INSPECTION AND QUALITY CONTROL

A MANAGEMENT GUIDE

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npc

national productivity council

ABOUT NPC

The National Productivity Council, established in 1958, is an autonomous organisation registered as a society. It is tripartite in its constitution and representatives of Government, employers and workers and various professional bodies participate in its working. Besides its headquarters at New Delhi, NPC operates through eight Regional Directorates. Its activities are further extended by a nation-wide network of 49 Local Productivity Councils.

The objective of NPC is to stimulate productivity consciousness in the country and to provide productivity services with a view to maximising the utilisation of available resources of men, machines, materials and power; to wage war against waste; and to help secure for the people of the country a better and higher standard of living. To this end, NPC collects and disseminates information about the concepts and techniques of productivity through various publications including periodicals and audiovisual media of films, radio and exhibitions. It organises and conducts seminars and training programmes for various levels of management in the subjects of productivity.

With a view to demonstrating the validity and value in application of productivity techniques, NPC offers a Productivity Survey and Implementation Service (PSIS), for which the demand has been steadily and steeply rising. This service is intended to assist industry adopt techniques of better management and operational efficiency, consistent with the economic and social aspirations of the nation.

NPC has established various other specialised services, such as, Fuel Efficiency, Plant Engineering and Production Engineering Services; Productivity Services for public sector undertakings, public utilities, public administration, post-harvest operations in agriculture and small industries; Applied Productivity Research for evolving trends and indices of productivity in the core-sector of economy; National Scheme of Supervisory Development, under which an examination is held and National Certificates in Supervision are awarded to the successful candidates; and Productivity Programmes for Trade Union Officials and Workers. NPC also conducts institutional training programmes for the development of consultants in productivity and management in the areas of Industrial Engineering, Fuel Efficiency, Plant Engineering, Behavioural Sciences, Financial Management, and Marketing Management.

MANAGEMENT GUIDE

INSPECTION AND QUALITY CONTROL

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Introductory Note

Practically the world over, there has been increasing recognition that the development of supervisory skills can significantly contribute to the improvement of productivity of an enterprise. From its inception in 1958, the National Productivity Council has laid stress on supervisory development programmes, but since it needed a more concerted drive, it introduced during the Asian Productivity Year 1970 a nationwide scheme to prepare candidates through self-study and classroom or enterprise-level guidance for a professional qualifying examination leading to the award of National Certificate in Supervision.

The response to the NPC scheme has been quite good. Management of all forward-looking enterprises have evinced considerable interest, and over five thousand candidates in all have appeared for the examination during the last five years. In implementing the NPC's Supervisory Development Scheme, some of the local Productivity Councils have extended their co-operation and support. The success of any self-study scheme ultimately depends on making available adequate study material prepared by competent experts, and written in a lucid and simple style. NPC has brought out as many as 27 Management Guides so far which attempt to give a basic understanding of the various topics included in the syllabus.

This Guide on Inspection and Quality Control has been prepared by Shri M. V. V. Raman Director, Industrial Engineering, NPC, New Delhi.

These Guides are also designed to be of help to managerial personnel as well as students of Management who wish to have some basic understanding of the science and practice of management.

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INSPECTION AND QUALITY CONTROL

1. Introduction

1.1 Quality is an essential requirement of any product. Modern quality control is an integrated approach to the quality function in an organisation with the basic objective of providing a definite quality assurance and keeping the quality costs at an optimum; the integration has to take place in the fields of design, manufacture and use.

1.2 One of the basic principles of a quality control programme is the principle of prevention of defects or building quality as the manufacturing continues. Though quality control personnel assist in the discharge of this function, the responsibility for building quality rests with the production personnel. Thus supervisory personnel have a major responsibility towards quality; the quality control group assists them in the maintenance of quality and its improvement.

1.3 In exercising the function of quality control, inspection and testing play a fundamental role. They provide a basis for quality evaluation in various stages of manufacture including acceptance of raw materials and other bought out items; through this evaluation adequate control procedures could be designed so that the specified 'quality' is built into product and placed in the hands of the consumer.

2. Measurement

2.1 The development of science and technology have been successful in providing consumers with better and consistent quality products. However, it should be emphasised that this development would not have been possible without development of better methods of measurement, and laying down product specifications. The progress in the science of measurement has always played a fundamental part in the practical applications of many researches in the field of science and technology. This has found clear emphasis in the statement by Lord Kelvin, "that when you can measure what you are speaking about, and express it in numbers, you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be".

2.2 Specifications are clear statements of requirements. The need and use of specifications in every day life is fairly obvious. Without specifications, we cannot buy and sell, we cannot express what we want; the work in offices, banks, factories would probably come to a standstill without them. The need for the specifications in modern industry can be appreciated readily by realising the fact that materials may have to be purchased from difficult sources, fabricated by different groups of people at different places and assembled into a finished product; obviously without specifications desired results cannot be achieved. The blue prints, operation sheets, purchase requirements, packaging instructions, organisation charts, and the like used in factories are all examples of specifications.

2.3 The clearest way of writing down specifications is expressing through numerical values; when this is done a universal understanding is created. Here comes the importance of measurements. If we cannot measure, we cannot specify numerically. When we cannot specify, we cannot reproduce it also. It is also to be appreciated that when we can measure, specify and produce it, the use of it and experience will help in the development of new products, processes and procedures; this again requires refinement in measurement and accuracy and further leads to better specifications and manufacture which in turn leads to new and better products; this contributes to higher standards of living.

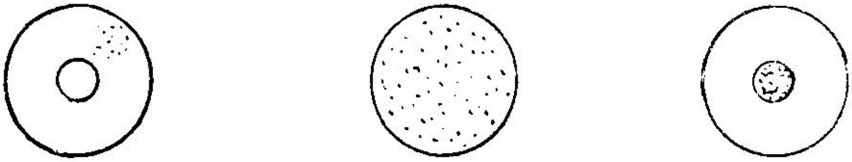
2.4 The development of science of measurement, whether it relates to physical, chemical, electrical or other characteristics, makes a fascinating study which brings to the fore that until measurement and refinement in measurement to greater accuracies were done, the progress in engineering and technology was very slow.

2.5 The numerical value of any quality characteristic—hardness, tensile strength, wattage, weight etc., is determined with the aid of a necessary device. It should be emphasised that no measuring process can translate the exact numerical value of the quality characteristic. Thus, the recorded values actually represent errors in measurement and variation of product quality The errors in measurement are not only produced by the measuring instrument alone but also by the person using the instrument and environmental conditions. The errors in measurement assume great importance in some industries (e.g. chemical) and also in situations where the specifications are tight.

2.5.1 The accuracy of measurement refers how closely it represents the true value. It may be said that usually it is impossible to know the true value.

2.5.2 Measurements taken by the same instrument on a single piece several times will not yield same numerical values. The numerical measure of the variation of these readings, given by the standard deviation, is called the precision of the measurement.

2.5.3 It should be noted that the measurements may show any of the following situations:



PRECISE, BUT NOT ACCURATE

ACCURATE, BUT NOT PRECISE

ACCURATE AND PRECISE

FIGURE-1

2.5.4 There are many situations in industry where direct measurements are not possible and the results of inspection are subjective. Examples would be polishing, plating of metal, painting, counting defects, etc. Here also the reliability of observations have to be assessed.

2.5.5 Thus, while standardizing inspection procedures in any plant the reliability of measurements have to be taken into consideration. This analysis also brings to light how it is essential to keep check on testing equipments and the ability of inspectors in using them. Also, the moment an instrument is put to use it begins to deteriorate in accuracy. Hence, a regular programme of checking and calibrating the instruments is a very important function. These will be discussed later

3. Some Basic Ideas

3.1 The modern industrial inspection arose as a result of mass production. The product now produced in industries is the result of various processes, each independent by itself, of parts and components produced at different work centres and assembled together; this is particularly true of engineering industries. Thus arises the need for dimensional inspection and control. Some basic ideas with regard to dimensional inspection will be discussed in the succeeding paragraphs.

3.2 The dimensional control, though essential, should not be interpreted to mean inspecting parts and components to 'exact' dimensions. In practice this would be uneconomical and may not be required for performing the required function; dimensional control means inspecting parts for conformance within specified limits set by the design. Thus, in engineering drawings the specification gives the basic dimension, that is the theoretically perfect dimension and the permissible variation around it; this is the function of the designer and depends on the functional requirement of the part, or component. This is a recognition of the fact that in mass production it would be impossible (in the sense uneconomical) to produce each item to exact dimension, due to various factors; machines, men, materials, environment etc.

3.2.1 The extent of variation intentionally permitted is called tolerance. Thus dimensions are expressed as $2.000'' \pm 0.001''$. This means that as long as the parts are within 2·001" and 1.999" it is satisfactory. In this example, the tolerance spread is on both sides of the basic dimension and is called as a bilateral tolerance. Sometimes the tolerances are specified as $2.000''^{+0.001''}_{-0.000''}$ particularly for mating parts. Here the tolerance spread is only on one side and is referred to as unilateral tolerance. The maximum and minimum dimensions as permitted by the tolerances are called limits. Specification of tolerances is an important aspect as cost aspects are involved; very close tolerances may require skilled workers, precise machines, and high grade materials.

3.3 The interchangeable manufacture requires that it is necessary to specify the type of fit or clearance on component parts.

3.3.1 Clearance is the difference in size between the mating parts, where the critical dimension of the male part is smaller than the corresponding internal dimension of the female part. The degree of clearance is determined by the functional requirements. Allowance is the term used to specify the minimum clearance between mated parts.

3.3.2 When the male member is made intentionally larger than the female, so as to make a relatively permanent assembly, the difference is called interference. Allowance (negative) then refers to the maximum permissible interference between mated parts.

3.3.3 Thus "allowance means the intentional difference (minimum clearance or maximum interference) between mated parts to attain a specific class of fit."

3.4 When interference exists and parts have to be assembled by force, it may not be possible to rely on interchangeable methods of assembly. In these cases 'Selective Assembly' is resorted to, so as to provide a predetermined fit. Selective assembly also has to be resorted when an assembly consists of large number of parts. This type of assembly is also referred to as zoning assembly.

3.5 Experience with assembling of shafts into holes and the types of fits (loose, free, push press etc.) and tolerance needed has now been consolidated into a standard developed by the International Federation of the National Standardization Associations (ISA) published in 1942. It comprises*:

(i) A system of 20 classes of fits ranging from loose clearance to extreme interference

(ii) A system of tolerance related to the variable of diameter in accordance with the formula (expressed in microns—0.001 mm):

$$\text{Tolerance} = 0.52\sqrt[3]{D} + 0.001\,D$$

where D = diameter. The tolerances are divided into 16 grades of graduated precision.

(iii) A system of gauges comprising working, acceptance and reference gauges.

(iv) A system of terminology and symbols.

4. Inspection Function

4.1 In industry items or products are manufactured to meet specific requirements. In simple terms, inspection might be called the function of comparing or determining the conformance of the product to specifications. Of course, this function is not merely confined to the finished product, but extends to the various stages and processes in the entire manufacture, including raw materials and purchased components.

4.2 The scope, vastness and varieties of inspection aspects can be visualised by studying the inspection procedures and practices involved in several types of industries, e.g. engineering, foundry, chemical, textiles, pharmaceuticals, etc.

4.3 Inspection function in industry has a vital role to play in seeing that the established quality requirements are put in the product, as vital as other functions like design, manufacture, purchasing, etc. In fact, the function

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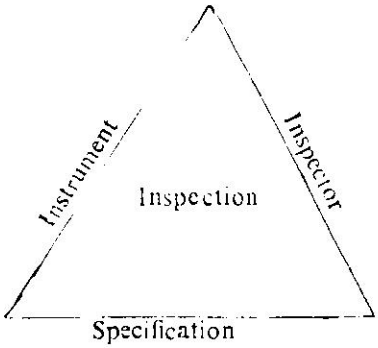
* J.M. Juran, Quality Control handbook, 3-24.

of inspection is to see that the requirements as specified by the design department are actually met by the production department. Its main function, thus, is to interpret the design requirements and stand in judgment between design and production. It may also be said that the inspection department in a factory represents the customer.

4.4 A detailed study of inspection function includes a variety of aspects pertaining to inspection which may be visualised as under:--

Fig. 2



Other aspects:

- Planning
- Procedures
- Training
- Calibration
- Records
- Standardization

4.5 The need for inspection in a modern set-up is fairly obvious. The most compelling reason is the requirement of interchangeability in mass production. Without inspection it would be difficult to see things are assembled together. The materials, parts, accessories may have to be purchased from various sources which necessitates that the purchased items are as per requirements. Another reason is that inspection of the final product is not sufficient and therefore inspection in several stages is necessary before the final product is acceptable. Another important reason for inspection and measurement is for improvement of products, processes.

4.6 Inspection has come to be classified in terms that are descriptive of the sort of work performed or the location of the inspection in the process or shop; according to the general sort of labour involved, we have: Manual inspection, Visual inspection, Test inspection, Automatic inspection; description of the area in which inspection is carried out; Process inspection, Final inspection, Receiving inpection, Tool and gauge inspection. They may be broken down into other operations, such as: Patrol inspection, First piece inspection, Sampling inspection, 100% inspection.

4.7 Basically, the duties of inspector are as under:

- (i) interpretation of the specification
- (ii) measurement of the product
- (iii) comparison with the standard
- (iv) judging for conformity
- (v) disposition of the product
- (vi) recording the data.

4.7.1 Inspection personnel are also classified under variety of names depending upon the work carried out. In some cases the knowledge required is simple, but there are situations where highly competent and specialised knowledge is required.

ıspection Planning

5.1 Inspection planning is an essential aspect in the inspection function; it should be appreciated though inspection is absolutely essential, it does not add to the value of the product. Too much inspection or too little inspection is harmful, in the sense one adds to the cost and the other may not provide requisite quality assurance.

5.2. Inspection planning consists of five elements:

- (i) What to inspect: determining important characteristics to achieve desired quality economically.
- (ii) How to inspect: right equipment, clear definitions, trained inspectors; use of too much precision when not required, lack of precision when it is necessary; wrong procedures, etc., are costly in the long run.
- (iii) When to inspect:
  - (a) whether setting can change and this affects quality e.g. tool wear;
  - (b) whether subsequent failure may result in costly rework/rejections;
  - (c) whether areas are not available for inspection after the assembly is completed e.g. a rivetted structure;
  - (d) whether quality of work depends on the skill and experience of the operative e.g. pressing a bearing in a housing,
  - (e) whether defective part can be isolated during subsequent inspection/check, e.g. a defective valve in radio.

(iv) Where to inspect : that is the areas which should be covered by inspection :

- (a) Incoming materials
- (b) Manufacture
- (c) Tools
- (d) Assembly
- (e) Functional tests
- (f) Final inspection
- (g) Shelf tests
- (h) Environmental tests

(v) How much to inspect: This is an important question; minimum inspection should be done consistent with requirements.

6. Inspection Techniques

6.1 The techniques of inspection vary according to the situation and type of indtistry, that is the nature of the product. A broad scheme will be discussed which will apply generally in industry. There are three stages in the progress of material through works. They are:

- (i) Incoming or receiving inspection
- (ii) Inprocess inspection, and
- (iii) Final inspection and testing

6.2 Incoming inspection is essential in order to determine whether purchased materials satisfy the stipulated requirements. Proper incoming inspection will prevent waste of time and money in production by identifying non-conforming items at the receiving stage itself.

6 2.1. In the incoming inspection the problem is of acceptance of materials already produced. Supplier will have done inspection before delivering. Sampling inspection may be resorted in majority of the situations. The acceptance of right quality material does not entirely lie in inspection alone, but also depends on suppliers ability and good vendor-vendee relations. These may be achieved through the development, specifications, inspection and mutual discussions for solving problems between vendor and vendee.

6.3 Inspection in the various stages of manufacture is an important function. Each time an operation is added, the cost of the item goes up and therefore the stage inspection has the responsibility of seeing that operations are added only to those items which are acceptable functionally. Here inspection is not merely for acceptance purposes but also guide and correct as manufacturing is continuing and produce items that meet the stipulated specifications, production and inspection are closely located and immediate action is possible.

6.3.1 In engineering industry it is a common practice to check the first piece carefully, called first-off inspection or first piece inspection, before production is allowed to continue. It is good to follow this practice as otherwise the whole lot produced may be liable to rejection. The information provided by first piece inspection, helps the setup man and the operator to rectify and correct the process.

6.3.2 The first piece inspection helps in starting the production run smoothly. It would then be necessary to see that the job continues to produce items according to specifications. Many factories employ patrol inspection technique for this purpose. The interval of visits may vary according to the nature of operation. It may be mentioned that operative themselves check the pieces and petrol inspection may be thought of as additional check, but of course by a qualified inspector who is a specialist in measurement and interpretation of drawings.

6.3.3 If the in-process inspection is organised properly it would be possible to keep the rejections and rework at a low level and in many cases may make corrections to process even before any rejections are produced, particularly in the case of dimensional control.

6.4 The final inspection is the inspection of the finished product before it is despatched to the customer. The inspection is for the purpose of "acceptance", but the knowledge of how it is built is available as contrasted to the incoming inspection. Here the product is examined for both its appearance and performance keeping customer in view.

6.4.1 There are various practices with regard to final inspection. They may be complete inspection, or sampling inspection. In some companies sampling inspection as a form of quality audit is followed after complete inspection.

6.5 By 'quality' in industry is meant, any characteristic measurable or not either of raw materials, or component parts, or assemblies or finished products. In order that we may produce finished products of standard, quality and maintain uniform quality, it is essential to have check on incoming materials, processes at the various stages of manufacture and on the finished products. This is the function of inspection in industry which checks the quality against specifications; thus, there will be inspection of incoming materials, inspection at several stages in the manufacture and final inspection of finished products either by consumer or producer or both. Generally, the inspection adopted in industry is visual, by measurement, by gauging or sensory.

6.5.1 Quality characteristics observed in industry can be classified generally into any one of the following categories:

(i) Directly measurable quality characteristics: examples would be wattage, shear strength, thickness, specific gravity, etc.

(ii) Non-measurable quality characteristics: examples would be rejections due to cracks, dents, flaws, breakages, etc., and generally inspection results obtained by classifying the product as good or defective. A defective item may contain one or more defects.

(iii) Inspection results obtained by counting defects: examples would be surface defects, coil winding break, packing defects, assembly defects etc.

(iv) Sensory qualities: Inspection results obtained by human beings through the senses without the aid of any equipment or other facilities examples would be: odour, taste, appearance etc.

7. Tools of Inspection

7.1 It has already been mentioned that inspection is "the function of comparing or determining the conformance of product to specifications". From this it is obvious that specifications are tools of inspection; others are: inspection equipment, calibration of equipment, inspection records and sampling inspection.

7.1.1 In industry it is an accepted practice to write detailed specifications for items (component, assembly, finished item, or raw material) which it manufactures or purchases from outside sources. This practice greatly helps in the understanding and manufacture of the items. It is necessary to evolve a method of maintaining these specifications, keep them current and available when needed. If the specifications and drawings are not up-to-date, or contain wrong specifications or not clear in terms of dimensions, tolerances costly errors may be committed.

7.1.2 In engineering industry the most common form of specification is the blueprint. The part or product is described in great detail. It actually conveys how a point or product should be made, including material.

7.1.3 In the modern set-up of manufacturing detailed specifications are very important as many groups of people are involved in manufacture, including outside sources. Though blueprints are available in many situations they may have to be amplified by explanations. In non-engineering industry mostly specifications are elaborately written documents. Generally the specifications are of three types: purchase (or incoming material) specification, process specification and product specification.

7.1.4 Incoming material refers to the components, parts or items that enter into manufacture or assemblies, which are purchased from outside sources. Therefore, they must conform to the specification requirements in order that the finished products are to be satisfactory. In addition, incoming materials may also include items that may not directly enter into manufacturing or assemblies. Examples would be, uniform for employees, soap, sand papers, packing materials etc. Even these items have to meet specified requirements.

7.1.4.1 A good incoming material specification should include sufficient information so as to make it clear to the supplier as to what is required. Some of the essential information are, apart from identification, details of the specifications, lot identifications, sampling details, detailed requirements including physical, electrical, chemical and other properties with tolerances, packaging details, methods of test, and sampling plans to be applied and other requirements.

7.1.5 A process may be visualised to include men, machine, materials, inspection equipment and procedures, environmental conditions both for production and inspection, tools, dies, jigs and fixtures, speeds, settings, temperature pressure, etc. as in figure 3 on page 11(a). This brings out clearly the requirements for drafting process specifications.

7.1.5.1 The engineering drawings provide the necessary details with regard to process specifications. However, detailed requirements have to be written down in many industries, e.g. chemical industries. The object

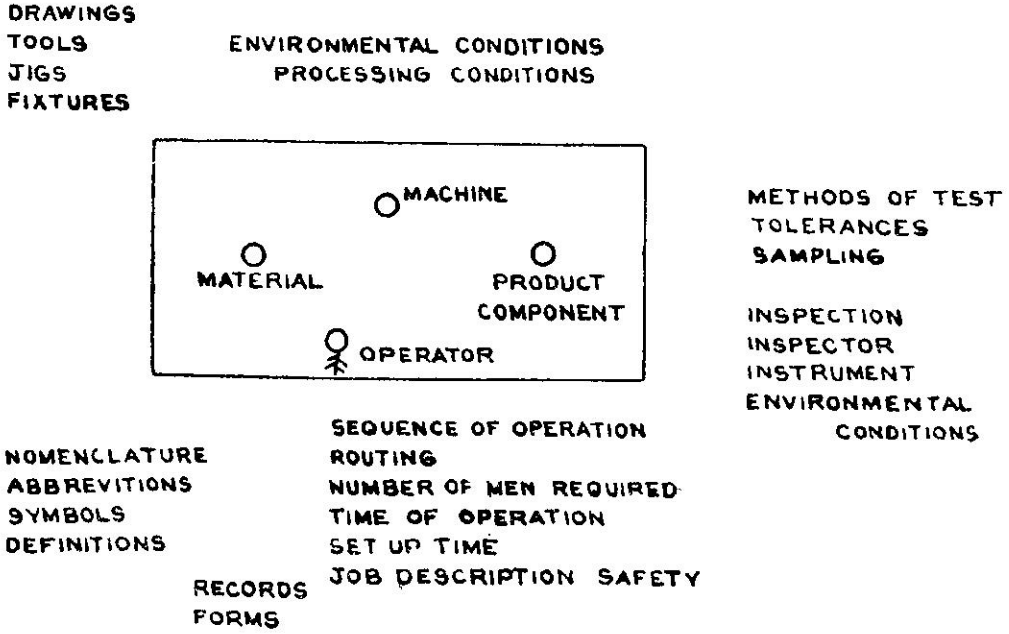

DRAWINGS
TOOLS
JIGS
FIXTURES
ENVIRONMENTAL CONDITIONS
PROCESSING CONDITIONS
MACHINE
MATERIAL
PRODUCT
COMPONENT
OPERATOR
METHODS OF TEST
TOLERANCES
SAMPLING
INSPECTION
INSPECTOR
INSTRUMENT
ENVIRONMENTAL CONDITIONS
NOMENCLATURE
ABBREVITIONS
SYMBOLS
DEFINITIONS
SEQUENCE OF OPERATION
ROUTING
NUMBER OF MEN REQUIRED
TIME OF OPERATION
SET UP TIME
JOB DESCRIPTION
SAFETY
RECORDS
FORMS

FIGURE - 3

of process specifications are really to provide information on right processes and processing conditions.

7.1.6 Product specifications, though follows the pattern of purchase or incoming material specifications in terms of drafting, serve a different purpose. To provide customers a consistent standards, it is necessary to have product specifications. This will not only inform the customers as to the quality standards, but assist in producing items to obtain the finished product according to the final specifications of the product.

7.2 The specifications provide the necessary details as to what is required and what is to be done; then the inspection has the responsibility of seeing that what is produced is in fact what was desired; this determination requires equipment which will enable inspectors to measure or compare the items produced to specifications. This may involve equipment for a particular component, an inspection equipment that may be used for a variety of parts or components; this also involves speed of inspection, precision, nature of tests -- destructive or non-destructive and skill required. Broadly the different methods of inspection in engineering industry may be grouped as under :—

(i) Inspection by measurement
(ii) Limit gauges
(iii) Multiple gauging
(iv) Optical comparators
(v) Air gauges
(vi) Non-destructive testing
(vii) Visual inspection

7.2.1 Some other methods of inspection and test may be added to show the wide scope of inspection and test and equipment: Metallurgical, chemical, electric and electronic testing.

7.2.2 Exact measurements are required in many situations for controlling processes; the characteristics may include linear dimensions, surface finish, weight, strength, tightness of screws etc. Examples of inspection equipment would be: micrometer, vernier calipers, torque-indicating spanners etc.

7.2.3 Fixed Limit Gauge: Fixed limit gauge is a simple instrument which can be used even by an unskilled operator to know quickly whether the product is within the limits laid down in the specification; but it is not useful when it is necessary to know the exact amount of variation.

7.2.3.1 Comparator Type Limit Gauge: This is an improvement on fixed limit gauges and provides more information than the latter. It is also capable of being set to cater for different jobs without difficulty. It is more rapid in use and it is possible to check several dimensions in one set up.

7.2.4 Multiple Gauging. The gauging unit consists of electrical contacts operating a series of coloured signal lamps which indicate whether the dimension is correct, over-size or under-size.

7.2.5 Optical Comparators: The object is projected on a screen and magnified 10 to 50 times. This is compared against a known standard.

7.2.6 Air Gauges: Preliminary setting is made with reference to a master ring and the gauging plug is introduced into the job for checking any diameter. Variation is read on dial. It is very useful for inspecting mass production work.

7.2.7 Automatic Gauging: Useful where sampling cannot replace total inspection because of unavoidable inconsistencies such as occur with a close tolerance which cannot be held or where the dimension or characteristic is very important. The degree of mechanisation varies depending on the type and accuracy of product. In a fully automatic factory the gauging mechanism is utilised to reset the machine.

7.2.8 Non-Destructive Testing: The testing methods for detecting flaws and defects in materials without impairing the usefulness or serviceability of the material is termed as non-destructive testing (NDT). The increased demand on product reliability especially the critical requirements in the fields of aircraft, missiles, nuclear energy and electronic components have been responsible for the rapid growth of non-destructive methods of testing. The test methods utilised are visual, pressure and leak, penetrant, thermal, radiography, acoustic (sonic and ultrasonic), magnetic, electrical and electrostatic, electromagnetic induction and others.

Visual Testing: Visual method is the oldest and simplest of methods of NDT. Of course, visual inspection is also an integral part in other methods of NDT. In this method the test piece is illuminated with light and examined with the eye, sometimes with magnifying glasses. It should be emphasised that high magnification may not always be necessary or desirable. High power magnification are intended for looking in detail at something already found. Visual methods of inspection always require skill and experience.

Pressure and Leak Testing: In this type of testing the flow of air, gas or liquids through the defects reveals the presence. The pressure within the hallow test object is made greater than the outside pressure; a simple example would be testing of automobile tubes and leaks are detected when inflated tube is immersed in water.

Penetrants: Liquid penetrant inspection may be thought of as an extension of visual inspection methods. The difference is that the liquid penetrant methods provide a contrast between the defect and the background and makes detection fairly easy. In this method of inspection only surface defects or defects which are open to the surface are revealed. The following defects could be detected provided they are open to surface, and act as capillaries to drawing the penetrant: grinding cracks, welding cracks, casting cracks, fatigue cracks, shrinkage, blowholes, seams, laps, pores coldshuts, porosity, lack of bonding, pinholes in welds, through cracks, forging laps and bursts, gauges, tool marks and die marks.

Thermal Methods: The method consists in applying heat (direct, electric, induction, infra-red) to the test specimen and observing the temperature distribution. Flaws alter this distribution which can be detected by the use of temperature indicative substances, wax, temperature sensitive phospors, infra-red film thermocouples, non-conducting areas (poor bonding) are outlined. The method could be used for checking brazed or bonded areas.

Magnetic Flaw Detection: This test is applied to magnetisable components and relies on the fact that the defects have a lower permeability than the material itself and consequently distort the magnetic field. At or near the surface this distortion causes a leakage field which is strong enough to attract fine particles of magnetic material. The accumulation of particles indicates the defect which may be a crack, slag inclusion, segregation, or change of structure. Not all of these are necessarily causes for rejection.

Eddy current techniques can be used to inspect electrically conducting specimens for defects, irregularities in structure, and variations in composition. Applications of eddy current testing include metal sorting detection of cracks, voids, and inclusions, measurement of plate or tubbing thickness, determination of coating thickness, and measurement of thickness of non-conducting films on electrically conducting base material. Eddy current tests are most effective for locating irregularities near the surface of the specimen. When a coil carrying alternating current is brought near a metal specimen, eddy currents are induced in the metal by electromagnetic induction. The eddy currents induced in the metal set up a magnetic field which opposes the original magnetic field. The impedance of the exciting coil or any pick-up coil in the close proximity to the specimen is affected by the presence of the indnced eddy currents. The path of the eddy currents is distorted by the presence of a defect or other homogenetics. The apparent impedance of the coil is changed by the presence of a defect. This change in impedance can be measured and used to give an indication of defects or differences in physical, chemical and matellurgical structure.

Ultrasonics: Vibrational waves which have a frequency above the hearing range of the normal ear (a frequency greater than 20,000 cps) are called ultrasonic waves. Certain phenomena which occur at ultrasonic frequencies are not usually observed in the audible range. This works on the principle of reflected wave. When a beam of sound wave of ultrasonic frequency over 20 Kcs, strikes one surface of the part through the transmitting crystal, a portion of it is reflected from the top surface into receiving crystal. When this wave is converted into an electrical impulse and projected on the screen of the oscilloscope, a vertical pip is produced. When the un-reflected portion of the wave strikes the opposite inter face it gets reflected and received by the receiving crystal and will be seen as another vertical pip away from the first pip. The distance between the two pips is a measure of the thickness of the material.

If, however there is a discontinuity like crack inside the material, the wave gets reflected from it, instead of from the opposite inter face and creates another pip on the oscilloscope. The distance of the intermediate pip from the first pip will be a measure of the distance the defect from the top surface. In order to help the inspector to interpret the indications on the oscilloscope, standard test blocks having known size holes drilled are used.

Radiography: The use of X-ray or gamma radiation is termed as Radiography. The intensity of the penetrating radiation is modified by passage through material and by defects in the material. The phenomenon of differential absorption is the basis of radiography. The contrast (different in density) on the developed film between the image of an area containing a defect and the image of a defect-free area of the specimen permits the observer to distinguish the flaw.

7.2.9 Visual inspection is performed with or without the aid of the ordinary magnifying glass. To aid the inspector visual standards are provided for comparing quality characteristics which cannot be directly measured. Examples would be: Shade of a painted surface, scratches and defects on an optical surface etc

7.3 In order that parts produced are of consistent and of acceptable quality, it is necessary to keep the production and inspection gauges and test equipments always accurate. No tool can produce a job more accurate than its own inherent accuracy. Also no gauge can measure an article more accurately than its own inherent accuracy. Hence, systematic maintenance and control of gauges and test equipments is an essential requisite for maintaining the quality level.

A planned system of gauge control aims at planned maintenance of all gauges and test equipments to a desired accuracy and periodic withdrawal for readjusting or reconditioning and checking with a substandard of known accuracy.

7.4 Adequate inspection records are absolutely essential. They provide valuable information as to recurring troubles, and help in keeping track of rejections and reworks and scrap produced. Records of tests and customer complaints help in improving quality. In addition there should be specific provision for communicating inspection or test results to production personnel as quickly as possible.

7.5 Though inspection in industry cannot be eliminated completely, it is possible to reduce the inspection substantially. In fact a good quality control programme will ensure this reduction in inspection. However, there are situations in industry where 100 per cent inspection will be essential. In cases where requirements are considered critical, as for example certain components in aeroplane, it is essential to check each part. Also in cases where the production is very small, all the parts may be inspected. Apart from these situations there is considerable scope for reducing inspection in industry which will cut down costs.

7.5.1 Sampling inspection is not new to industry. Technicians and quality control workers, make observations for studying processes or judging operations; this sort of observations can arise in many fields. The number of measurements taken depends upon the process and circumstances. However, it may be noted that, generally, we take measurements only on a few items that are produced to draw inferences about the quality that is being obtained. For example, in order to know whether we are spinning the nominal count, we take a few 'bobbins' out of a large number of bobbins that are being processed; to know the average life of the lamps in a batch, we take a few lamps (obviously we must take only a few) burn them and obtain an idea of the life of the batch. The few measurements we make are called the sample and the large aggregates of these measurements is called the population or universe. The sampling inspection is not only common in the actual manufacture but also in checking incoming material and outgoing product as well.

8. Quality Control

8.1 Quality control activities relate to the evaluation, maintenance, and improving quality economically; the broad areas of application are: incoming material control, process control and product control.

The approach to the solution of quality problems involves three aspects:

(i) Engineering: The creation and development of a product is basically engineering; the development of quality evaluation through improved inspection procedures is also engineering; again, the knowledge of the causes of defects and sub-standard products and their rectification is engineering.

(ii) Statistical: The concept of the behaviour of a process, which has brought in the idea of 'prevention' and 'control' is statistical; building an information system to satisfy the concepts of 'prevention' and 'control' and improving upon product quality, requires statistical thinking.

(iii) Managerial: The competent use of the engineering and statistical technology is managerial; the creation of a climate for quality consciousness in the organisation depends upon the policies and practices of the management; the effective coordination of the quality control function with those of others is managerial.

8.2 The inspection function of quality control has been dealt at length in the earlier sections. A brief description of statistical technology in quality control function will be discussed in the following sections.

9. Froquency Distribution

9.1 Frequency distribution is a fundamental concept in quality control; in fact the frequency distribution provides a basis for exercising control and provides a basis for improving of quality. This may be demonstrated with the aid of an example.

9.2 The example considered relates to a turning operation; the quality characteristic being diameter of the pedal axle, specifications being 0.526″ ± 0.002″. Measurements made on 96 axles produced in a shift are given in Table 1. Before going further, it may be useful to generalise a few points based on this example. The study of any quality characteristic of a product or a part from a manufacturing process—precision bore, length or tensile strength—shows that no two pieces are exactly alike. The recorded measurements of the individual pieces differ from one another in spite of our best efforts; whether small or large, variation does exist from piece to piece. This fact is well recognised, for, in the manufacture of any product certain amount of tolerance is specified in the drawing. Thus, when a set of measurements are taken on a quality characteristic the measurements will not be identical but will be found to lie within a range. Generally, most of the measurements will cluster round the value and as the deviation from this value increases on either side, the number of pieces having these deviations will be less and less. The actual spread of the measurements depends upon the process and control exercised over it.

9.3 Variability observed in a set of measurements can be graphically represented whioh brings out several interesting features. In the above example, the recorded measurements will not be exactly 0.526″, but exhibit variation. This variation could be clearly demonstrated with the aid of a graphical presentation called the frequency distribution.

9.4 A frequency distribution of a set of measurements is an arrangement

TABLE 1

Part name : Pedal axle.
Characteristic : Diameter

Operation : Turning
Specification : 0.526±0.002″

Measurements of 96 diameters are given :

0.525	0.524	0.526	0.524	0.526	0.527
0.527	0.527	0.526	0.526	0.527	0.526
0.526	0.526	0.526	0.526	0.526	0.526
0.524	0.525	0.525	0.523	0.526	0.527
0.528	0.528	0.529	0.529	0.527	0.528
0.526	0.528	0.528	0.528	0.527	0.527
0.529	0.529	0.529	0.527	0.530	0.527
0.528	0.527	0.527	0.527	0.528	0.527
0.528	0.527	0.527	0.527	0.528	0.528
0.528	0.527	0.527	0.528	0.527	0.526
0.526	0.527	0.527	0.527	0.528	0.526
0.528	0.527	0.527	0.528	0.528	0.527
0.530	0.529	0.529	0.530	0.530	0.528
0.529	0.529	0.529	0.528	0.528	0.526
0.527	0.527	0.528	0.529	0.529	0.528
0.529	0.528	0.529	0.529	0.530	0.528

TABLE 2

Frequency Table

Dimension	*Tally*	*Frequency*
0.523	I	1
0.524	III	3
0.525	III	3
0.526	卌 卌 卌 II	17
0.527	卌 卌 卌 卌 卌 III	28
0.528	卌 卌 卌 卌 IIII	24
0.529	卌 卌 卌	15
0.539	卌	5
		96

FREQUENCY DISTRIBUTION OF DIAMETER OF AXLES
(SEE TABLE-1)

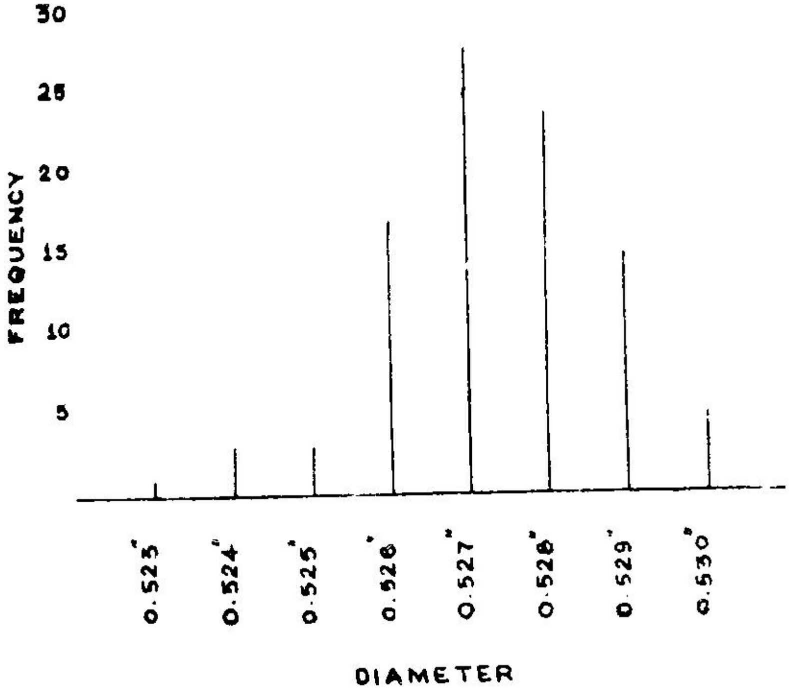


FIGURE-4

of the observed data into ordered groups or classes which show the frequency of measurements in each of the classes, or individual values.

9.5 Table 2 illustrates a convenient method of classifying the measurements. For each measurement a tally mark is put in the appropriate cell or individual value and these tally marks may be grouped in fives in each cell as tallying of the measurements continues.

9.5.1 Using a convenient horizontal scale for the measurements and vertical scales for the frequencies, the frequency distribution can be represented graphically in several ways, such as frequency bar diagram, frequency polygon, or histogram. The bar diagram for the distribution in table is shown in figure 4 at 20 (a).

9.6 When a frequency distribution is drawn the basic points to be remembered are:

(i) To effect a condensation of the data so that the mind can grasp the significance easily.

(ii) The pattern of variation described by the data.

(iii) Computation of certain numerical constants from the data which describe a process clearly.

The figure 4 describes the pattern of variation for the diameter of the axle of table 1. At this juncture it is necessary to pause for a while and understand this implication. The data in Table 1 is the quality evaluation of a process with reference to the characteristic, diameter of axle; again this is the result of certain technical and operating conditions obtained during manufacture. The frequency distribution (bar diagram) may therefore be thought of as representing the process pattern or behaviour of the process at the time of obtaining the date. This indicates the correspondence between the frequency distributions and the technical and operating conditions of a process and thus opens up an interesting area for further investigation.

9.7 What would be the frequency distribution of the axle diameters, if taken on another day ? Still more interesting, what would be the frequency distributions for other quality characteristic of the processes, e.g. strength, length, resistance, weight etc. ? Is the pattern observed satisfactory or what would be the pattern that may be considered satisfactory ? Unless a universal approach is developed, it would be difficult to use the idea of frequency distribution for practical purposes to control or improve processes.

9.8 Without going into the details of the theory it may be mentioned, that, if a process is working under reasonably constant conditions of manufacture (see definition of process on page 11) whatever be the measurable characteristic under consideration, the frequency distribution always takes the same shape as shown in figure 5. The smooth curve is drawn to emphasize that this will be achieved when large number of diameters are taken from the process. This curve is called the normal curve or normal frequency distribution.

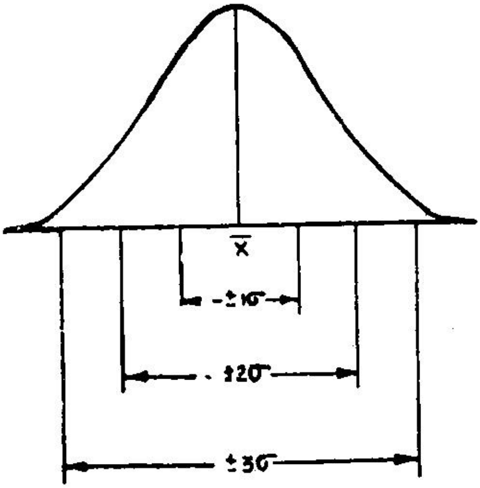


FIGURE-5

Thus the normal curve represents a desirable state of affairs, as this is the best that could be done in any given circumstances. If a process gives rise to this type of distribution the process is said to be in a state of control.

9.9 The properties of the normal curve then becomes the properties of a process in a state of control. The distribution is completely specified by the mean ($\bar{X}$) and the standard deviation (σ), a measure of variation, and are related to each other when the process is in control:

$\bar{X} \pm 1\sigma$ comprises 68.3% of observations
$\bar{X} \pm 2\sigma$ comprises 95.5% of observations
$\bar{X} \pm 3\sigma$ comprises 99.7% of observations

9.9.1 This indicates that almost all observations will be within a law of $\bar{X} \pm 3\sigma$ (that is 99.7%) provided the process is in a state of control. The values of $\overline{X}$ and σ could be obtained from the process. Thus a process in a state of control is predictable and this concept used in exercising control over processes discussed under control charts.

9.10 The understanding of process through the aid of frequency distribution may be appreciated by the following explanation:

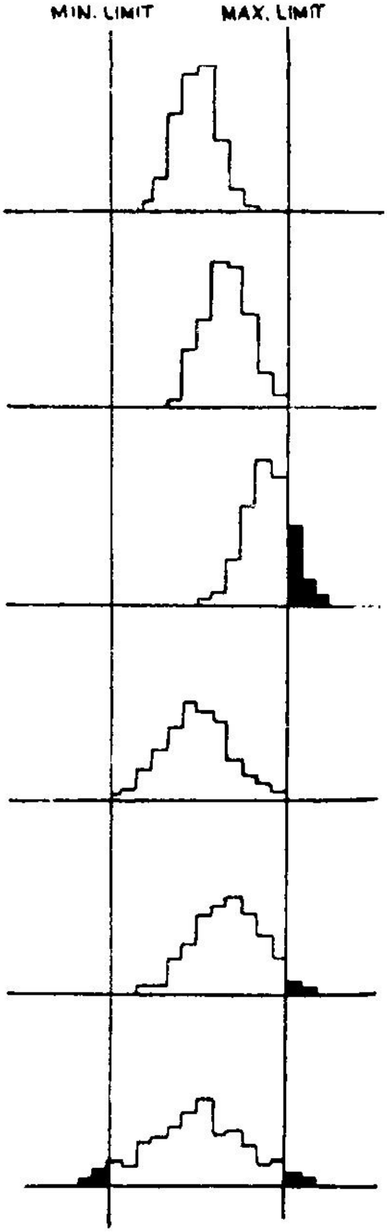


Fig. (i) Product range substantially less than specified and distribution is well centered. Consider using smaller samples on subsequent lots.

Fig. (ii) Product range substantially less than specified but distribution is off center. Production of defects imminent.

Fig. (iii) Product range substantially less than specified but distribution is badly off center, producing defects above maximum limit. Vendor can meet tolerance and eliminate defects by centering the distribution.

Fig. (vi) Product range approximately same as specified and distribution is well centered. Slight shift off center will produce at one limit. Vendor may require increased tolerance.

Fig. (v) Product range approximately same as specified but distribution is off center, producing defects above maximum limit. Vendor must reduce product range through change in process or by better control and distribution must also be centered. May require increased tolerance.

Fig. (iv) Distribution is well centered but exceeds specified range and defects are occurring at both limits. Change in process or better control required to reduce range. Vendor may require increased tolerance.

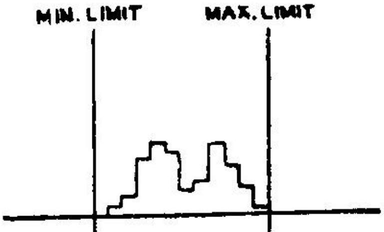


Fig. (vii) Double distribution suggests possibility of two sets of tools, change in process or material during running of this lot. Vendor can easily hold tolerance since range of either distribution is smaller than specified.

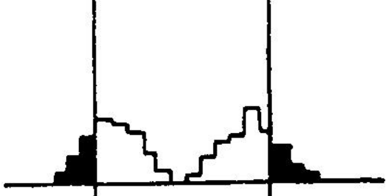


Fig. (viii) Same as Fig. 7 except that the two centers are far apart to cause defects outside both limits. No increase in tolerance needed. Condition should be easily corrected.

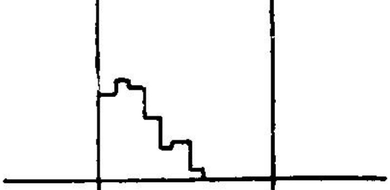


Fig. (ix) Distribution off center to minimum limit and lot has been inspected 100 per cent before shipping. If production is centered vendor may be able to eliminate the 100 per cent inspection.

Fig. (x) Same as Fig. 9 except operator is passing defects or gauge is slightly off.

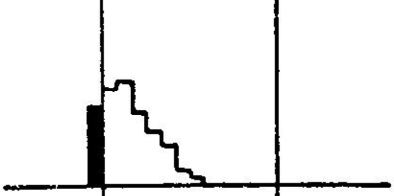


Fig. (xi) One hundred per cent inspection gauges are probably not set to correct limits and defects appear below the minimum limit. Operator may be having difficulty deciding borderline cases.

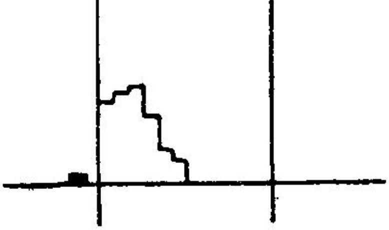


Fig. (vii) Same as Fig. 9 Gauges set correctly but operator has missed some parts.

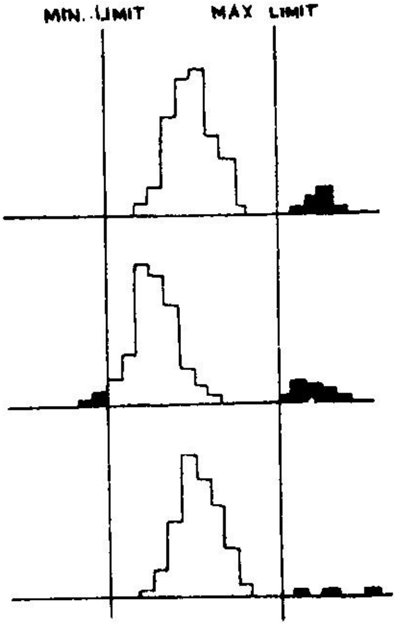


Fig. (xiii) Principal distribution has narrow range and is well centered. Small distribution above maximum limit may be parts from tool and set up try outs not set aside. Vendor should be able to ascertain cause and correct condition.

Fig. (xiv) Similar to Fig. 13 except main product distribution is off center to minimum limit, producing defects outside both limits. Vendor should be able to correct condition. No increase in tolerance required.

Fig. (xv) Distribution has narrow range and is well centered. A few individual pieces are exceeding maximum limit. May be due to misses by operator or machine. Vendor should have no difficulty in overcoming this condition.

9.11 For exercising control over process another technique, namely, the control chart is available. The chart is based on the frequency distribution model developed and provides an excellent basis for effecting control over processes as the manufacture continues.

10. CONTROL CHARTS

10.1 The control charts for measurements, also called $\bar{X}$-R charts, can be used whenever an observed quality characteristic is expressed in actual measurements, like weight in pounds, length in inches or temperature in F° etc. Prior to running the X-R charts on any process, several points have to be considered. They are:

(i) The quality characteristic to be studied
(ii) The measuring equipment and gauges
(iii) Selection of samples (rational sub-grouping)
(iv) Recording of the data.

10.1.1 After collecting the data, due regard paid to the points mentioned above, the analysis can be done by drawing the control chart for $\bar{X}$ and

R. The information provided by this preliminary study can then be used for control of the process.

10.2 In deciding on what characteristics the control chart should be run, past experience may help. For example, inspection records might show that a product is being rejected too often on a particular characteristic. If the same product is inspected for several quality characteristics charts for each of the characteristics may be run.

10.3 It is to be clearly recognised that analysis of the data will not yield results of utility unless the data collected are free from errors. Errors in measurement can enter into the data by use of faulty instruments, lack of experience in the use of instruments; in some situations the accuracy of the instrument may not be sufficient. Also lack of clear-cut definition of the quality characteristic and the method of taking measurements may lead to error in measurements. It is essential to obtain data that are free from error so that valid conclusions can be drawn.

10.4 In order that maximum information is obtained from a control chart, due regard should be paid in the selection of samples, or sub-groups as they are called. The interpretation that may be placed on the information provided by the chart entirely depends on the choice of these sub-groups. For example, a sub-group may be chosen at a particular time by collecting four or five consecutive items of the product, or the products produced during a period may be collected in a box and four or five items may be chosen to form the sub-group; or again the inspector may go to the machine at fixed interval of time and collect four or five items to form the sub-group.

10.4.1 The choice of the sub-groups depends on the purpose of the control chart. If the chart is maintained for controlling the quality the object would be to reveal any differences in sub-groups due to assignable causes so that corrective action can be taken. In such circumstances, consecutive items produced during a short time may be preferred. Sub-groups should be chosen in such a way that measurements within a group tend to be more alike than amongst the groups. Such groups are called rational sub-groups. If the purpose is to know whether units produced over a period of time are homogeneous the sub-group can be formed by taking units from those already produced.

10.4.2 The choice of the rational sub-groups is of fundamental importance in control chart work. As Shewart points out "The ultimate object is not only to detect trouble but also find it, and such discovery naturally involves classification. The engineer who is successful in dividing his data initially into rational sub-groups based upon rational hypothesis is therefore inherently better off in the long run than the one who is not thus successful". The classification involves the suspected source of causes of variation of products of different machines, different spindles in a machine, different operators, different shifts, differences in materials (or materials entering production over time) environment etc.

10.4.3 The choice of the number of items in a sub-group, also called sample size, and the frequency of sampling depend upon the process and no general rule can be laid down in the choice. Generally samples of size 4 or 5 may be preferred. The frequency of sampling or the time between the selection of two successive groups depends on the state of control exercised. In initial studies more frequent samples will be required (e.g. 15 min. or 30 min.) and when a state of control is being maintained the frequency may be relaxed. About 25 sub-groups of size four or about 20 groups of size five under control will give good estimates of the process average and dispersion.

10.4.4 While collecting data it may not be necessary to go exactly at the specified time; in fact this should not be practised. This is to avoid the operative being careful at the time of sampling or any periodicities of the process to coincide with sampling.

10.5 The collection of the data for control chart purposes should be done in properly designed forms. The design of forms depends on the process and type of inspection. While recording the data the following points should always be remembered :

(i) The order of the measurements

(ii) The conditions under which the measurements were taken

(iii) The observer who made the measurements

(iv) The time at which the measurement was taken

(v) Other details which would help in the interpretation of the data.

10.6 Preliminary data for constructing the control chart for a process may be obtained by collecting 20 or 25 samples. The preliminary data may be collected within a shift. In case it is not possible to obtain 20 or 25 samples, as few as 10 successive samples may be used pending accumulation of data.

10.6.1 To know whether an unknown process shows a state of control or not, it is necessary to establish the trial control limits. When once the data have been collected the calculation of trial control limits is a simple numerical procedure. The steps in the calculation are:

(i) Calculate the average of all the items or the average of all the sub-groups ($\overline{\overline{X}}$)

(ii) Calculate the averages and the ranges of all the sub-groups (R)

(iii) Obtain the relevant factors from the Table A. These are A_2, D_3 D_4 and D_2 (Note that these depend on the sample size)

(iv) The control limits on the chart for averages are given by:

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R} \quad LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$$

(v) The control limits for the chart for ranges are given by:

$$UCL_R = D_4\overline{R}$$

$$LCL_R = D_3\overline{R}$$

(vi) Plot the averages of the sub-groups in one chart, in the order collected and the ranges in another chart which should be below the $\overline{X}$ chart so that the sub-groups correspond to one another in both the charts.

(vii) Draw the central lines $\overline{\overline{X}}$ and $\overline{R}$ on the $\overline{X}$ and R charts respectively.

(viii) Draw the control limits on both $\overline{\overline{X}}$ and $\overline{R}$ charts (It is customary to draw these in dotted lines).

(ix) Any change in the process that might have been noted in the data sheet, such as tool grind, new stock, repair, operator change setting, etc., should be noted below $\overline{X}$ chart.

10.6.2 The control chart can thus be drawn. Lack of control is indicated in the chart by one or more samples falling outside the control limits.

This is an indication of the assignable causes influencing the process. If a record of conditions under which the measurements were made---time, new stock, operator change, etc.---it might be possible to assign definite reasons for the points falling outside the control limits. These sub-groups are eliminated and the process average $\overline{\overline{X}}$ and dispersion $\overline{F}$ are calculated from the sub-groups which show a state of control. While doing this it is assumed that the assignable causes have been found and that they have been eliminated. Control limits calculated on these estimates are then used for control of the process.

10.6.3 In some cases it might so happen that the desired average and the actual process average may differ. If it is easy to change the level (e.g, setting) this adjustment can be made and this is taken as the standard. In case it is difficult or costly to make this adjustment in the level a suitable standard has to be evolved and used for future control purposes.

10.6.4 The trial control limits serve the purpose of knowing whether a process is in control or not. The revised limits as explained earlier have to be used to control the process---to hunt for any assignable cause when a point falls outside the control limits and to take action to eliminate the same. The control limits may be revised, if found necessary, as data accumulate.

10.7 The control charts drawn or more specifically the points plotted on the chart, describe a pattern. A knowledge of the production process and the pattern of points on the control charts will lead to a proper interpretation of the working of the process In fact for any process, it is possible and will be useful to prepare a list of causes which might give rise to particular pattern of points. The pattern of the points in a control chart is key to its interpretation. These aspects and other information including process capability, may be studied by consulting references given at the end of the booklet.

10.8 An example may be discussed to make the points clear. Table 3 gives the data compiled for analysing the process with the aid of control chart with regard to the diameter of pedal axles. The control chart calculations are explained in Table 3 itself. The control chart for the process is shown in fig. 6.

TABLE 3

Department M/C Shop	Operation: Turning	Characteristic: **Diameter**
Drawing No: 3425	Operator: L. Singh	Sample size: 6
Part Name: Pedal axle	Specification: 0.526" ± .002"	Sampling Internal : 30 mm
Machine A 22	Inspector : BK Pal	Date: 13-1-70

No.	Time	Individual Measurements*						Average	**Range**
1	8.00 AM	−1	−2	0	−2	0	1	−0.7	3
2	8.30 AM	1	1	0	0	1	0	0.5	1
3	9.00 AM	0	0	0	0	0	0	0	0
4	9.30 AM	−2	−1	−1	−3	0	1	−1.0	4
5	10.00 AM	2	2	3	3	1	2	2.2	2
6	10.30 AM	0	2	2	2	1	1	1.3	2
7	11.00 AM	3	3	3	1	3	1	2.5	3
8	11.30 AM	2	1	1	1	2	1	1.3	1
9	12.00 noon	2	1	1	1	2	2	1.5	1
10	1.00 PM	1	0	1	2	1	0	0.8	2
11	1.30 PM	0	0	1	1	2	0	0.7	2
12	2.00 PM	2	1	1	2	2	1	1.5	1
13	2.30 PM	4	3	3	4	4	2	3.4	2
14	3.00 PM	3	3	3	2	2	0	2.2	3
15	3.30 PM	1	1	2	3	3	2	2.0	2
16	4.00 PM	3	2	3	3	4	2	2.8	2
								20.9	31

*Measurements, deviation from 0.526"x1000

$X = 20.9/16 = 1.3$; $\overline{R} = 31/16 = 1.9$

For $n = 6$, from Tables $A_2 = 0.48$, $D_3 = 0$, $D_4 = 2.0$, and $d_2 = 2.5$.

Control limits for Averages	Control limits for **Ranges**
$1.3 \pm 0.48 \times 1.9$	$LCL = D_3 \overline{R} = 0$
$UCL = 2.2$; $LCL = 0.4$	$UCL = D_4 \overline{R} = 3.8$

Process capability: $\dfrac{\overline{R}}{d_2} = \dfrac{1.8}{2.5} = 0.7$;

CONTROL CHART FOR AXLE DIAMETERS

(SEE TABLE-3)

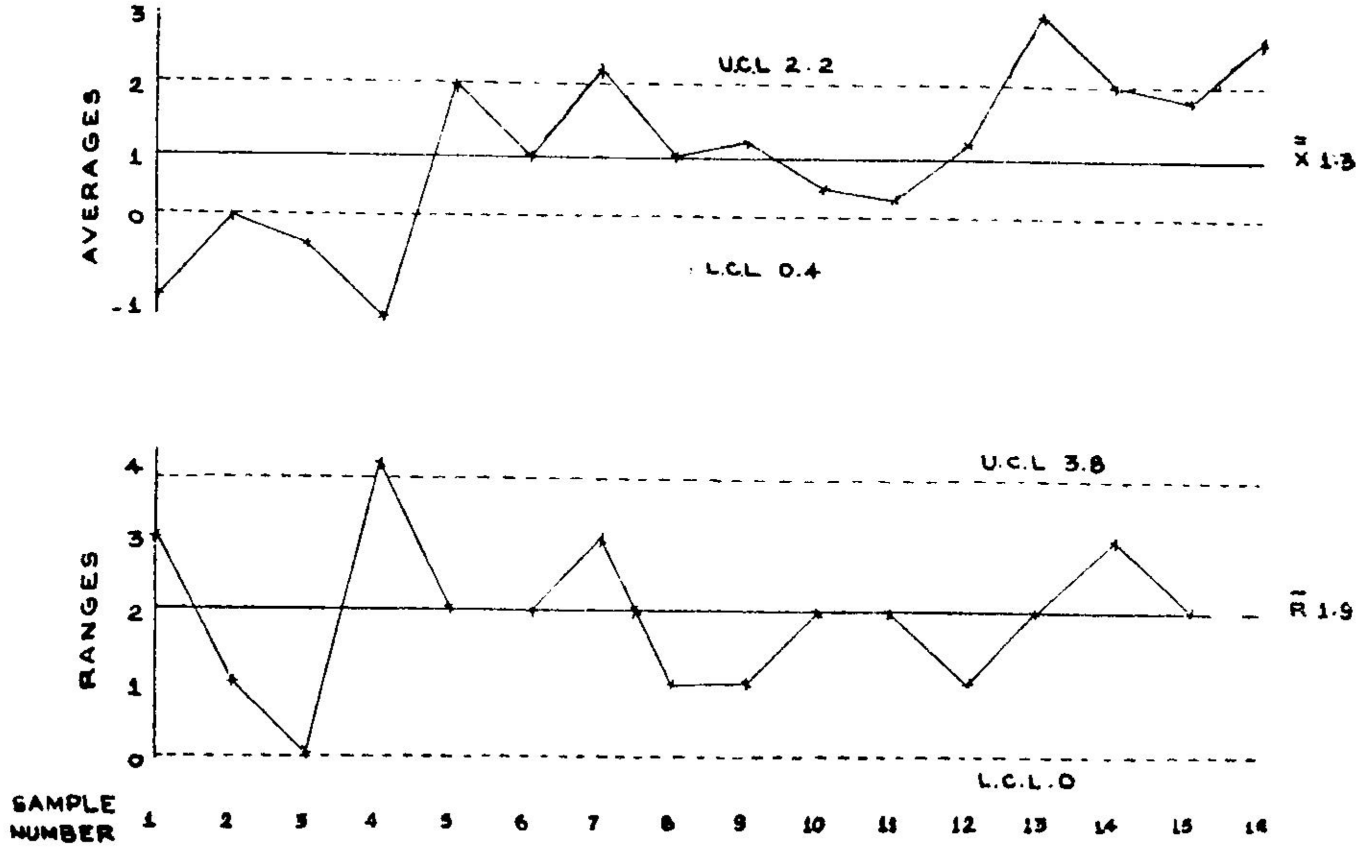


FIGURE-6

10.8.1 The examination of the control chart reveals many interesting points:

(i) The process is not in a state of control.

(ii) The process has gone out of control on both sides of the control limits.

(iii) A gradual increase in dimensions indicate tool wear and further that the operator is not sure as to when the tool should be taken for grinding.

(iv) The initial low values and readjustment (at sample 5) indicate that the operator has difficulty in initial setting.

(v) Sample 4 indicates that attempts at adjustment has been made but not successful. the point falling outside control limit in both the charts.

(vi) The average dimension which should be zero (in new units) is actually 1.3 indicating higher dimension.

(vii) The actual average dimension achieved during the shift is much higher than 1.3. After sample 5, adjustment is made on the higher side and the average of points 5 to 16 works out to 1.8.

(viii) The range chart shows control except for sample point 4, the reason for which is known i.e. adjustment.

(ix) Since the range chart is exhibiting good control it would be possible to compute the ability of the process to produce the parts, that is the process capability which may be compared to specifications. In this case the factor is 0.7 (see table 3) and the process can produce parts within ± 2.1 units. This may be compared to the process required that ± 2 units (0.002") which indicates that the machine is just sufficient to meet the requirement provided the average dimension is controlled adequately.

(x) It is also possible to calculate* the proportion of axles which will have dimensions above the upper specification limit (i.e. 0.528) if the present average is maintained (that is 1.3 in new units or 0.527"); 26% of the items would have to be reworked.

(xi) In essence the operator is playing safe, in the sense he is working at higher dimension with the result no rejections would result, but rework has to be done.

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*Supervisors are advised to consult their quality control department for this explanation.

10.8.2 The information obtained in one day and by the use of control chart analysis gives a great understanding of the process. The same chart could further be used for a proper initial setting, watching the process for adjustments and for knowing when trouble has crept into the process.

10.9 The control charts for X—R are applicable to quality characteristics that are directly measurable. However, in industrial practice, situations are many, where direct measurements are either not feasible or possible but necessitate some other type of quality evaluation. For instance, the colour of paint or the surface finish of a casting do not lend themselves to direct measurement. In these circumstances, the inspection results in the classification of the items as defective or non-defective, good or bad, passable or non-passable according as the item conform to specifications or not. In these situations the quality characteristics are said to be observed as attributes.

10.9.1 A defective article can further be examined for the type and number of defects in it. A defective item may contain one or more defects of various types. When the product is examined as a whole for conformity to specifications, the inspection results in the classification of the product as defective and non-defective. However, where consideration is given to the type and the number of defects, a count of the number of defects on an item of product helps in the evaluation of the quality of the item. For example, a casting may be defective because of blow holes, cracks, cuts, scabs, sponginess, swells, runouts, misruns, bad surface, etc. Each of them is called a defect. A casting that has any one or more of these defects is a defective casting.

10.9.2 There are also cases where the direct measurement of the quality characteristic is possible, but is not done in practice for reasons of economy and time. It is common practice in such cases to check the component parts by gauges which decide whether a dimension falls within specified limits rather than determine the actual dimension of the product. The result of such tests is again the classification of items as acceptable or not.

10.9.3 In some cases a single part has to be inspected for a number of dimensions. In such cases for ease of inspection, economy and time attribute inspection is done with the aid of gauges.

10.9.4 Quality characteristics observed as attributes may be expressed in the following ways:

(i) Fraction defective (p): This is defined as the ratio of the number of defective articles found in an inspection to the total number of articles inspected.

$$p = \frac{\text{Number of defective articles found}}{\text{Total number inspected}}$$

(ii) Percent defective : The fraction defective expressed as percentage gives percent defective.

(iii) Number defective : The actual number of defective articles found in the samples inspected.

(iv) Number of defects observed in a given area, length or time.

10.9.5 The control chart for defectives, known as p-chart, is used whenever the quality characteristic observed results in the classification of items as defectives or not. The concept of rational sub-groups plays an important part in the interpretation of p-charts also. Thus, the inspection results by different inspectors, fraction defectives of different machines doing the same job, or of different shifts, have to be charted separately until the evidence shows that the performance of machines, inspectors have different shifts are the same. It is important that in the first instance the method of inspection should be standardised. The recording of inspection results should be made in properly designed forms. In some situations, it may be necessary to maintain charts on defectives due to some selected major defects.

10.9.6 Generally preliminary data for the construction of p-chart may be obtained from the past records. About 20 to 25 samples may be sufficient to get an idea of the working of the process and to evaluate the standard fraction defective for future control.

10.9.7 To know whether a process is in a state of control or not, it is necessary to calculate the trial control limits. The calculation is explained below:

(i) Compute the fraction defective for each of the samples. The fraction defective is given by

$$p = \frac{\text{Number of defectives in the sample}}{\text{Number of items in the sample}}$$

(ii) Obtain estimate of the standard fraction defective

$$\bar{p} = \frac{\text{Number of defectives in all the samples combined}}{\text{Total number of items in all the samples combined}}$$

(iii) The trial control limits are given by:

$$UCL = \bar{p} + 3\sqrt{\bar{p}\,(1-\bar{p})\,/\,n}$$

$$LCL = \bar{p} - 3\sqrt{\bar{p}\,(1-\bar{p})\,/\,n}$$

If the number of items inspected (n) varies, the control limits have to be calculated for each sample. This type of limits is called variable control limits. However, if the sample size remains the same, one set of limits can be used for all samples.

(iv) Plot the individual fraction defective (or per cent defective) values.

(v) Draw the central line at $\bar{p}$ and the control limits.

10.9.8 In cases where the sample size varies, the control limits on the p-chart are calculated for each sample. It is to be noted that smaller the sample size, wider the control band and *vice versa*. If the sample size does not vary appreciably a single set of control limits may be used based on the average sample size. This holds good for practical purposes in situations where the largest sample size does not exceed the smallest sample size by more than twenty per cent of the smallest sample size.

10.9.9 The process is judged for control in the same way, as is done for $\bar{X}$—R charts. If all the points fall within the control limits without giving rise to any specific pattern, the process is said to be in control under these conditions the observed variations in the fraction defective are due to chance causes and the average fraction defective $\bar{p}$ is taken as the standard fraction defective (p). If a point falls above the upper control limit it is a clear indication that this sample does not come from a process with fraction defective $\bar{p}$. This indicates deterioration in quality. If details of conditions under which the data were collected were known, it might be possible to know the reason for this deterioration. Of particular importance is whether there was any change of inspection or inspection standard. If a point below the lower control limit, it is a situation showing improvement.

However, before accepting this improvement it should be investigated whether there was any slackness in inspection or not. When several points fall outside the control limits, the revised estimate of the standard fraction defective may be obtained by eliminating all the points that fall above the upper control limit (it is assumed that the points that fall below the lower control limit are not due to faulty inspection) The standard fraction defective may be revised periodically.

10.9.10 An example with the details of the construction of the p – chart is given in Table 4. The control chart is shown in figure 7. The control chart reveals hopelessly out of control situation. In this case the reason is obvious as different types of stems are included together, violating the principle of rational sub-grouping. The per cent defective is different for different types of stems though produced on the same machine. For further analysis to reduce rejections separate control charts for different types should be drawn and the process watched.

10.10 On a similar basis control charts for the counted data may be drawn called the C-chart. The sample size is usually, either fixed time, length, an area, a single unit, or group of units. The sample size is also called the 'Areas of opportunity'. In the case of coil winding the fixed length of wire for which the break are observed constitutes the sample size or area of opportunity. In the case of surface blemishes, area of the surface is the sample size. In the case of casting defects, a single part (e. g., base plate, side cover) is the sample size. The sample size may be same or varying.

10.10.1 The construction of the control chart for number of defects (called c-chart) where the sample size is constant is as follows:

(i) Compute the average number of defects $\bar{c}$

$$\bar{c} = \frac{\text{Number of defects in all samples}}{\text{Total number of samples}}$$

(ii) The trial control limits are given by:

Upper control limit: $\bar{c} + 3 \times \sqrt{\bar{c}}$

Lower control limit: $\bar{c} - 3 \times \sqrt{\bar{c}}$

(iii) Plot number of defects in the individual samples

(iv) Draw the central line at $\bar{c}$ and the control limits

TABLE 4

Control of Rejections

Name of Component..........Stem (all types) Machine I

Date	*Number Inspected (n)*	*Number Defective*	*Fraction Defective*	*Control Limits*	
				Upper	*Lower*
Sept. 1955					
2	3,000	518	0.1727	0.1500	0.1130
3	4,000	675	0.1688	0.1478	0.1152
4	1,250	263	0.2104	0.1602	0.1028
6	2,500	462	0.1848	0.1518	0.1112
7	500	34	0.0680	0.1768	0.0862
8	5,300	346	0.0653	0.1454	0.1176
9	4,500	517	0.1149	0.1466	0.1164
11	3,000	318	0.1060	0.1500	0.1130
13	4,500	482	0.1071	0.1466	0.1164
14	6,000	632	0.1053	0.1446	0.1184
15	3,250	355	0.1092	0.1493	0.1137
16	5,750	891	0.1550	0.1449	0.1181
17	3,000	540	0.1800	0.1500	0.1130
18	2,500	424	0.1696	0.1518	0.1112
20	7,500	1,088	0.1451	0.1432	0.1198
21	9,000	1,094	0.1216	0.1422	0.1208
22	4,750	675	0.1421	0.1462	0.1168
23	7,750	807	0.1041	0.1430	0.1200
24	5,000	655	0.1310	0.1458	0.1172
25	4,250	563	0.1325	0.1471	0.1159
27	4,000	666	0.1665	0.1478	0.1152
28	8,250	1,095	0.1327	0.1427	0.1203
30	7,750	1,014	0.1308	0.1430	0.1200
	1,07,300	14,114			

$$\bar{p} = \frac{14{,}114}{1{,}07{,}300} = 0.1315$$

$$3\sigma = 3\sqrt{\bar{p}\,(1-\bar{p})/n} = \frac{1.014}{\sqrt{n}}$$

$$UCL = \bar{p} + 3\sqrt{\bar{p}\,(1-\bar{p})\,/n} = 0.1315 + \frac{1.014}{\sqrt{n}}$$

$$LCL = \bar{p} - 3\sqrt{\bar{p}\,(1-\bar{p})/n} = 0.1315 - \frac{1.014}{\sqrt{n}}$$

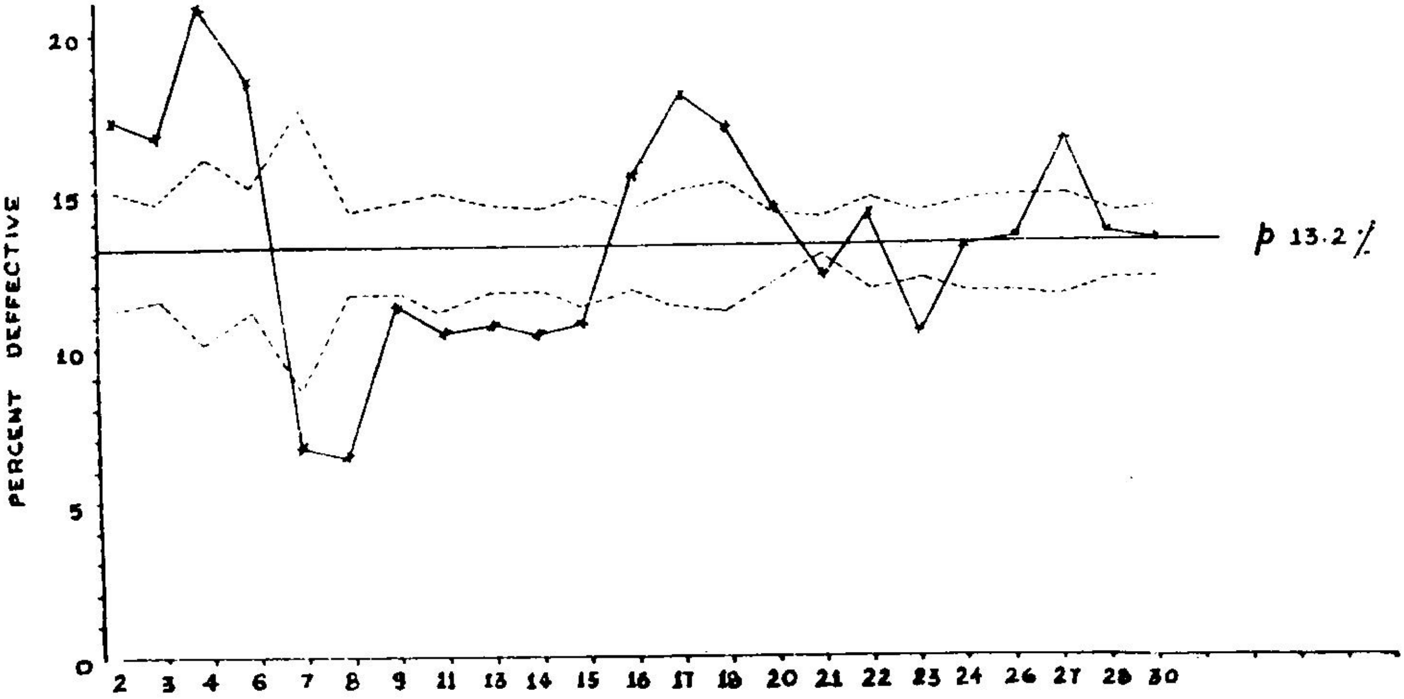


FIGURE -7

CONTROL CHART FOR REJECTIONS

(v) If the lower control limit is negative then LCL is taken as zero.

10.10.2 Whenever the sample size varies instead of plotting the actual number of defects, c, u = c/n is plotted, where n is the sample size which is varying. The central line will be drawn at u and the control limits are given by:

$$\text{Upper control limit} : \bar{U} + 3\times\sqrt{\bar{U}/n}$$

$$\text{Lower control limit} : U - 3\times\sqrt{\bar{U}/n}$$

Here u, is the estimate of the standard number of defects per unit. In this case the control limits will be varying for each sample.

10.10.3 The interpretation of these charts is similar to the charts for fraction defective and number defectives. The evaluation of the standard is also done on the same lines.

11. SAMPLING PLANS

11.1 Sampling plans may be used for the acceptance (or rejection) of products or items already produced on the basis of sampling inspection. The uses of acceptance sampling are:

(i) To determine the acceptability of the incoming products and outgoing products;

(ii) To determine the acceptability of the products from one department to another within the plant;

(iii) To select the vendors who supply specified quality materials required for processing; and

(iv) To improve the quality of the material supplied by the vendors.

11.2 The acceptance sampling procedures of incoming material control can be applied to a variety of products and situations. The product may be a component part, an assembly, or finished product in bulk, in solid, liquid or gaseous form. The product may be submitted in lots, stored in heaps, or tanks or may be moving on a conveyor etc. In all these situations, procedures for acceptance on sampling basis could be worked out.

11.2.1 The problem of acceptance sampling may be stated as follows when the material is supplied in lots:

> A producer (supplier) submits lot/lots consisting of a large number of items manufactured to certain specifications. The number of defective items is not known. The consumer (buyer) has to decide whether to accept the lot/lots as conforming to stipulated specifications or reject the same as not conforming to specifications.

11.2.2 When the acceptance of the lot is decided on the basis of sampling inspection statements regarding the lot quality cannot be made with certainty, since all the items are not inspected. Lots of acceptable quality, on some occasions might be rejected; or lots of inferior quality may be accepted. However, statistical methods can provide sampling schemes which will minimise these risks.

11.2.3 The lot quality can be expressed in several ways. If the inspection of the individual items (or units) taken from the lot is carried out by actual measurement, called variables inspection, the lot quality may be expressed as:

(i) The average of the individual items, that is, arithmetic means;
(ii) The variability of the individual items, that is, standard deviation.
(iii) The ratio of the variability of the average of the individual items, that is, the co-efficient of variation.

If the inspection is carried out by classifying the items in sample as defective or non-defective called, the attribute inspection the lot quality may be expressed as:

> Percentage of defective items, that is, percent defectives.

If the inspection is carried out by counting the number of defects in the sample of items, also called attribute inspection, the lot quality is expressed by:

> The average number of defects per units, that is, defects per unit.

Sometimes the sample items are classified as defective or non-defective even though the quality characteristics are directly measurable; for instance, the items may be classified as short or long even though the length could be measured.

11.2.4 When lots are submitted for purpose of acceptance the decision of acceptance (or rejection) is made on the basis of sampling plan. A sampling plan gives the sampling procedure to be followed with quantitative estimates of the risks to be taken by the producer and the consumer. The sampling plan depends on the product and the 'Quality' of the product supplied. The sampling plan has to be chosen that is best suited to the particular situation. The suitability of any plan can be judged by the properties it possesses. A good sampling plan should invariably accept all good lots, reject all bad lots and the amount of inspection needed should be small and easy to administer in practice.

11.3 The sampling plans may be grouped into three categories. They are called 'single', 'double' and 'multiple' sampling plans.

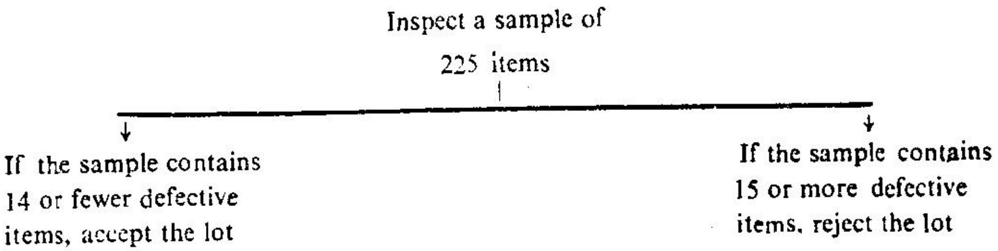
The examples of these types of plans are given below:

INSPECTION LOT SIZE 3400

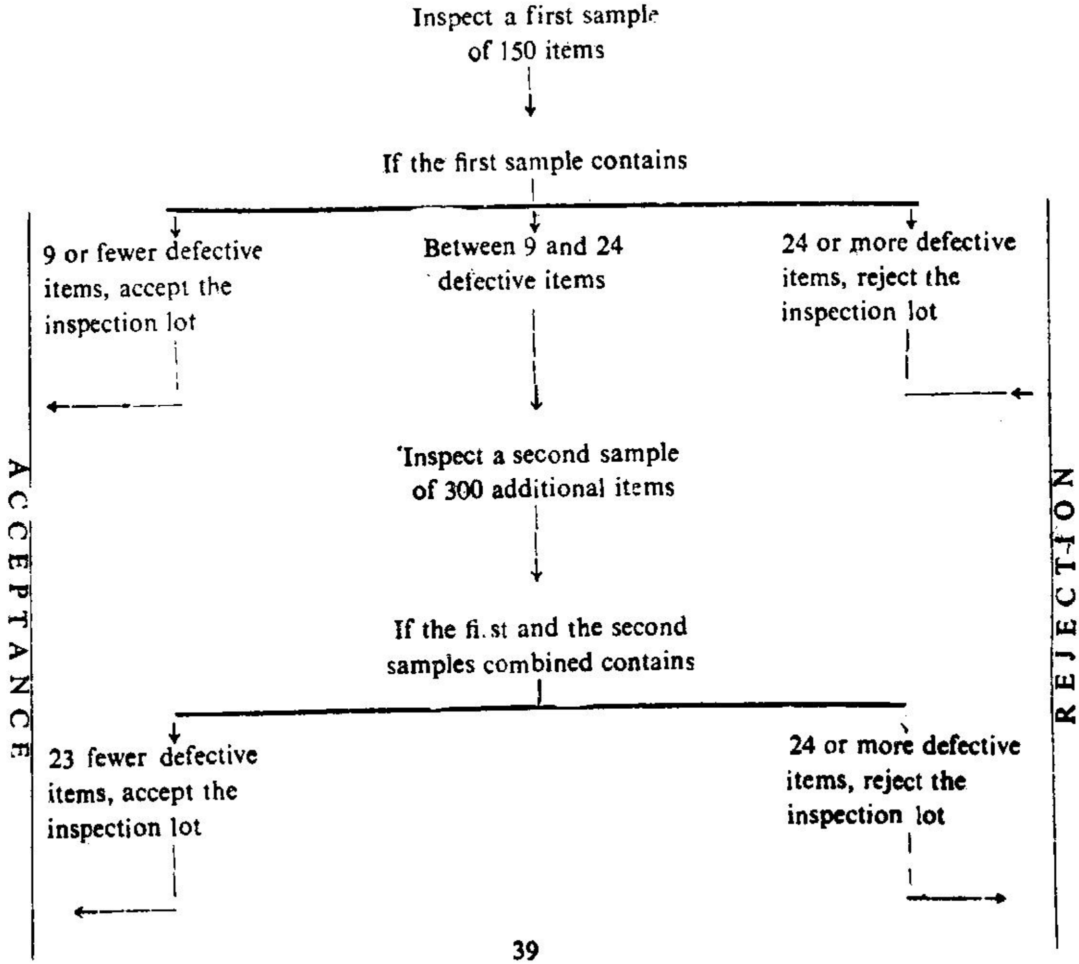
Type of Sampling		*Sample*	*Sample size*	*Combined Samples*		
				Size	*Acceptance No.*	*Rejection number*
(i)	Single	First	225(n)	255(n)	14(c)	15(r)
(ii)	Double	First	150(n_1)	150(n_1)	9(c_1)	24(r_1)
		Second	300(n_2)	450(n_1+n_2)	23(c_2)	24(r_2)
(iii)	Multiple	First	50(n_1)	50(n_1)	1(c_1)	6(r_1)
		Second	50(n_2)	100(n_1+n_2)	3(c_2)	9(r_2)
		Third	50(n_3)	150($n_1+n_2+n_3$)	7(c_3)	13(r_3)
		Fourth	50(n_4)	200($n_1+n_2+..+n_4$)	10(c_4)	16(r_4)
		Fifth	50(n_5)	250($n_1+n_2+..+n_5$)	13(c_5)	19(r_5)
		Sixth	50(n_6)	300($n_1+n_2+..+n_6$)	16(c_6)	22(r_6)
		Seventh	50(n_7)	350($n_1+n_2+..+n_7$)	19(c_7)	25(r_7)
		Eighth	50(n_8)	400($n_1+n_2+..+n_8$)	24(c_8)	25(r_8)

11.3.1 The method of using these plans is given below :

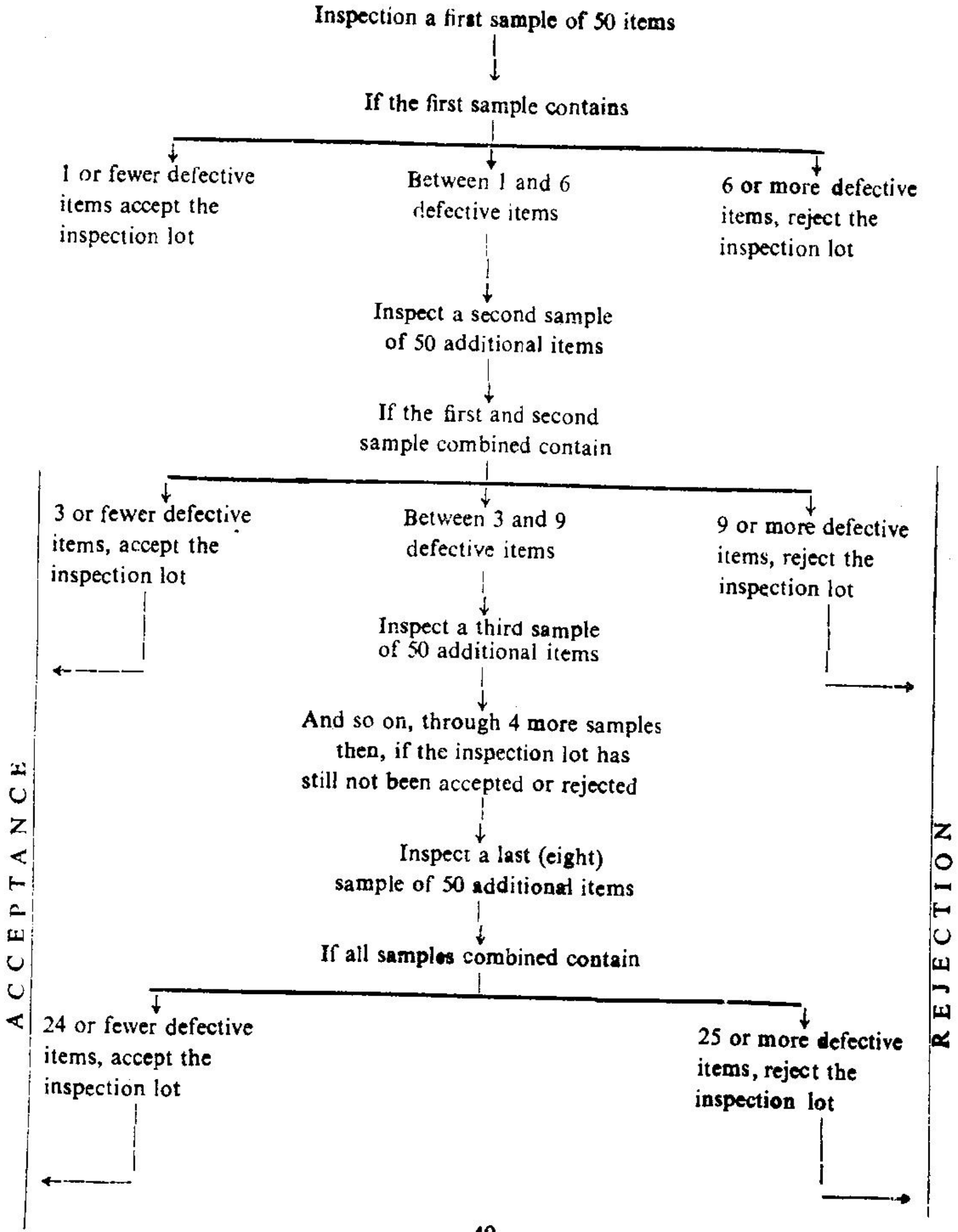
SINGLE SAMPLING PLAN



DOUBLE SAMPLING PLAN



MULTIPLE SAMPLING PLAN



11.3.2 Example (i) is called a Single Sampling Plan as the **acceptance or** rejection is decided on the basis of a single sample drawn from the lot. A plan of this type requires three quantities to be specified: **the lot size**, that is, the number of items in the lot (denoted by N); **the sample** size, that is, the number of items in the sample (denoted by n); the acceptance number, that is, the number defective items allowable in the sample (denoted by c) and a rejection number (denoted by r).

Example (ii) is called a Double Sampling Plan. This involves the possibility of taking a second sample from the inspection lot and basing the decision of acceptance (or rejection) on the two samples combined. Thus, after the first sample, the lot may be accepted or rejected by taking up of another sample. Such a plan is specified by the lot size (N), first sample size (n_1), first acceptance number (c_1), first rejection number (r_1), second sample size (n_2), second acceptance number (c_2), for the two sample combined and a second rejection number (r_2) for both the samples combined.

Example (iii) is called a Multiple Sampling Plan where there is possibility of taking more than two samples before a decision is reached. This is an extension of the double sampling plan and is completely specified by the lot size (N), first sample size (n_1), first acceptance number (c_1) first rejection number (r_1) second sample size (n_2), second, acceptance number (c_2) for the two combined samples, second rejection number (r_2) for the two samples combined and so on.

QUESTIONS

1. Why is industrial inspection necessary?
2. Define: Tolerance, limits, interference, allowance, selective assembly.
3. What are the factors that determine the setting up of tolerances for an item?
4. Explain what is meant by direct measurement, comparison measurement and direct check measurement with examples.
5. Write brief notes on : Micrometer, Plug, Ring, and Snap Gauges, Gauge Blocks, Dial Indicators, and Thread Gauges.
6. Describe the role of optical instruments in inspection in industry.

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