Air Operated Chipping Hammers
Air Operated Grinders
Various sizes of Electric Portable drills
2 "Bicep" hand trucks with hand hydraulic table lift
Jig Saws
Pop Rivet Pliers
Tungsten Electrodes for Argon Torches
Nozzles for Saffire Cutters
Oxygen Acetylene Propane and Argon Regulators
Cable for Welding and Eearth Leads
Oxygen and Acetylene Hose
Grinding and Sanding Discs
Nozzles for Welding Blow Pipes
Spare Cutters for Trumph Bevelling M/C
Blades for Jig Saws

Welder Tool Kit

Ball Pein
Hammer
Flat Chisel
Round Nose Chisel
Cross Cut Chisel
8″ Screw Driver
Off—Set Pinch Bar
8″ Combination Pliers
Hack Saw
Centre Punch
Wire Brush
Welding Shields
Chipping Hammer
Spanners from $\frac{3}{8}$″ up to 1 1/16″ AF
"Gilbow" Tinsnips

5 CIVIL TRADES WORKSHOP

Personnel

1 Foreman
6 Joiners/Carpenters
5 Painters
2 Bricklayers
4 Sheeters (For work on building roof and side sheeting)
4 Laggers
3 Building Cleaners
9 General Labourers

Workshop Equipment

MACHINE	H.P.	
Large Circular Saw	15	Capable of cutting 10″ Depth
Small Circular Saw	6	Capable of cutting 5″Depth with rise and fall table
Bandsaw	4	Capable of cutting 2' 6″ Diameter—6″ depth
Cross-cut Saw	$\frac{1}{2}$	Cuts to 3″ depth
Wilson Planer and Thicknesser	3	Surfacing width 12$\frac{1}{2}$″ Thicknessing capacity 7″ Rebating depth $\frac{1}{2}$″
Wood lathe	$\frac{3}{4}$	5″ Radius 3' 6″ between centres
Mortiser	1	Hollow chisel type $\frac{1}{4}$″ to $\frac{7}{8}$″
Vertical Milling Machine	5	For pattern making

ELECTRIC PORTABLE EQUIPMENT

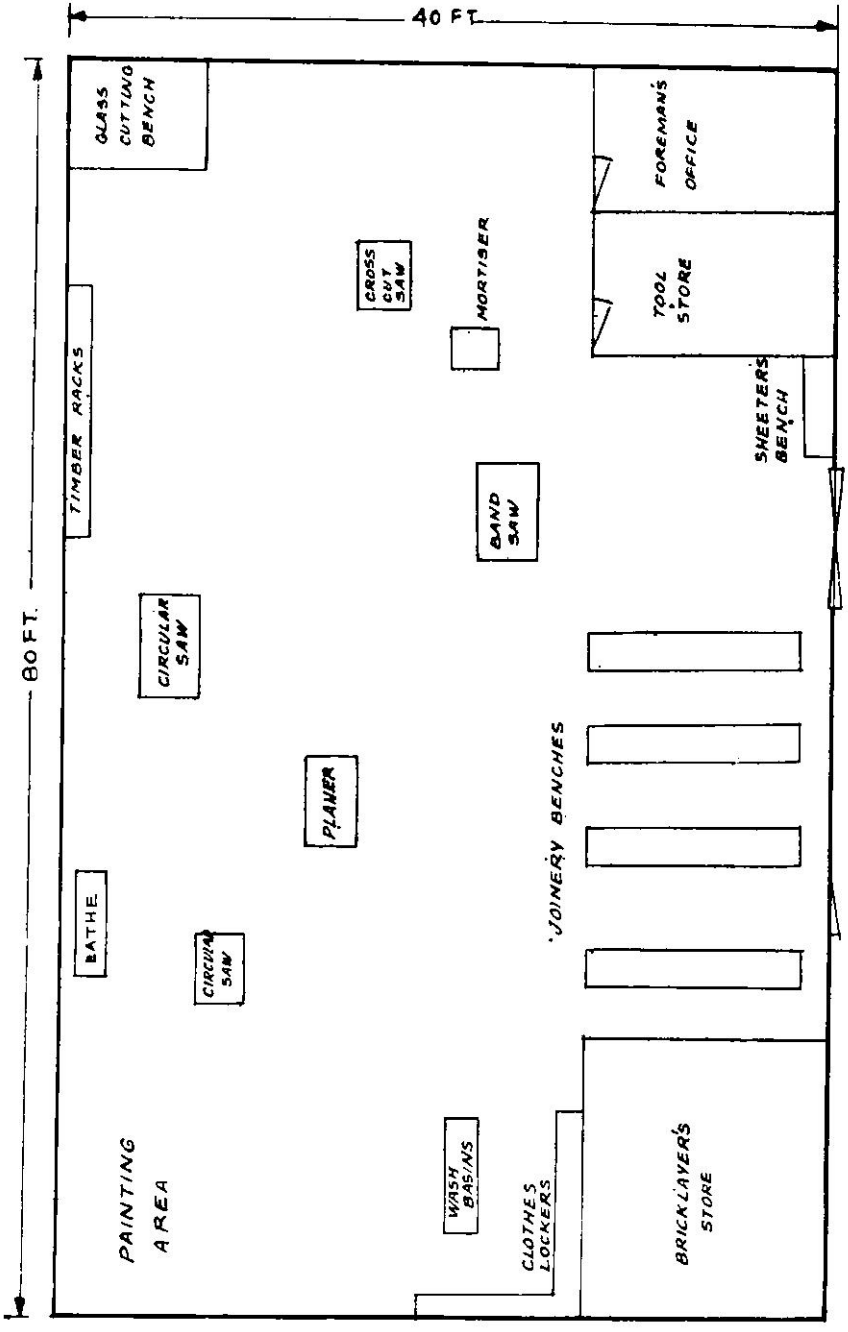
TOOL

2 Speed Heavy-Duty Drill	$\frac{1}{2}$″ Capacity. 1200 & 525 r.p.m.
140 Type D.G. Drill	$\frac{1}{4}$″ Capacity 1400 r.p.m.
Heavy-Duty belt Sander	Belt Size 3″×24″ 1500/Belt ft/min.
General Duty Jig-Saw	3000 min.
Electro-Pneumatic Rotary Pereussion Drill	$\frac{1}{2}$" to 2" Capacity
Cordless Electric Drill	$\frac{1}{4}$" Capacity

AIR OPERATED EQUIPMENT

Heavy-Duty Concrete Breaker Hammer Drill	With Spring-type retainer for use with chisel, peg-point or spade end Dry type with coil spring retainer $\frac{1}{2}$" to 2" capacity

Cement Mixer 10/7 cu. ft.
2 Wheelbarrows
6 Shovels
2 Picks
2 Sledgehammers



CIVIL TRADES WORKSHOP

Bricklayer Tool Kit

Hand Trowel
Pointing Trowel
Plastering Trowel
Brick Hammer
Masons Club Hammer
Bolster Chisel
Assortment of Plugging chisels and drills
3' 0" Plumb Level
12" Pocket Level
Plumb-bob
Chalk-lines and pins

Painter Tool Kit

Various size paint brushes
7" Flat Brush
Variety of Scrapers
Shave hooks
Dust Brushes
Blow-lamp
Paper Brushes
Paper Hangers Scissors
Sanding Blocks

Joiner/Carpenter Tool Kit

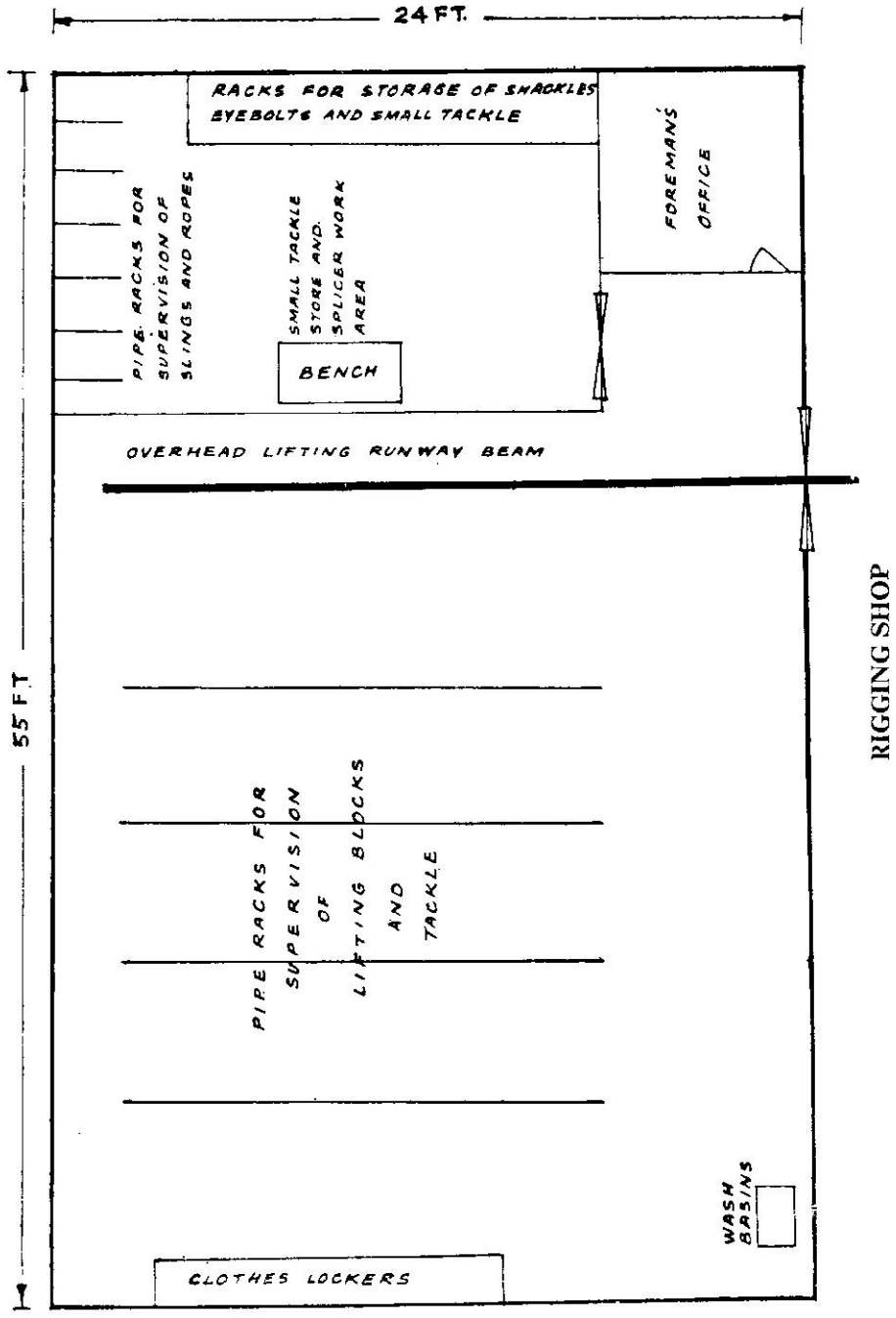
Handsaw 26"—8 teeth to inch

Panel saw 24"—10 teeth to inch
Dove Tail saw
Steel jack plane
Steel smoothing plane
Rebate Plane
Try Square
Mitre Square
Marking Gauge
Mortise Gauge
Hand brace
Set of twist bits $\frac{1}{4}$" to $1\frac{1}{4}$" in 1/16" ths
Set of firmer chisels $\frac{1}{4}$" to $1\frac{1}{4}$" in $\frac{1}{8}$" ths.
Set of Mortise chisels $\frac{1}{4}$" to 1" in $\frac{1}{8}$" ths.
Bevel
20 oz. claw hammer
Warrington hammer—Pane Hammer
Tack hammer
12" Pocket level
Plumb-bob
Assortment of screwdrivers
4 lb. Axe.

6. RIGGING SHOP

Inventory of Rigging Tackle held for General Use

ITEM	SAFE WORKING LOAD	NOS. OFF
Manual Chain Blocks	15 Tonnes	2
Manual Chain Blocks	10 Tonnes	2
Manual Chain Blocks	6 Tonnes	2
Manual Chain Blocks	5 Tonnes	2
Manual Chain Blocks	4 Tonnes	2
Manual Chain Blocks	3 Tonnes	6
Manual Chain Blocks	2 Tonnes	7
Manual Chain Blocks	1.5 Tonnes	2
Manual Chain Blocks	1 Tonne	7
Manual Chain Blocks	.5 Tonne	14
Mini Lift Hoist	.25 Tonne	1
Mini Lift Hoist	.5 Tonne	1
Monkey Winch and Equipment	5 Tonnes	1


24 FT.
55 FT
RACKS FOR STORAGE OF SHACKLES EYEBOLTS AND SMALL TACKLE
FOREMAN'S OFFICE
PIPE RACKS FOR SUPERVISION OF SLINGS AND ROPES
SMALL TACKLE STORE AND SPLICER WORK AREA
BENCH
OVERHEAD LIFTING RUNWAY BEAM
RIGGING SHOP
PIPE RACKS FOR SUPERVISION OF LIFTING BLOCKS AND TACKLE
WASH BASINS
CLOTHES LOCKERS

ITEM	SAFE WORKING LOAD	SIZE	NOS. OFF
"Tirfor" Winch	1.5 Tonnes		1
Scissors Girder Clip	1.5 Tonnes		4
Scistors Girder Clip	2 Tonnes		12
Scissors Girder Clip	3 Tonnes		2
Scissors Girder Clip	4 Tonnes		2
"Felco" Girder Clip	2 Tonnes		8
"Felco" Girder Clip	5 Tonnes		1
"Yale" Pullifts	1.5 Tonnes		2
"Yale" Pullifts	3 Tonnes		1
Plate Lifting Clamps	1 Tonne for up to	16 mm Plate	1
Plate Lifting Clamps	.75 Tonne for up to	16 mm Plate	1
Runway Trolley	1 Tonne to fit	76 mm to 102 mm joists	1
Runway Trolley	.5 Tonne to fit	178 mm joists only	1
Runway Trolley Scissors	.5 Tonne to fit	76 mm to 178 mm joists	1
Eye Bolts	2.2 Tonnes	25 mm Shank	3
Eye Bolts	1.6 Tonnes	22 mm Shank	1
Ring Bolts	1.5 Tonnes	32 mm Shank	5
Ring Bolts	1 Tonne	22 mm Shank	4
Ring Bolts		16 mm Shank	2
Chain Slings			
Chain Sling	4.2 Tonnes	2 Leg Duplex at 90°	2
Chain Sling	4.5 Tonnes	Single Chain 19 mm	4
Chain Sling	2.5 Tonnes	Three Leg..	1
Chain Sling	3.1 Tonnes	Single Chain 16 mm	16
Chain Sling	2.5 Tonnes	Single Chain 14 mm	14
Chain Sling	2 Tonnes	Single Chain 13 mm	6
Chain Sling	1.5 Tonnes	Sing'e Chain 11 mm	8
Chain Sling	1 Tonne	Single Chain 9 mm	7
Chain Sling	.5 Tonne	Single Chain 6 mm	6

Chains vary in length from 1 metre to 4 metres

Lifting Beams			
3 Sheave Rope Block	.75 Tonnes		3
2 Sheave Rope Block	.75 Tonnes		4
1 Sheave Rope Block	.5 Tonnes		3
Jacks			
Ladder Jacks	15 Tonnes	305 mm lift	3
Hyd. Traverse Jack	10 Tonnes	305 mm lift	1
"Hydralite" Hydraulic Jack	25 Tonnes	225 mm lift	1
"Hydralite" Hydraulic Jack	25 Tonnes	125 mm lift	1
"Hydramite" Hydraulic Jack	5 Tonnes	80 mm lift	2
Shackles			
Bow Shackles	12 Tonnes	51 mm	10
Bow Shackles	8.5 Tonnes	47 mm	2
Bow Shackles	7.5 Tonnes	44 mm	6
Bow Shackles	6.5 Tonnes	41 mm	6
Bow Shackles	6 Tonnes	38 mm	10
Bow Shackles	2.75 Tonnes	25 mm	3
Bow Shackles	2 Tonnes	13 mm	4
"D" Shackles	8.5 Tonnes	41 mm	2
"D' Shackles	6 Tonnes	35 mm	2
"D" Shackles	5.5 Tonnes	35 mm	2
"D" Shackles	5 Tonnes	31 mm	2
"D" Shackles	4 Tonnes	25 mm	1
"D" Shackles	3 Tonnes	25 mm	1
"D" Shackles	2.25 Tonnes	19 mm	4
"D" Shackles	2 Tonnes	22 mm	1
"D" Shackles	1.25 Tonnes	25 mm	5

Wire Rope Slings

Wire Rope Sling	2.5 Tonnes	16 mm×2 m.	6
Wire Rope Sling	2.5 Tonnes	16 mm×4 m.	6
Wire Rope Sling	2.5 Tonnes	16 mm×5 m.	6
Wire Rope Sling	2.5 Tonnes	16 mm×6 m.	6
Wire Rope Sling	2.5 Tonnes	16 mm×7.5 m.	6
Wire Rope Sling	4 Tonnes	22 mm×2 m.	6
Wire Rope Sling	4 Tonnes	22 mm×4 m.	6
Wire Rope Sling	4 Tonnes	22 mm×6 m.	6
Wire Rope Sling	4 Tonnes	22 mm×7.5 m.	6
Braided Rope Sling	5 Tonnes	4 m.	2
Braided Rope Sling	10 Tonnes	5 m.	4
Wire Rope Sling	For RA Autos		12
Wire Rope Sling	For 4D Autos		4
Felco Self Adjusting Sling	1.5 Tonnes		1

Scaffolding

"Zip Up" Quick erect scaffolding—5 Stairway sections 2 sets of handrails Fully erected to 10 m.

"Zip Up" Span Staging+handrails
Fully erected to 4 m.

"Mills" Frames 1.5 m. Fully erected to 31 metres complete with braces.

Scaffold Tubing 137 metres in various lengths

Scaffold Clips 300 of various types.

7. GARAGE WORKSHOP

Personnel

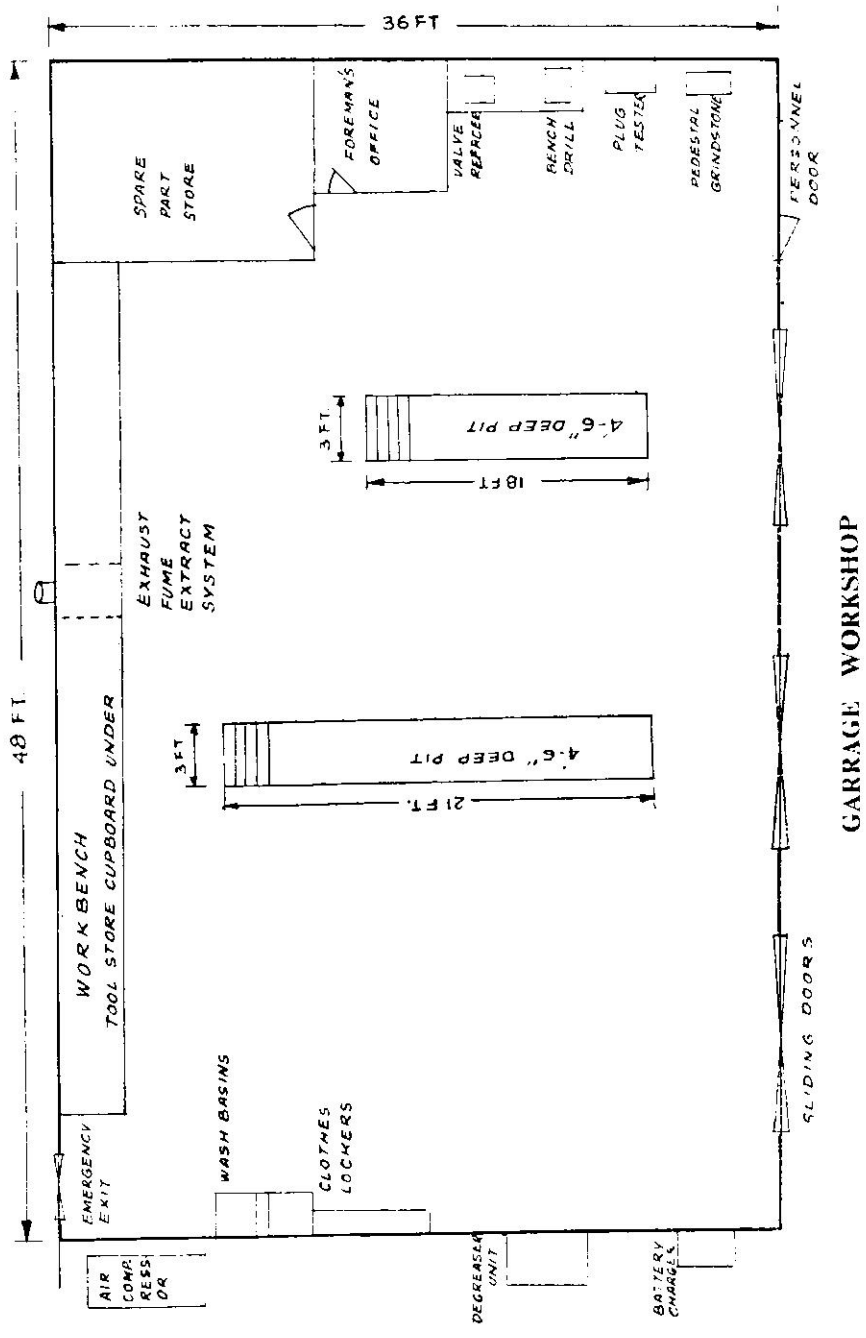
1 Foreman
4 Motor Mechanics
1 Non-Craft Men

Workshop Equipment

Grindstone—10″ Pedestal (2 stone)
Pillar Drill—up to $\frac{5}{8}$" dia.
Tyre Removal Equipment (Hand Press) up to 40×8
Commercial Vehicle Tyres
Valve Refacer
Spark Plug Tester
Power Lubricating Equipment
Guillotine (Hand $\frac{1}{8}$" plate)
Compressor (150 p.s.i. 40 c.f.m.)

Workshop Tools

Full Whit. A.F. and Metric Socket Set
3 Pneumatic Impact Wrenches $\frac{1}{2}$" $\frac{3}{4}$" Medium and $\frac{1}{4}$"
Long Square Drive and Impact Sockets
$\frac{1}{4}$ and $\frac{3}{8}$ Portable Drills (Elec.—50 v.)
Portable Sander (6" dia.—240 v.)
Gas Welding Equipment
Pop Riveter
Universal Hub Pullers—Hand Hydraulic
Injector and Fuel Pump Testers


36 FT
48 FT
SPARE PART STORE
FOREMAN'S OFFICE
VALVE REFACER
BENCH DRILL
PLUG TESTER
PEDESTAL GRINDSTONE
PERSONNEL DOOR
4'-6" DEEP PIT
3 FT
18 FT
EXHAUST FUME EXTRACT SYSTEM
4'-6" DEEP PIT
3 FT
21 FT
WORK BENCH
TOOL STORE CUPBOARD UNDER
EMERGENCY EXIT
WASH BASINS
CLOTHES LOCKERS
AIR COMPRESSOR
DEGREASER UNIT
BATTERY CHARGER
SLIDING DOORS
GARRAGE WORKSHOP

Mercer Gauges and Micrometers 1" to 6"
Clutch Reset and Alignment Mandrills
Set of Expanding Reamers ½" 1⅛"
Compression Tester
Torque Wrenches 0—500 ft. lbs 500-1000 ft. lbs
Pressure Gauges 200 to 2000 p.s.i. (For Hydraulic system testing)
Stocks and Dies and Taps Whit. A.F. 3/16 to 1"
Circlip Removal Tools

Motor Mechanic Tool Kit

A. F. Metric and Whit. Spanners Ring and Open ended up to 1" A.F.
⅞" Whit. and 36 mm.+B.A.
1½ lb. and ½ lb. Ball Pein Hammers
Universal, side cutting, long nose, and circlip pliers
8", 6" and No. 1, 2 and 3 Phillips Screwdrivers
Universal Frame Hacksaw
Scissors
Centre and Parallel Assorted Punches
10" and 14" Stillson Wrenches
8" Half Round and Flat Scrapers
6 Assorted Files

Universal Spares

Tyres
Spark Plugs
C/B PTS
Bulbs
Dyno and Starter Brushes
Injectors
Fan Belts
Hoses Water and Hyd.
Ignition Coil
W. Wipe, Arms and Blades
Washer Fibre Plain Copper Shakeproof
Unif. Nuts and Bolts and Nyloc Nuts 3/16"—2/8"
14×.012 cable 28×.012 cable
Starter Cable
Boxes Assorted Elect. Terminals

Various amounts of Vehicles spares held, applicable to each individual type Vehicle

8. ELECTRICAL WORKSHOP

Personnel

3 Foremen
18 Electricians—daywork
1 Electrician—shiftwork (1 per shift)
1 Electrical fitter—daywork
7 Non craft men—daywork

Workshop Equipment

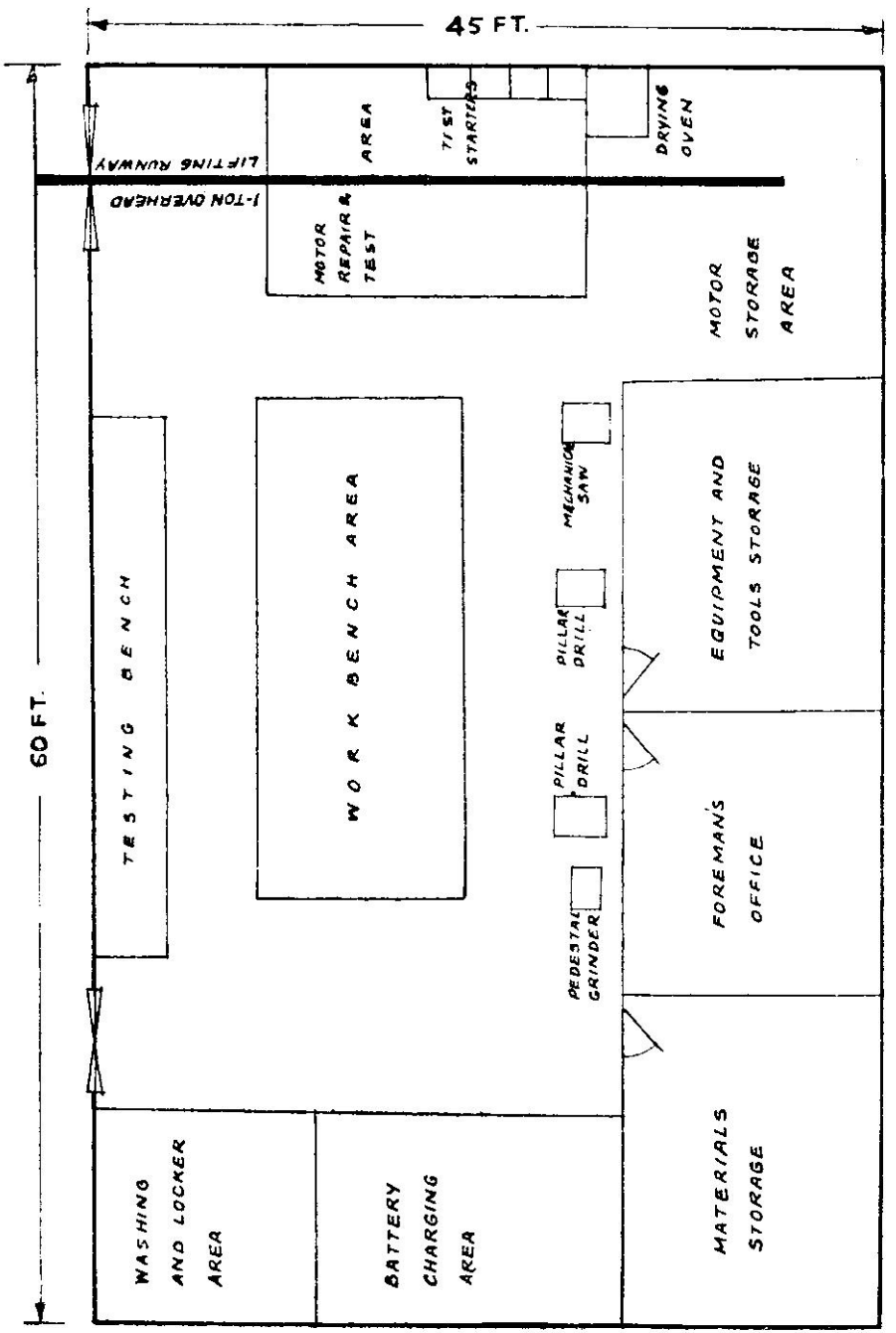
Mehcanical saw
Pillar drill up to ½" dia
Pillar drill up to 1" dia
Pedestal grinder—2 stone
Bar and angle hand bender (2×2 angle)
4—Battery chargers 250 volt input 6 or 12 volt output 20 amp hours capacity
Test Bench—fitted with power supplies from full range of socket outlets over range of voltages in factory use. Also fuel gas supply. Motor test bench—fitted with range of starters in current factory use.
1 ton lifting runway fitted with trolley and hand chain block—serving motor test area and through shop doorway.
Drying oven—4 ft.×4 ft.×4 ft.—Maximum temperature 150°C
7 Monitored earth control boxes
5 Monitored earth extension leads
9 50 V: 25V. transformers
4 1,000 volt "Meggar" insulation and continuity tester
6 5000 volt "Meggar" insulation and continuity tester
2 "Avo" multitester wide range model
1 "Avo" minor tester
4 "Sanwa" meters (voltage resistance etc.)
3 "Ferranti" 'clip-on' ammeters
Earth Loop impedance tester
'Clip-on' watt meter

Workshop Tools

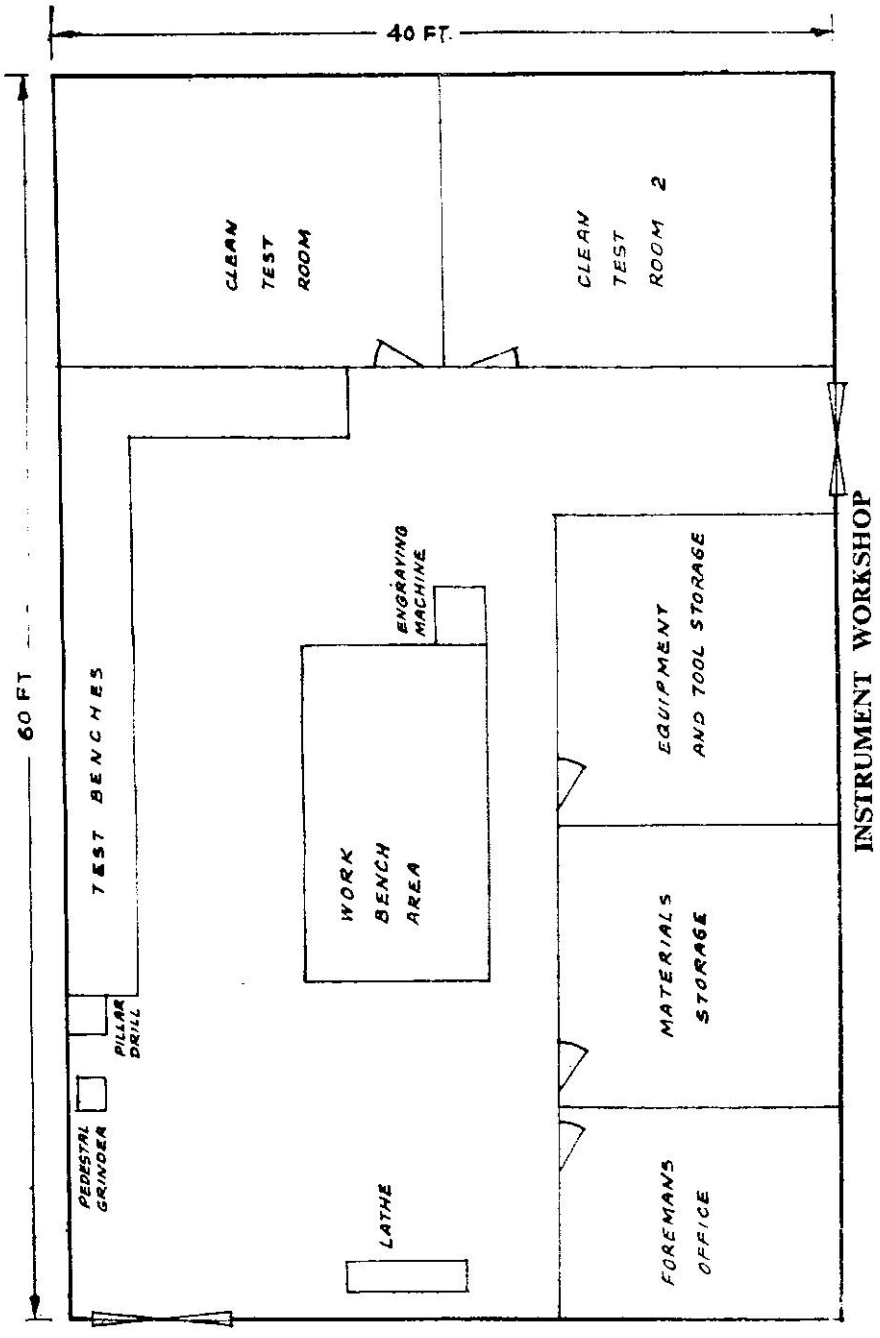
4 Vibro Drills
2 Hammer Drills
1 "Rapid" masonry drill
1 "Lesto" Jig Saw
1 Mineral Insulated Callender Cable stripper
1 ⅜" "Desoutter" Pistol Drill 50 volt
1 ¼" Desoutter" Pistol Drill 250 volt
2 ¼" "Desoutter" Pistol Drill 250 volt
1 ¼" "Desoutter" Pistol Drill 50 volt
1 ¼" "Wolf" Pistol Drill 50 volt
1 ¼" "Black & Decker" Pistol Drill (Battery Power)
1 "Secomak" Hot Air Blower
2 "Sturtevant" Cold Air Blower
"Pickstone" instant heat soldering iron 250 volts.
"Henly" soldering iron 250 volts.
2 "Henly" soldering iron 50 volts
Large, Medium and Small "Pickavant" hydraulic bearing extractor
"Pickavant" bearing inserting kit
Double burner for lead and pitch melting
3 Assorted gas blow torches
2 "Hilti" cartridge gun
As set of bronze spark resisting tools for use in flameproof areas
1 "Erma" hydraulic crimping tool with a range of dies to suit various cables

Electrician's Tool Kit

Set Whitworth Spanners open end
Set Metric Spanners open end
Set Metric and 1 set Whit. Allen Keys
Set Whit. Box Spanners



ELECTRICAL WORKSHOP


40 FT.
60 FT.
CLEAN TEST ROOM
CLEAN TEST ROOM 2
TEST BENCHES
ENGRAVING MACHINE
WORK BENCH AREA
EQUIPMENT AND TOOL STORAGE
MATERIALS STORAGE
FOREMANS OFFICE
PILLAR DRILL
PEDESTAL GRINDER
LATHE
INSTRUMENT WORKSHOP

Pair Side Cutters
Pair Insulated Pliers
Pair Long Nose Pliers
Small, Medium and Large Screwdrivers
Small, Medium and Large Star Screwdrivers (Philips head)
Stillson Wrench 10"
Test Lamp (Neon Indicator model)
1.5 lb. Ball and Pien Hammer
Knife
Cable Stripping Tool
Set B.A. Box Spanners
Set B.A. Open end Spanners
Centre Punch
Chisel
Copper Drift
Tape Measure
Kit Pyrotenax Accessories
Set A.F. Spanners open end
12" Hacksaw
Junior Hacksaw

INSTRUMENT WORKSHOP

Personnel

3 Foremen
17 Instrument Mechanics—daywork
1 Instrument Mechanic—shiftwork (1 per shift)
2 Non-craft men

Workshop Equipment

Instrument lathe—6" swing over bed 2' 6" long
Pillar drill—up to ½" dia.
Pedestal grindstone—2 stone
Engraving machine—for production of nameplates
Millivolt potentiometer
Radio Frequency equipment—Beat Frequency Oscillators and R. F. signal generator, digital counter with range to 999,000 cps for "Multitone" personal paging equipment
"Wallace and Tiernan" pneumatic test sets with 30 psig supply for instrument output testing with input signal range of up to 24 psig in steps of .01 psi.
'Avometers"—20,000 ohms/volt-resistance voltage tester
Bench Oscilloscope—Waveform measurement
Standard pressure gauges
Dead weight tester for gauges
Heated sand bath—for temperature indicator testin
Manometers (Mercury and water)
Stopwatch
Pistol drills and monitored earths ¼" and ½" dia 240 Volt
Battery drill 5/16" dia.
"Megger"—continuity tester
pH test units

Instrument Mechanic Tool Kit

1½ lb. Ball pein hammer
½ lb. Ball pein hammer
Set of Whitworth open jaw spanners
Set of A.F. open jaw spanners
Set of B.A. open jaw spanners
Set of metric open jaw spanners
Pair of 5" Dividers
Pair of 5" inside calipers
Pair of 5" outside calipers
Small screwdriver
3", 6" and 8" screwdriver
Phillips head screwdriver
12" Hacksaw
Junior hacksaw
Tweezers
Watchmakers screwdriver
Watchmakers eyeglass
Gauge pointer extractor
Set of Allen keys
10" and 14" Stillson Wrenches
Penknife
Set of Needle files
Assortment of large files
Insulated pliers
Centre punch
Set of pin vices
Pyrotenax Stripping and crimping tools
5" side cutters
Long nose pliers
Pencil brush.

APPENDIX VII

MAINTENANCE WORK REQUEST SYSTEM

I. Purpose

To define the correct methods to be used for requesting work from Maintenance Department and to define the responsibilities of the various Works Personnel involved.

II. Policy

It is the aim of Works Management that all requests for Maintenance effort shall be recorded in writing either by entry in the Area Maintenance Log Sheet system or through the Work Order System.

This will ensure that:

1. Clear instructions are received by the execution group.

2. That the work is correctly reported against cost classifications.

3. That information is provided and recorded of all work carried out by Maintenance Department. This information, together with Cost Records, will provide staff with historical information for improvement investigations and recapping purposes.

4. That an equitable system of priorities is operated.

5. That the workload of Central Trades and Centralised Maintenance Group can be planned and scheduled.

III. Procedure

All work will fall within two systems:

(*a*) *The Area Log Sheet System*

Work can be requested verbally or in writing directly to the Area Maintenance Foreman or Supervisor. For control and information purposes requests executed by Area Workshop Labour will be entered on Section Log Sheets by the Maintenance Foreman responsible. The Log Number will be used for all time-booking and material requisitioning purposes.

(*b*) *The Work Order System*

A Work Order is required for:

(*i*) All work to be carried out by the Centralised Maintenance Group and Instrument/Electrical Group. Minor assistance work of less than two manhours can be requested verbally.

(*ii*) All installation, replacement installation and major repair work for which senior management authorisation has been received. These will be given a Job Number.

Work Orders will be issued by the Work Order Clerk in Central Planning Group. Emergency work may be started without a Work Order but it will be the responsibility of the appropriate Maintenance Supervision to obtain the necessary Work Order at the earliest opportunity.

(*c*) *Allocation of Priorities*

(*i*) Priorities will be allocated by the work Order Clerk on the recommendation of the Originator.

(*ii*) There will be three priority ratings:

Priority 1: A job which requires immediate attention and on which Overtime should be worked if necessary for completion. These would be jobs:

(*a*) To avoid serious hazard to personnel or plant.

(*b*) To prevent plant shutdown or minimise downtime to avoid serious production loss.

Priority 2: Work which does not require an immediate start (i.e. more than 20 hours notice) but which has a critical completion time requirement.

Priority 3: All other work which will be completed to an agreed date, or on a scheduled basis.

(*iii*) Safety jobs dealing with an immediate hazard should normally be given Priority 1 and other safety jobs will be given favourable priority in drawing up Priority 2 schedules. Such Work Orders must be endorsed 'Safety'.

(*iv*) In the event of disagreement regarding priorities the decision of higher levels of Management up to Works Manager will be sought.

(*v*) To ensure effective planning, Priority 1 should be avoided. The use of this priority will be investigated by Maintenance Improvement Group and reported regularly.

(*d*) *Distribution of Work Orders*

(*i*) Work Order Forms will be printed on sensitised paper with pre-printed serial numbers with prefix letter 'W' to distinguish work order numbers from job numbers which will bear the prefix letter 'J'.

(*ii*) Three copies will be issued as follows:

Copy No. 1—To the Planner Foreman Craftsman

On completion of the job this copy will be passed to the appropriate Central Files, in the case of Centralised Maintenance Group jobs via the Planner, in the case of Construction jobs via the Project Progress Planning section.

Copy No. 2—To be retained in Planning Group for information and plant record purposes.

Copy No. 3—To the appropriate General Superintendent when improvement or work to assist production.

To the appropriate Maintenance Superintendent or Engineer when true repair work. *This copy will then be forwarded to the Originator.*

(*e*) *Labour and Material Costs*

Engineering labour, Supply Stores and Machinery Stores transactions will be charged to the appropriate Work Order Number, Job Number, Log Number or Department/Section Classification.

IV. Responsibilities

A. Originator

1. When a Work Order is requested adequate details should be given to the Work Order Clerk. If necessary, there should be prior consultation with Engineering Supervision.
2. Where appropriate, sketches or written requests may be sent by internal mail to Planning Group.
3. The priority rating must be recommended.
4. A Cost Classification must be agreed with the Work Order Clerk.
5. Maximum notice of requirements should be given.

B. Central Work Order Clerk or Engineering Supervision Issuing Work Orders.

1. Work Order must be written legibly, clearly and promptly.
2. There must be a brief descriptive title.
3. The appropriate distribution and date of issue must be recorded.
4. A suitable priority rating must be quoted.
5. A Cost Classification must be allocated.
6. Where necessary, work requirements will be referred to Service Engineers, or the Maintenance Improvement Group for investigation.

C. Engineering Supervision

1. Production Department will initiate Work Orders for Maintenance Work to be executed by Centralised Maintenance Group after discussion with Area Maintenance of the work required.
2. Work Orders will also be initiated by other departments for work to be carried out by Central Trade and Centralised Maintenance Group or by Construction Group.
3. Work Orders received will be executed strictly in accordance with instructions.
4. Amended instructions will be obtained if the job appears impracticable, inefficient or undesirable.
5. For construction work, Trade assistance will be obtained by issue of a Work Order.

APPENDIX VIII

MAINTENANCE AND REPAIR COSTING

Engineering Cost Classifications

I. *Purpose*

The purpose of this procedure is to provide a guide to the correct classification of engineering expenditure and to define the responsibilities of those concerned.

II. Policy

1. Capital expenditure will be segregated from revenue expenditure for Taxation purposes.
2. The responsibility for capital expenditure will be properly allocated to maintenance or operating departments.
3. The responsibility for various types of maintenance expenditure will be properly allocated to maintenance or operating departments.
4. Repair expenditure will be sub-divided for control purposes.

III. Procedure

A. CAPITAL EXPENDITURE

1. *Definition*

It is necessary for taxation purposes, that certain types of expenditure are classified as capital additions to our plants and are not paid for out of revenue.

Any expenditure which increases the value of our plant is, strictly speaking, a capital addition but it is not always easy in practice to distinguish between Capital and Revenue expenditure. The final authority on such matters rests with the Inland Revenue Department but our Accounting Department will provide guidance.

2. *Sub-Classification of Capital Expenditure*

For management purposes, Capital Expenditure will be further sub-divided as follows:

(*a*) *Maintenance Capital*: Any capital expenditure designed to reduce true repair costs, prolong the life of equipment or increase its mechanical availability.

(*b*) *Earning Capital*: Any capital expenditure justified on the basis of additional earnings or reduction of operting costs.

(*c*) *Plant Improvement Capital*: Any capital expenditure not covered above i.e. which is designed to improve plant safety, appearance or convenience without any additional earnings.

NOTE: A capital job may be distributed on a percentage basis over these three classifications.

B. MECHANICAL EXPENSE

All maintenance expenditure chargeable to revenue will be known as the 'Total Mechanical Expense'. It will be sub-divided as follows:

(*a*) *True Repairs*

Normal repairs to increase mechanical availability or prolong the life of equipment. It will include planned maintenance inspections, statutory inspections and all painting costs not classified as capital expenditure.

(*b*) *Plant Improvement*

Work carried out by Maintenance Department, chargeable to revenue, but designed to improve the safety, appearance or operating convenience of the plant.

(*c*) *Work to Assist*

Work carried out by Maintenance Department to assist operating departments in maintaining process availability, e.g. cleaning blocked lines or heat exchangers, cleaning extruders, etc.

NOTE: All maintenance jobs will be allocated to *one* class—whichever is predominant.

C. DISMANTLING EXPENSE

This covers the expenditure associated with the removal of capital equipment from the plant and will always be covered by a dismantling job number.

It will be included in the appropriate section of Mechanical Expense according to the nature of the associated capital job. If not associated with an installation, it will be classified as plan improvement.

D. START-UP EXPENSE

This covers the expenditure associated with the start-up and commissioning of new plant and will always be covered by an engineering job number. It will be costed as a direct expense on the product cost sheet.

Allocation of Engineering Costs

I. Purpose

To outline the methods to be employed for accumulating engineering costs under the various classifications and to define the responsibilities of the Works personnel involved.

II. Policy

It is the intenton of Management to promote the proper control and review of engineering expenditure by providing a detailed breakdown of engineering costs.

Such costs must, in the first instance, be divided between capital and revenue expenditure and be allocated to the various product cost centres for normal financial costing.

In addition, these costs will be further sub-divided to assist in their effective control.

This information will be summarised and issued monthly by Accounts Dept. in the manner outlined below. It is important that all employees understand the need for accuracy and consistency in following these procedures.

III. Procedure

(*b*) *Engineering Cost Summary*

For costing purposes the Works is divided into operating sections of the various departments. A list of these cost sections is provided by Accounts Dept., who will notify revisions as they are necessary. A Mechanical Expense Report is issued monthly by the Accounts Dept. for each of these sections.

The total True Repair cost is sub-divided into four calssifications:

Dept. No./Section/10—All General Repairs
Dept. No./Section/11—All Instrument Repair work

Dept. No./Section/12—All painting work
Dept. No./Section/14—All electrical repair work.

Further cost classifications utilising equipment sub-groups may be added as appropriate.

The other types of mechanical expense have been allocated the following cost numbers.

Plant Improvement	Dept. No./Section/91
Work to Assist	Dept. No./Section/92
Earnings Expense	Dept. No./Section/93

(*B*) *Time Allocation*

Maintenance labour costs will be collected by means of a Daily Job Card which is coloured to denote each particular trade. These cards have no bearing on actual wages paid, but are for cost allocation purposes only.

The approximate time allocation must be recorded for each maintenance employee each day on his Daily Job Card. The hours worked will be allocated to the Log Number, Work Order Number, Job Number or to the appropriate cost classification as outlined below.

More than one job card per employee may be required.

(*C*) *Materials Cost Allocation*

Materials drawn from Machinery or Supply Stores account will be charged to the Job Number, Work Order Number, Log Number and Dept./Section/Classification as appropriate.

(*C*) *Contract Charges or Outside Supplies*

Contract services or equipment purchased from outside suppliers will be charged to a Job Number, Work Order Number, Log Number or cost classification number as appropriate.

IV. Responsibilities

A Daily Job Card, coloured according to his trade, must be issued to each employee at work and returned to Accounts Department the following morning.

Job cards covering week-end work will be submitted on Monday morning.

1. *All Maintenance Supervision*

(a) All time will be allocated to the nearest half-hour and will be covered by the following reference numbers, entered in the appropriate column of the Daily Job Card:

(i) *A Serial Number*: This will either be a Work Order Number or Log Number.

(ii) *Charge Number*: This will either be a Job Number or a Dept./Section/Classification Number.

(b) All work carried out by shift men outside normal working hours will be entered on a weekly Time Sheet instead of daily job cards, and be charged to "Shift Maintenance".

(c) All work carried out on a Job Number for construction work—Charge to Job Number or Project Number only.

A separate weekly return will be required listing men on holiday. It is intended that this information will be recorded on the employee Clock Card before it is returned to Accounts Dept.

Maintenance Department foremen whose men are not on maintenance or construction work should submit a Weekly Time Sheet.

APPENDIX IX

SAMPLE JOB DESCRIPTIONS FOR:

1. General Superintendent of Maintenance
2. Superintendent of Area Maintenance
3. Maintenance Improvement Staff Engineer
4. Maintenance Planning Engineer
5. Area Maintenance Foreman
6. Maintenance Planner

I—POSITION DESCRIPTION

Title

General Superintendent of Maintenance

Department

Maintenance

Reports to

Works Manager

Draft Approved by———Date ———

Function

Provides a service to the Plant by controlling the in-works engineering and maintenance function (exclusive of process and design engineering and major new construction) to ensure the safe and timely execution of engineering work at minimum cost consistent with maximum overall operating efficiency. Assists in the development of works equipment directed towards improving its reliability or reducing its maintenance costs.

Duties

1. Prepares and submits for approval plans, objectives, and budgets: reviews and progresses plans with subordinates to achieve optimum effective maintenance programmes; develops and directs the implementation of preventative maintenance and repair programmes.
2. Confers with the Works Manager on plans, problems, priorities and achievements.
3. Negotiates with Trade Union Representatives on personnel problems, interpretation of procedures and introduction of new methods within the maintenance department.
4. Develops subordinates, administers salaries and training in order to achieve maximum utilisation of manpower resources and eliminate restrictive practices.
5. Controls Engineering Stores, reviews inventories, authorises new stock items, write offs, etc. to maintain inventories at reasonable levels.
6. Establishes and maintains procedures and policies to ensure the safety of personnel and that housekeeping is of a high standard.

Supervision

Direct: Supervises the activities of the following personnel:—6 senior salaried staff and through these the activities of 42 salaried and 380 hourly employees.

Functional: Nil.

II—POSITION DESCRIPTION

Title

Superintendent of Area Maintenance

Department

Maintenance

Reports to

General Superintendent of Maintenance

Draft Approved by———Date———

Function

Directs and controls day-to-day mechanical maintenance and emergency repairs of production plants, utilities and non-mechanical services to ensure maximum availability of equipment at minimum cost.

Duties

1. Directs day-to-day mechanical maintenance of production plants, utilities and Works service to keep equipment in safe and efficient condition at minimum cost.
2. Initiates repairs in cases of plant breakdown and emergency to minimise loss of production.
3. Reviews stock levels of plant spares with Stores Supervisor to ensure availability of spares consistent with minimum inventory.
4. Controls the use of Company-controlled waste disposal tipping sites to prevent chemical contamination of the river or adjacent farm land.
5. Maintains good communications with other maintenance and production staff for discussion of maintenance priorities, plans problems in order to make best use of Company resources.
6. Develops and executes objectives and cost improvement programmes; prepares and reviews area maintenance administrative budgets and true repair budgets for manufacturing plans, utilities and non-mechanical services.
7. Implements Company personnel and safety policies to achieve Company objectives and promote employee welfare.
8. Assists in formulation and execution of training programmes for foremen, craftsmen and apprentices.

Supervision

Direct:	Supervisors and Foremen	10
	Clerical	1
	Hourly	94
		105

Functional: Nil

III—POSITION DESCRIPTION

Title

Staff Engineer

Department

Maintenance

Reports to

Superintendent Maintenance Improvement Group

Draft Approved by———————Date———————

Function

Performs staff engineering work to reduce maintenance costs and provide technical assistance to maintenance line supervision.

Duties:

1. Develops maintenance cost improvement programmes for an assigned production group; analyses maintenance costs to identify areas where economies could be made.
2. Performs engineering design work to implement cost improvement projects and assigned minor capital jobs according to statutory requirements Company standards and Codes of Practice.
3. Prepares enquiries, expenditure appropriation requests, purchasing requistions and design packages; checks drawings and manufacturers specifications.
4. Checks installation work and assesses the effectiveness of projects in meeting objectives.
5. Provides line supervision with technical advice and information when requested.
6. Assists in the preparation and presentation of Maintenance department training programmes on specialised techniques.
7. Studies technical literature and holds discussions with manufacturers' representatives to keep up-to-date with new equipment and materials.

Supervision

Direct: Nil

Functional: Frequently provides directon and guidance on the carrying out of engineering work to draughtsmen, craftsmen, planners, foremen and contractors.

IV—POSITION DESCRIPTION

Title

Planning Engineer

Department

Maintenance

Reports to

Superintendent Central Workshops & Planning

Draft Approved by———Date———

Function

Directs planning and scheduling of maintenance work to ensure most economical utilisation of human and material resources and minimum interference to production; develops improved planning methods.

Duties

1. Supervises the day-to-day work of planning staff to ensure an acceptable standard of planning; resolves problems involving engineering considerations, priorities and emergencies.
2. Develops and controls long-term plans for major engineering work, planned maintenance, plant shutdown maintenance and insurance inspections.
3. Reviews cost of maintenance jobs to anticipate over-expenditure and requests authorisation for further expenditure when necessary.
4. Reviews Work back-log and directs scheduling of work to ensure steady workload for each craft group.
5. Controls the maintenance of essential records and ensures that full use is made of them as a tool to prove maintenance efficiency.
6. [illegible] new techniques to improve the planning [illegible] prepares objectives for the group and [illegible] works to achieve them.
7. Maintains good communications and promotes good relations with maintenance supervisory staff and other departments.
8. Issues reports for plant shut-downs and other matters; supervises preparation of monthly job list.
9. Implements Company personnel, safety and housekeeping policies to achieve Company objectives and promote employee welfare.
10. Develops training programmes for planning staff.

Supervision

Direct:	Professional/Administrative	7
	Clerical	2
		9

Functional : Nil

V—POSITION DESCRIPTION

Title

Area Maintenance Foreman

Department

Maintenance

Reports to

Area Maintenance Supervisor

Draft Approved by———Date———

Function

Supervises craftsmen carrying out day-to-day maintenance and emrgency repairs of production plants; ensures good engineering standards, safe working methods and minimum costs.

Duties

1. Plans day-to-day maintenance and minor repairs of production plants in conjuction with production staff to ensure maximum availability of equipment; arranges emergency repairs in cases of plant breakdown.
2. Allocates work to craftsmen and issues instruction on working methods and safety precautions; supervises work in progress to maintain adequate work tempo and ensure that work is performed according to instructions.

3. Raises work orders on other maintenance sections when necessary and maintains close liaison with other sections so that activities are co-ordinated for maximum efficiency; assists Planning Section in arranging and implementing planned maintenance programmes.

4. Orders special spare parts and checks regularly that stores stocks are maintained at optimum levels.

5. Arranges training of craft apprentices as specified in the Apprentice Training programme: gives on-the-job instruction to craftsmen in the use of new tools and equipment.

6. Enforces safe working methods and conducts monthly safety meetings with subordinate employees; investigates accidents and takes action to eliminate hazards; enforces good housekeeping to promote safety and efficiency.

7. Fills in job cards, log sheets, employees' time cards and weekly time sheets to computation of wages and allocation of cost charges; prepares monthly maintenance reports, inspection reports and reports on safety matters.

8. Applies personnel and other Company policies to achieve Company objectives and promote employees' welfare; maintains good labour relations and, whenever possible, resolves problem directly with employees and trade union representatives.

Supervision

Direct: Hourly employees. 16-17

Functional: Nil.

VI—POSITION DESCRIPTION

Title

Maintenance Planner

Department

Maintenance

Reports to

Planning Engineer

Draft Approved by———————Date———————

Function

Investigates engineering work requests and prepares detailed work instructions for the execution of maintenance work with most economical use of human and material resources and minimum interference to production.

Duties

1. Investigates engineering work requests as necessary to determine the exact job content, feasibility, priority and plant availability in order to collect all information needed for planning the work execution.

2. Prepares detailed instructions and cost estimates for engineering jobs, specifying the work to be performed, requirements of manpower, materials and tools, to allow scheduling and execution of work at minimum cost and with minimum interference to production; checks progress of work on site and modifies instructions if necessary.

3. Plans plant shutdown maintenance programmes using Gantt charts where a number of jobs are to be performed simultaneously.

4. Requisitions equipment and materials required for planned maintenance work and progresses their delivery.

5. Plans installation of new capital equipment based on design packets prepared by T.S.D. or M.I.G.

6. Inspects equipment under repair and reports on its condition for information and record purposes.

7. Prepares standard instruction sheets for repetitive work.

8. Checks cost of jobs and collects cost data to facilitate future planning of work by cheaper methods.

Supervision

Direct: Nil

Functional Nil

A Bibliographical Guide to Information Sources on Maintenance and Repair*

THE promotion of industrialization of the developing countries has led to the build up of an ever-growing stock of machinery and equipment. The stage has now been reached where awareness and understanding of maintenance and repair problems and a better knowledge of the specialized techniques involved is necessary.

The United Nations Industrial Development Organization (UNIDO) programme of work provides for aid to developing countries to improve their maintenance and repair facilities. In this connection, it was agreed that a survey of existing information material should be made by compiling the relevant literature and other information sources.**

Among the recommendations worked out by UNIDO in its basic Report ID/1. of 21 April 1967, special attention was drawn to the need to: **" . . . collect and disseminate information on maintenance and repair and inventory problems and practices, and to answer queries from industry on this subject."** and to make **" . . . available to Governments, firms and other relevant institutions of developing countries all available books, pamphlets, and other documents on maintenance and maintenance management."**

It is hoped that the present bibliographical guide prepared by the Industrial Information Section of UNIDO will render assistance to government agencies, organizations and enterprises in developing countries in their difficult task of promoting and improving maintenance and repair facilities.

This guide does not aim to give a full coverage of all existing documents, references and information media on the subject, but attempts to list, on a rather selective basis, relevant information. Organizations which can be contacted for further and more detailed information on specific questions are also listed.

A supplement to this guide will be published at a later date which will include a subject index.

UNIDO would like to take this opportunity to express its thanks to all the information

5. pared by the secretariat of UNIDO.

   imation sources listed include not only manufac- also servicing industries, as well as machinery

6. Develop nt in use for agricultural purposes and the function; f roads, bridges, dams and other buil- systematically

centres and agencies which contributed to the compilation of the Guide, and in particular, to the Techno-inform OMKDK Budapest, Hungary, which made a major contribution to this bibliography.

1. HANDBOOKS, MANUALS AND TEXTBOOKS

General

1. BREWER, A.F.: Basic Lubrication Practice. New York, Reinhold, 1955. 300 p.

2. CLEMENT, E.J., HARRINGTON, C.C.: Plant maintenance manual. 2nd. ed. New York, Conover-Mast, 1952. 340 p.

3. CORDER, G.G.: Organizing Maintenance. London, British Inst. of Management, Gee and Co., 1963. 230 p.

4. DETHOOR, J.M., GROBOILLOT, J.L.: La vie des equipments. Paris, Dunod, 1968. 252 p.

5. Effective Maintenance Management. Organization, motivation and control in industrial maintenance. New York, McGraw-Hill, 1967. 368 p.

6. ELLIS, E.G.: Fundamentals of Lubrication. Bresely, Shorpsh. Scientific Publications Ltd. 1968. 133 p.

7. L'entretien et l'inspection des equipments dans les pays en expansion industrielle. - Equipment, inspection and maintenance in industrially expanding countries. Part 1.2., Paris, Institute Francais du Petrol-Bureau d'Etudes industrielles et de cooperation, 1967. 21+21 p.

8. FORBES, W.G. - POPE, C.L. - EVERITT, W.T.: Lubrication of industrial and marine machinery, New York, Wiley, 1954. 351 p.

9. GELBERG, B.T., PEKELIS, C.D.: The Maintenance of Industrial Equipment. Moscow, Proftekhizdat, 1964. 280 p. (in Russian).

10. IL'ENCSENKO, M.: Complex Organization Methods of Maintenance and Servicing Equipment; their economic efficiency. Kiev, 1968. 44 p. (in Russian)

11. Manual of maintenance. Vol. 1-11. Ed. R. Clements and D. Parker. London, 1964. 590 p.

12. Mellan, I.: Corrosion resistant materials handbook 1966. Park Ridge, Noyes Development Corp., 1967. 240 p.

13. MILLER, E.J., BLOOD, J.W.: Modern Maintenance Management. New York, American Management Association, 1963. 144 p.

14. MORROW, L.C.: Maintenance Engineering Handbook. 2nd ed. New York, McGraw-Hill, 1958.

15. NEWBROUGH, E.T.: Effective management. Organization, motivation and control in industrial maintenance. New York, McGraw-Hill, 1967.

16. Production Handbook, Ed. G.B. CARSON. 2nd ed. New York, Ronald Press Co. 1967, div. p.

17. REED, Jr.: Plant location, layout and maintenance. London, Irvin, 1967. 470 p.

18. SACK, T.F.: A Complete Guide to Building and Plant Maintenance. Englewood Cliffs, Prentice Hall, 1965. 512 p.

19. Le service entretien. Methods actuelles de gestion de gestion par les collaborateurs de la Revue entretien et travaux neufs. Paris, Entreprise moderne d'edition, 1968. 400 p.

20. SKIBA, I.F.: Economic Efficiency of the Techniques, organization and technology of repairing. Moscow, Izd. Transport, 1964. 242 p. (in Russian).

21. STANIAR, W.: Plant Engineering Handbook. 2nd ed. New York-London, McGraw-Hill, 1959. 2150 p.

22. STEWART, H.V.M.: Guide to Efficient Maintenance Management. London, Business Publ. 1963. 168 p.

23. WILSON, C.L., OATES, S.A.: Corrosion and the Maintenance Engineer. New York, Hart Publ. Co., 1968. 196 p.

Specific

24. ABBEY, S.: Diesel fault tracing maintenance and repair. 4th ed. London, Pitman, 1968. 283 p.

25. HUBERT, C.I.: Preventive Maintenance of Electrical Equipment. New York, 1955. McGraw-Hill, 214 p.

26. JOHNSON, S.M.: Deterioration, maintenance and repair of structures. New York etc. 1965. 373 p.

27. JUDGE, N.: Maintenance of High-speed Diesel-Engines. London, Chapman and Hall, 1968. 422 p.

28. KEMBALA, G.: Maintenance of Mechanical Equipment. Budapest, Muszaki Kiado, 1965. 287 p. (in Hungarian).

29. LAUGHNER, V.H., HARGAN, A.D.: Handbook of fastening and joining metal parts. New York, McGraw-Hill, 1956. 622 p.

30. Maintainability of Electronic Equipment. London, Reinhold, 1968. 140 p.

31. Maintenance and Repair of Motor Vehicles, a practical instruction manual. ILO, Geneva. 518 p. Nr. 50-002.

32. MALOLETKOV, E.K., GORDEEV, L.F.: Organization and technology of repairing building machinery. Moscow, Gosstojizdat, 1962. 276 p. (in Russian).

33. NAUMOV, V.I., SIDOROV, N.G., SAHAROV, U.K.: Operation, technical servicing and repair of motor cars. Manual. Moscow, Masinostroyenie, 1965. 512 p. (in Russian).

34. Planned Previous Maintenance of Building Machinery. Budapest, Epitesgazdasagi es Szervezesi Intezet, 1966. 83 p. (in Hungarian).

35. PRONIKOV, A.S.: Wear and durability of machine tools. Moscow, Mashgiz, 1962. 320 p. (in Russian).

36. Successful electrical maintenance. New York, McGraw-Hill, 1969. 128 p.

37. SADRICEV, V.A.: Repair of motor cars. Moscow-Leningrad, Mashinoutroenie, 1965. 614 p. (in Russian).

38. SRSEN, M. et alii: The organization of the repairing work in the light industry. Praha, Statni nakladatelstvi technicke literatury, 1966. p. 10-13, 39-43, 56-93, 96-99. (in Czech).

39. REYNOLDS, P.A.: Maintenance of horticultural equipment. London, Allen and Unwin, 1968. 183 p.

40. SVERDEL, I.S., RUDAKO J.N Repair of electrical equipment in mineral dressing plants. Moscow, Nedra, 1967. 307 p. (in Russian).

41. TIHONOV, V.V.: System of planned preventive maintenance of pipe-line structures and equipment. Moscow, Nedra, 1966. 178 p. (in Russian).

42. VERESICHAK, E.P., ALELEVITCH, L.A.: Mechanical engineer's manual; projecting maintenance and repair workshops for motor cars. Moscow, Transport, 1966. 333 p. (in Russian).

43. WILKINSON, K.: Rewinding and repair of electric motors. Princeton, Van Mostrand, 1954. 208 p.

44. WILSON, C.L., OATES, S.A.: Corrosion and the maintenance engineer. New York, Hart Publ. Co., 1968. 196 p.

2. CURRENT PERIODICALS DEALING WITH MAINTENANCE AND REPAIR

45. *Achats et entertien du material Industriel*
Monthly, dealing with the efficient selection and buying of equipment, including maintenance technology. Publisher; Les Nouvelles du Monde, 8, rue de la Michodiere, 75—Paris 2e.

46. *Anti-corrosion Methods and Materials*
Monthly, dealing with corrosion control, prevention, engineering and research.
Publ.: Brampain Press Ltd.
The Tower, 229-243 Sheperds Bush Road, Hammersmith, London, W. 6.

47. *Cleaning and Maintenance*
Official monthly of the British Institute of Cleaning Science including methods of maintaining and cleaning factory and office premises with regular guide to new equipment and products.
Publ.: Wheatland Journals Ltd., 65/66 Trunmill Street, London, E.C.I.

48. *Corrosion, Traitement, Protection, Finition*
Monthly, publishing papers and news on anti-corrosion measures to protect material and equipment.
Publ.: Societe de productions documentaires (SOPRODOC), 80, route de Saint-Cloud, Paris.
92, Rueil-Malmaison, Paris.

49. *Corrosion, Prevention and Control*
Monthly for engineers and technicians on how to prevent corrosion; dealing with systems and organizational methods on controlling corrosion.
Publ.: Corrosion Prevention and Control 11A Gloucester Road, London, S.W.7.

50. *Dun's Review and Modern Industry*
Monthly on business trends, developments and problems of industry including management of maintenance systems.
Publ.: Dun Bradstreet Publication,
99 Church Street, New York, N.Y. 10008.

51. *Electrical Construction and Maintenance*
Monthly, treating all aspects of electrical product trends and technical electrical practice. Reports on the design, installation and maintenance of a well integrated functional electrical system for engineers, contractors and plant men.
Publ.: McGraw-Hill Inc.
330 West 42nd Street, New York, N.Y. 10036.

52. *Electrical Contractor and Maintenance Supervisor of Canada*

Monthly, for contractors, consulting engineers, electrical maintenance supervisors and foremen. (Professionals may receive copies without charge.)
Publ.; McLean-Hunter Publ. Co. Ltd.
481 University Ave., Toronto, Ont., Canada.

Factory

See Modern Manufacturing.

53. *Factory and Plant*

Monthly, dealing with industrial management and production engineering including maintenance organization and systems.
Publ.: Tail Publishing Co., Pty. Ltd.
415 Bourke St., Melbourne, Australia.

54. *Factory Management*

Monthly, concerned with management of various industrial plants, including maintenance management problems.
Publ.: Production Publications Ltd.
Elm House, 10-16 Elm House, London, W.C.I.

55. *IMI Newsletter*

Monthly, containing reports of the International Maintenance Institute, Greenwich, Conn.
Publ.: IMI
P.O. Box 409, Greenwich, Conn. 06830.

56. *Industrial Maintenance and Plant Operation*

Monthly on maintenance and operation of plant equipment, plant operating products, methods, buildings.
Publ.: Ames Publishing Co.
I.W. Olney Ave., Philadelphia, Pa. 19120.

57. *Iron and Steel Engineer*

Monthly, disseminating world-wide, new and complete information relating to the design, construction, operation and maintenance of equipment, machinery and plants for the production and processing of iron and steel.
Publ.: Association of Iron and Steel Engineers
Empire Bld., Pittsburgh 22, USA.

58. *Maintenance*

Monthly on maintenance, modernization and extension of plant facilities, buildings, grounds, moving, maintenance of production machines, equipment and systems.
Pub.: Cleworth Publ. Co. Inc.
One River Cos Cob, Conn. 06807, USA

59. *Maintenance Engineering*

Monthly on engineering methods and techniques of maintenance and repair in manufacturing industries, transport, building, construction, etc.
Publ.; Factory Publications Ltd.
89 Blackfriars Road, London. SEI.

60. *Maintenance News*

Monthly, house organ of the Maintenance Co. Inc.
Publ.:
10-40 45 th Av., Long Island City, N.Y.

61. *Maintenance Supplies*

Monthly, for distributors of maintenance equipment, cleaning materials, sanitary supplies. (Circulation restricted to distributors of maintenance equipment.)
Publ.: McNair-Dorland Co. Ing.
254 W. 31st. St., New York, N.Y. 10001.

62. *Material Handling Engineering*

Monthly, covering the entire field of material handling including maintenance and repair of machinery and equipment.
Publ.: Industrial Publishing Corp.
812 Huron Rd., Cleveland 15, Ohio, USA.

63. *Materials Protection*

Monthly, concerned with all methods of protecting materials from environment. Includes coatings, electrical systems, economics, administration and safety of materials protection.
Publ.: National Association of Corrosive Engineers
M and M Bld., Houston 2, Texas, USA.

Mill and Factory

See Plant Operation Management

64. *Modern Maintenance Management*

Monthly on planning, managing and administering building maintenance and sanitation operations in industrial and institutional buildings. Covers cleaning programmes, training procedures.
Publ.: Powell Magazines Inc.
855 Ave. of the Americas, New York, N.Y. 10001.

65. *Modern Manufacturing*

Monthly, edited for manufacturing men in production, engineering, maintenance and plant management. Provides basic technical and operational help through evaluation of new equipment and trends.
Publ.: McGraw-Hill Co., Inc.
330 West 42nd St., New York, N.Y. 10036.

66. *Modern Plant Operation and Maintenance*
Quarterly dealing with new plant procedures and equipment, especially for those responsible for plant operation and maintenance.
Publ.: U.S. Industrial Publications, Inc.
209 Dunn Ave., Stamford, Conn. 06905.

67. *Plant Administration and Engineering*
An industrial methods monthly for plant managers and plant engineers.
Publ.: McLean-Hunter Publishing Co. Ltd.,
481 University Ave., Toronto. Ont., Canada.

68. *Plant Engineering*
Monthly, presenting articles on plant equipment, its maintenance and improvement, and on organizational aspects of industrial plant management; of interest both to business and supervisory technical personnel.
Publ.: Technical Publishing Co. Inc.
308 E. James St., Barrington, Ill, USA.

69. *Plant Engineering and Maintenance*
Monthly for engineers and technicians, on plant and production equipment maintenance.
Publ.: McLaughlin Publishing Co.
93 Railside Rd., Don Mills, Ontario, Canada.

70. *Plant Operating Management*
Monthly to satisfy interdisciplinary information needs of plant men in charge of manufacturing and maintenance, covering functional areas of electrical energy and equipment, mechanical power transmission, manufacturing production and operations, material handling and maintenance and plant service.
Publ.: Conover-Mast Publication Inc.
205 East 42nd st., New York 10017, USA.

71. *Reparatur und Kundendienst (Repair and Customers' Service)*
Monthly on repairing techniques and servicing materials and equipment for maintenance purposes.
Publ.: Technic, Ing. E. Neubauer
Schuppstr. 83. Pf 1600, 6200 Wiesbaden—Sonnenberg, FRG.

72. *Revue Technique De L'entretien et Des Travaux Neufs*
Publ.: Enterprise moderne d'edition,
7, rue Cauebon, 75—Paris 1.

73. *Safety Maintenance*
Monthly, concerning industrial safety, fire protection, industrial hygiene, and sanitary maintenance.
Publ.: Alfred M. Best Co., Inc.
Morristown, N.J. USA.

74. *Stanki I Instrument (Machine Tools and Tools)*
Monthly, dealing with machine-tool and tooling equipment including maintenance in mechanical workshops.
Publ.: Izd. Mashinostroenie
ul 25-go Oktyabrya, 10 Moscow K 12 USSR. Sovietunion.

75. *Technische Uberwachung (Technical Survey)*
Monthly on technical plant control and surveying methods including maintenance methods and preventive planning systems. With abstracts in English and French.
Publ.: VDI-Verlag GMBH
Postfach 10250, 4 Dusseldorf, FRG.

76. *Wear-usure-verschleiss*
International bi-monthly on fundamentals of friction, lubrication, wear and their control in industry (text in English, French and German).
Publ.: Elsevier Publishing Co.
Box 211, Amsterdam, W. Holland.

77. *Werkstattstechnik, Zeitschrift fur Produktion und Betrieb (Shop-Practice)*
Monthly on production methods and maintenance in machineshops, their organization and special requirements of maintaining a steady production flow.
Publ.: Springer-Verlag, 31 Heidelberg Platz, 3, Berlin. 175 Fifth Ave., New York, N.Y. 10010.

78. *What's New in Plant Engineering Services*
Bi-monthly covering plant and equipment maintenance, electrical services, plant utility services, buildings and grounds, fluids and material handling, and mechanical power transmission.
Publ.: Putman Publ.
111 E. Delaware Place, Chicago, 111. 60611, USA.

Selected Articles in Periodicals

79. Alabama mill men discuss slasher roll buffing cycles.=Textile Industries, Vol. 129, No. 7, 1965. pp. 77-78.

80. ALBRINGER, A. : Organisation de l'entretien dans une petite enterprise.=Travail et Methodes, No. 185, 1964. pp. 21-23.

81. ALLEN, A.D.: Impact of automation on the maintenance function; some empirical conclusions.=Journal of Industrial Engineering, August 1968. suppl. pp. 10-14.

82. ALTHOFF, P., MULLER, K.D., Dr Problem der Reparaturkosten in den USA.=Chemische

Industrie, Nr. 8. 1965 pp. 296.

83. ANDERS, H.: Die Reparaturkosten sind teils fix. teils proportional. Maschine und Werkzeug, Nr. 13. 1965. pp. 48.

84. ANDERSON, G.A.: Standard Estimates Can Cut Maintenance Costs.=Hydrocarbon Processing and Petroleum Refiner, Vol. 45, No. 1. 1966. pp. 119-122.

85. Are Your Maintenance Costs in Line?=Mill and Factory, Vol. 82, No. 1, 1968. pp. 45-55.

86. ARCHER, G.: Methods and Necessity of Cleaning High Speed Cards. =Textile Bulletin, Vol. 90, No. 5, 1964. pp. 39-42.

87. Automatic Cleaning of PRSL Diesel Engines.= Railway Locomotives and Cars, Vol. 141, No.2, 1967. pp. 28-29.

88. Automating the Paper Mill's Maintenance Programme.=The Paper Industry, Vol. 43, No. 10. January 1962. pp. 708-709, 718.

89. BARLOW, R.E., HUNTER, L.C.: Optimum Preventive Maintenance Policies. =Operations Research, No. 8, 1960. pp. 90.

90. BECHT, C.: 1-How to Set Up A Working Corrective Maintenance Programme. New ways to take the guesswork out of maintenance. =Mill and Factory, March 1966. pp. 48-50.

91. BERGER, H.: Organisation and Aufwant der Instandhaltung im Chemiebetrieb. Ein Beitrag zur Rationalisierung.=Chemische Technik, Vol. 8, 1966. pp. 513-519.

92. BIRKNER, E.: Minderung der Maschineninstandhal tungskosten, aber wie?=Kostenrechnungs—Praxis, No. 2, 1964. pp. 77-79.

93. BOND, V.C.: Training builds maintenance crew at Phoenix cable plant.=Plant Engineering, 8 August 1968. pp. 90, 91.

94. BRIOULT, R.: La voiture de demain sera-t-elle reparable?=Revue Technique Automobile, vol. 23. no. 263, mars 1968. pp. 89-96.

95. BROADWELL, M.M.: Developing the maintenance supervisor as a trainer.=Plant Engineering, 13 June, 1968, pp. 95-97.

96. BROADWELL, M.M.: Planning; key to successful maintenance training.=Plant Engineering, 18 April 1968. pp. 107-109.

97. BROWER, M.W.: Developing the maintenance function; the influence of operators on maintenance function; the influence of operators on maintenance productivity.=American Paper Industry, April 1968. pp. 42.

98. BUTSERY, L.M., ZAMAN, A.A.: In Kuwait; deaily planning is mechanized.=Hydrocarbon Processing, January 1968. pp. 123-126.

99. BUZZANCA, V., GOLDSTEIN, M.J.: Equipment maintenance procedures. =Operations Research, No. 11. 1963. pp. 519.

100. BYRER, V.H.: How to start a preventive maintenance programme? =Factory, October 1961, pp. 236-244.

101. CAMERON, A.: Here's how reorganization of maintenance utilities saved $ 74, 000. =Mill and Factory, Vol. 78, No. 6, 1966. pp. 43-45.

102. CAMPBELL, F., PIERCE D.: The maintenance game.=Journal of Industrial Engineering, No. 15. 1964 pp. 30.

103. Care and maintenance of calander stacks and rolls.=Paper Trade Journal, Vol. 147, No. 51, 23 December 1963, pp. 32-33.

104. CARSON, B.: Organising and controlling maintenance during mill shutdowns.=Paper Trade Journal, Vol. 148, No. 18, 4 May 1964. pp. 38-41.

105. CARSON, B.: What information is needed to control maintenance costs? =Paper Trade Journal, Vol. 148, No. 52, 28 December 1964. pp. 26-28.

106. CARSON, B.: What is the best type maintenance organization for Your mill? =Paper Trade Journal, 2 January 1967. pp. 28-33.

107. CARSON, B.: The maintenance organization.= Southern Engineering, June 1966, pp. 28-32.

108. CARSON, B., LOONEY, J.: Maintenance labour standards can be established=Plant Engineering, April 4, 1968. pp. 87-89.

109. CARSON, B., MAILHOS, J.E.: Plan carefully for a sound maintenance budget.=Plant Engineering, 7 March, 1968. pp. 132-134.

110. CLAPHAM, J.C.R.: Economic life of equipment. =Operational Research Quarterly, Nr. 3, 1967. pp. 181.

111. CLARK, Ch. V.: Maintenance measurement and Control.=Tappi, Vol. 45, No. 7, 1962, pp. 176A-182A.

112. CLAUSING, E.L.: Optimum spot shop-repair operations. An example of a queuing model.= American Railway Engineering Association Bulletin, Vol. 67, No. 594, September—October 1965. pp. 1-5.

113. CLOET, D.F.: Maintenance pays dividends.= Woodworking Industry, Vol. 23, No. 2, 1966. pp. 21-22.

114. Le coin du mecanicien.=Vetir, No. 119, avril 1968. pp. 59-61.

115. COLLING, J.F.: How to control maintenance work?=Supervisory Management, Vol. 11, No. 9, 1966. pp. 47-48.

116. COLLINS, J.F.: How to control maintenance work?=Supervisory Management, New York, Vol. 11, No. 9 1966. pp. 47-48.

117. COLLINS, R.V.: Significant reduction in utility maintenance costs through ultrasonics.—Material Evaluation, Vol. 24, No. 2, 1966. pp. 109-110.

118. Component replacement—we all do it differently. = Material Handling Engineering, Vol. 22, No. 3, 1967. pp. 67-71.

119. Component maintenance keeps downtime away from the door.=Material Handling Engineering, Vol. 22, No. 3, 1967. pp. 72-76.

120. CORMACK, L.J.: Inspection reports improve preventive maintenance programmes.=Power, February 1968. pp.84-85.

121. Correct maintenance lengthens rolling bearing life. =Metals, Vol. 2, No. 11, April 1967. pp. 50-53.

122. COTTON A.: Electrical maintenance procedures —preventive maintenance.=Textile Recorder Vol. 80, No. 950 May 1962 pp. 68-70.

123. CSONKA J.C.: Maintenance of steel mill control.—Iron and Steel Engineer, Vol. 43, No. 2, 1966. pp. 114-118.

124. Cutting maintenance cost with controlled chip separation.=Safety Maintenance, Vol. 134, No. 6, December 1967. pp. 48-49.

125. CZINER R.M.: How to control maintenance costs.=Petroleum Refiner, No. 33, 1954. pp. 106.

126. DANIELCZYK N.: Vorbeugende Reparaturen in Spinnereien. (Preventive maintenance in spinning mills).=Melliand Textilberichte Vol. 47, No. 6, 1966. pp. 605-606.

127. DENBY, D.C.: Minimum downtime as a function of reliability and priority assignments in component repair.=Journal of Industrial Engineering, July 1967. pp. 436-439; May 1968. pp. 255-256.

128. DENGLER W.J.: Preventive maintenance by critical path method.=Canadian Mining Journal, Vol. 87, No. 6, 1966.

129. DIEHL, C.E., DICKMAN, R. E.: Maintenance management protile; how does your organization stack up?-Public Works, May 1968. pp. 72-73.

130. Diminution des frais d'entretien et de reparation dans les sucreries, grace a l'emploi bien compris des techniques de soudage.=Sucrerie Francais, Vol. 109, No. 3, pp. 49-53.

131. DRAGON, G.O., FREEMAN, M.C.: Control and measurement of maintenance labour.= Chemical Engineering Progress, Vol. 63, No. 6, June 1967. pp. 36-38.

132. DUKELOW, J.S.: Operation and maintenance of total energy systems.=Heating, Piping and Air Conditioning, Vol. 39, No. 4, 1967. pp. 136-140.

133. EDMONDSON, C.: Cost and control of maintenance.=Europe and Oil, vol. 6, No. 4, 1967. pp. 16-20.

134. ELLINGTON, J.W.: Shuttle care that counts.= Textile Industries, Vol. 127, No. 4, 1963. pp. 115-118.

135. ELONKA, S.: 1966 maintenance conference up-to-dates PM thinking.=Power, Vol. 110, No. 6, 1966. pp. 79-81.

136. ELONKA, S.: Contract installation and maintenance.=Power, July 1968, pp. 167-174.

137. EMMETT, J.O.: Guidelines to preventive maintenance.=Biscuit and Cracker Baker, Vol. 55, No. 5, 1966. pp. 26-29, 60.

138. ENGELGAU, N.A., BURNETTE, H.M. et alii.: A company-wide long-range programme of installing a standard maintenance procedure for all its mills=Paper Mill News, Vol. 85, No. 35, 27 August 1962. pp. 22-26.

139. L'entretien et la reparation.=L'Usine Nouvelle, Vol. 23, no. 51, 21 December 1967. pp. 110-113.

140. De l'entretien a la maintenance industrielle.= Travail et Methodes, no. 226, December 1967. pp. 7-12.

141. EPP, R.: Is preventive maintenance a money saver or lavish fancy? =Canadian Forest Industries, Vol. 88, No. 6, 1968. pp. 64-67.

142. Evaluating your maintenance.=Textile World, Vol. 114, No.4, 1964. pp. 55-60.

143. FAHRMANN M.L.: Maintenance management profit as a team. =The Oil and Gas Journal, Vol. 64, No. 35, August 1966. pp. 66-69.

144. FAJTELSZON, Ja. E.: Centralizacija remontnyh rabot na predprijatii (Centralization of maintenance in the plant).=Chimitskeskie Volokna, No. 3, 1966, pp. 66-69.

145. FAUSEL, C.E.: Preliminary steps toward an effective lube programme =Plant Engineering, December 1967. pp. 109:-106.

146. FENWICK, H.T., ROBINSON, R.B.: Planned maintenance in a continuously operating paper mill.—Appita, Vol. 14, No. 2, September 1960, pp. XXVIII-XXXVIII.

147. FERAT, A.: Comment "suivre" dans le temps le potential technique d'une parc de machines.—=Revue Technique de l' Entretien, vol. 19, no. 183, fevrier 1967. pp. 3-12.

148. FINLEY, H.F.: Use system effectiveness to reduce maintenance costs.=Hydrocarbon Processing. Vol. 48, No. 5, 1967. pp. 191-194.

149. FOWQUOIRE, P.: Rentabilite de la preparation en entretien.=Revue Technique de l'Entretien.. vol. 20, no. 194, mars 1968. pp. 3-9.

150. GELMA, N.L., et alii.: O perioditshnosti remontov. (Periodicity of maintenance)=Elektritsheskie Stantsii, No. 9, 1965. pp. 74-76.

151. GEORGE, J.E., McHOLLAN, J.A.: Here's how CWACC helps keep maintenance costs in line. =Power, Vol. 108, No. 5, 1964. pp. 68-71.

152. GILCHRIST, A.B.: Introducing management controls into a maintenance department using universal maintenance standards.=Chemistry and Industry, July 20, 1968. pp. 966-970.

153. GLASSFORD, W.: Handbook of preventive maintenance.=Modern Power and Engineering, Vol. 60, No. 3, 1966. pp. 83-102.

154. GOURAUD, M.: Comment calculer la rentabilite d'un entretien preventif? =Revue Technique de l' Entretien...vol. 19, no. 182, janvier 1967.

155. GOYAL, S.K.: Turnaround tips from India.= Hydrocarbon Processing, January 1968. pp. 129-130.

156. GOYAL, S.K.: Can you have zero defects in plant maintenance? =Hydrocarbon Processing, January 1968. pp. 131-132.

157. GREENBERG, H.: Failure testing in preventive maintenance. =Operations Research, No. 8, 1960. pp. 406.

158. GREENE, T.W., PALMER, N.: The SHARP Equipment Maintenance Programme=Chemical Engineering Progress, Vol. 63, 1967. pp. 22-28.

159. GUITTARD, N.J.: Organization du graissage des machines outils.=Ingenieurs de l' Automobile, vol. 41, no. 11, 1967. pp. 581-594.

160. HAYNES, R.M., HORN, E.W.: Practical tips on contract maintenance.=Hydrocarbon Processing and Petroleum Refiner, Vol. 45, No. 1 1966, pp. 115-118.

161. HEBESTREIT, W.H.: A new maintenance approach...=Paper Mill News, Vol. 86, No. 15, 15 April 1963. 0pp. 26, 34, 36, 37.

162. HENNEY, B.E.: Designing control systems for simplified maintenance =Electrical Construction and Maintenance, October 1967. pp. 129-138.

163. Here's how reorganization of maintenance utilities saved $ 74,000=Mill and Factory, Vol. 78, No. 6,1966. pp. 43-45.

164. HERITAGE, J.O.:·Planning; key to high performance.=Hydrocarbon Processing, January 1968. pp. 127-128.

165. HILL, P.W., le FEIRE, K.G.: Sprayed urethane form coats and insulates plant roof.=Plant Engineering, October 1967. pp. 140-141.

166. HOFFMAN, N.M.: Establishing a workable lubrication programme.=Plant Engineering, May 16, June 13, July 11, September 19, October 17, 1968. pp. 96-89; 105-107; 92-94, 106-107; 100–101.

167. HORWITZ, M.: Evaluating maintenance costs.= Foundry, Vol. 91, No. 6, 1963. pp. 112, 115-116, 118.

168. HOVAN-HOCUTT, R: Automated cleaning.= Textile Research Journal, Vol. 33, No. 12, 1963. pp. 1049-1054.

169. How can you stem the tide of rising maintenance costs? =Mill and Factory, Vol. 82. No. 1, 1968. pp. 56-67.

170. HUMMEL, H.: Recording system keeps maintenance on schedule.=Plant Engineering, 11 January 1968. pp. 100-101.

171. HUMPHREYS, J.: Planned maintenance.=Bri-

tish Clayworker, Vol. 71, No. 836, January 1962. pp. 22-26.

172. HUNT, M.P.: Steel plant uses two-part maintenance plan=Electrical Construction and Maintenance, Vol. 65, No. 6, June 1966. pp. 110-113.

173. HUNT, M.P.: Programmed maintenance.=Iron and Steel Engineer, June 1968. pp. 175-181; 181-183.

174. JABOT, J.: La methode d'entretien preventif en U.R.S.S.=Hommes et Techniques, vol. 22, no. 259/60, juin-juillet 1966. pp. 680-726.

175. JAMES EARL: Successful maintenance reorganization.=Hydrocarbon Processing, Vol. 46, No. 3, 1967, pp. 191-194.

176. JANSEN, R. What plant engineers think of maintenance labor standards? Plant Engineering, March 7, 1968, pp. 96-98.

177. JERRY, R.L.: How small operators can eliminate parts-chaos?=Canadian Forest Industries, Vol. 86, No. 8, 1966. pp. 22-23.

178. JOLLIFF, J.V.: Work study; the fleet needs it. —Naval Engineers Journal, February 1968. pp. 51-55.

179. JORDAN, J.H. How to evaluate the advantages of contract maintenance. =Chemical Engineering, March 25, 1968. pp. 124+

180. JUERGENS, R.E.: Maintenance by computer? yes-no-maybe.=Construction Methods and Equipment, November 1967. pp. 58-79.

181. Kalnitz, M.C.: One-line control strategy reduces downtime costs.=Control Engineering, Vol. 13, No. 11, 1966. pp. 79-81.

182. KING, F.: New approaches to cleaning machinery with air=Textile Bulletin, May 1964. pp. 44-47.

183. KISIELNICKI, J. The analysis of the maintenance costs of single machines and equipment on the example of three selected sugar plants. = Gazeta Cukrownicza, Vol. 76, No. 3, 1968. pp. 61-63. (in Polish).

184. KORPELA, T.J.: Preventive maintenance control. =Iron and Steel Engineer, December 1967, pp. 149-151.

185. KULMANN, E.J.: Cutting maintenance demand by effective cost control.—Instrumentation Technology, Vol. 15, No. 2, 1968. pp. 59-64.

186. LAUTERS, V.G.: Maintenance programme developed for top maintenance. = Plant Engineering, February 8, 1968. pp. 81-83.

187. LA VALLEY, L.: Managing electrical maintenance. = Textile Industries, Vol. 128, No. 1, 1964. pp. 51-53.

188. LIFSEY, J.A.: Optimization of maintenance resources. = Operations Research, No. 6, 1965. pp. 1007-1019.

189. LONGO, J.: Organization and operation of an electrical maintenance programme.=Electrical Construction and Maintenance, February 1968. pp. 90-93+.

190. Lubrication know-how pays off. = Modern Power and Engineering, Vol. 60, No. 11, 1966. pp. 41-43.

191. MACAVOY, R.F.: Mechanical services. = Steel Times, Vol. 192, No. 5108, June 1966, pp. 779-781.

192. MAHOOD, R.F., PLACETTE, H.S.: At Du Pont's Sabine River Works centralized maintenance pays off.=ISA Journal, Vol. 13, No. 6, 1966. pp. 49-52.

193. MAHOOD, R.F., PLACETTE, R.S.: Centralized maintenance pays off. = ISA Journal, Vol. 13, No. 6. pp. 49-52.

194. Maintenance of top rollers.=Canadian Textile Journal, Vol. 78. No. 25, 8 December 1961. pp. 55-56.

195. Maintenance on a critical path.=Electrical Review, Vol. 181, No. 10, 8 September 1967. pp. 352.

196. Maintenance; organisation, policy, practice.= Coat Age, October 1968. pp. 159-166.

197. Maintenance: North American Coal Corp.= Coal Age, October 1967. pp. 138-141.

198. MANN, L.J: Towards a systematic maintenance programme.=Journal of Industrial Engineering, Vol. 17, No. 9, 1966. pp. 461-473.

199. Maintenance organization; what's the best for you. =Mill and Factory, Vol. 81, No. 6, December 1967. pp. 39-46.

200. MARSH, E.M., UPFOLD, A.T.: Instrument cost index saves maintenance dollars.=Instrumentation Technology, Vol. 14, No. 5, 1967. pp. 37-40.

201. MASKASKY, J.L., FIELD, R.G.: Automatic maintenance improves systems reliability.=Electronic Engineer, July 1968. pp. 49-52.

202. Micro Switch, plant engineering and maintenance developed a combination.=Plant Engineering, May 16, 1968. pp. 66-69.

203. MILCIC, B.: Technological improvement of machine tool maintenance to shorten time and costs of repair.=Strojartstvo, Vol. 10, No. 1-2, 1968. pp. 8-16. (in Serbian).

204. Mill maintenance on contract.=The World's Paper Trade Review, Vol. 162, No. 10, 3 September 1964. pp. 694-696.

205. MORRIS, T.R.: Maintenance control in a New Zealand integrated mill.=Appita, Vol. 20, No. 5, March 1967. pp. XXII-XXVI.

206. MORRISON, J.: European maintenance men out costs, increase efficiency.=The Oil and Gas Journal, Vol. 66, No. 3, January 1968. pp. 78-84.

207. MANCE, R.E., LLEWELYN, R.W.: Effects of secondary duties on efficiency.=Textile Industries, Vol. 132. No. 2, 1968. pp. 98-104.

208. NEEB, A.F.: Good preventive maintenance.= Meat, Vol. 32, No. 11, 1966. pp. 26-31.

209. NEUMANN, H.: Maintenance in wood-working plants; preventive measures.=Moderne Holzverarbeitung, Vol. 3, No. 5, 1968. pp. 287-291. (in German).

210. New maintenance lifts solve old problems. = Material Handling Engineering, Vol. 21, No. 12, 1966. pp. 76-79.

211. Non-destructive testing as a maintenance procedure. = Marine Engineer and Naval Architect, Vol. 89, No. 1087, October 1966.

212. NOONAN, G.C., FAIN, C.G.: Optimum preventive maintenance policies when immediate detection of failure is uncertain.=Operations Research, No. 10, 1962. pp. 407.

213. On-load pipeline engineering (maintenance).= Power and Works Engineering, April 1967. No. 62. pp. 12-15.

214. Organization sparks bleachery maintenance.= Textile World, Vol. 114, No. 1, 1964. pp. 74-76.

215. OSBORN, R.J.: Integration of preventive maintenance into sound management.=Iron and Steel Engineer, September 1963. pp. 86-90.

216. PALKO, E.: Plant Engineering and maintenance decentralized for better service. Armstrong Cork Co.=Plant Engineering, October 31, 1968. pp. 70-73.

217. PALKO, E.: Communications system reduces equipment downtime.=Plant Engineering, June 27, 1968. pp. 74-76.

218. PALKO, E.: Stretching the maintenance dollar at Goodyear.=Plant Engineering, September 19, 1968. pp. 78-81.

219. PARSON, J.A.: Preventive Maintenance Policy Selection.=Journal of Industrial Engineering, No. 16 1965. pp. 321.

220. PASSEMAR, P.: Comment organiser une graissage rationelle en filature.=L'Industrie Textile, no. 893, juillet-aout 1961. pp. 563-565.

221. PFEIFFER, S.: Le systeme MI/DAC=Nouvelle methode d'organisation d'un service entretien sur des bases mecanographiques.=Revue ATIP vol. 21, no. 3, 1967. pp. 97-101.

222. PINDER, H., TURNER J. et alii.,: Preventive maintenance and servicing of looms. = Textile Recorder, Vol. 82, No. 984, March 1965. pp. 62-64.

223. Pointers on preventive maintenance. Routine in grain milling plants. = American Miller and Processor, Vol. 91, No. 1, 1963. p. 32.

224. PRESSLEY, R.B.: Getting more from maintenance.=Textile World, Vol. 111. No. 4, 1961, pp. 69.

225. PRESSLEY, R.B.: Preventive maintenance. Why you need it? What it can do? = Textile World, Vol. 110, No. 9, 1960. pp. 43-47.

226. La protection des materials de confection: deux recommendations adoptiees par le Comite Technique National du Vetir, No. 86, decembre 1964. pp. 79-86.

227. Put method in your maintenance.=Commercial Motor, Vol. 127, No. 5, April 1968. pp. 99-101.

228. PUTMAN, G.: Blueprint of a modern maintenance shop.=Fleet Owner, Vol. 62. No. 2, 1967. pp. 101-105.

229. RECORDS, W.N.: Horizons in highway maintenance.=Public Works Vol. 34, No. 11, December 1967. pp. 235-241, 250.

230. Records control is tops at Yellow Transit.=Diesel Equipment Superintendent, March 1968. pp. 40-42.

231. REHNER, L.A.: Reduced maintenance cost means higher operating profits.=Iron and Steel Engineers, Vol. 43, No. 9, 1966. pp. 105-108.

232. RIBBENS, J.C.: Preventive—corrective maintenance monitors equipment costs.=Plant Engineering, May 16, 1968. pp. 75-77.

233. ROBBINS, M.D.: Predicting your maintenance

costs.=Chemical Engineering, No. 66, 1959. p. 172.

234. ROBERTS, A.: The inseparables: quality control and upkeep.=Textile Industries, Vol. 126, No. 9, 1962. pp. 91-92.

235. ROTH, S.E.: A look at instrument maintenance cost tends.=Proceedings American Petroleum Institute, Vol. 45, No. 3, 1965. pp. 291-296.

236. SCHILLING, K.J.: Maintaining a fleet.=Compressed Air, Vol. 3, No. 1, 1968. pp.4–9.

237. SEIDEL, J.J.: Plant maintenance training—a practical training programme at Monsanto.= Training and Development Journal, Vol. 21, No. 12, December 1967. pp.18–23.

238. Selective technique holds record keeping to minimum for small New England fleet.=Diesel Equipment Superintendent, January 1968. pp. 26–27.

239. SHERWOOD, P.W.: Automating the textile plant maintenance programme.=Canadian Textile Journal, Vol. 79, No. 12, 8 January 1962. pp.49–50.

240. SHERWOOD, P.W.: Computer control of textile plant maintenance stores. Cost reduction= Canadian Textile Journal, Vol. 70, No. 15, 20 July 1962. pp.55–56.

241. SHERWOOD, P.W.: Cost reduction by maintenance standards in woodworking plants.=Wood, Vol. 29, No. 11, 1964. pp.54-55.

242. SHERWOOD, P.W.: New benchmarks for better maintenance cost control in refinery operations=Petroleum, Vol. 30, No. 1, 1967. p.23.

243. SKUBIK, E.B.: Maintenance is a vital ingredient at Bristol laboratories.=Plant Engineering. 22 August 1968.

244. SLADE, F.H.: Textile mill maintenance.=Textile Manufacturer, Vol. 85, No. 1018 October 1959. pp.437-441; Vol. 86, No. 1021, January 1960. pp.3–8; Vol. 86, No. 1025, May 1960. pp.181-185; Vol. 86, No. 1027, July 1960. pp. 265–268; Vol. 86, No. 1030, October 1960. pp. 397–400.

245. SMITH, G.W.: Maintenance planning/scheduling; preliminary steps.=Plant Engineering, 25 July, 5 September, 3 October, 1968. pp.72-73; pp. 88–91; pp.70–72.

246. SMITH, N.P.: Maintenance scheduling by sequential testing.=Instruments and Control Systems, Vol. 39, No. 8, 1966. pp.123-128.

247. SMITH, L.L.: Programming structural integrity maintenance.=Civil Engineering, October 1967. pp.34-37.

248. SNIDER, R.C.: Quality control-in a medium-sized plant.=Graphic Arts Monthly, Vol. 39, No. 10, 1967. pp.82-92.

249. SPARKES, C.A.: Maintenance of numerically controlled machine tools.=Machine Shop and Engineering Manufacture, Vol. 27, No, 4, 1966. pp.132–137.

250. SPITZER, H.: Low cost cdp provides high preventive maintenance reliability.=Plant Engineering, November 1967. pp.167–169.

251. STAFF: Gauges in draper-loom maintenance.= Textile Industries, Vol. 126 No. 9, 1962. pp.82–84.

252. STAFF: Slasher rolls need TLC/tender loving care/.=Textile Industries, Vol. 128, No. 7, 1964. pp.73-75, 78.

253. STERN, F.L.: Practical lighting maintenance service concepts.=Electrical Construction and Maintenance, April 1968. pp.118-123.

254. STEVE E.: 1966 maintenance conference updates PM. thinking.=Power, Vol. 110, No. 6, 1966. pp.79–81.

255. SUMMERSCALES, J.B., DAVENPORT, W.H.: Automatic cleaning of straight bar knitting machines.=Hosiery Trade Journal, Vol, 72, No. 862. October 1965. pp.102-103.

256. SWATEK, W.T.: Maintenance of reeds and harnesses.=The Textile Journal of Australia. Vol. 40, No. 12, 1965. pp.34–36.

257. SZMANIA, R.A.: Organisez votre entretien. Rendez-le dynamique.=Revue du Bois, vol. 15, No. 6, 1960. pp.27–30.

258. THOMPSON, F.B.: Maintenance foreman; fulltime coaching job.=Safety Maintenance, May 1968. pp.47-50.

259. THOMPSON, J.T., WARREN, W.J.: Preventive instrument maintenance must be sold.=Combustion, April 1967. pp.31-34.

260. THORNTON, L.W.: Visual records will update your maintenance programme=Ceramic Age, vol. 83, No. 2, 1967. pp.24–26.

261. TIFFANY, H.E.: Investigate lubrication programme to uncover hidden costs.=Plant Engineering, October 1967. pp.195+.

262. TONINI, J.A.: How nomographs can speed

your maintenance estimating.=Mill and Factory, Vol. 80, No. 4, 1967. pp.57–59.

263. TURBAN, E.: The use of mathematical models in plant maintenance decision making=Management Science, February 1967. Ser. B. pp.342-357.

264. TORLAY, D.L., STROWKOFF, M.: Optics; a practical maintenance tool.—Iron and Steel Engineer, December 1967. pp.87–91.

265. TORLAY, D.L.: Planned maintenance simplified.=Iron and Steel Engineer, 1964. pp.132.

266. TURNBULL, J.C.; Maintenance.=Institution of Electrical Engineers Proceedings, January 1968. pp.241-242.

267. TURVEA, G.: The law of vehicle maintenance. =Commercial Motor, Vol. 27, No. 2364. 5 April 1968. p.88.

268. UPTON, R.A.: Lubrication of construction equipment.=International Construction, Vol. 6, No. 6, 1967. pp.86-77.

269. Use this method to link machine maintenance with quality control.=Modern Textile Magazine, Vol. 43, No. 1, 1962. pp.33–34.

270. VAN ROBAIS, C: Rappel de notions de base pour le traitment analytique des problemes d'entretien.=La Sucrerie Belge, Vol 86, no. 7, mars 1967. pp.317-332; vol. 86, no. 6, fevrier 1967, pp.261-281; vol. 86, no. 8, avril 1967. pp. 369-380.

271. VERGIN, R.C.: Scheduling maintenance and determining crew size for stochastically failing equipment.=Management Science, Vol. 13, No. 2, October 1966. pp.B–52—B–65.

272. VILLAIN, W.: The nerves of maintenance.= Pulp and Paper Magazine of Canda, Vol. 67. No. 9, 1966. pp.T414—T420.

273. VLAHOS, C.J.: FRANK, J.: Know-how special report: attack on overhead.=Mill and Factory, Vol. 79, No. 6, December 1966. pp.44–54.

274. WARDWELL, N.P.: How to keep saw mill chippers in top shape.=Canadian Forest Industries, Vol. 86, No. 1, 1966. pp.49.

275. WARREN, M., BUTTERWORTH, C.I.: Preventive maintenance programme for hydroelectric generators windings.=IEEE Transactions on Power Apparatus and Systems, May 1968. pp.1283-88.

276. WEISS, W.H.: Simulation determines size of maintenance crew=Plant Engineering, October 1967. pp.146-148.

277. WELDE, D.J.: Planification de construction et de reparation par la programmation dynamique. =Genie Chimique, vol. 87, no. 1, 1962. pp.2–13.

278. WIERINGEN, J.: Shell develops maintenance target costs.=The Oil and Gas Journal, Vol. 65, No. 9, 27 February 1967. pp.147-151.

279. WILKINSON, J.J.: How to manage maintenance.=Harvard Business Review, March, 1968. pp.100-111.

280. WILLIAMSON, D.: Non-destructive testing moves into maintenace and safety.=Foundry, November 1967. pp.56–61.

281. WOLNEZ, G.J.: Ten important steps to safety. =Plant Engineering, October 1967. pp.131–133.

282. WOOD, R.: Mechanized line maintenance in Dow Chemical Co. plant.=Power Engineering, June 1968. pp.37+.

283. WYDER, G.G.: Maintenance today. What's best and new? How to manage it? How it pays off?=Textile World, Vol. 114, No. 1, June 1964. pp.38–42.

284. YARBROUGH, C.T.: Optical checks put plant in line for low mainteance future.=Iron Age, Vol. 197, No. 3, 1966. pp.60-61.

285. Your guide to maintenance cost control.=Modern Power and Engineering, Vol. 60, No. 3. p.102.

3. REPORTS, DISSERTATIONS AND CONFERENCE PAPERS

*United Nations Industrial Development Organization**

286. Repair and maintenance of machine tools in developing countries. UN 5th Session 15 March 1965, Committee for Industrial Development. 39 p. (E/C.5/68 mim).

Basic methods of extending the use of life of machine tools, principles of repair services with special reference to the requirements.

287. PRONIKOV, A.S.: Repair and maintenance of machine tools in the developing countries.= Industrialization and Productivity, Bull. No.10, New York, 1966. pp.74–90 (with bibliogr.). (Sales No. 66.II.B8).

288. A report of the Group of Experts on Maintenance and Repair of industrial equipment in deve-

*Symbols and sales numbers of United Nations documents and publications are given in parenthesis after the titles.

loping countries. New York, 28 Nov.–9 Dec. 1966. 52 p.+I-VI annexes. (ID/1) (mim).

*Food and Agricultural Organization***

289. Forestry and Forest Products Div.–Forest product processing; working paper on mobile unit for sawmill improvement and maintenance and repair. 5 p. (02392-68-WS).

290. Ghana–report on survey of the Lower Volta river flood plain vol. 3, agronomic considerations.

Irrigation system, operation and maintenance and repair, irrigation practices incl. soil water relation and plant water, measurement formula. Vol. 3 of 5-7 p., 15 tab., 1 org. chart, 1 app. with 8 tab., 6 ref. 9 large maps and 1 plan in folder. FAO 1963-UNDP/SF report (54604-63-MR

291. Lockwood Survey Co. Somalia agricultural and water surveys final report, Vol. 5, engineering aspects of development.

Water management, Somalia UNDPSF project. Vol. 5 of project report; details on reservoirs spec.UARS construction; programmes and maintenance and repair, giving cost analysis.-137 p., 36 tab., 2 graphs, 3 plans, 1 map, 3 app. with 9 tab, and 9 maps attached UNDP/SF report 36/Som. 1. (04017–68–MR).

292. RICCI, C.: Somalia—Grain silos, report to the Government.

Cost analysis of storage structure incl. equipment cost, handling equipment, transport equipment, laboratory equipment and their maintenance and repair. 28 p., 7 tab., 3 app. (FAO 1964-APTA report No. 1905.) (51905-64-MR).

293. Tanganyika—Hydrology. Lecture notes for hydrologic training course in Tanganyika on pressure type water level measuring instrument; notes on installation of recorder, spare parts, their operation, testing, maintenance and repair. 1963, 42 p., 9 dwgs. (61459-63-WS) (61450-63-WS).

294. NAZARETH, P.:—Tanganyika—Operation and maintenance of stream gauging stations. On operation, maintenance and repair. 1963, 66p., 5 graphs, 1 drwg. (61460-63-WS).

295. GIRSPERGER, F.: United Arab Republic, Southern Region—Agricultural machinery workshops: report to the Government. 1958.

Agricultural engineering EPTA project report on management of workshops for maintenance and repair of agricultural machinery in UAR. Suggestions for workshop layout, workshop equipment and services incl. machine tools, cleaning and spare parts replacing. Notes on technical education and training of workshop personnel and on the agricultural engineering section of Ministry of Agriculture. 50 p., 1 plan, 6 app. with 10 phot. (50914-58-MR).

296. LONNEMARK, H.: United Arab Republic—Report on survey of needs for training farm machinery operators, maintenance, repair, supervisory and management personnel.

Report on survey of agricultural training of farm machinery operators and maintenance staff in UAR. Needs for training of agricultural machinery maintenance and repair, supervisory and management staff. 1965, 11p. (61490-65-MR).

297. GOLDING, E.W., STODHART, A.H.: The potentialities for rural electrification in Asia and the Far East.

Monograph on agricultural mechanization anp electrical equipment in Asia and Far East. Data on farm power supplies spec. engine power and its cost, according to fuel required and maintenance and repair. 103 p., 16 tab., 50 phot., 79 ref., 1 app. with 3 tab., 2 drwgs., 3 phot. (61374-62-MR).

298. Paris FJH—Aden—Recommendations concerning the organization of a well drilling programme to develop the underground water resources of the Federation of South Arabia and the Eastern Aden Protectorate. Report to the Government. 1963.

Water management, EPTA Project report. Cost analysis, construction, drilling equipment and equipment cost of pumping plants. Forecasting of wells operation, maintenance and repair costs according to well depth and water supply. 59 p., 4 tab., 6 app. with 3 tab., 2 forms, 9 maps. (51768-63-MR).

299. HUNT, J.E.: Burma—The maintenance of agricultural tractors and machinery. Report to the Government. 1963.

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Project report on workshop, practices and equipment maintenance and repair at base workshops in Rangoon, Burma. 8 p. (51985-65-MR).

301. COLEMAN, F.: Ceylon—Services in agricultural mechanization. Report to the Government. 1959.

EPTA project report on services in agricultural mechanization in Ceylon. Notes on agricultural administration, reorganization and on agricultural machinery, spare parts, storage, structures requisition and control. Need for specialized scientific personnel and for training in agricultural machinery operation and maintenance and repair workshops. 107 p., with 7 org. charts, 2 phot., 2 drwgs, 12 forms. (51035-59-MR).

302. LAWRENCE, W.J.A.:—Ceylon—Repair and maintenance of earthmoving and irrigation construction equipment. Report to the Government. 1953.

EPTA Project report on maintenance and repair of irrigation and earthmoving equipment in Ceylon. working plan and assistant personnel needed for farm equipment maintenance and repair. 21 p. 50196-53-MR).

303. HASLETT, R.S.: Ceylon—Maintenance and repair of earthmoving and irrigation construction equipment. Report to the Government. 1954.

EPTA Project report on maintenance and repair of earthmoving machinery and irrigation equipment in Ceylon. Workshop organization, recommendations on engine, spare part supply, personnel training and welfare. 21 p., 1 app. with 1 org. charg. (50305-54-MR).

304. GIRSPERGER, M.: Ceylon—Workshop practices and equipment maintenance at the base workshops of the Gal Oya Development Board, Amparai. Report to the Government. 1961.

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305. KONEKE, B.C.: India, Uttar Pradesh—Agricultural workshop organization and practices. Interim report to the Government. 1953.

Progress report on aspects of agriculture workshop management in India. Maintenance and repair of workshop machinery and staff training incl. teaching aids. 11p. (51498-53-MR).

306. THOMAS, M.P.: India, Uttar Pradesh—Personnel training and development in agricultural and irrigation workshops. Report to the Government. 1957.

EPTA Project report on training and technical education in workshops for maintenance and repair of irrigation equipment and agricultural machinery in Uttar Pradesh, India. 16 p. (50621-57-MR).

307. GIRSPERGER, F.: India—Removal of defects from agricultural implements of indigenous manufacture. Report to the Government. 1954.

EPTA Project report data on rehabilitation of Pashabai Patel Company tractors and farm machinery and on spare parts stores and machines maintenance and repair. 54 p., 4 app. with 3 tab. (50223-54-MR).

308. RYAN, R.K.: India, Uttar Pradesh—The use of welding processes in the repair and fabrication of agricultural machinery. Report to the Government. 1954.

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First and second EPTA Project report on forest utilization, spec. maintenance and repair of sawing equipment. Vol. 1 of 2, 9 p., 3 app. (50367-55-MR) (51237-60-MR).

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327. Interim report to the Government of the Syrian Arab Republic on the development of accelerated training (automobile mechanics section). Geneva, 1963. 13 p. (ILO/TAP/Syria/R.5 52-001).

328. Maintenance and repair of motor vehicles: a practical instruction manual. Geneva, 1955. 518 p.

329. Report to the Government of Indonesia on motor vehicles maintenance and repair. Geneva, 1958. 36 p. (ILO/TAP/Indonesia/R.9 52-001)

Other Reports

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353. Machine Shop. Machine repairs handbook Nov. 1966. 202 p. (PB-175 995).

354. Machine Shop. Machine Repairs Formulas, Nov. 1966, 211 p. (PB-176 181).

355. Automotive Maintenance equipment in Thailand, Business Research Ltd., Bangkok, Thailand, for the Business and Defense Services Admin., Sept. 1965, 8 p. A Foreign Market Survey to help U.S. firms initiate, develop and/or expand their exports. (PB-174 785).

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*Rand Reports**

363. Alchian, A.A.: Economic replacement policy. Report R-255, 1952.

364. BELL, Ch.F.: Information needs for effective maintenance management. Report P-3180, 1965.

365. BELL, Ch. F., KAMINS, M.: Planned replacement. Report P-3052, 1965.

366. ECKLES, J.E.: Optimum maintenance with incomplete information. Report RM-5390, 1967.

367. HAYTHORN, W.W.: Maintenance scheduling decisions and the importance of information. Report P-2302, 1961.

368. JORDAN, N.: Human factors in maintainabilty. Report P-2459, 1961.

369. SEWELL, W.P.: Maintenance of a group of machi es utilized intermittently and subject to several types of malfunctions; operational requirements and resource allocations. Report P-818, 1956.

Miscellaneous

370. Ship repair and maintenance. Indonesia. Agency for International Development. (Investment Information and Opportunities Communications Resources Division. Businessmen's Information Centers.) 1960. II. 3731. 4/0400673.

371. Report on the organization of maintenance in iron and steel works. Paris, 1963. OECD, 64 p. (With organization diagrams).

372. MURPHY, N.C.: Industry and government cooperate to train in automotive skills. Manpower training facts (Washington) 1-3 July 1965.

373. SUMNER, W.Training service-station mechanics in 34 weeks. Industrial arts and vocational education (Milwaukee), 55 (6), June 1966, 32-33. illus. Microfilm.

374. PLIASOV, M.T.: The training of personnel at the Moscow Light Car Plant. London, Evans, 1968. (In-LAUWERYS, J.A., SCANLON, D.G. Education within industry, p. 271-285.).

375. JACOBY, G.A.: Education and training in General Motors, USA. London, Evans, 1968. (In-LAUWERYS, J.A., SCANLON, D.G., Education within the industry, p. 338-340).

* Rand reports may be obtained against order and payment from The Rand Corporation, 1700 Main Street, Santa Monica, California, 90406, Attention Reports Department.

376. WELKER, E.L.: Relationship between equipment reliability, preventive maintenance policy and operating costs. ARINC Report No. 7, Washington 1959.

377. British Standards Institution. Glossary of General Forms used in maintenance organization. London, BSI, 1969. 90 p. (BS. 3811:1964).

378. Canada, Department of Labour—1967. An analysis of the heavy duty repair trade. Ottawa, 1964. 114 p.

379. Canada, Department of Labour—1964. An analysis of the motor vehicle repair trade—mechanical. Ottawa, 1964. III, 215 p.

380. India, Labour Bureau—1966. Report on survey of labour conditions in motor vehicle manufacturing and repairing factories in India. Sicule, 1966, V, 67 p.

Dissertations

381. BRAGAW, L.K. Jr.: Reliability and maintainability of mechanical systems. Massachusetts Institute of Technology (MIT) 1964.

382. CARLSON, R.W.: Balancing repair and production facilities in a job shop. Carnegie Institute of Technology (CIT) 1961.

383. DETTMER, R.G.: An application of statistical control charts to equipment maintenance. Massachusetts Institute of Technology, (MIT) 1955.

384. EAGLES, J.R.: The maintenance function within industry. (MIT) 1956.

385. HANSON, G.M.: Planning and control for the small maintenance department. University of Pennsylvania, 1958.

386. JUCKLER, F.H.: Preventive maintenance of equipment components—Theory and applications. Carnegie Institute of Technology (CIT) 1962.

387. MORGAN, J.I.: Maintenance planning in a large chemical plant. Carnegie Institute of Technology (CIT) 1960.

388. MYERS, C.E.: Standards and incentives in preventive maintenance. Harvard University, 1956.

389. LONG, W.R.: Maintenance organization. Massachusetts Institute of Technology, (MIT) 1960.

390. PALZER, E.W.: Control of maintenance costs. Temple University, 1952.

391. SHIPLEY, W.E.: Performance measurement of maintenance costs for plant and equipment. Carnegie Institute of Technology. (CIT) 1960.

392. STEWART, D.I.: Some overall models of maintenance and replacement. Carnegie Institute of Technology (CIT) 1963.

Conference Papers

393. Maintenance of heavy duty commercial automotive equipment. Seminar on the Establsihment and Development of the Automotive Industry in Developing Countries. Karlovy Vary, 24 February to 14 March 1969. (UNIDO-ID/WG. 13/4)

394. Problems related to the production and supply of automotive components. Seminar on the Establishment and Development of the Automotive Industry in Developing Countries. Karlovy Vary, 24 Feburary to 14 March 1969. (UNIDO-ID/WG. 13/6)

395. The use of old and second-hand road transportation equipment. Seminar on the Establishment and Development of the Automotive Industry in Developing Countries. Karlovy Vary, 24 February to 14 March 1969. (UNIDO-ID/WG. 13/14)

396. Maintenance and repair of radio communication equipment. Development meeting on the Manufacture of Telecommunications Equipment. Vienna 13 to 24 October 1969. (UNIDO-ID/WG. 15/9

397. The problems of servicing and maintaining agricultural machinery in developing countries. Expert Group Meeting on the Agricultural Machinery Industry in Developing Countries. Vienna, 18 to 22 August 1969. (UNIDO-ID/WG. 40/9)

398. Service and maintenance problems of agricultural machinery in developing countries. Expert Group Meeting on the Agricultural Machinery Industry in Developing Countries. Vienna, 18 to 22 August 1969. (UNIDO-ID/WG. 40/14)

399. Forest product processing conference Africa, Near East; Cairo, March 1965. (FAO-03962-68-MR)

400. Annuals of reliability and maintainability. Fourth annual reliability and maintainability conference. Los Angeles, 28-30 July 1965.—Washington, 1965. Sparton, 945 p.

401. ASME—10th Plant Engineering and Maintenance Conference, Detroit, April 10-12 1967. Mechanical Engineer, Vol. 89., June 1967. p. 106-108.

402. Concours entretien organise par la SERSID parmi les ingenieurs des usines siderurgiquest Vol. 1 and 32. Paris 1956. SERSID. 113 p.

403. Corrosion and its prevention in motor vehicles. Symposium. London, Institution of Mechanical Engineers, March 1968. 375 p.

404. L' entretien preventif. Session d'etude Agence Europeaenne de Productivite Centre Audivisuel de I AFAP. Paris, AFAP, 1959. div. p.

405. International Congress. Papers of the maintenance conference. 25-26 Nov., 1965. Budapest, Gepipari Tudomanyos Egyesulet, 1966. 194 p.

406. International Institute of Welding. Welding and allied processes in maintenance and repair work. Report of the 1969 Public Session of the International Institute of Welding, Opatija, Yugoslavia, 1961. X 590 p.

407. Journees d'etudes; 7-10 October 1946 de la CEGOS I'organization technique ecdes entreprises. 5 eme fascicule "Enteretien , Paris, CEGOS, 1947. 43 p.

408. Journees d'etudes des 30 Mai—3 Juin 1949 de la CEGOS. "Entretien , Paris, CEGOS, 1949. 262 p.

409. Journees d'etudes des 16-17-18 janvier 1950 de la CEGOS. "Entretien , Paris, CEGOS, 1950. 143 p.

410. Konferenz fur die Instandhaltung der Baumaschinen. (Conference on the maintenance of building machinery,) Budapaest 23-35 Nov 1966. 244 p.

411. Plant Engineering and Maintenance Conference and Show. Chicago, January 30-February 2, 1967. Power, Vol. III., April 1967, pp. 88-89. Plant Engineering, Vol. 21, January 1967, pp. 181-247 Material Handling Engineering, Vol. 22 March 1967. pp. 77-83.

412. The Report of the International Plant and Maintenance Engineering Conference. London, 17-21 June 1963. In 4 volumes. London Factory Publ., 1963. 194 p.

413. Some maintenance problems in steel production; symposium.—Iron and Steel Engineer, Vol. 44. July 1967. pp. 95-101.

414. Annual Symposium on Reliability, January 10-12, 1967. Analysis techniques for maintainability specification, J. KLION, K.C. KLOTZKIN. Maintainability Prediction Assessment—New Concept. E.P. O'CONNEL.—Proceedings of the IEE, 1967. p. 501-510 p. 527-523.

415. Reliability and Maintainabilty Conference, 5th July 18-20, 1966. Maintenance Dependency Chart, New Troubleshooting Technique, R. GLENN, J.D. MARTIN, M.R. McDONOUGH. "Frequency of Maintenance, O.N. GABRIELSEN —Proceedings of the IEE, 1967. p. 92-99 p.428-433.

416. The Proceedings of the 10th Annual Industrial Engineering Conference 1959. Measuring and controlling maintenance costs (R.I. REUL) Morgantown, West Virginia University Technical Bulletin No. 54 1969 pp. 12-21.

417. Techniques of plant maintenance and engineering 1956. Proceedings of the Technical Sessions held concurrently with the 7th National Plant Maintenance and Engineering Show. Philadelphia, January 1956. pp. 5-33.

418. Les traitements de surface contre l usure. Description et applications industrielles. Journees d'etude. Lyon, 25-26 mai 1967. Paris, I Dunod, 1968. XXIV, 397 p. (Ecole Centrale Lyonnaise. Centre de Recherches mecaniques hydromecanique et frottement).

419. Improved maintenance at reduced cost. Text material developed for organization and administration of maintenance labour standards. Orientation seminar of the American Management Association, New York, Ernest and Ernest Management Services Division, 1964. 30 p.

Films on Maintenance

420. ALUMINIUM WELDING
(Le soudage de l'aluminium)
16 mm sd col—28 min.
Origin: France, 1965
Prod: Les Films du Centaure, 10-rue du Chateau, La Gaureene-Colombes (Seines)
Sp: L'Aluminium Francais, 23, rue Balzac, Paris
Dist: L'Aluminium Francais

Detailed description of various techniques employed in the welding of aluminium parts.
OCD No. 2993/7959

421. ARC WELDING AT WORK
16 mm sd col—26 min.
Origin: USA, 1948
Sp: General Electric Company
Dist: General Electric Company

This film defines and generally describes the use of (1) Metal arc welding (2) atomic hydrogen welding and (3) intert-gas arc welding.
OECD No. FOA/5147

422. THE ART OF SOFT SOLDERING
16 mm sd col—13 min.
Origin: USA, 1956.
Prod: Precision Film Laboratories, 21 West 46th St., New York.

Sp: International Business Machines Corporation, Manufacturing Division, Poughkeepsie
Dist: International Business Machines Corporation, Dept. of Information, Film and Television Activities, 590 Madison Avenue, New York 22, N.Y.

A training film which indicates the basic steps in soft soldering. "Close-ups" show the soldering of various types of electronic connections, action of flux, melting, and cooling of solder, preparation of soldering equipment.
OECD No. 10690/6602

423. ASSEMBLING IN A JIG
(Drilling and Riveting)
16 mm sd bw—20 min.
Origin: USA, 1943
Sp: United States Office of Education, Weashington 25, D.C.
Dist: United World Films, Inc., 1445, Park Avenue, New York 29, N.Y.

How to drill the pilot holes in a skin assembled in a jig. It is wise to follow a pattern to eliminate waste motion and assure drilling holes. How to redrill holes to full rivet size, again using a pattern. Numbering of the parts of the assembly. Then the skin can be removed to drill inner structure. How all drilled holes must be burred and cleaned. Parts are tied together to prevent misplacing. Dimpling of material in which flush-type rivets are to be used. Necessity for identifying each number on a part. Assembling of the parts in the jig. Actual riveting of the pattern. Inspection of each riveted piece.
OECD No. 10074/FOA 523

424. ADVANTAGES OF AC WELDING
16 mm sd col—15 min.
Origin: USA, 1950
Sp: Westinghouse Electric Corporation, Film Division, 3 Gateway Center, Pittsburgh Pennsylvania.
Dist: Westinghouse Electric Corporation

The film shows briefly the effectiveness of AC welding of mild steel, cast iron, stainless steels, and alloy steels. Emphasis is placed on the versatility of AC welding for vertical, overhead and horizontal welding, for light and heavy guage steel, and for inside and outside construction. Shows how AC welding eliminates virtually all arc blows. A few printed captions appear in the film explaining the many advantages of AC welding. The speed of AC and DC welding are compared, and the speed of AC welding is shown to be superior. The higher quality of welding that results from the AC method is pointed out in the film by both regular and slow motion. The ease and economy of operation and the minimum maintenance costs of AC equipment as compared to DC equipmet are clearly depicted in this film.
OECD No. FOA/5082

425. BASIC PRINCIPLES OF LUBRICATION
16 mm sd bw—25 min.
Origin: USA, 1945
Prod: Caravel Films, Inc. 730, Fifth Avenue, New York, N.Y. 10019
Sp: General Motors Corporation, Department of Public Relations, Film Distribution Section, Detroit 2, Michigan
Dist: General Motors Corporation

Animated diagrams show how the outer layers of tiny oil globules adhere to the metal surfaces. Lubricating oils differ in viscosity and the choice is determined by weather and temperature factors. Explains the following important functions of lubrication; to reduce friction in order to increase efficiency; to cool power in the cylinder and to prevent contamination and deterioration of engine parts.
OECD No. 10139/FOA 441

426. BETTER MAINTENANCE WELDING WITH EUTECTIC
16 mm sd—20 min. (1965)
Eutectic Welding Alloys Corporation

This film in full colour, describes the process of surface alloying and indicates how research has helped the welder by providing the special alloys so necessary to modern industry. The various methods are shown, together with the latest welding processes, torch alloys and electrodes.

From: Educator's Guide to Free Films.

427. BUILT FOR THE JOB
16 mm sd bw—11 min.
Origin: United Kingdom, 1951
Prod: Trident Films Ltd., 9 Netheravon Rd. Chiswick, London. W.4.
Sp: Shell International Petroleum Co. Ltd., Shell Centre, London, SEI.
Dist: Shell International Petroleum Co. Ltd.

The "tailor making" of lubrication to meet special conditions, such as intense heat or cold, under water work, pressure, abrasive dust, intense vibration, etc.
OECD No. 2506/7123

428. BURNING BLADES
16 mm sd col—29 min.
Origin: USA, 1960
Prod: Air Reduction Sales Company, 150 East 42 nd Street, New York 17, NY

Sp: Air Reduction Sales Company
Dist: Air Reduction Sales Company

The film illustrates, by use of live and animated sequences, construction, working principles and operation of several types of gas cutting machines used in the shaping, forming, cutting and trimming of metal parts. The oxygen torches, in some instances positioned and guided by remote control, overcome considerable barriers of thickness and size. These tools use up to eight torches at one time for a variety of shapes, contours and levels. Radiograph, Oxygraph, Monograph and Travograph, cutting with several types of tracers (manual, mechanical, magnetic, electronic) demonstrate that this method of cutting can be adapted to the most complex design.

OECD No. 11100/7423

429. CARE AND MAINTENANCE OF BUILDING PLANT
16 mm cd bw—13 min.
Origin: United Kingdom, 1945
Sp: Ministry of Works, London
Dist: Ministry of Works

This film illustrates how a little time spent on the routine maintenance of building machinery and equipment can prevent time and money being wasted on breakdowns requiring premature complete overhauls.

OECD No. FOA/5296 UK 1238

430. CARE AND MAINTENANCE OF ROPES: I. STEEL WIRE AND CORDAGE INTRODUCTION
2 reels 18 mins
War Office—World Wide, 1945

Preventive care and maintenance applicable to both wire rope and cordage. Of value to traffic departments and to all concerned with the use of ropes in materials handling.

UK 1586

431. CARE AND MAINTENANCE OF ROPES: III. CORDAGE
2 reels 18 mins
War Office—World Wide, 1945

The nature, lay and types of construction of cordage in common use,, with details of practical and sensible handling. Of value to traffic departments and to all concerned with the use of rope in material handling.

UK 1587

432. CARE OF A TRACTOR
(Farm Work Series—Equipment Maintenance)
16 mm sd. bw—22 min.
Origin: USA, 1944
Sp: United States Office of Education, Washington 25, D.C.
Dist: United States Office of Education

Film show in detail the process of lubricating a tractor.

OECD No. FOA/5078

433. CHEMISTRY REPAIRING
2 reels—555 metres
A black and white popular science film
(Kuibyshew Newsreel Studio)

Polymers are forging their way powerfully into all fields of life. At present they have been made to serve in the repairs and maintenance of farm machines. Applying chemistry for this machine is economically efficient. (From catalogue 4. To be asked for at Soveport film. Moscow. USSR)

SOVEXPORTFILM,
Moscow, USSR

434. 1000 CHIPS
3 reels 30 mins
Warner and Swasey, USA

A comprehensive technical training film on the proper selection, use and maintenance of cutting tools. The different cutter requirements for mild steel, cast iron and brass are demonstrated by slow-motion magnified photography.

V 1000

435. THE CRANE DRIVER
(Le Grutier)
16 mm sd. col.—34 min.
Origin: France 1964
Prod: Je vois tout, 10, rue du Chateau, La Garenne-Colombes
Sp: OPPBTP Paris
Dist: OPPBTP Paris.

Film instructs crane drivers to pay ultimate attention to the proper maintenance and correct mainpulation of their cranes and hoisting equipment. Emphasis is put on safety rules for tower crane operators.

OECD No. 2971

436. DIESEL LUBRICATION AND COOLING SYSTEMS
16 mm sd. bw—9 min.
Origin - English, 1942
Prod - Audio Productions, USA
Dist - United World Films, Inc., USA (for sales or loan)

Parts of diesel lubricating and cooling systems and how they work in relation to each other

are shown using a combination of diagrams, animation and straight photography.

FAO 571

437. DIMPLING AND COUNTERSINKING
16 mm sd. bw—21 min.
Origin: USA, 1944
Prod: The Jam Handy Organization, 2821 East, Grand Boulevard, Detroit 11, Michigan
Sp: United States Office of Education, Washington 25, DC.
Dist: United World Films, Inc., 1445, Park Avenue, New York, N.Y. 10029

Defines dimpling with close-up of an example. Shows checking drawing and reference book for specification of size and angle of dimple. Close-up shows insertion of fird in anvil and plunger, adjustment of anvil, and making of trial dimples until rivet head is flush with the surface of sheet metal. Demonstrates method of holding workpiece while dimpling. Reviews operating steps in dimpling thin material. Defines machine countersinking by means of cross-section drawing. Shows selecting and installing proper countersink in hand drill chuck, adjusting depth stop, and making test on scrap metal.

OECD No. 10193 POA 647

438. DROPS OF DANGER
16 mm sd. bw—10 min.
Origin: United Kingdom, 1945
Sp: ESSO Petroleum Company, Ltd., London
Dist: ESSO Petroleum Company, Ltd.

Shows some of the symptoms of inefficient tractor operation. A case history is taken as an example. On receipt of the farmers claim that his tractor is not working efficiently although not exhibiting any obvious mechanical defects, an analyst is sent from the company office. He observes symptoms, takes samples of the fuel oil and lubricating oil and reports back that the tractor is not being allowed sufficient warm-up time.

OECD No. FOA 5304

439. THE EASIER WAY
16 mm sd. bw—12 min.
Origin: USA, 1947
Sp: General Motors Corporation, General Motors Building, Detroit 2, Michigan
Dist: General Motors Corporation

This film demonstrates that any operation can be reduced to its lowest terms in energy and time expenditure by resolving the sequence of the steps and by convenient placing of the working materials. It gives a convincing treatment of economies which can be effected by time-and-motion studies.

OECD No. FOA 5144

440. ECONOMY—No. 1 WORK IN THE GARAGE
(Ergonomie—No. 1. Travaux de Garage)
(also in Dutch)
16 mm sd bw—6 min.
Origin: Belgium 1962
Prod: Office Belge pour L'Accroissement de la Productivite, 60 rue de la Concorde Bruxelles 5.
Sp: Office Belge pour l'Accroissement de la Productivite
Dist: Office Belge pour l'Accroissement de la Productivite.

A simple film record of "do's" and "don'ts" in car maintenance in garages. Layout of controls, the carrying of tools, suspension of power tools, time and effort in service station work are demonstrated.

OECD No. 2802/7687

441. INSTALLATION AND MAINTENANCE OF ANTI-FRICTION BEARINGS
(Einbau und Wartung der Walzlager)
16 mm sd bw—23 min.
Origin: Fed. Rep. of Germany, 1952
Prod: Commerz Film AG., Berlin W 30
Sp: Kugelfischer Georg Schafer and Co., Schweinfurt
Dist: Kugelfischer Georg Schafer and Co.

The film gives a review of the procedure to be followed in the installation of anti-friction bearings from the smallest to the largest sizes.

OECD No. 1702/FOA 5672

442. FACE PLANNING UNEVEN SURFACES
(Operations on the Jointer)
16 mm sd bw—14 min.
Origin: USA, 1945
Sp: United States Office of Education, Washington 25, D.C.
Dist: United World Films, Inc., 1445, Park Avenue, New York 29, N.Y.

The film indicates that the stock must be checked to determine if it is crooked, warped or twisted, before face planing uneven surfaces. The knives of the cutterhead and the place guards must be properly checked and adjusted. The film shows how to measure the sock and set the infeed table to make the desired cut. The following types of face planning are depicted: the making of several cuts.

OECD No. 10149/FOA 488

443. FARM MACHINERY MAINTENANCE
16 mm col. sd—11 mins
Origin: English, 1959
Prod. and Dist: Australian Commonwealth Film Unit (for sale or loan)

Every machine has its special maintenance needs, and it is important to get an operator's manual and have maintenance points explained when buying a new farm machine. General maintenance advice for continuous good service is outlined; become familiar with your machinery, keep track of spare parts, use grease, oil and paint where and when needed, keep machinery under cover when not in use, and do off-season maintenance.

FAO 362

444. FARM TRACTOR SAFETY—A FAMILY AFFAIR
16 mm col sd—22 mins
Origin: English
Prod. and Dist: American Petroleum Institute, USA (for sale or loan) for non-commercial use.

Of the alarming number of farm accidents reported each year, many involve machinery, and specifically tractors. This film shows how one farming community began a safety programme involving the entire family. Sequences show the causes and results of tractor accidents and how to avoid them. It is emphasized that the most effective means of avoiding accidents is the proper mental attitude of the tractor operator.

FAO 362/A

445. FITTING AND SCRAPING SMALL BEARINGS
(Bench Work)
16 mm sd bw—20 min.
Origin: USA, 1943
Sp: United States Office of Education, Washington 25, D.C.
Dist: United States Office of Education.

This film shows a method of fitting and scraping small bearings of the split and solid type. It illustrates bearings with the main bearings of an automobile engine. It explains in animation the three requirements of bearings and pictures the types of scrapers used for scraping bearings. It shows method of locating high spots in split bearings with a shaft coated with Prussian blue.

OECD No. FOA/614

446. FRONTIERS OF FRICTION
16 mm sd bw—21 min.
Origin: United Kingdom, 1961
Prod: Shell Film Unit
Sp: Shell International Petroleum Co., Ltd., No. 1 Kingsway, London, W.C.2.

Dist: Shell International Petroleum Company Ltd.

Analysis of the phenomena of friction. Role of lubricants and their various types. Examples of research to develop new lubricants adapted to various environments: lubricating at high temperatures, in vacuum and rocket technology, in radiation environments etc. Principles of gas lubrication.

OECD No. SC 176

447. GREASE
(Les Graisses)
16 mm sd bw—27 min.
Origin: United Kingdom, 1951
Prod: The Merlin Film Company, Ltd., Clopham Park Studios, London, S.W. 4
Sp: Shell International Petroleum Company Ltd., Shell Centre, London, S.E.1
Dist: Shell International Petroleum Co. Ltd.

The film shows the manufacturing of ball and roller bearings and discusses the various lubricants devised for different tasks and different climatic conditions.

OECD No. 2503/7122

448. GRINDING SINGLE POINT CARBIDE TOOLS
16 mm sd bw—25 min.
Origin: USA, 1945
Sp: United States Office of Education, Washington 25, D.C.
Dist: United World Films, Inc., 1445, Park Avenue, New York 29, N.Y.

Pictures a cutting tool in operation. Narrator describes how the cutting edges must be sharpened to do a specific job. Compares the cutting of sharp and dull tools. Pictures how to semi-finish grind a dull tool. Shows how to dress a grinding wheel. Pictures a procedure for finish-grinding a tool. Shows the procedure for sharening a badly chipped tool. Shows rough grinding, semi-finish grinding and finish grinding. Pictures the process for sharpening a tool for cutting steel. Shows the finish grind of the tool.

OECD No. 10103/FOA 585

449. GRINDING WHEEL SAFETY
16 mm sd bw—21 min.
Origin: USA, 1945
Sp: Norton Company, Worcester 6, Massachusetts
Dist: Norton Company

The film illustrates the common causes of grinding wheel breakage and the use of proper guarding.

OECD No. FOA/1432

450. GROUP TRAINING
16 mm sd bw—23 min.
Origin: United Kingdom 1966
Prod: World Wide Pictures Ltd., 34 Cursitor Street, London E.C. 4
Sp: British Productivity Council, Queen Street Place, London E.C. 4
Dist: British Productivity Council

The film illustrates the advantages of small and medium sized companies pooling their resources to provide better and more comprehensive training for apprentices. Besides explaining the principles of group training, it also provides information about how schemes are organised, administered and financed.

OECD 6o. 3027/8029.

451. HAND-SOLDERED JOINTS IN ELECTRONICS
1 reel—8 mins.
Mullard, 1967
Colour

A training film which shows by close-ups and in slowmotion how to make good soldered joints and how to avoid making bad ones. Tag and wire examples are used throughout, but the techniques shown apply as well to other types of electrical joint. For apprentices, operatives and supervisors.

UK 1863

452. THE HIDDEN POWER
(also in German, Danish, Norwegian, Swedish and Dutch)
16 mm sd bw—20 min.
Origin: United Kingdom, 1960
Prod: Derek Stewart Productions Ltd., 6 Westbourne Mews, London, W. 11
Sp: The British Petroleum Company Ltd., Britannic House, Finsbury Cirous, London E.C. 2
Dist: The British Petroleum Company Ltd.

In almost any mechanical transmission system, efficiency and power are lost due to friction. Friction is overcome by lubrication. A thin layer of oil takes a great part of the loan in many machines. Oils must be designed for specific jobs. Testing of the breakdown point of oil film Extreme pressure oils. Oxidisation of turbine oils. Special qualities of hydraulic oils. Heat transfer in cutting oils. Special non-splash oils. Test-loading of grease. Emphasis on friction as a source of waste.

OECD No. 2726/7527

453. HIGH-FREQUENCY SOLDERING
(Accessory Assembly—Tools and Procedures)
16 mm sd bw—17 min.
Origin: USA, 1944
Sp: United States Office of Education, Washington 25 D.C.
Dist: United States Office of Education.

This film explains the function of a high frequency circuit and shows how to adjust the converter and how to prepare the work pieces.

OECD No. FOA/663

454. IF ROPES COULD TALK
16 mm sd col—21 min.
Origin: United Kingdom, 1960
Prod: Verity Film Ltd., Build House, Upper St. Martin's Lane, London W.C. 2
Sp: British Ropes Ltd., Carr Hill, Doncaster, York.
Dist: British Ropes Ltd.

Sequences on rope production, selection of the correct type for the job, handling, storage and faults in use, together with hints on how to avoid trouble through correct maintenance.

OECD No. 2898/7814

455. INDUSTRIAL METAL SPRAYING
2 reels Free 20 mins
Metallisation
Turners, 1965
Colour

The process of metal spraying by the electric-arc pistol, and its applications in modern industry. After illustrating conventional uses for anti-corrosive and heat-resistant coatings, and for the reclamation of worn parts, the film shows modern developments in the hardfacing of slideways and rolls, and the manufacture of moulds, electrical and electronic devices. For engineers, operatives and students.

UK 2274

456. THE INSIDE OF ARC WELDING—1. FUNDAMENTALS
16 mm sd col—8 min.
Origin: USA, 1942
Sp: General Electric Company, Visual Education Division, Schenectady 5, N.Y.
Dist: General Electric Company.

This film describes the four fundamentals of arc welding as: the correct current setting, the correct angle of the electrode, the correct length of the arc, and the correct speed of travel. It emphasizes the importance of wearing proper clothing, using adequate face protection, and special protection for the eyes. How to strike the arc is demonstrated. How to recognise correct welding is explained. Points out that a sharp frying sound will accompany proper operation. The appearance of the weld should be a uniform smooth bead with ripples, but no under or over cuts. Results of the wrong current setting, the wrong angle of the electrode, the wrong length of arc, and the wrong speed of travel are explained and corrections demonstrated.

OECD No. FOA/527

457. THE INSIDE OF ARC WELDING—2. FLAT POSITION
16 mm sd col—8 min.
Origin: USA, 1942

Sp: General Electric Company, Visual Education Division, Schenectady 5, N.Y.
Dist: General Electric Company.

This film explains how to maintain the correct setting of current, the correct angle of the electrode, the correct length of the arc, and the correct speed of travel in welding materials in the flat position. How to make welds of the proper size and shape are clearly illustrated. How to fillet a weld and how to groove a weld are demonstrated. Changes in angle of electrode to control arc blow are illustrated. Dangers of using too short an arc pictured. Results of uneven speed of travel, too slow and too fast travel are shown. Close-up shots show a correct weld, which has good fusion and is uniformly flat throughout the face.

OECD No. FOA/528

458. THE INSIDE OF ARC WELDING—3. HORIZONTAL POSITION
16 mm sd col—9 min.
Origin: USA, 1942
Sp: General Electric Company, Visual Education Division, Schenectady 5, N.Y.
Dist: General Electric Company.

This film explains how to maintain the correct setting of current, the correct angle of the electrode, the correct length of the arc, and the correct speed of travel in welding materials in the horizontal position. The importance of maintaining the control of the molten pool is based on these four things. The film explains results if the current setting is too low or too high. How to control the angle of the electrode is demonstrated in order to control the arc blow. The film explains results if the arc is too long or too short. The importance of the speed of travel in welding is demonstrated. Close-ups of both groove welds and fillet welds are shown and explained.

OECD No. FOA/530

459. THE INSIDE OF ARC WELDING—4. USE OF ALTERNATING CURRENT
16 mm sd col—10 min
Origin: USA, 1942
Sp: General Electric Company, Visual Education Division, Schenectady 5, N.Y.
Dist: General Electric Company.

The advantages of using alternating current in arc welding are shown and explained in this film. Welding in the flat position and in the horizontal position are demonstrated. Examples of correct welds are shown and described. It is explained that the four basic principles of welding are as essential in alternating current welding as they are in direct current welding. Results of the wrong way of applying each of these four basic principles are shown and described and corrections suggested. The main advantages of using alternating current are enumerated. The fact that larger elecrodes can be used is explained.

OECD No. FOA/531

460. THE INSIDE OF ARC WELDING—5. VERTICAL POSITION
16 mm sd col—10 min.
Origin: USA, 1942
Sp: General Electric Company, Visual Education Division, Schenectady 5, N.Y.
Dist: General Electric Company

This film shows arc welding being done in the vertical position. Demonstrations are given in welding of both grooves and fillets. The limits of the angles of grooves are given. The size of electrodes to be used in fillet welds are explained, their size being determined by the thickness of the plate to be welded and the current setting. The results of changing the angle of the electrode are demonstrated. The results of using too short or too long an arc are shown. The results of using too high and too low current settings are explained. The results of travelling too slow or too fast are illustrated.

OECD No. FOA/532

461. THE INSIDE OF ARC WELDING—6. OVERHEAD POSITION
16 mm sd col—12 min.
Origin: USA, 1942
Sp: General Electric Company, Visual Education Division, Schenectady 5, N.Y.
Dist: General Electric Company

This film shows how to do arc welding overhead and demonstrates both fillet and groove welding. It is explained that the limits are wider in overhead welding than any other kind. Apart from the inconvenience, overhead welding is basically the same as any other kind. Successful control of the molten pool depends on the four basic principles of welding. Animation is used to show the build-up on the overhead plate and the downward plate. Good appearance characteristics are enumerated and shown. Results of improper use of each of the four basic principles are shown and explained.

OECD No. FOA/533

462. THE INSIDE STORY
(Fundamentals Behind Correct Lubrication)
16 mm sd bw—42 min.
Origin: USA, 1937

Sp: Socony-Vacuum, Film Library, 26, Broadway, New York, N.Y. 1004
Dist: Socony Vacuum.

This film illustrates the various lubricating requirements of operating parts and shows how this lubrication is accomplished.
OECD No. FOA 712

463. HOW TO WELD ALUMINIUM—ARC WELDING
16 mm sd bw—10 min.
Origin: USA, 1947
Sp: Aluminium Company of America, Motion Picture Department, 818, Alcoa Building, Pittsburgh 19, Pennsylvania
Dist: Aluminium Company of America.

Pictures welding process with best use of arc and the removal of flux slag. Explains welding of butt joints, lap welding, vertical welds. Describes pre-heating, use of filler rods, and removal of flux from finished, products. Pictures mechanized welding, and atomic hydrogan welding. Illustrates the uses of arc welding in industry.
OECD No. FOA/153

464. HOW TO WELD ALUMINIUM—TORCH WELDING
16 mm sd bw—17 min.
Origin: USA, 1947
Sp: Aluminium Company of America, Motion Picture Department, 818, Alcoa Building. Pittsburgh 19, Pennsylvania
Dist: Aluminum Company of America.

Illustrates equipment needed for torch welding such as hydrogen and oxygen torches, preparation of flux and application to the welding rods. Pictures tacking of sheet aluminium. Describes the tacking and welding of flanges and the uses of flange welding. Explains butt welding. Shows fill-up welding on both the horizontal van vertical planes. Pictures heavy welding. Describes the use of test plates and explains the various types of failures in welds. Shows the removal of flux by boiling water, acid rinse, and water rinse.
OECD No. FOA/5029

465. HOW TO WELD ALUMINIUM—RESISTANCE WELDING
16 mm sd bw—12 min.
Origin: USA, 1947
Sp: Aluminium Company of America, Motion Picture Department, 818, Alcoa Building, Pittsburgh 19, Pennsylvania
Dist: Aluminium Company of America.

Demonstrates by animated drawing the alternating current welding machine, stored energy machine, and the condenser type storage machine. Explains cleaning materials and chemical etching of part. Describes selection of electrodes, installation of electrodes in machine, table of machine settings, current settings, weld of electrodes in machine, table of machine settings, current settings, weld settings, and adjustment of pressures. Pictures test welds and weld defects. Describes cleaning of electrodes, the materials used, and the testing of complete welds. Portrays hints on better weld. Describes the process of seam welding.
OECD No. FOA/102

466. A LESSON IN FINISHING
(La Lecon d'Ajustage)
16 mm. sd bw—34 min.
Origin: France, 1959
Prod: Office de Documentation par le Film, 31, rue du General Delestraint, Paris 16e
Sp: Le Bureau de l'Enseignement de la Direction des Etudes et Fabrications d'Armement/Le Centre d'Entrainement du Personnel l'Enseignant de l'Armement
Dist : Office de Documentation par le Film.

During a course for finishers, the Instructor explains and demonstrates taping in detail. The film shows the gestures of the Instructor and shows the importance of careful preparation for a course and of accurate and orderly presentation.
OECD No. 2402/6885

467. LUBRICATING GREASES
16 mm sd bw—31 min.
Origin: United Kingdom, 1955
Prod: Technical and Scientific Film Ltd., 53, New Oxford Street, London W.C.I.
Sp: Mobil Oil Company Ltd., Caxton House, Tothill Street, Westminster, London. S.W.1.
Dist: Mobil Oil Company in respective countries.

This film illustrates the importance of lubricating greases in modern industry. It stresses the necessity for correct manufacture under carefully controlled conditions, demonstrates the advantages of using the correct grease and explains how it should be selected.
OECD No. 1853/6615

468. LUBRICATION AIN'T NO PROBLEM
16 mm sd bw—10 min.
Origin: USA, 1961
Prod: Westinghouse Electric Corporation, No. 3, Gateway Centre, Pittsburg 30, Pa
Sp: Westinghouse Electric Corporation
Dist: Westinghouse Electric Corporation

The lubrication of motors is quite simple, or so Joe—the lubrication maintenance man—

thinks. Following him on his rounds gives food for thought. The good advice which follows is well worth taking.
OECD No. 11221/7714

469. LUBRICATION IN INDUSTRY
16 mm sd bw and col—20 min.
Origin: United Kingdom, 1958
Prod: Shell International Petroleum Co., Ltd., Shell Centre, London, SE1.
Sp: Shell International Petroleum Co., Ltd.,
Dist: Shell International Petroleum Company Ltd.

This film shows installation, flushing and testing of lubrication system in various industrial plants (steel mills, power stations etc.). It stresses the necessity of establishing a detailed lubrication survey according to plant layout and machinery used. Modernisation and expansion of industry means that lubrication has to cope with heavier loads, higher speeds, higher temperatures. The work of the specialists to create the required lubricants is illustrated.
OECD No. 2499/7118

470. LUBRICATION
(Lubrificazione)
(also in French)
16 mm sd col—15 min.
Origin: Italy 1958
Prod: Cinefiat, Turin
Sp: Oliofiat, Turin
Dist: Cinefiat, Turin.

Nobody, in industrial circles, denies the importance of lubrication.. Animation shows loading of tankers and refining. Surface tension. Microscopic examination of a drop of oil. Alteration tests. Device for determining behaviour of grease under conditions similar to those in motor-car wheels. Examination of pistons after use. Oils of different composition.
OECD No. 2224/6487

471. MAINTENANCE IN THERMAL GENERATING STATIONS
(L'Entretien dans les Centrales Thermiques)
16 mm sd col—22 min.
Origin: France, 1958
Prod: Bureau des Temps Elementaires, Service Cinematographique du BTE, 27 rue Bassano, Paris 8e
Sp: Electricite de France
Dist: Electricite de France

Electric power consumption will double in the next ten years. The role of thermic generators, the block principle, and the importance of constant maintenance, the methods office and its staff, preventive maintenance, types of periodic inspections overhaul.
OECD No. 2274/6620

472. MAINTENANCE OF TRACTOR MOTOR
(Wartung des Schleppermotors)
16 mm sd bw—20 min.
Origin: Fed. Rep. of Germany, 1959
Prod: RCF—Film Gmbh, Karlsboderstrasse 16, Berlin Grunewald
Sp: Institut fur Film und Bild in Wissenschaft und Unterrricht Museuminsel 1, Munchen 26
Dist: Institut fir Film Bild in Wissenschaft and Unterricht.

In the opening scenes the film shows various types of tractors at work on the road and in the fields. It then continues to demonstrate the principal maintenance work necessaryt or assure the smooth running of the tractor motor. Function and maintenance of the following parts are explained; Tank, filter, fuel filter, injection pump, jet, greasing system oil change, air and water cooling. The importance of valve control is underlined and the film closes by illustrating valve adjustment on a four-stroke diesel engine.
OECD No. 2634/7359

473. MAINTENANCE PAINTING, AN ENGINEERING APPROACH TO LOWER COSTS
16 mm sd col—25 min.
Origin: USA, 1960
Prod: Farrell and Gorge Films Inc., 213 East 38th St., New York NY, 10016
Sp: Hercules Powder Co., 910 Market Street, Wilmington 99, Delaware
Dist: Farrell and Gorge Films Inc.

Protective painting in industry is not given the attention it deserves. Some alternatives to regular maintenance painting are described and their higher costs indicated. The reasons why paint fails, the growth of corrosion, how the design engineer can help overcome corrosion, the best types of paint, field testing, surface prepartion. The importance of inspection and good records of maintenance painting. A new type of protective undercoat is described.
OECD No. 11165/7577

474. MEN WORKING
16 mm sd col—35 min.
Origin: USA, 1945
Sp: Pennsylvania Highway Department, Harrisburg, Pennsylvania
Dist: Pennsylvania Highway Department.

Compares the maintenance of a home to that of the highways. Shows a new highway and

compares it to a new house. Pictures some bad stretches of highway and explains that it takes men to keep it in shape. Scenes of maintenance: bituminous patching of roadside signs, care given to guard rails and posts, planting of grass and trees in road cuts, bridge repair jobs. Explains how cracks are repaired in bridges by gunning. Shows the steps in skin-patching a highway and methods of concrete patching by sawing out the slab, soft-sealing and mud tamping. Diagrams the resurfacing of a road with black top. Laying of a black to highway, describes and shows how the traffic lines are painted on the highways.

OECD No. 10051 FOA 5140

475. METAL SHOP SAFETY
(Industrial Arts Series)
16 mm sd bw—18 min.
Origin: USA 1959
Prod: Centron Corporation, West, 9th Avalor Rd., Lawrence, Kansas
Sp: McGraw-Hill Book Company Inc., 330 West. 42nd St., New York, N.Y. 10036
Dist: McGraw Hill Book Company Inc.

The film covers the subject of safety in the metal shop from a great variety of angles; safe clothing, proper handling of tools and power machinery, use of goggles and gloves and correct behaviour in the shop in general. Safety procedures for operation of forges, molding, casting, soldering, welding and use of acids.

OECD No. 10912/6975

476. MOBILE CRANES ON WORK SITES—MOBILE TOWER CRANE TRACKS
(Les grues de chantiers—Les vogies des grues a tour mobile)
16 mm sd col—24 min.
Origin: France, 1960
Prod: Je Vois Tout, 10, rue du Chateau, La Garenne-Colombes (Seine)
Sp: Organisme Professionnel de Prevention du Batiment et des Travaux Publics, 2 bis, rue Michelet, Issy-les-Maulineaux (seine)
Dist: Je Vois Tout.

Correct installations of the rails of mobile tower cranes is extremely important if serious accidents are to be avoided. The following points are emphasized: Correct construction of a perfectly level railway. Adequate and effective buffers at the end of rails. Electrically earthing the crane and rails. Correct calculation of loads and strains. Granes should be assembled by experts.

OECD No. 2786/7659

477. MODERN REPAIR SHOP
(ET Moderne Verksted)
16 mm sd bw - 38 min.
Origin: Norway, 1953
Prod: V.N. Productions
SP: Norges Statsbaner, (Norwegian, Railways), Hovedstyret, Presse-og Opplysningskontoret, Storgata 33, Oslo
Dist: Norges Statsbaner.

In 1953, the Norwegian Railways built new repair shops for steam engines. They endeavoured to make them as functional as possible. They aimed at the maximum of safety, and careful planning simplified operations. Dismantling of a locomotive and repair of components in the various shops are shown.

OECD No. 2190/6446

478. THE PERMANENT-WAY MAN
(Monsieur Untel. . . . Cantonnier)
16 mm sd bw - 24 min.
Origin: France, 1954
Prod: Ste Nationale des Chemins de Fer, Section Centrale Cinematographique, 9, Quai de Seine, Saint-Quen (Seine)
Sp: Ste Nationale des Chemins de Fer.
Dist: Ste Nationale des Chemins de Fer.

Films on the handling of permanent-way equipment and fittings. Prevention of accidents and standing instructions for carrying out heavy work.

OECD No. 1195/6915

479. PIPE TOOLS FOR INDUSTRY
3 reels Free 27 mins.
G. and J. Hampton
Cinechrome, 1966
Colour.

A training film on the use of industrial pipe tools. A brief introduction showing manufacture of pipe tools at the sponsor's works is followed by a lecture with demonstrations on the selection, use, care and maintenance of pipe vices, cutters, wrenches and tongs. We then see trainees handling pipe tools under instruction, and the film finally underlines the important part played by pipework in industry. For technical college students and apprentices.

UK 2308

480. PLAN TURNING ON THE METAL-WORKING LATHE
(How to Run a Lathe Series)
16 mm sd col - 22 min.
Origin: USA, 1941
Prod: Burton Holmes Films
Sp: South Bend Lathe Works, South Bend 22, Indiana
Dist: South Bend Lathe Works

Points out that turning between centres allows heavier cuts because of rigidity of materials. Explains and shows the marking of stock ends. Describes the preparation of the centre with a combination drill-center punch or 180 rpm. Shows the setting-up of the lathe and stresses the thorough cleaning of the lathe parts. Shows the lubrication and setting on the fact plate. Describes the setting-up of the head stock lathe and tail stock. Shows the squaring of the shift ends and the grinding and setting of the cutter in the tool holder. Shows the setting of the tool post, compund test and center point. Describes test cuts with caliper checking. Demonstrates scribing and sharpening of the tool.

OECD No. 10096/FOA 5248

481. PLAN YOUR MAINTENANCE
16 mm sd bw - 32 min.
Origin: United Kingdom 1960
Prod: Anvil Films Ltd., Beaconsfield Studios, Beaconsfield, Bucks.
Sp: British Productivity Council, Queen Street Place, London E.C.4.
Dist: British Productivity Council.

The film is built round three candidates for the post of Maintenance Engineer who are being interviewed by the management of a factory which has suffered considerably from mechanical breakdowns. By means of this device several possible approaches to the problem of maintenance are shown.

OECD No. 3029/8031

482. PLAN YOUR MAINTENANCE
3 reels 32 mins.

Planned maintenance as a method of preventing mechanical breakdowns. Three candidates are interviewed for the post of maintenance engineer in a factory which has suffered from frequent breakdowns. In the course of these interviews, several approaches to the problem of maintenance are presented and discussed. Stress is laid on the importance of a planned system and one simple, yet effective system.

UK 1602.

483. PLIERS AND SCREWDRIVERS
16 mm sd bw - 17 min.
Origin: USA, 1943
SP: Plomb Tool Company, Advertising Dept., Box 3519, Terminal Annex, Los Angeles 54, California
Dist: Plomb Tool Comapny.

This films uses a "do" and "don't" approach on the uses of pliers and screwdrivers. A training type film.

OECD No. FOA/5058

484. PREVENTIVE MAINTENANCE—EFFECTIVE LUBRICATION
(Preventief Onderhoud - Doelmatig Smeren)
16 mm sd bw - 20 min.
Origin: Netherlands
Prod: Starfilm N.V.
SP: Contactgroep Opvoering Productiviteit Supervision of Technish Filmcentrum, Stathouderslaam 152, The Hague
Dist: Technisch Filmcentrum, Stadhoudrslaam 152, The Hague

Thorough preventive maintenance is required for plant machinery. One machine, stopped may bring the whole production line to a standstill. Provisional and hasty repairs are not satisfactory. A programme must be set up based on the inventory of the machines, results of tests, frequency of use, role of the various components, and time required for maintenance. The maintenance department must keep the various departments informed of the number of complete or partial overhauls of each machine. Thus a maintenance calendar can be made. A greasing and inspection programme is set up for each machine, reports and maintenance reduces production costs (diagrams)

OECD No. 2240/6549

485. THE PREVENTION AND CONTROL OF DISTORTION IN ARC WELDING
16 mm sd col - 20 min.
Origin: USA, 1958
Prod: Walt Disney Productions, Educational Film Division, Burbank, California.
SP: Lincoln Electric Company, Cleveland, Ohio
Dist: Lincoln Electric Company.

Largely by use of animation, this film demonstrates methods to prevent faulty welding. Three rules are emphasized: (1) Reduce the effective shrinkage force; (2) Make shrinkage work for you; (3) Balance shrinkage forces with other forces. The conclusion: controlled shrinkage prevents distortion.

OECD No. 10860/6874

486. PRINCIPLES OF LUBRICATION
2 reels - 15 mins.
U.S.O.E., 1945

This film shows the basic principles of lubrication in terms of viscosity and the relationship to it of cohesion and adhesion. The

method of determining absolute viscosity and the conditions which must be considered in selecting a proper lubricant viscosity are discussed. A useful training film for students and apprentices, and of interest to all concerned with the maintenance of plant.

V 1089 (UK)

487. PRODUCTIVE MAINTENANCE
16 mm sd col - 25 min.
Origin: USA, 1954
Prod: Welding Picture Productions, 1345, Argyle St., Chicago 40, Ill.
Sp: General Electric Company, Motion Picture Div., Schenectady 5, N.Y.
Dist: General Electric Company.

Tells in story form how one harassed maintenance supervisor learns about productiye maintenance and applies its principles to systematizing his maintenance procedures.

OECD No. 10415/6155

488. RAMROD
(also in French)
16 mm sd col - 13 min.
Origin: United Kingdom, 1959
Prod: The Glacier Metal Co., Ltd., Alperton, Wembley, Middlesex
Sp: The Glacier Metal Co., Ltd.
Dist: The Glacier Metal Company Ltd.

A research film on the lubrication of engine bearings. The danger of a break-up of the oil film (cavitation) is pointed out and the way in which this limits the life and power output of engines. By using a test rig fitted with a transparent bearing, the sponsors have been able to analyze cavitation and to develop a system of high-pressure oil injection which floods the bearing at the critical moment of maximum load.

OECD No. 2564/7237

489. REMOVING DEFECTIVE RIVETS
(Assembling and Riveting)
16 mm ad bw - 14 min.
Origin: USA, 1943
Sp: United States Office of Education, Washington 25, D.C.
Dist: United States Office of Education.

Shows the procedure used in removing defective rivets in aircraft manufacture. It shows in detail the steps necessary for drilling out a defective bucked head and the necessity of removing the head without damaging the parts.

OECD No. FOA/733

490. RESERVICING CARBIDE TOOLS
16 mm sd col - 25 min.
Origin: United Kingdom, 1960
Prod: Wickman Ltd., Banner Lane, Coventry
Sp: Wickman Ltd.
Dist: Wickman Ltd.

In order to understand the correct methods of servicing carbide tools, the composition and manufacture of carbide steel is discussed. The correct procedures for sharpening single point and secondary point tools are clearly demonstrated and the correct use of various types of grinding wheel is also illustrated. Some common faults of sharpening are shown.

OECD No. 2804/7689

491. A SAFE SHOP
(Industrial Arts Series)
16 mm sd bw - 11 min.
Origin: USA, 1965
Prod: Centron Corporation West, 9th Avalon Rd., Lawrence, Kansas
Sp: McGraw-Hill Book Co., Inc. 330 West, 42nd Street, New York, N.Y. 10036
Dist: McGraw-Hill Book Company Inc.

This film illustrates some safety problems and procedures applicable to a small workshop. Among the subjects discussed are: safe clothing; use of goggles, shields and gloves; marking of work areas; clean and orderly shop; checking and storage of gas cylinder and inflammable liquids; good lighting etc.

OECD No. 10924/7065

492. SAVE THOSE TOOLS
16 mm sd bw - 10 min.
Origin: USA, 1944
Sp: Foreign Operations Department, International Harvester Co., 180 N. Michigan Avenue, Chicago 1, Illinois
Dist: International Harvester Company.

Shows a large machine shop, as narrator explains the need for tool salvage and conservation programme. The importance of an educational programme is pointed out as the film reviews briefly procedures to follow, which will eliminate much tool breakage. The salvage programme is reviewed. Depicts briefly the broken tool collection bins and inspections to determine the cause for breakage. Shows the reparing of tools and the central storage dept, which all member plants are free to call on for salvaged parts. The importance of low temperature brazing for repairing tools is stressed.

OECD No. FOA/5023

493. SCRAPING FLAT SURFACES
(Bench Work)
16 mm zd bw - 14 min.
Origin: USA, 1944
SP: United States Office of Education, Washington 25, D.C.
Dist: United States Office of Education.

The narrator explains that machines require flat surfaces for accurate guides and liquid-tight joints; how this flat surface is obtained through machine scraping is illustrated. How to check surfaces with with surface plates is shown; explains how to check surfaces for steadiness, how to clean with alcohol, how to remove burrs, and how to locate high points by use of Prussian blue.

OECD No. FOA/698

494. SERVICE PROCEDURE FOR BALL BEARINGS
16 mm sd bw - 20 min.
Origin: USA, 1950
Sp: General Motors Corporation, General Motors Building, Detroit 2, Michigan
Dist: General Motors Corporation

The film illustrates the fundamental procedures in removing, cleaning, inspecting and reassembling ball bearings. Films emphasizing the need for thorough cleaning and oiling of the ball bearings and raceways. Good close-ups contrast correct with incorrect methods and procedures.

OECD No. FOA/5206

495. SHARPENING CUTTING TOOLS
(Omslipning Av Hardmetallsvarvstal)
16 mm sd col - 10 min.
Origin: Sweden
Prod: A.K.A. Film, Riddorgatan 23 B, Stockholm
Sp: A.K.A. Film
Dist: A.K.A. Film

This is a special educational film known in Sweden as "moment-film", i.e. it is designed so that the instructor can stop the film at a certain frame in each important sequence. The film reviews the various occasions when the blade must be sharpened; broken, cutting edge out of square, insufficiently sharp or doubled. How to control the angle.

OECD No. 2201/6437

496. SHOP SAFETY
16 mm sd bw - 28 min.
Origin: USA, 1958
Prod: United States Army Pictorial Service, Signal Corps, Washington D.C.
Sp: United States Army Pictorial Service, Signal Corps.
Dist : United World Films Inc., 1445 Park Avenue, New York N.Y. 10029

This film treats some aspects of safety in the motor repair shop. The following common faults are carefully depicted: improper blocking of vehicle raised for repair; disregard of fundamental safety rules in welding, drilling and use of machine tools, lack of ventilation and cleanliness; improper lifting, misplaced playful humour, etc.

OECD No. 10971/7071

497. SOFT SOLDERING
2 reels, - 19 mins.
Topical, 1949

An introduction to soft soldering. The reasons for cleaning, heating and applying flux to the surfaces to be joined, and the making of a sweated joint. The use of soldering bits. Capillary action in the fixing of a base ring to a copper ashtray. The making of killed spirits (zinc chloride) and the importance of cleaning after using it. A useful training film for technical college students and apprentices.

UK 1464

498. SOLDERING LUGS AND SPLICING STRANDED CONDUCTORS
2 reels - 17 mins.
U.S. Office of Education, 1945

This film shows how to solder lugs and splice stranded conductors. Animated diagrams show the use of electric soldering tongs and illustrate a method of splicing the cable, and how to solder the splice. Procedure for soldering large lugs, using a solder pot, ladle, and gasoline furnace, is explained. A useful film for technical college students, and for electrical manufacturers, electricity supply authorities, and others, for training purposes.

499. STUDY OF PLANING OPERATIONS
(Theory of Metal Cutting)
16 mm sd bw - 13 min.
Origin: USA., 1945
Sp: General Electric Company
Dist: General Electric Company

This film shows study, with a high speed camera, of planning operations. Diagrams are used to point out and pictures show the chip compression and distortion of steel at eighty feet per minute and at one hundred and sixty feet per minute.

OECD No. FOA/823