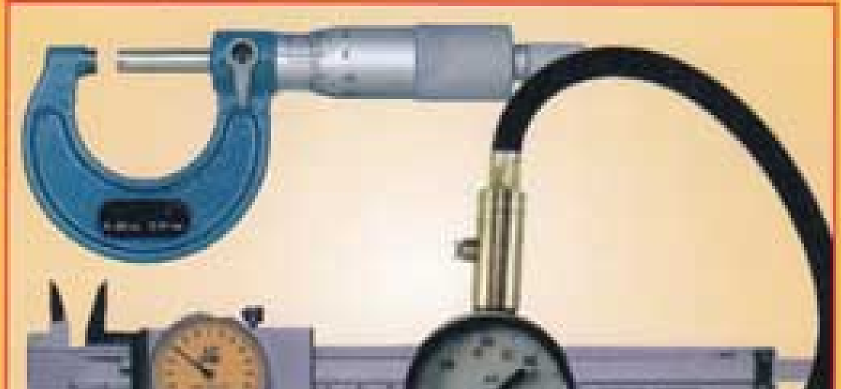
THIRD YEAR DIPLOMA COURSE IN
MECHANICAL ENGINEERING GROUP

'G'
Scheme
Semester
V
MSBTE

METROLOGY AND QUALITY CONTROL

VINOD THOMBRE-PATIL



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Text Book Of

METROLOGY AND QUALITY CONTROL

For

Semester - V

Third Year Diploma Courses in Mechanical and Production Engineering/Production Technology

As Per MSBTE's 'G' Scheme Syllabus

Vinod Thombre Patil
B.E. (Mech.) M. Tech. (Energy Technology)
Vice-Principal and Head of Department - Mechanical,
S. H. Jondhale Polytechnic, Dombivili

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Dedication …

In the loving memory of my Father,

Late Mr. S. T. Thombre Patil
Advocate, Jalna.

Thanks to my Wife,

“Apeksha”

and Beloved Son,

“Abhishek”

Preface ...

I am glad to present the Vth edition of book entitled **"Metrology and Quality Control"** for IIIrd year Diploma in Mechanical engineering as per the "G" Scheme code syllabus prescribed by MSBTE.

I have observed the students facing extreme difficulties in understanding the basic principles and fundamental concepts without adequate solved problems along with the text. To meet this basic requirement of students, sincere efforts have been made to present the subject matter with frequent use of figures and lots of numerical examples.

I am thankful to Mr. Dineshbhai Furia, Mr. Pradeepbhai Furia, Mr. Jigneshbhai Furia, Mr. Shashikant Patel, Mr. Malik Shaikh, Mrs. Manasi Pingle, Ms. Chaitali Takle and Mr. Ramesh Zunjare of Nirali Prakashan along with their staff members for bringing this publication timely to the Market.

I must acknowledge special gratitude to Mr. Raosaheb Patil Danve (M.P. and BJP Chief - Maharashtra), Mr. Ankushrao Tope (President), Er, Rajesh Tope (Secretary of Matsyodari Shikshan Sanstha, Jalna), Er. Sagar Jondhale (Director, Jondhale Educational Group), Mr. Pawar Uttamsingh (Ex. M. P., Jalna), Mrs. Aglawe Vimal (President, District Congress, Jalna), Mr. Aglawe M. R., (Designated Member, Maharashtra Revenue Tribunal, Aurangabad), Dr. Ram Reddy, (Principal, LRT College of Engineering, Mumbai), Dr. R. G. Tated (Principal, Sandip Foundation, Nashik), Prof. Shinde N. N. (HOD – Energy Technology, DOT, SUK), Prof. Hemant Sarje (Dean, Fabtech Technical Campus, Sangola), Dr. Nehte (Principal, Father Agnel), Prof. S. L. Pawar (HOD, E&TC DEPT, Fabtech Technical Campus), Prof. S. A. Magar (Assistant Professor, Vidyalankar, Mumbai), Dr. Pable M. J. (G. P. Bandra), Prof. R. K. Nandarage (Principal, S. S. Jondhale Polytechnic, Ambernath), Prof. Patil A. B. (Principal, IT, Ulhasnagar), Prof. Nayak (Principal, VPM, Thane), Prof. Ibrahim (Principal, Saboo Siddiqui Polytechnic, Mumbai), Prof. R. B. Sholapurkar, (Principal, Virar Polytechnic), Prof. Chavan Manoj (Principal, JMM Trust's Polytechnic, Shahapur), Prof. Nathe (Principal, G. P., Thane), Prof. Taskar (Principal, G.P., Mumbai), Prof. Kantute (Principal, SBM, Mumbai), Prof. Bavaskar (Principal, Muchala Polytechnic, Thane), Prof. Tandon (Principal, Bharati Vidyapeeth, Mumbai), Prof. Mange Amar (Principal, Pillai Polytechnic, Rasayani), Prof. Pawar (Principal, Acharya Polytechnic, Shelu), Prof. Tambe (Principal, Shantiniketan Polytechnic, Panvel), Prof. Bilwade (Principal, Khopoli Polytechnic), Prof. Padmavat (Principal, IET, Aurangabad), Prof. Susheel Kumar (Principal, Shreeram Polytechnic, Airoli), Prof. Nagesh Patil (Principal, Mhatre Polytechnic, Badlapur), Prof. Sanap (HOD, G. P., Nashik), Prof. Anoop Kumar and Prof. Sawant (H.O.D., S.S.J.P., Ambernath), Prof. S. N. Mahajan (H.O.D., V.B.V.P., Vasai), Prof. Deshpande (H.O.D., Khopoli Polytechnic), Prof. Wagh (DOT, Shivaji University), Prof. Ansari, Prof. Lonkar, Prof. Khandekar, Prof. Ambadekar, Prof. P. P. Chaudhari, Prof. Shele, Prof. Pandit, Dr. Kamble, Prof. Salunkhe, Prof. Sanghvikar (G.P., Thane), Prof. Gawande, Prof. Kadam, Prof. Lahoti (Shreeram Polytechnic, Airoli), Prof. Bhosale, Prof. Vishwakarma (V.B.V.P., Vasai), Prof Jamiloddin (HOD, Kalsekar Polytechnic, Panvel), Prof. Nehal Muchala (HOD, Thakur Polytechnic), Prof. Bindale (HOD, Muchala Polytecnic, Thane), Prof. Sable and Prof. Wagh (HOD, Tasgaonkar Polytechnic, Karjat), Prof. M. G. Bagale, Prof. Killedar (G.P., Solapur), Prof. Kamble (HOD, Navjeevan Polytechnic, Mumbai), Prof. A. S. Dayma, Prof. K. A. Jawalkar, Prof. S. S. Bhadane (HOD, Asangaon) and many more, who have extended their co-operation and suggestions time to time.

I specially thank my colleagues and students for motivation and encouragement for completing this book.

Any errors or suggestions for the improvement of this book brought to notice will be thankfully acknowledged and incorporated in the next edition.

Vinod Thombre Patil

Syllabus ...

1. Introduction of Metrology (09 Hours, 18 Marks)

1.1 Metrology Basics (06 Marks)

Definition of metrology, Objectives of metrology, Categories of metrology, Scientific metrology, Industrial metrology, Legal metrology, Need of inspection, Revision of - Precision, Accuracy, Sensitivity, Readability, Calibration, Traceability, Reproducibility, Sources of errors, Factors affecting accuracy, Selection of instrument, Precautions while using an instruments for getting higher precision and accuracy. Concept of least count of measuring instruments (No questions to be set on revision).

1.2 Standards and Comparators (12 Marks)

Definition and introduction to Line standard, End standard, Wavelength standard and their comparison, Slip gauge and its accessories. Definition, Requirement of good comparator, Classification, Use of comparators, Working principle of comparators, Dial indicator, Sigma comparator, Pneumatic comparator- high pressure differential type, Electrical (LVDT), Relative advantages and disadvantages.

2. Limits, Fits, Tolerances and Gauges (06 Hours, 08 Marks)

2.1 Concept of Limits, Fits, and Tolerances, Selective assembly, Interchangeability, Hole and Shaft basis system, Taylor's principle, Design of plug, Ring gauges, IS919-1993 (Limits, Fits & Tolerances, Gauges IS 3477-1973), Study of relation gauges, Concept of multi gauging and inspection.

3. Angular Measurement (04 Hours, 08 Marks)

3.1 Concept, Instruments for Angular measurements, Working and Use of Universal Bevel Protractor, Sine bar, Spirit level, Principle of Working of Clinometers, Angle Gauges (With Numerical on Setting of Angle Gauges). Angle dekkor as an angular comparator.

4. Thread and Gear Metrology (06 Hours, 16 Marks)

4.1 Screw Thread Measurements (08 Marks)

ISO grade and fits of thread, Errors in threads, Pitch errors, Measurement of different elements such as Major diameter, Minor diameter, Effective diameter, Pitch for Internal and External threads, Three wire method, Thread gauge, Screw thread micrometer, Working principle of floating carriage micrometer.

4.2 Gear Measurement and Testing (08 Marks)

Analytical and functional inspection, Measurement of tooth thickness by constant chord method, Base tangent method, Gear tooth vernier, Errors in gears such as backlash, Run out, Composite, Concentricity.

Parkinson gear tester.

5. Testing Techniques (06 Hours, 10 Marks)

5.1 Measurement of Surface Finish (06 Marks)

Primary and secondary texture, Sampling length, Lay, Terminology as per IS 3073-1967, Direction of lay, Sources of lay and its significance, CLA, Ra, RMS values and their interpretation, Symbol for designating surface finish on drawing, Various techniques of qualitative analysis.

5.2 Machine Tool Testing (04 Marks)

Parallelism, Straightness, Squareness, Coaxiallity, Roundness, Run out, Alignment testing of machine tools such as Lathe, Milling machine and Drilling machine as per IS standard procedure. Study of optical flat for flatness testing.

6. Quality Control (07 Hours, 12 Marks)

6.1 Quality (06 Marks)

Definitions, Meaning of quality of produce & services, Quality characteristics, Quality of design, Quality of conformance, Quality of performance, Concept of reliability, Cost, Quality assurance, Cost of rework & repair, Quality & Inspection, Inspection stages.

6.2 Total Quality Management (06 Marks)

Principles and concept of total quantity management.

a) Quality Audit: Concept of audit practices, Lead assessor certification.
b) Six sigma: Statistical meaning, methodology of system improvement.
c) Introduction of ISO 9001-200, ISO-14000 and TS 16949.

7. Statistical Quality Control (10 Hours, 28 Marks)

7.1 Statistical Quality Control (20 Marks)

Basics of Statistical concepts, Meaning and importance of SQC, Variable and attribute measurement. Control charts – inherent and assignable sources of variation, Control charts for variables – $\overline{X}$ & R charts, control charts for attributes p, np, C charts, process capability of machine, C_p and C_{pk} calculations, Determination of statistical limits, Different possibilities, Rejection area, Statistically capable and incapable processes.

7.2 Acceptance Sampling (08 Marks)

Concept, Comparison with 100% inspection, Different types of sampling plans, Sampling methods, Merits and demerits of acceptance sampling. OC Curve.

***

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5. Screw Thread Measurements 5.1 – 5.28

8. Machine Tool Testing 8.1 – 8.28

9. Quality Control 9.1 – 9.22

10. Total Quality Management 10.1 – 10.30

11. ISO Standards 11.1 – 11.10

12. Statistical Quality Control 12.1 – 12.58

13. Acceptance Sampling 13.1 – 13.16

***

Chapter 1

METROLOGY BASICS

About This Chapter ...

This chapter has a weightage of 6 marks and assigned duration is 3 hours. In this chapter, we learn Basics of metrology such as definitions of metrology, inspection, accuracy and precision etc. We also learn types of metrology, Sources of errors, Factors affecting accuracy, Selection of instruments, Precautions while using an instrument.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	04 Marks	S-09	04 Marks
W-09	04 Marks	S-10	04 Marks
W-10	08 Marks	S-11	04 Marks
W-11	11 Marks	S-12	08 Marks
W-12	08 Marks	S-13	08 Marks
W-13	12 Marks	S-14	08 Marks
W-14	08 Marks	S-15	04 Marks
W-15	12 Marks	S-16	04 Marks
W-16	08 Marks	S-17	04 Marks

1.1 METROLOGY

QUESTIONS

1. What is Metrology? **(W-10, 12, S-13)**
2. Define the term 'Metrology'. State its types **(W-08,11, S-12, S.Q.P., S.T.P.-I, S-16)**
3. Define metrology and mention its necessity. **(S-14, 15, W-16)**
4. Define 'Metrology' and state the necessity of metrology. **(W-16)**

- **Metrology** is the science of measurements. It deals with (i) Establishment, (ii) Reproduction, (iii) Conservation and (iv) Transfer of units of measurements and their standards.
- Metrology consists of comprehensive study of different measuring instruments for defining precision, accuracy, possible sources of errors, and methods for elimination of errors to improve accuracy.
- Generally, raw material received by a manufacturing industry from an external source (supplier) is processed by number of operations carried out on various machines to give a final finished product, which can be sold to customers in market.
- During entire process of transformation of raw material into finished product, inspection is carried out for inspecting the product being processed at various

stages of manufacturing. It is done with the help of measuring instruments and gauges.

1.1.1 Scope of Metrology

- In addition to linear and angular measurements, "Metrology" covers the following aspects.
  - **(a) Manufacturing:** Metrology is concerned with the manufacturing of various instruments.
  - **(b) Range and capabilities:** Metrology is used to find the ranges and capabilities of various instruments used for measurement.
  - **(c) Calibration:** Metrology is used to calibrate the measuring instruments according to the prescribed standards with a high degree of accuracy.
  - **(d) Methods of measurements:** Metrology is concerned with the different methods of measurements, essential to obtain precise measurements.
  - **(e) Preparation of design and drawings:** Metrology is concerned with the preparation of design and drawings for different types of gauges.
  - **(f) Maintaining and defining the standards:** For accurate measurements, metrology is concerned with defining and maintaining the standards.

1.1.2 Activities of Metrology

Activities of Metrology are given in following table.

Sr. No.	Activity	Brief Explanation
(i)	Units of measurement	Establishment, reproduction, conservation and transfer of units of measurement and their standards.
(ii)	Inspection	Testing, verification and standardization of measuring instruments.
(iii)	Testing	After carrying out the measurements on prototype models of measuring instruments, the results obtained can give predictions about the performance of actual instruments (if developed).
(iv)	Confirmation	Examination of a measuring instrument to verify, whether its specifications confirm with the statutory requirements (standards) or not.
(v)	Gauges	Design, manufacturing and testing of all kinds of gauges.

1.1.3 Objectives or Necessity of Metrology

QUESTIONS

1. State the necessity of metrology. **(W-11, S-12,14)**
2. Define metrology and state its four objectives. **(S-15, S.T.P.-I, S.Q.P.**
3. Define 'Metrology' and state the necessity of metrology. **(W-16)**

(a) To achieve **standardization**.
(b) To find out **sources of errors**.
(c) Useful in **selection** of proper measuring **instruments and gauges**.
(d) To have good **accuracy** and **precision**.

(e) To **reduce cost** of inspection by effective and efficient use of available facilities.
(f) To **evaluate newly developed** products.
(g) To enhance **consumer satisfaction**.
(h) To **reduce rework** and **rejections**.
(i) It helps in **achieving interchangeability** of parts.

1.1.4 Categories or Types of Metrology

QUESTIONS

1. State the various types of metrology. **(W-10, S-16)**
2. Define the terms, 'Scientific metrology' and 'Industrial metrology'. **(W-13)**
3. List down different categories of metrology. State specific use of each of them. **(S.T.P.-I)**
4. What is legal metrology? State any two functions of legal metrology. **(S-17)**

Metrology is categorized in three categories with different levels of complexity and accuracy.

(a) Scientific Metrology: It deals with the *establishment* and *development* of *measurement standards* along with their maintenance.

(b) Industrial Metrology: It has to ensure the *'adequate functioning of measuring instruments'* used in 'industry' as well as in 'production and testing' processes.

(c) Legal Metrology: Mandatory and legal bindings are specified on units of measurement, methods of measurement, measuring instruments, which are to be strictly followed during the act of measurement. Legal metrology is concerned, to find out, whether the above conditions are fulfilled or not ?

Activities of Legal Metrology :

(i) Legal metrology assures that, act of measurement is secured and accurate.
(ii) Legal metrology includes control testing, verification, standardization and testing of measuring instruments.
(iii) Legal metrology is concerned with measurements, where they influence the transparency of economic transactions, health and safety.

1.2 INSPECTION

QUESTION

1. What is the need of inspection in industries? **(W-08, 11, 12; S-09**

Definition:

- *Inspection* is the act of checking of all materials, products or parts of a component produced at various stages during entire production activity.
- Inspection can be considered as first step, "to check, how many manufactured components can be accepted for further operations or shipment sales to market by confirming the actual dimensions of component with the design specifications".
- The manufactured components not satisfying design specifications are called as **rejected components**.
- Thus, we conclude that, the act of inspection involves the practice of comparing materials, products or components with the established standards.

Need of Inspection:

1. It ensures that, the product manufactured confirms to the desired standards and specifications.

2. Results of inspection provides a way to find out the drawbacks or shortcomings in the current production process, producing defective components. These results can be analyzed to modify existing production process parameters, so that, number of defectives can be reduced to minimum.
3. It judges, "how well the purchase department is performing to procure (buy) raw material of best quality from market, which will be processed to produce high quality finished products".
4. It finds out and removes the defective products from the entire lot of products manufactured. Therefore, only non-defective products will be available in market, which results in customer satisfaction about quality products and goodwill of the organization.
5. It helps to co-ordinate the functions of various departments of the organization, such as purchase, production, quality control, sales etc.
6. It makes possible the manufacturing of interchangeable parts, which is a key factor in mass production.

In short, metrological inspection of the product decides the closeness of its actual dimensions with the given design specifications or standard values. If the permissible deviations from the standard values are known, the results of inspection determine the acceptability of product. However, usefulness and efficiency of inspection activity depends upon various factors like reliability, precision and accuracy of the measuring instruments used in inspection.

1.3 ACCURACY AND PRECISION

1.3.1 Accuracy

- Accuracy compares the measured value of a manufactured component with its true value.
- True value means the specified value of a component before start of production.
- Measured value is the reading obtained after inspecting the actually produced component.
- Therefore, **accuracy** is defined as, "the closeness of measured value of component produced with its true value".
- The act of measurement should indicate true dimensions of a part. But, in actual practice no measurement can be absolutely accurate. Therefore, there is always some error and the amount of error or inaccuracy depends upon various factors.
- More the error, less will be the accuracy and vice versa.

1.3.2 Factors Affecting the Accuracy

QUESTION

1. List any four factors affecting accuracy of instruments. **(W-13, 15)**

1. **Calibration standards:** Accuracy may be affected by ambient (atmospheric) conditions, such as, expansion of metal used in measuring instruments due to rise in temperature, elastic properties of metals, and stability of instrument over a long period etc.
2. **Workpiece being measured:** Accuracy may be affected by the condition of workplace such as, cleanliness, surface condition, proper arrangement etc.

3. **Measuring instruments:** Measuring instruments and hence accuracy may be affected by sources of errors, such as, hysteresis, backlash, friction, zero drift error, deformation in handling or use of heavy workpieces.
4. **Human error:** The person or inspector carrying out the measurement may not have the required skill. Improper training or lack of handling skill or casual attitude of inspector may affect the measured value and hence accuracy.
5. **Environment influences:** Changes in atmospheric (ambient) conditions such as temperature, vibrations, lightening, pressure etc. may affect the accuracy.

1.3.3 Precision

- Precision has no meaning for only one measurement, but exists only when number of measurements are carried out for the same quantity under identical conditions.
- For any set of measurements, the individual results obtained may vary slightly from the **mean value**. **Lesser the variations** in the measurements, **more** is the **precision**. To understand 'precision', read the example given below.
- **Example:** Let us take a component having true length of 100 mm. The inspector/worker takes number of readings to measure length of this component, with the same instrument, in same environmental conditions and within short intervals of time. If the readings obtained are 100.001, 100.002 and 100.003 mm, then we say that, readings are not close to true value. Therefore readings are said to be in-accurate.
- But, if we calculate the average value or arithmetical mean value of these readings, we get,

$$\bar{x} = \frac{x_1 + x_2 + x_3}{3} = \frac{100.001 + 100.002 + 100.003}{3}$$

$$= \mathbf{100.002\ mm}$$

This value is referred as **mean value**.

- We observe that, readings taken are close to mean value. Also, they are close to each other. This is called as precision.
- Therefore, **Precision** is defined as, '*the repeatability of a measuring process'. For example, if numbers of measurements are carried out for a single quantity in identical conditions (i.e. by the same observer, with same instrument and within short intervals of time) and all readings are close to each other as well as mean value, the readings are said to be precise.*
- Modern industrial system is based on mass production, where, the different parts of a machine are made in large quantities in different plants and assembled in some another plant. So, it is essential that any one part, chosen randomly should fit properly with any other mating part.

1.4 DIFFERENCE BETWEEN ACCURACY AND PRECISION

(W-09, 11; S-10, 13, 14)

QUESTION

1. Distinguish between accuracy and precision with suitable sketch. (W-15)

Accuracy	Precision
1. Accuracy is the agreement of measured value with the true value of measured quantity.	1. Precision is the repeatability of measuring process. It shows, 'how well identically performed measurements agree with each other'.
2. Accuracy is concerned with true value.	2. Precision is concerned with mean value. Precision has no concern with true value. Precision has no meaning for only one measurement, but exists only when number of measurements are carried out for measuring same quantity under identical conditions.
3. If true value is 10 mm, then 9.99 mm is more accurate than 9.91 mm.	3. If true value is 10 mm, and readings obtained are 10.001, 10.002, 10.003, 10.004 and 10.005 mm, then mean value of readings will be 10.003 mm. Therefore, the measurements are said to be precise, because all the readings are very close to their **mean value** (10.003 mm).
4. It is difficult and expensive to have good accuracy.	4. It is much easier and cheaper to achieve precision than to achieve great accuracy.
5. High accuracy cannot be obtained with low precision.	5. High precision can be obtained with low accuracy.

Note: The difference between accuracy and precision can be easily understood. The arrangement shown in the Fig. 1.1 corresponds to "A shooting range", where a person is asked to strike a target represented by a centre circle.

- The centre circle represents true value. The marks 'X' indicate results/shoot points achieved by the striker after shooting 6 bullets on the target.

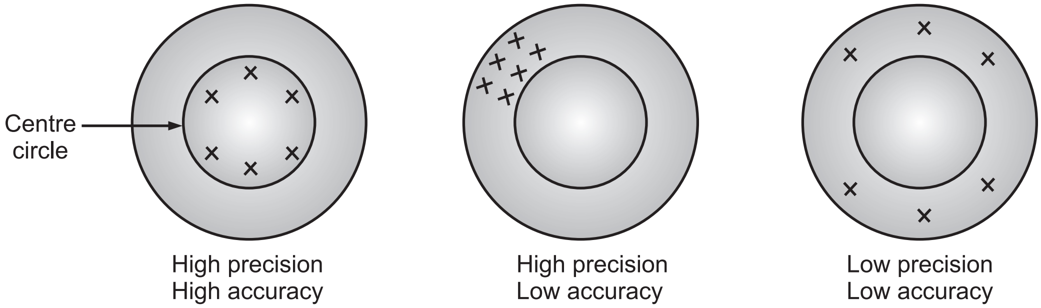


Fig. 1.1

Precautions while using an Instrument to get 'High Accuracy and Precision':

1. Every important source of inaccuracy should be known.
2. As errors cannot be eliminated completely, therefore, efforts should be made to reduce them to least value.
3. As far as possible, the **principle of similarity** must be followed i.e. the atmospheric conditions, at which, measurements are carried out must be similar to the conditions, at which, the instruments was calibrated.
4. Magnifying devices should be used in the instruments, so that, proper readings can be taken by involving skilled persons to avoid parallex errors.

1.5 SENSITIVITY, READABILITY, REPEATABILITY, REPRODUCIBILITY

Sensitivity:

- Sensitivity is defined as, *"the ability of a measuring device to detect small variations in a quantity being measured"*. Higher the ability of such detection of an instrument, more sensitive it is.
- If an instrument is more sensitive than requirement, the readings displayed on its graduated scale will fluctuate continuously due to variations in external parameters and thus, it becomes difficult for operator to obtain a reliable reading.
- The external parameters include temperature of surrounding atmosphere, vibrations etc.
- Therefore, too much sensitivity leads to affect the working of instrument. It will adversely affect the accuracy and precision of measurements.

QUESTIONS

1. Explain the terms, (i) Readability, (ii) Repeatability, (iii) Reproducibility. **(W-10)**
2. Explain the terms: (i) Repeatability, (ii) Reproducibility. **(S-13)**

Readability: **(W-10)**

- Readability is defined as, *"the ability of a measuring instrument or device to have its indications converted to a meaningful number".*
- Refer following methods used to increase readability of measuring instruments.

(i) Micrometers can be made more readable, if they are provided with vernier scale.
(ii) Measuring instruments can be made more readable, if magnifying devices are used.

Note: Sensitivity and readability are primarily associated with measuring instrument, while precision and accuracy are associated with method of measurements.

Repeatability: **(W-10, S-13)**

- Repeatability is defined as, *"the ability of measuring instrument to repeat the output readings consistently".*
- In other words, repeatability is defined as, "the closeness of readings obtained during multiple number of measurements of same quantity, when individual measurements are carried out by same observer, using same measuring instrument under same environmental conditions within short intervals of time.

Reproducibility: **(W-10, S-13)**

- Reproducibility is defined as, *"the closeness of readings obtained during multiple number of measurements of same quantity, when individual measurements are carried out by different observers, by different methods, using different instruments under different environmental conditions".*

1.6 CALIBRATION (W-12, 13, 14)

QUESTIONS

1. Why it is necessary to calibrate measuring instrument and unit gauges? **(W-12, 14)**
2. Explain the terms, calibration and traceability. **(W-13)**

- Calibration is defined as, *"the process of framing of scale of measuring instrument by applying some standards".*
- Calibration is said to be a **pre-measurement** process, carried out at the **time of manufacturing** the measuring instrument.
- In simple words, it is the process of marking the lines on scale of measuring instrument by applying some standards, which are agreed and followed all over world.
- Calibration is the entire procedure laid down (specified), which includes marking, adjusting, checking etc., so that, reading obtained will confirm to the agreed standards.

Necessity of Calibration:

- Consistent use of instruments affects their accuracy. If we need to maintain the accuracy, the measuring instruments must be checked and followed recalibrated.
- The periodic schedules of such calibration process depend upon the severity of use, surrounding environmental conditions, required accuracy etc.
- It is tried to perform 'calibration' under those environmental conditions, which are very close to the conditions, under which, actual measurements will be carried out.
- Even if, the sensing system and measuring system are different, then also it is necessary to calibrate the system, so that, the error producing components are eliminated or rectified.
- Calibration is done by applying the standards in such a way that, 'Output read-out device shows zero output for zero input' and similarly, 'it should show an output equivalent to the known input'.

1.7 TRACEABILITY

QUESTION

1. Explain the terms, "calibration and traceability". **(W-13, 15)**

- In order to maintain accuracy and interchangeability in the manufactured parts by various industries in a country, it is necessary that, each and every industry located anywhere in the country should follow the standards of units and measurements specified by 'National Standards of Country'. Similarly, standards of any country should follow International standards.

- This process is called traceability.
- Traceability is defined as, "transfer of international standards (higher grade) to national standards (lower grade) and then transfer of national standards to working standards of all industries located in that country".
- Traceability is also defined as, *'the property to trace working standards (local) from National Standards and to trace National Standards from International Standards'.*
- Due to traceability, valid calibration of a measuring instrument can be established as per the specified standards.
- International standards and National standards are also called as *primary and secondary standards* respectively.

1.8 MAGNIFICATION (S-08)

- **Magnification** is the process of increasing the magnitude of output **many times** to make it **more readable**.
- It is made possible by using principles of mechanical, optical, electrical, electronics or pneumatics etc.
- **Electrical magnification** is based on *'sensing change in inductance or capacitance, which is measured by a Wheatstone bridge'.*
- **Electronic magnification** is more reliable and accurate.
- **Pneumatic magnification** is preferred and suitable for internal measurements. For example: Measurement of inside diameter of a hole.
- **Mechanical magnification** is usually grouped or combined with any other type of magnification to get more readable output. This arrangement combines the advantages of two principles for reading the output very easily.

1.9 ERROR AND SOURCES OF ERRORS IN MEASUREMENTS

QUESTIONS

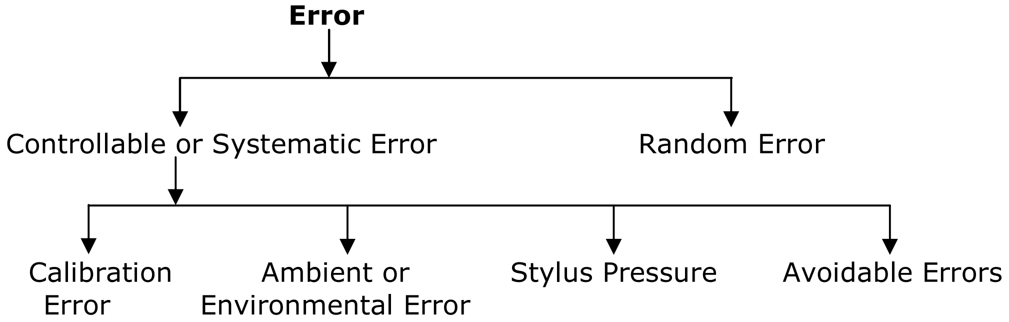
1. List the major errors in measurements and explain. **(S-11)**
2. Explain the various sources of errors in measurements. **(W-16)**

Error:

- *Error* is the 'difference between measured value and true value of the measured quantity'.
- The errors may arise due to characteristics of measuring instruments or the process of measurement may be influenced by environmental conditions.

1.9.1 Classification of Errors/Sources of Errors

- While taking measurements with the help of different measuring instruments, several types of errors may arise.
- These errors can be broadly classified into two categories, namely (a) Controllable or Systematic errors and (b) Random errors.



(a) Controllable or Systematic Errors:

These errors are controllable in both, their magnitude as well as direction (or algebraic sign). If proper attempts are made to analyze these errors, they can be identified, reduced and controlled.

Controllable errors are mainly due to:

1. Calibration errors:

- These types of errors are caused due to variation in the calibrated scale from its nominal value.
- The actual length of line standards and end standards such as engraved scales and slip gauges respectively may vary from nominal value by small amount.
- Sometimes, inertia and hysteresis effects of instrument do not allow the instrument to give accurate readings. For example: Signal transmission errors, such as, voltage drop along the wires connecting sensing element (transducer) with output readout device (electric meter) of measuring instruments.

2. Ambient or environmental errors:

- Variations in the atmospheric conditions from the internationally agreed standards (such as 20°C temperature and 1.01325 bar pressure) may introduce errors in the measured sizes of component.
- Variation in the atmospheric temperature is more severe factor. Error occurs in the measurement due to expansion or contraction of either component being measured or measuring instrument.
- The internationally agreed temperature during measurement is 20°C. Therefore the measuring instruments or gauges are made and calibrated to correct sizes at 20°C temperature. However, it is not necessary that, all the measurements must be taken at this standard temperature.
- Alternatively, if all the measurements of workpiece are carried out by measuring instrument at same temperatures.
- But, if temperatures of measuring instrument and work-piece are not same, then error in measurement is bound to be there. This amount of error is directly proportional to temperature difference. Difference in their temperatures give rise to errors in the measurements.

3. Stylus/Contact pressure:

- Stylus or contact pressure applied to measuring instrument and the work-piece being measured at the time of measurement is important to have precise measurement. Stylus or spindle of the instrument is made up of harder metal. Therefore, if contact pressure applied is more than required, it may distort the work-piece damaging its shape, or dimension being measured. This will introduce an error in measurement due to improper contact/stylus pressure applied.
- Whenever any component is measured after applying contact pressure (stylus pressure), its surface may get deformed.
- **For example:** If diameter of shaft is to be measured by using micrometer, then variation in the contact pressure applied by the anvils of micrometer on the surface of shaft (whose diameter is to be measured) may lead to errors in readings. To avoid this effect of variation in contact pressure, the micrometer is fitted with a ratchet mechanism with an operating thimble. The ratchet slips, when the contact pressure applied is greater than the minimum required contact pressure.

4. Avoidable errors/Observational errors:

- These errors mainly occur due to misalignment of the work-piece centers. The error due to misalignment is caused, when the centre line of work-piece is not perpendicular to the lines of graduations or divisions engraved on scale.

- **For example:** When reading is taken with the help of a pointer, then some error may be induced in measurement, if the graduated scale does not lie in the plane, in which, the pointer moves. Refer Fig. 1.2. This type of error is called as **Parallax error**. This error can be avoided by modified instrument.
- **For example:** In order to remove Parallax error, a good precision instrument is fitted with a mirror placed or located behind the graduated scale. Correct reading is taken when the pointer coincides with its image seen in the mirror.

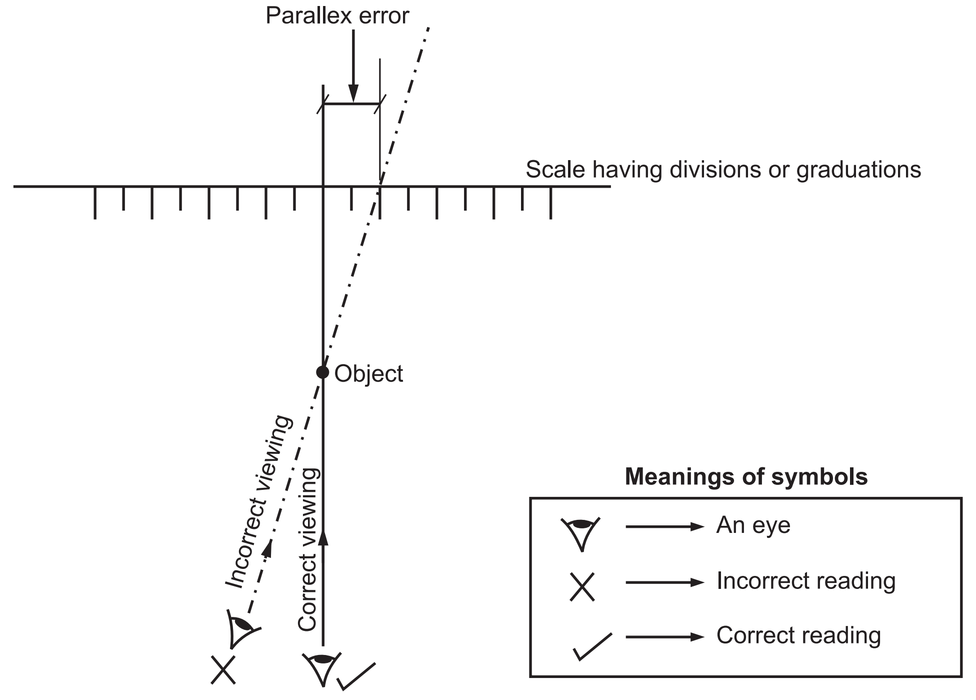


Fig. 1.2: Parallax error

- One more observational error may occur due to incorrect positioning of measuring instrument. It is called as instrument location errors.
- **For example:** Temperature measurement of air in a room. If a measuring instrument such as, 'Thermometer is placed in sunlight, it may be heated due to direct radiations incident on its surface. Therefore, the reading given by thermometer will be obviously inaccurate, and more as compared to room temperature.

(b) Random errors/Unavoidable errors:

- This type of errors are accidental in nature, and they occur randomly at any time.
- Specific causes of their occurrence cannot be determined by any method. Therefore they cannot be predicted or avoided.
- Random errors are **non-consistent**, but they are inherent in the measuring system.
- Sources of these random errors may be,
  - (i) Small variation in the positions of standard and the work-piece being measured, during set up of measuring arrangement.
  - (ii) Little displacement of lever joints in the measuring instruments.
  - (iii) Transient fluctuations in friction in measuring instrument.
  - (iv) Operator error in reading pointer type displays or engraved scales.

1.10 DIFFERENCE BETWEEN SYSTEMATIC AND RANDOM ERRORS

Systematic Errors/Avoidable Errors	Random Errors/Unavoidable Errors
1. These errors are consistent and repetitive in nature and are of similar form.	1. These errors are non-consistent and accidental in nature.
2. They occur due to improper conditions or methods of measurements.	2. They are inherent in the measuring system or measuring instruments. It is assumed that random error occurrence is bound to be there.
3. Except human error, all other systematic errors can be controlled in magnitude and sense.	3. Specific causes, magnitude and sense of random errors can not be determined from the knowledge of measuring system or conditions at the time of measurement.
4. These errors can be identified and reduced, if attempts are made to analyze them.	4. These errors can not be eliminated, but the results obtained can be corrected.
5. They include calibration errors, errors due to variation in environmental conditions, variation in contact pressure, parallax error etc.	5. They include errors caused due to (i) small variations in the positions of Standard and the work-piece, (ii) Slight displacement of lever joints in the measuring instruments, (iii) Transient fluctuations in friction in measuring instrument, (iv) Operator error due to incorrect reading of engraved scale on readout display device.
6. Statistical methods do not operate on the systematic errors.	6. Statistical methods only operate on the random errors.

1.11 FACTORS TO BE CONSIDERED WHILE SELECTING THE SUITABLE MEASURING INSTRUMENT

1. Quantity to be measured, e.g. Length, Height, Angle etc.
2. Range of measuring instrument.
3. Precise measurements.
4. More accuracy.
5. Sensitivity and Readability of instrument.
6. Computability of instrument.
7. Easy to operate.
8. Low capital cost.
9. Easy for maintenance at low cost.
10. Simple in design with constructional details.

1.12 ESSENTIAL CHARACTERISTICS FOR AN ACCURATE MEASURING INSTRUMENT

(a) Measuring instrument should possess the desired requirements and consistent *'accuracy'*.

(b) Every important source of possible error should be known and the instrument itself should have adjustments to eliminate the errors.

(c) If error cannot be eliminated completely, then at least, the measuring instrument should be capable of reducing it to a very small value.

(d) Less response to avoid influence of varying atmospheric conditions.

1.13 CHARACTERISTICS OF MEASURING INSTRUMENT GIVING PRECISION OR PRECISE MEASUREMENTS

QUESTION

1. State at least four characteristics, which a precision instrument should have to function properly. **(S-12)**

- Dimension of a manufactured part is measured for number of times and number of readings are noted down, to
  (i) Define the extent of precision achieved, and
  (ii) Define how well the obtained readings (measurements) are closer to each other and near their mean (average) value.
- In obtaining high precision, the measuring instrument plays vital role along with the other factors, such as method of measurement, skilled labour and environmental conditions.
- Therefore, measuring instruments should possess the following characteristics:

(a) High degree of sensitivity.	(b) High degree of accuracy.
(c) Good amplification.	(d) Proper calibration.
(e) Minimum inertia.	(f) Less wear.

1.14 PRECAUTIONS WHILE USING AN INSTRUMENT

1. Finished and polished contact surfaces of instrument should not be touched by hand, because the natural acids deposited on the skin are likely to corrode the contact surfaces.
2. Temperature of human body may affect the dimensions of instrument when touched.
3. Before using the instruments, wash the hands thoroughly. The instrument surfaces should be provided by coating thin film of pure petroleum jelly.

4. Standard temperature for measurement is 20°C. But, sometimes it is not possible to maintain this standard temperature while taking measurements, then it is suggested to do measurements, when temperatures of both, the measuring instrument and the workpiece are same. If not, then they should be allowed to attain same temperature may be, other than 20°C, before use.
5. Equipments like slip gauges having high accuracy are allowed to be handled only by using a piece of chamois leather.
6. Brushing over contact surfaces is not recommended.
7. When the measuring instrument is not in use, it should be protected from atmospheric corrosion. For this purpose, the highly finished surfaces are first wiped with a solvent to remove any finger marks and then coated with mixture of heated petroleum jelly and petrol.

1.15 CONCEPT OF LEAST COUNT OF MEASURING INSTRUMENTS

- Whenever two different scales having slight differences in sizes are used, then the difference between them is utilized for the purpose of accurate measurement.
- A measuring instrument has a main scale with 24 divisions (graduations), which are coinciding with 25 divisions of vernier scale.
- Refer Fig. 1.3 showing main scale having each graduation or division of 1 mm. So 25 divisions show the total length of main scale as 25 mm, whereas, 25 divisions on vernier scale measure 24 mm. Therefore, value of each division on vernier scale = $\frac{24}{25}$ = 0.96 mm.
- So, we say that, smallest division on Vernier scale is 0.96 mm, whereas, value of smallest division on Main scale is 1 mm.
- Least count can be calculated by using two methods as given below.

(1) L.C. = Main scale division − Vernier scale division

= 1 − 0.96 = **0.04 mm**

(2) Least count can also be calculated as, *"ratio of value of smallest division on main scale to the number of divisions on vernier scale".*

$$\therefore \quad \text{L.C.} = \frac{\text{Value of smallest division on Main scale}}{\text{Number of divisions on Vernier scale}} = \frac{1}{25} = \mathbf{0.04\ mm}$$

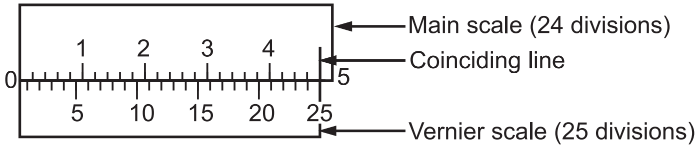


Fig. 1.3: Vernier scale with main scale

Important Points

(a) Basics of Metrology:

Metrology means science of measurements. It includes the activities like testing, verification, standardization and testing of models of measuring instruments.

(b) Categories of metrology:

(i) Scientific metrology, (ii) Industrial metrology and (iii) Legal metrology

Definitions:

(1) *Accuracy* can be defined as, 'the agreement of measured value of quantity with its true value'.

(2) *Precision* can be defined as, 'repeatability of a measuring process'.

(3) *Sensitivity* is the ability of a measuring device to detect small variations in a quantity being measured.

(4) *Readability* refers to the ability of a measuring device to having its indications converted to a meaningful number.

(5) *Repeatability* is the ability of a measuring instrument to repeat the output readings consistently.

(6) *Reproducibility* is the closeness of agreement between the results of measurements of the same quantity.

(7) *Calibration* is the process of framing of scale of the instrument by applying some standards.

(8) *Magnification* means increasing the magnitude of output many times to make it more readable.

(9) *Error* is 'the difference between measured value and true value of the measured quantity'.

Theory Questions for Practice

1. Define metrology. What are its objectives?
2. Write a short note on categories of metrology.
3. Differentiate between accuracy and precision.
4. Define (i) sensitivity, (ii) readability, (iii) repeatability, (iv) reproducibility.
5. Define (i) calibration, (ii) traceability, and (iii) magnification.
6. What is error? Explain the sources of errors in measurement.
7. Differentiate between systematic errors and random errors.
8. What are the factors are to be considered for the selection of instrument?

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2014

1. List any four objectives of metrology. **(4M)**

Ans. Refer Article 1.1.3.

2. Why is it necessary to calibrate measuring instruments and unit gauges ? **(4M)**

Ans. Refer Article 1.6.

Summer 2015

1. Define metrology and state its four objectives. **(4M)**

Ans. Refer Articles 1.1 and 1.1.3.

Winter 2015

1. Explain the terms, 'Calibration' and 'Traceability'. **(4M)**

Ans. Refer Articles 1.6 and 1.7.

2. Distinguish between accuracy and precision with suitable sketch. **(4M)**

Ans. Refer Article 1.4.

3. Define any four factors affecting accuracy of measurements. **(4M)**

Ans. Refer Article 1.3.

Summer 2016

1. Define metrology. State its types. **(4M)**

Ans. Refer Articles 1.1 and 1.1.1.

Winter 2016

1. Define ‘Metrology’ and state the necessity of metrology. **(4M)**

Ans. Refer Articles 1.1 and 1.1.3.

2. Explain the various sources of errors in measurements. **(4M)**

Ans. Refer Article 1.9.

Summer 2017

(a) What is legal metrology? State any two functions of legal metrology. **(4M)**

Ans. Refer Article 1.1.4 (c).

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 2

STANDARDS AND COMPARATORS

About This Chapter ...

This chapter has a weightage of 12 marks and assigned duration is 6 hours. In this chapter, we are learning line standard, end standard, wavelength standard, slip gauges, length bars. We also learn different types of comparators with their advantages, disadvantages and applications etc.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	11 Marks	S-09	24 Marks
W-09	22 Marks	S-10	14 Marks
W-10	06 Marks	S-11	14 Marks
W-11	18 Marks	S-12	20 Marks
W-12	14 Marks	S-13	14 Marks
W-13	10 Marks	S-14	16 Marks
W-14	16 Marks	S-15	22 Marks
W-15	12 Marks	S-16	22 Marks
W-16	18 Marks	S-17	20 Marks

2.1 STANDARDS

- For engineering purposes, the measurements are restricted to the measurement of length, angle and quantities, being expressed in linear or angular terms.
- For every kind of quantity to be measured, there must be a unit to express the result of measurement and a standard (working as a reference) to perform the measurements.
- **Standard** is defined as, "a physical or material presence of a unit".
- A standard is set up and established by authorities as a rule for the measurements of any dimension or quantity. The role of standards is to support the system, which makes measurements possible throughout the world.
- For example, Imperial Standard 'Yard' and 'Metre' have been used as standards.
- But since 1960, the wavelength of light has been adopted as the standard of measurement.

2.2 LINE STANDARD

QUESTION

1. Define line and end standards. **(W-13, 15)**
2. Discuss the characteristics of line standard. **(S-15)**

- When length being measured is expressed as distance between two parallel lines, the standard is known as **line standard**.
- For example:
  (i) Steel rule,
  (ii) Measuring tip
- Here, the unit of length measured is 'yard' or 'metre'.
- Line standards are quick and easy to use, but they are not accurate.
- Accuracy of measurement depends upon the skill of operator performing the measurements, which varies from person to person.
- In addition to human error, calibration error also leads to inaccuracy. During calibration of scale, very small deviations in the graduations or divisions engraved on scale leads to highly inaccurate measurements.

2.2.1 Characteristics of Line Standard

QUESTION

1. Discuss the characteristics of line standard and end standard. **(S-15; W-16)**

1. Scale should be accurately engraved.
2. A scale is quick and easy to use over a wide range.
3. The scale markings are not subjected to wear. But, as significant wear occurs at the measuring ends of scale due to its continuous use.
4. Scales are subjected to parallax error.
5. Scales are not convenient to use for measurement of length of component manufactured with close tolerances, due to more chances of inaccurate results.
6. It is difficult to find out exact length, when the measuring end point lies between two graduations of scale.

2.2.2 Calibration of Line Standards

- Calibration of a line standard is determined by comparison with a master scale in an optical comparator.
- While comparing the unknown scale with the master or standard scale, it is possible to obtain eight sets of observations corresponding to eight possible arrangements of one scale with respect to the other.

2.3 END STANDARD

QUESTION

1. What is end standard ? What are its advantages ? Give example of end standard. **(S-10)**

- When length being measured is expressed as distance between two parallel, flat surfaces, the standard is known as ***End standard***.
- End standards are very commonly used in laboratories and engineering workshops for all the practical purposes.

- For example: (i) Slip gauges, (ii) Ends of micrometer anvils, (iii) End bars, (iv) Jaws of vernier caliper etc.
- End standards can made to a very high degree of accuracy. A modern end standard consists of a hardened block or bar of steel. Their end surfaces are made truly flat and parallel by the process of lapping or superfinishing. Since primary standards are line standards, end standards must be calibrated from line standards.
- Slip gauge is the frequently used end standard in all metrological laboratories. Slip gauges are made of high grade cast steel, which is hardened and stabilized throughout. With the set of slip gauges, combination of slip gauges enables the measurement to be done in the range of 0.001 mm to 100 mm.

2.3.1 Characteristics of End Standard

QUESTIONS

1. Discuss the characteristics of end standard. **(S-15; W-16)**
2. State the characteristics of the end standards. **(S-17)**

1. End standards are highly accurate.
2. Dimensional tolerance as small as 0.005 mm can be obtained.
3. They are not subjected to parallax error.
4. They are commonly used in standard laboratories, precise measurements of parts manufactured with close tolerance.

- However, following characteristics of end standard may lead to error in measurement.
  1. End standards are time consuming in use and prove only one dimension at a time.
  2. They are subjected to wear on their measuring faces, which may lead to error in measurements.

2.4 DIFFERENCE BETWEEN LINE STANDARD AND END STANDARD

QUESTIONS

1. Distinguish between line standard and end standard (Any eight points). **(W-09, 11, 12, 14; S-11, 12, 13,14; S.T.P.-I)**
2. Differentiate between line standard and end standard. **(W-15)**

Sr. No.	Comparative Point	Line Standard	End Standard
1.	**Principle of measurement**	Distance between two engraved lines is used as a measure of length.	Distance between two flat and parallel surfaces is used as a measure of length.
2.	**Accuracy of measurement**	Limited to ± 0.2 mm. For high accuracy, scales have to be used in combination with microscope.	Highly accurate for measurement of close tolerances upto ± 0.001 mm.
3.	**Alignment**	Can not be easily aligned with the axis of measurement.	Can be easily aligned with the axis of measurement.
4.	**Time of measurement**	Quick and easy.	Time consuming.
5.	**Errors**	Parallax error can occur.	Improper wringing of slip gauges may introduce errors. Change in laboratory

Sr. No.	Comparative Point	Line Standard	End Standard
			temperature may lead to some errors.
6.	**Skill**	Semi-skilled workers can do the measurement.	Highly skilled workers are required.
7.	**Manufacturing process**	Simple	Complex
8.	**Cost of equipment**	Low	High
9.	**Examples**	Steel rule and measuring tape.	End bars and slip-gauges.

2.5 LINEAR MEASUREMENT

QUESTION

1. What do you understand by linear measurement ? List the various instruments used for linear measurement ? **(S-12)**

- Linear measurement includes to measurement of length, height and thickness alongwith external and internal measurements.
- Linear measuring instruments are designed either for line measurements or end measurements.
- In linear measuring instruments such as scale, a series of accurately spaced lines is marked.
- Lines marked on scale are called as divisions or graduations. If length of a component is to be measured, then scale is aligned with the component and graduations are read to take down measured value.
- In end measuring instruments, the measurement is taken between two end surfaces, such as, in micrometers and slip gauges.

Classification of instruments used for linear measurement

Direct measuring instruments **Indirect measuring instruments**

Graduated instruments	Non-graduated instruments
(a) Steel rule	(a) Calipers
(b) Vernier caliper	(b) Surface gauges
(c) Vernier height gauge	(c) Straight gauges
(d) Vernier depth gauge	(d) Radius gauges
(e) Micrometers	(e) Slip gauges

- Direct measuring instruments are also classified as,
  (a) **Non-precision instruments** such as steel rule, caliper etc.
  (b) **Precision measuring instruments**, such as vernier instruments, micrometers, dial gauges.

2.6 WAVELENGTH STANDARDS

- **Wavelength standard** is natural and invariable unit of length.
- Line standards and End standards are material (physical) standards, which are subjected to destruction and their dimensions vary with time.
- Also, a considerable difficulty is observed, while comparing and verifying the size of gauges by these standards.
- To overcome the above difficulties, wavelength of light is introduced as standard of measurement. It is highly accurate and does not depend on any physical standard. With monochromatic light, we have the advantage of constant wavelength.
- Wavelength standards works on the principle based on the phenomenon of 'interference of light waves'. This interferometric technique enables the size of slip gauges and end bars to be determined directly in terms of the wavelength of light, instead of metres.
- Since wavelength does not have physical form, therefore, it is not needed to be preserved, like material standards. Therefore wavelength standard is called as reproducible standard of length.
- Error in reproducibility is very small (1 part in 100 millions). Therefore, this error can be neglected.
- Krypton–86 is the most suitable source of radiations of constant wavelength. Due to its high degree of accuracy, it is accepted as *International wavelength standard*.
- According to this standard, 1 metre is expressed as 1,650,763.73 times the wavelength of red-orange radiation of Kr-86 in vacuum. Also, we know that, 1 yard is equal to 0.9144 metre, therefore wavelength standard can be easily transferred to line standard and end standard.

  Therefore, we can write,

  1 metre = 16,50,763.73 wavelengths

  and 0.9144 metre = 1 yard
- A unique and versatile group of techniques for achieving such high order accuracy is based on the natural phenomenon called as "*interference of light*".

2.6.1 Advantages of Wavelength Standard

QUESTIONS

1. State the advantages of wavelength standards over the material standards. **(S-17)**

1. Wavelength standard is not a material standard and hence, it is not influenced by variations in atmospheric conditions, such as temperature, pressure, humidity etc.
2. It is not subjected to destruction by wear or tear, because it is not physical or material standards.
3. Wavelength standard can be easily transferred to other standards, known as material standards having two types, such as line standard and end standard.
4. This standard is easily available in all standard laboratories and industries.
5. It gives a unit length, which can be reproduced consistently all the times, irrespective of change in surrounding conditions from one place to other.
6. It can be used for making comparative measurements of much higher accuracy.

2.6.2 Difference between Line, End and Wavelength Standards

QUESTIONS

1. Differentiate between Line, End and Wavelength standards. Give one application of each term. **(S.Q.P)**
2. Differentiate 'line standard', 'end standard' and 'wavelength standard'. (Give one application of each of them). **(S-16)**

Sr. No.	Comparative point	Line standard	End standard	Wavelength standard
1.	**Definition**	When length is expressed as distance between two engraved lines on a scale, the standard is called as Line standard.	When length is measured as distance between two flat parallel faces, the standard is called as end standard.	When wavelength of monochromatic light is used as natural and invariable (constant) unit of length, the standard is called as wavelength standard.
2.	**Cost of standard**	Less	High	Too expensive
3.	**Need for preservation**	Being material standard, preservation in safe custody is essential.	Being material or physical standard, it must be preserved against wear and corrosion.	No necessity of preservation. It can be reproduced, whenever required.
4.	**Time required for measurement**	Less	More	Most
5.	**Accuracy**	Less accurate (±0.1 mm)	Moderate accuracy (±0.001 mm)	Highest
6.	**Method or set up of measurement**	Easy	Little difficult	Very difficult to arrange set up of measurement
7.	**Cost of inspection**	Less	More	Highest
8.	**Errors**	Parallax error	Environmental error, Stylus pressure errors	No errors except human error.
9.	**Effect of changing environmental conditions on accuracy of measurement**	Less accurate measurements	Moderately accurate measurement	Highly accurate measurements, since they are independent of any change in atmospheric conditions.
10.	**Wear and Tear**	Less as compared to end standard.	As the measuring end surfaces of measuring instrument like micrometer and caliper, are always made to contact with the workpiece, therefore, more wear and tear occurs due to inaccurate stylus pressure applied and consistent use, and found at measuring ends.	No wear or tear, because it is not a physical or material standard.
11.	**Care**	Engraved scale markings should be protected.	Measuring ends should be protected by applying optimum stylus pressure.	They are not subjected to changes in ambient conditions. So less care is required.
12.	**Examples**	Steel rule, Measuring tape	Micrometer, Vernier height gauge.	Monochromatic source of light, like Cr-86, Cadmium etc.

2.7 SLIP GAUGES OR JOHANNSEN GAUGES (W-08)

- Slip gauges are used as standards of measurement for checking the accuracy of measuring instruments such as micrometers, vernier calipers, snap gauges, dial indicators etc.
- These were invented by C.E. Johannsen of Sweden, therefore, named as "Johannsen gauges".
- Slip gauges are referred as precision gauge blocks. They can be used as (i) Length standards, (ii) Height standards for setting up sine bars for angular measurements, (iii) For accurate measuring machines.

Construction:

- Slip gauges are rectangular blocks of section about 30 mm × 10 mm × thickness (as required). The common type of material used to make slip gauges is 'Alloy steel'.
- They are hardened and quenched before being finished to required size.
- In order to obtain a very high order of accuracy in flatness and parallelism of opposite faces, the contact surfaces of slip gauges are surfinished by grinding and lapping.

Grades of slip gauges:

- Five grades of slip gauges in increasing order of accuracy are given below.
  1. **Grade II (Workshop or production grade):** Less accurate, so used in workshops for setting up machine tools.
  2. **Grade I:** Used in tool room for more precise work such as setting up sine bars, checking gap gauges etc.
  3. **Grade 0 (Inspection grade):** Used as inspection grade for machine shop inspection.
  4. **Grade 00 (Reference grade):** Used for highest precision work, such as, measuring grades 'I' and 'II'. It is kept in a 'Standard' room for preservation purpose.
  5. **Calibration grade:** Highly accurate. This is a special grade used to calibrate the above 4 types of grades.

Sets of slip gauges:

- Slip gauges are supplied in different sets of suitable sizes, so that, number of combinations may be obtained for building up required lengths or heights. The commonly used sets are M105, M87 and M45 pieces respectively.

Set M 105:

Range (mm)	Steps (in mm)	Number of pieces
1.01 - 1.49	0.01	49
0.50 - 24.50	0.5	49
25, 50, 75 and 100	25	4
1.0025	-	1
1.005	-	1
1.075	-	1
		Total 105

Set M 87:

Range (mm)	Steps (in mm)	Number of Pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9
1.005	–	1
		Total 87

Set M 45:

Range (mm)	Steps (in mm)	Number of pieces
1.001 to 1.009	0.001	9
1.01 to 1.09	0.01	9
1.1 to 1.9	0.1	9
1 to 9	1	9
10 to 90	10	9
		Total 45

2.8 WRINGING AND ENFORCED ADHESION

QUESTION

1. What is wringing of slip gauges ? State the conditions of wringing of slip gauges. **(W-11)**

- Wringing is the method to build up various sizes either height using combination of different slip gauges of same set.
- **Principle of Wringing:** "When two clean and very accurately flat surfaces are slide together under pressure, they adhere firmly".
- Wringing is nothing but, adhering two flat and parallel surfaces by sliding or pressing the measuring faces of a slip gauge against measuring faces of other slip gauges.
- Slip gauges are also called as gauge blocks, whereas, measuring faces are also known as reference surfaces or datum surfaces or contact surfaces.
- Wringing effect is possible,
  (i) Partly due to molecular attraction, between the contact surfaces, and
  (ii) Partly due to atmospheric pressure.

Process of Wringing:

(1) For wringing together two slip gauges, their contact surfaces should be washed with degreasing agents.

(2) These two contact surfaces are made completely dry using a clean leather.

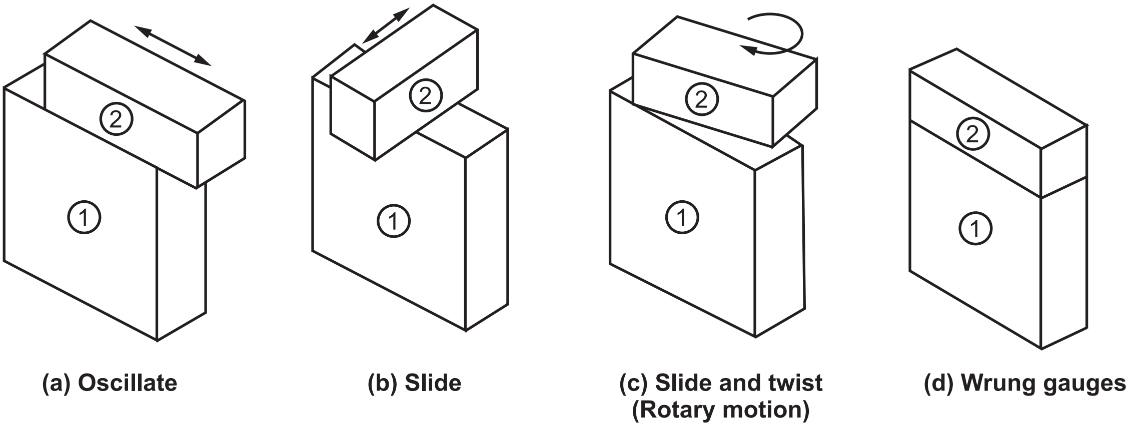
(3) Slip gauges are held across one another at right angle and then wrung by giving a rotary motion. It reduces the amount of surface rubbing.

(4) Gauges are wrung together by hand through combined sliding and twisting motions.

(5) Initially, one slip gauge labelled as ② (upper gauge) is oscillated slightly over the other slip gauge labelled as ① (lower gauge) by applying slight pressure. This process is performed to detect presence of any foreign particle between the two contact surfaces.

(6) One gauge (No. ②) is then placed over the other (No. ①) using standard gauging pressure at 90°. It means, both the slip gauges are held across one another at right angle. Refer Fig. (2.1) (b).

(7) Then rotary motion is imparted to the upper slip gauge, until it becomes exactly aligned with lower slip gauge. Rotary motion is combination of slide and twist. This method of applying rotary motion decrease the amount of rubbing between two contact surfaces of two slip gauges, thereby avoiding early wear of contact surfaces. Thus, life of slip gauges can be increased. Refer Fig. 2.1 (c) and (d).



(a) Oscillate (b) Slide (c) Slide and twist (Rotary motion) (d) Wrung gauges

Fig. 2.1: Wringing of slip gauges

- In case of highly précised measurements, process of wringing is closely observed and enough precautions are taken.
- Generally speaking, a very small amount of grease or moisture must be present between the contact surfaces for them to wring satisfactorily.

2.9 APPLICATIONS OF SLIP GUAGES

(a) As 'Reference standard for transferring'.
(b) For 'Verification and Calibration' of measuring instruments.
(c) As 'Length standard' for regulation and adjustments of indicating devices.
(d) For 'direct measurement' of linear dimensions of components.
(e) For 'setting up' different types of comparators for various purposes, such as:
  (i) Inspection of components,
  (ii) Setting up of milling cutters in between the centres of milling machine.

2.10 PROTECTOR SLIPS

Need:

- Two protector slips are provided on extreme sides (upper and lower) of combination of slip gauges, building up the required height or length.
- Function of protector slips provided in high grade slip gauge set, to protect the slip gauges against early wear. Thus, protector slips are used to have prolonged life of slip gauges.

- Protector slips are nothing but slip gauges available in a pair of 1 or 1.5 mm and 2 or 2.5 mm thickness.
- Any antiwear materials, such as, Tungsten carbide are used to manufacture protector slips.

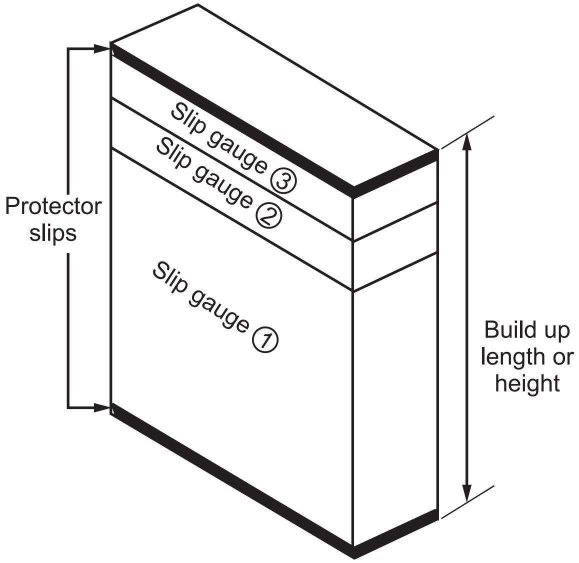


Fig. 2.2: Protector slips

2.11 MANUFACTURE OF SLIP GAUGES

Slip gauges are manufactured according to following guidelines prescribed along with sequential steps listed below.

1. High grade steel plates are machined in preliminary operation to obtain the required sizes of slip gauges.
2. These slip gauges are heat-treated to achieve good hardness and wear resistant property.
3. Slip gauges are grounded roughly (grinding operation).
4. Stabilizing is done by alternate cooling and heating of slip gauges. The temperature used at four different stages is 40°C, 70°C, 130°C and 200°C.
6. Slip gauges are heated in sand and cooled down slowly at each stage.
7. Measuring faces or contact surfaces of each slip gauge are grinded, so that, thickness of each slip gauge can be reduced to appropriate size.
8. Finally, measuring or contact surfaces of slip gauge are lapped and superfinished, at room temperature of 20°C to reduce its thickness upto required exact size with good surface finish.

2.12 PRECAUTIONS WHILE USING SLIP GAUGES

- Slip gauges are used for high precision measurements. Hence, sufficient care should be taken while using them.
- When not in use, all the polished surfaces of each slip gauge should be protected against atmospheric corrosion by applying petroleum jelly or other suitable anti-corrosive agents.
- Slip gauge should be always kept in their closed cases, supplied by manufacturers.
- Slip gauges should be touched and used by hand gloves made up of leather perspex or any other branded acrylic material. Slip gauges should not be touched by hand to prevent them from corrosion.
- After use of slip gauges, their measuring or contact surfaces should be made clean with solvent to remove finger marks, if any.
- To remove grease, a clean rag soaked in petrol is first used, followed by another dry and soft cloth. Final cleaning is done by leather.

2.13 SLIP GAUGE ACCESSORIES

Accessories used for slip gauges are,

Name of Accessory	**Functions**
1. Measuring jaws	Measuring jaws are always supplied in pairs and available in two types, used for internal and external measurements.
2. Scribing and centre point	Scribing point and centre point are used in combination with holder and slip gauges, which forms a very accurate device for **marking** purposes.
3. Holders	Holders are available in suitable designs and different ranges for rigidly holding any combination of slip gauges.
4. Base	Base has robust construction. It is designed in such a way that, maximum possible longest size holder can be rigidly held. Suitable provision is made for attachment of holder with the base in a position, normal or pendicular to the wringing surface of base.

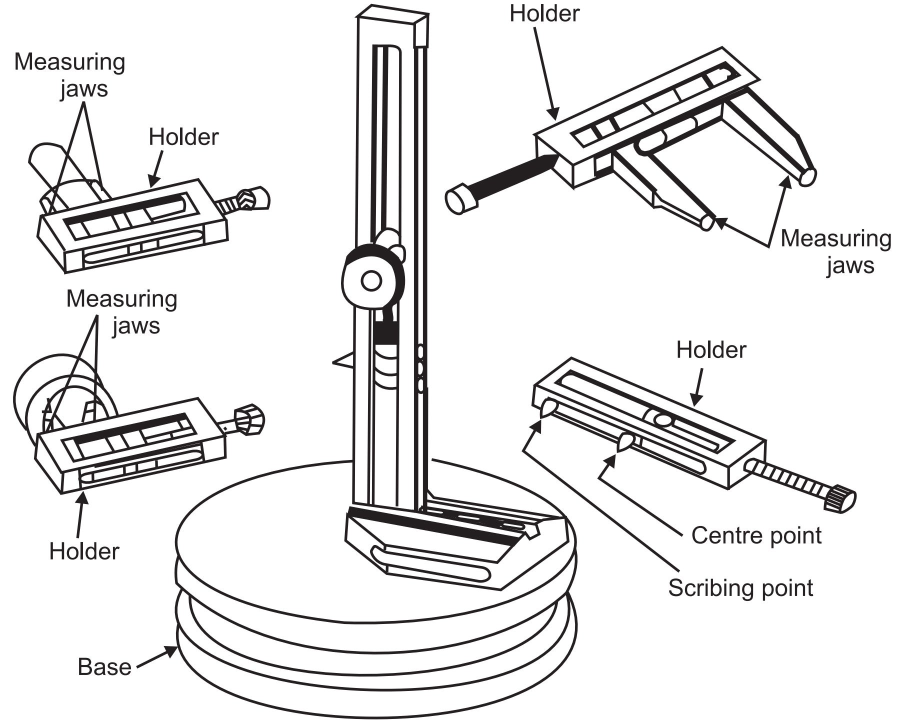


Fig. 2.3: Slip gauge accessories

2.14 COMPARATORS

QUESTION

1. Define: Comparators. **(W-08, S-16)**

Comparator:

- Comparators are used to make dimensional comparisons between two objects, such as 'work piece' and 'reference standard'.
- They are not capable of giving or displaying an absolute measured value of a quantity.
- Instead, they are used to measure the deviations in magnitude of two objects. **For example:** Comparison of measured value of a certain dimension of work-piece with standard or specified value of that dimension.
- **Comparator** is a device, which,

  (a) Picks up small deviation of actually measured dimension from standard dimension.

  (b) Magnifies the deviation.

  (c) Displays it by using indicating devices, so that, comparison can be made possible with reference to some standard value.

- Comparators are used for precise measurements during comparison of products manufactured and working gauges with standard or reference gauges. Measured dimension of a manufactured product is always subjected to certain amount of deviation from the standard value.
- Thus, inspection done by using comparator is defined as 'a process of comparing manufactured parts with a standard part known as 'Master'.
- If the deviation found is very very small, then same comparator can be used to amplify or magnify the small deviation, so that it can be easily read and noted down accurately.
- Thus, **comparator** can be defined as, *"an indirect type of instrument, with the help of which, an unknown dimension of a workpiece is compared with working standard".*
- Comparators are designed in several types according to the field of applications.
- Every type of comparator includes some kind of magnifying device to show and read the deviation accurately.
- A wide variety of comparators exists at present. In general, they differ principally in the method used for amplifying and recording the deviations measured.

2.14.1 Necessity/Advantages of Comparators

QUESTION

1. State the need and uses of comparators. **(S-17)**

- To achieve interchangeability, parts must be produced to close dimensional tolerances. Interchangeability calls for the inspection at various stages of manufacturing to compare manufactured part with the standard or master part.
- Use of vernier caliper, micrometer and other measuring instruments is not feasible for inspecting the parts produced in mass production, because of skill involved and the time required to measure dimension.
- Therefore, use of comparator is preferred in **mass production**. It has the following advantages.
  - (a) Comparator requires little or no skill of the operator.
  - (b) It eliminates the possibility of human errors in taking measurement.
  - (c) It gives quick and highly consistent results.

2.14.2 Requirements / Characteristics of Good Comparator

QUESTIONS

1. What are the requirements of good comparators ? **(W-08)**
2. State any four characteristics of good comparator. **(S-09,14 W-09, 11, S-16)**
3. State the essential characteristics of the good comparator (any eight). **(S-17)**

A good quality comparator is expected to have the following essential characteristics:

1. **Robust design and construction:** The instrument must be robust in design and construction, so that, it will withstand the effects of ordinary usage without affecting its measuring accuracy.
2. **Linear scale:** Recording or measuring scale should be linear and uniform (straight line characteristic) and its indications should be clear.
3. **High magnification:** Magnification of the instrument should be high as possible as to detect smaller deviation in size of component.

4. **Versatility:** Comparator should be so designed that it can be used for several purposes other than thickness or external diameter measurements.
5. **Material:** Contact plunger or stylus should be provided with tip made of hardened steel or diamond, to minimize its wear occurring due to consistent use.
6. **Response:** Indicating system should be such that, the readings are obtained in least possible time.
7. **Temperature effects:** Indicator should be provided with maximum compensation against temperature effects.
8. **Reset mechanism:** The pointer should come rapidly to rest and should be free from oscillations.
9. **Minimum inertia:** System should be free from backlash and unnecessary friction and it should have minimum inertia.
10. **Easy plunger lifting:** Provisions should be made in comparators for lifting the plunger for quick insertion of work.
11. **Readability:** Table of the instrument should preferably be adjusted in the vertical sense for the ease of readability.

2.14.3 Applications of Comparators

1. To check the components and newly purchased gauges.
2. As laboratory standards for the purpose of setting the working or inspection gauges.
3. As working gauge during important stages of manufacture.
4. As a final inspection gauge.
5. To check various dimensions, geometric forms and setting purposes.

2.14.4 Classification of Comparators

- Comparators are classified on the basis of method used to magnify and record variations in the dimensions of standard and work-piece being measured.
- The most common types are:
  1. Mechanical Comparators.
  2. Optical Comparators.
  3. Pneumatic Comparators.
  4. Electrical and Electronic Comparators.
  5. Mechanical Optical Comparators.

2.15 MECHANICAL COMPARATOR

QUESTION

1. With neat sketch, describe the construction and working of mechanical comparator.

(W-11)

Working Principle: Magnification of plunger movement can be obtained by using levers, gear and pinion arrangement or other mechanical means.

Examples: Dial Indicator, Sigma Comparator, Johansson Mikrokator, Reed type mechanical comparator.

2.15.1 Dial Indicator

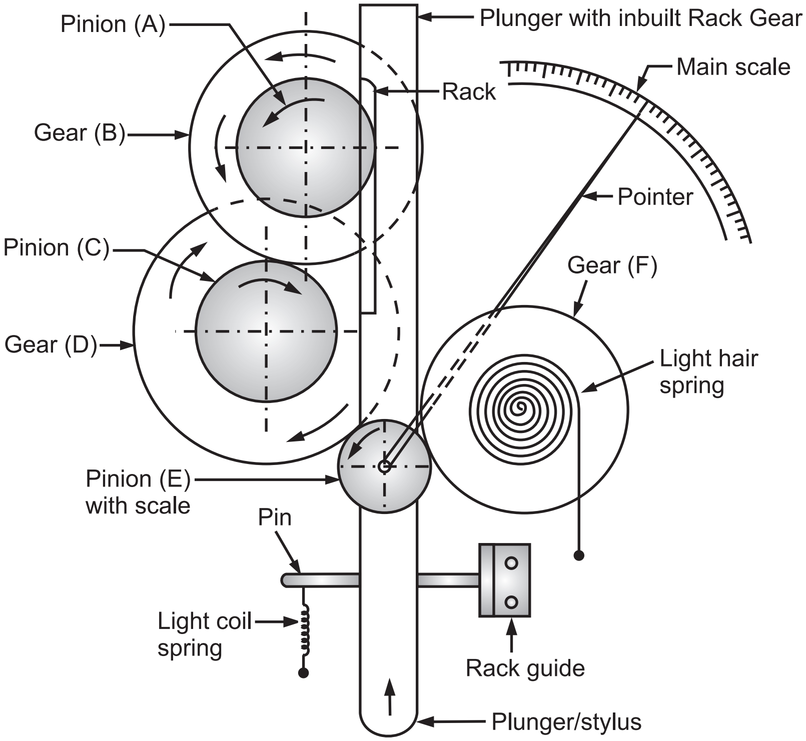
QUESTIONS

1. Draw a labelled diagram, showing working mechanism of a dial indicator. **(S-12, 15, 16)**
2. List four mechanical comparators. Draw labelled sketch of any one. **(W-13)**

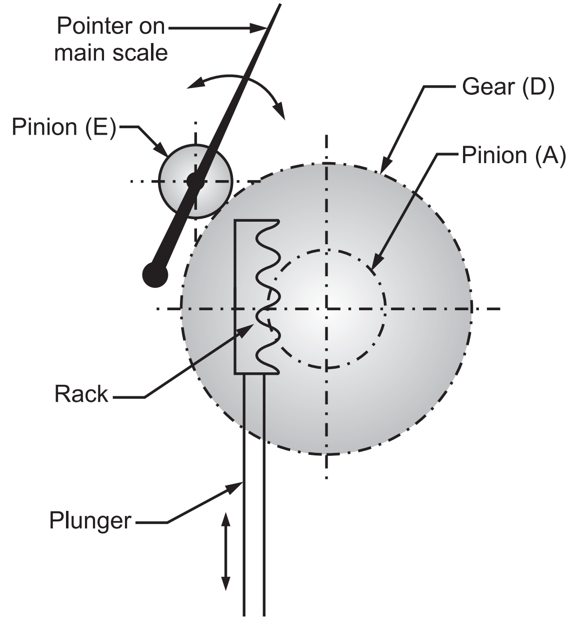
- Dial indicators are small indicating devices having a graduated scale and a contact plunger. The movement of plunger is magnified either by lever or gear and pinion mechanism.
- Graduated dials take the form of a circular or semicircular scale, upon which, a pointer gives an indication of movement of plunger in vertical direction upwards or downwards. Refer figure 2.4 (c) showing zero division or reference point, from which, the movement of pointer either on left side or right side, can be read to find out deviation from standard value.

Construction:

- It consists of plunger, which slides in bearing and carries a rack at its inner end. The rack meshes with a pinion (A), which drives another gears and pinions.
- Plunger is kept in extended position by means of a light coil spring.
- Linear movement of plunger is magnified by the gear train and transmitted to a pointer lying in the plane of circular dial scale.
- Pointer is mounted on the spindle of last pinion (E).
- A light hair spring loads all the gears in the gear train against the direction of gauging movement. This eliminates the possibility of backlash, which may occur due to wear of gears. Therefore, to take up the backlash, light hair spring is attached to the gear (F).



(a) Working mechanism of dial indicator



(b) Principle of operation of a dial indicator

Fig. 2.4

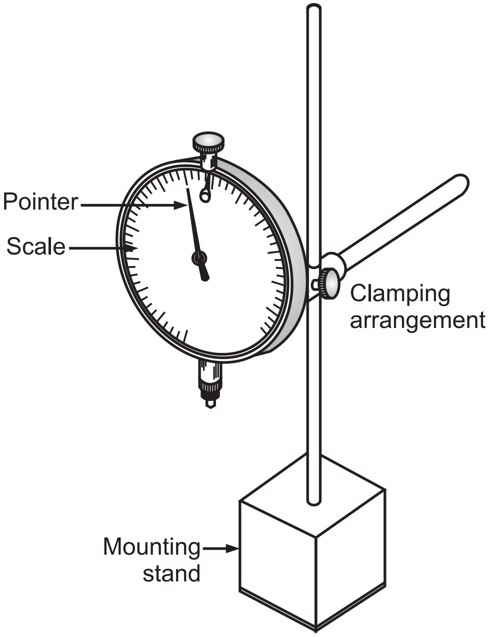


Fig. 2.4 (c) Dial indicator

2.15.1.1 Applications of Dial Indicators

1. Used for linear measurements to test and inspect the size and trueness of a finished work to an accuracy of 0.01 mm.
2. Used in conjunction with other measuring instruments. For example, inside and outside calipers, depth gauges etc.

3. Used for inspection of small precision machined parts and testing techniques to ensure alignment, roundness, parallelism of work-pieces etc.
4. Used with sine bar in angle measurement.
5. Used for alignment test of various machine tools.
6. Used in Parkinson's gear tester.
7. Used in pocket thickness gauge.
8. Used to determine errors in geometric forms, such as ovality, taper etc.
9. Used to determine positional errors of surfaces such as parallelism, squareness and alignment.

2.15.1.2 Advantages of Dial Indicators

Advantages of Dial indicators are as follows:

1. Easily readable.
2. Semiskilled labour can operate them.
3. Best suited for precision dimensional control and can be adopted in mass production.
4. Compact and robust in construction.
5. Portable, easy to handle and can be set very quickly.
6. Cheaper as compared to other types.
7. Simple in operation.
8. No need of power supply.
9. Wide measuring range.
10. Removable contact points, if worn out.

2.15.1.3 Disadvantages of Dial Indicators

Disadvantages of Dial indicators are as follows:

1. Wear of plunger gears, pinions etc. leads to error in measurement.
2. Low accuracy due to presence of backlash in rack and pinion or gear train. Backlash is small play inbetween two contact surfaces.
3. More chances of error due to variations in contact pressure applied to plunger.
4. Less accuracy due to more number of moving parts.
5. Mounting stand and auxiliary attachments are required.
6. Lagged response (slow response to variations in quantity being measured) may be problematic.
7. Limited range of dial indicator because of fixed scale.
8. Looseness of measuring rack guide may give variations.

2.15.1.4 Essentials of a Good Dial Indicator

- Instrument should be capable of giving troublefree and dependable measurements over a long period without attention. For this purpose, the design and construction must be robust.
- The pointer movement should be properly damped (free from vibrations) because oscillations should not be present, when the readings are being taken.
- There should be some provision to avoid damage to the instrument due to large movements of the plunger than the specified span on the circular scale.
- There should be well defined relative movement of pointer and scale to suggest the direction of movement of the measuring plunger. For example, an increase in the size of work must correspond to the upward movement of pointer in vertical scales and to right or clockwise movement in circular scales.
- It should be suitable for various sizes and ranges.

2.15.2 Sigma Comparator

QUESTIONS

1. Explain the working of sigma comparator. **(W-10)**
2. With sketch, describe the construction and working of mechanical comparator. **(W-11, S.T.P.-I)**
3. Draw labelled sketch of sigma comparator. **(W-14)**
4. Explain the construction and working of sigma comparator with neat sketch. **(W-16)**

Type of Comparator: Mechanical

Magnification obtained: 300 to 5,000.

Construction:

- The plunger is mounted on a pair of steel slit diaphragms to give a frictionless linear motion.
- Both moving and fixed members are connected to each other by mutually perpendicular flexible strips arranged alternatively at right angles to each other. This forms a cross-strip hinge, which can be used as a pivot. A knife edge is screwed into the plunger and it bears upon the moving member of cross-strip hinge. Therefore, when the plunger moves up or down, the knife edge exerts a force on moving member of cross-strip hinge assembly.
- The above process leads to deflection of an arm, which is connected or carried by moving member.
- During construction of sigma comparator, this is divided into two forked arms. Therefore, arm is called 'Y'-shaped arm.
- A thin phosphor bronze ribbon is fastened to the ends of forked arms and wrapped around a small drum of radius 'r', mounted on a spindle carrying the pointer.
- Due to force exerted by knife edge on the moving member, the Y-arm deflects and hence, rotates the driving drum.

- The spindle of pointer is connected at centre of driving drum. Therefore, rotation of driving drum makes the pointer to move on calibrated circular scale to show the reading.

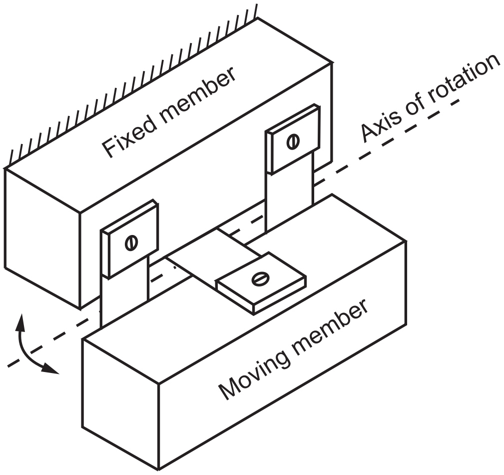


Fig. 2.5: Cross-strip hinge used in sigma comparator

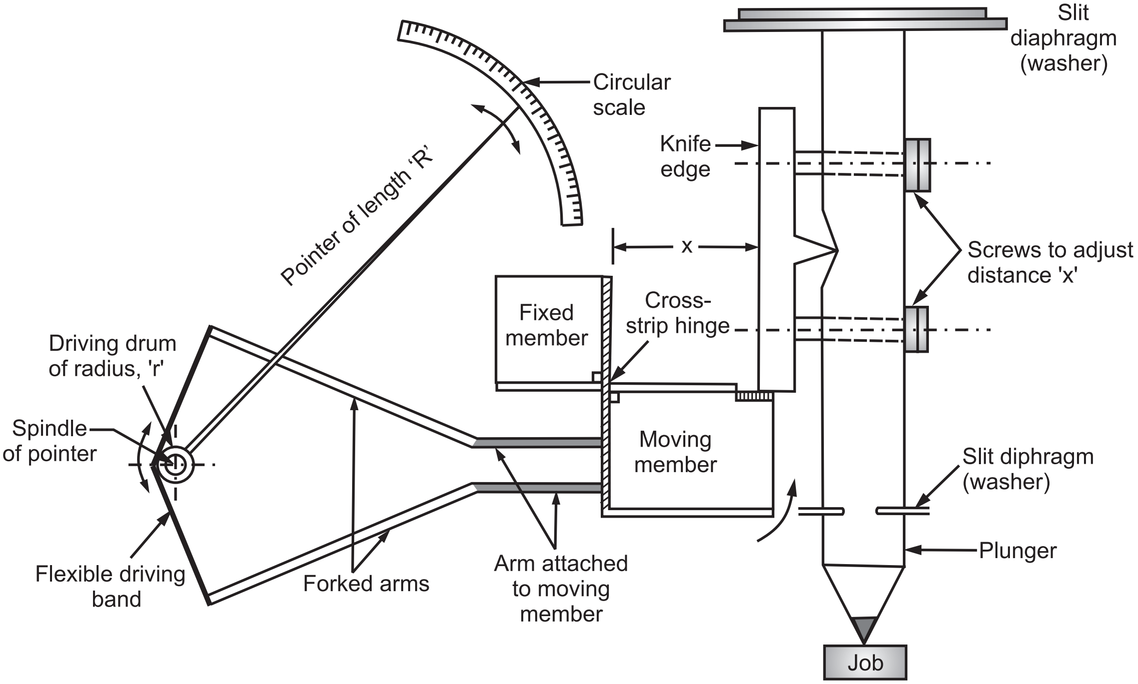


Fig. 2.6: Sigma comparator

Working:

- Any vertical displacement of measuring plunger (either upward or downward) and hence that of knife-edge makes the moving member of cross-strip hinge to act like a pivot. This causes rotation of forked arms. Metallic band attached to the arms makes the driving drum and hence the pointer to rotate. Deflection of pointer is the measure of deviation.
- **Magnification:** If the effective length of the arm is 'L' and the distance from the hinge or pivot to the knife edge is 'x', then first stage of magnification is $\frac{L}{x}$.
- A phosphor bronze band or strip is attached to the extremities of Y-arm (also called as ends of forked arms). This band is passed around a drum of radius 'r' attached to the pointer spindle. If the pointer is of length 'R', then the second stage of magnification is $\frac{R}{r}$ and the total magnification (M) is $\frac{L}{x} \times \frac{R}{r}$.
- Magnification can be changed by tightening one screw and slackening the other screw attaching knife edge to plunger, thereby adjusting the distance x.
- Another way to produce different magnifications is to use driving drums of different radii 'r' and suitable strip.

2.15.2.1 Advantages of Sigma Comparator

1. Least count upto 0.25 microns is available.
2. It has got a bold scale with longer indicating pointer.
3. Easily readable.

2.15.2.2 Disadvantages of Sigma Comparator

1. Due to more moving parts, considerable wear and tear takes place.
2. Less sensitive due to friction being present in the moving parts.

2.16 ADVANTAGES AND DISADVANTAGES OF MECHANICAL COMPARATORS (S-09,14)

QUESTION

1. State the advantages and limitations of mechanical comparator. (W-15)

Advantages of Mechanical Comparators:

(a) Compact and robust construction.
(b) Portable and easy to transport.
(c) Easy to understand and easy to use.
(d) Easy to handle and can be set quickly.
(e) Scale is linear and uniform, therefore, accurate and reliable reading can be obtained very easily.
(f) They are independent of any external power supply, so accuracy is not affected by fluctuations in power supply.

Disadvantages of Mechanical Comparators:

(a) More friction and wear due to more number of moving parts.

(b) Less accuracy.

(c) Due to inertia of moving parts, instrument becomes too much sensitive, which leads to show fluctuating readings for small vibrations. Therefore, operator finds difficulty in obtaining a reliable reading.

(d) Range of instrument is limited by range of fixed scale.

(e) Parallax errors are introduced, due to pointer-scale system.

2.17 PNEUMATIC COMPARATORS

QUESTIONS

1. Explain with neat sketch, construction and working of "Pneumatic Comparator". **(W-08; S-15)**
2. Which comparator is most useful for measuring the roundness and taperness of cylinder bore ? Explain its working. **(S-10)**
3. Draw labelled sketch of a pneumatic comparator. List down its components. **(S.Q.P.)**

Principle:

- In pneumatic comparator, the variations in the dimensions being measured with respect to reference dimensions (standard dimensions) are shown and amplified by a variation in air pressure.
- A jet of air is applied at constant pressure through the orifice and air escapes in the form of jets through a restricted space, which exerts a back pressure. The variation in the back pressure is then used to find the dimensions of a component.
- **Solex pneumatic comparator** uses a water manometer for the indication of back pressure.
- This system enables high magnification of the order 30,000 with good stability and reliability. Such a high order of magnification is possible with these instruments, because no physical contact is made either with the setting gauge or the part being measured.

Construction:

- It consists of a vertical metal cylinder (water tank) filled with water upto a certain level and a dip tube immersed into it upto a depth corresponding to air pressure.
- A calibrated manometer tube is connected between the cylinder and control orifice.

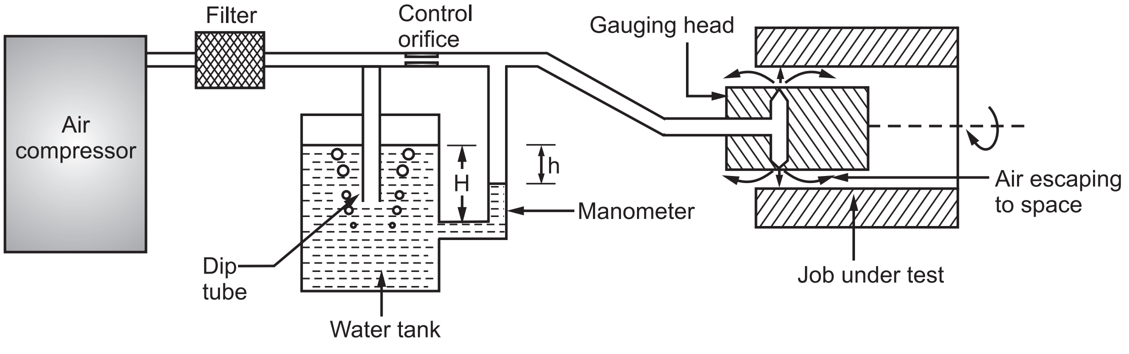


Fig. 2.7: Pneumatic comparator

Working:

- If the pressure of air supplied from compressor through filter is higher than the desired pressure, some air will bubble out from the bottom of the dip tube and air moving through the control orifice will be at the desired constant pressure. The constant pressure air then passed through control orifice and escapes through measuring jets to atmosphere. But, if there is restriction to the escape of air jets, a backpressure will be induced and level of water in manometer tube will fall down.
- When there is no restriction to the escape of air, the level of water in the manometer tube will coincide with that in the cylinder/tank.
- Due to restricted area at position A_1, the back pressure is generated by head of water displaced (h) in the manometer tube. Refer Fig. 2.8.
- To determine the roundness of job, the job is rotated along the jet axis. If no variation in the pressure reading is obtained, then it is concluded that, job is perfectly circular at position A_1.
- Same procedure is repeated at various positions A_2, A_3, …… and variation in the pressure is calculated.

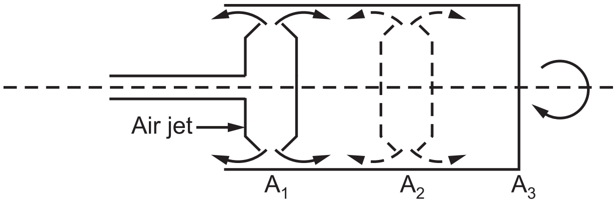


Fig. 2.8: Air jet pneumatic comparator

- Also, the diameter is measured at position A_1 corresponding to the portion against two jets. In the similar way, diameter is also measured at various positions along the length of the bore. Any variation in the dimension changes the value of h. For example, change in dimension by 0.002 mm changes the value of h from 3 to 20 mm.

2.17.1 Advantages of Pneumatic Comparators

Advantages of Pneumatic comparators are as follows:

1. The gauging head does not come in contact with the part to be measured and hence, practically no wear takes place on the gauging head.
2. It has usually no moving parts; hence, its accuracy is more due to absence of friction and less inertia.
3. Measuring pressure is very small and the jet of air helps in cleaning the dust, if any, from the part to be measured.

4. It is possible to achieve very high degree of magnification.
5. It is very suitable device for measuring diameter of holes, in the cases, where the diameter is small as compared to length.
6. It is probably the best method for determining ovality and taperness of circular holes.
7. High magnification [30,000 : 1] can be obtained.
8. It can be handled by semiskilled worker.

2.17.2 Disadvantages of Pneumatic Comparators

Disadvantages of Pneumatic comparators are as follows:

1. Limited range available.
2. It requires auxiliary equipments such as air filter, accurate pressure regulator, manometer etc.
3. Low rate of response as compared to electrical magnification system.
4. It is not portable.
5. Different gauging heads are required for different dimensions.
6. Need external power source to drive compressor.

2.17.3 Applications of Pneumatic Comparator

(a) To check bores of cylinder blocks.

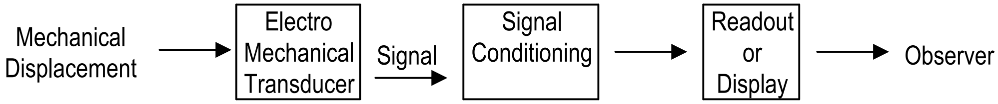
(b) To check straightness for various surfaces.

(c) To check outside diameters of cylindrical components.

2.18 ELECTRICAL COMPARATORS

- Electrical comparators can be categorized according to the electrical principle used in the pick-up head.
- These comparators use a differential transformer, an Inductance or Wheatstone bridge, a strain gauge or a capacitor as a means of detecting the movement of the gauging element or plunger.
- Electrical comparators has magnification, which ranges from 600 to 10,000.
- Electrical comparator is also known as *electromechanical measuring system as it consists* of an electromechanical device, which converts the mechanical displacement into electrical signal.
- Linear variable differential transformer (LVDT) is the most popular electromechanical device or electromechanical transducer used to convert mechanical displacement into electrical signal.
- A block diagram of an electromechanical measuring system, is as shown below.

- The signal is fed to signal conditioning unit, which increases strength of signal, so that, it can be given to display device, to give detailed quantitative information.



2.18.1 Advantages of Electrical Comparators

Advantages of Electrical Comparator are as follows:

1. An electrical comparator has very few moving parts, so less wear and tear.
2. It is possible to have high magnification and the same instrument can have two or more magnifications. Thus, wide range is available.
3. Mechanism carrying pointer is very light and not sensitive to vibrations.
4. As these instruments are usually operated on A.C. supply, the cycle vibration substantially reduces errors due to sliding friction.
5. Measuring unit can be made very small. It is not necessary that, the indicating instrument be placed close to the measuring unit, rather it can be placed to a remote/distant location.

2.18.2 Disadvantages of Electrical Comparators

Disadvantages of Electrical Comparator are as follows:

1. Electrical comparators require an external agency to operate, i.e. an A.C. electric supply. Thus, the fluctuations in voltage or frequency of electric supply may affect the result.
2. Heating of coils in the measuring unit may cause zero drift, leading to produce error in calibration.
3. Accuracy may be affected due to variations in temperature and humidity.
4. These instruments are generally more expensive than their mechanical counter parts.

2.18.3 Applications of Electrical Comparators

1. Used as measuring heads, when there is need of precise measurement. For example, checking or comparison of workshop trade slip gauges against inspection gauges.
2. Used as electrical gauging heads, to provide indications.

Measured dimensions	**Indication**
Within specified limits	Green light
Undersize dimensions	Red light
Oversize dimensions	Yellow light

3. Linear variable differential manometer (LVDT) is the most popular electrical comparator used in conjuction with mechanical arrangement, which converts the mechanical displacement into equivalent electrical signal.

2.19 LVDT

QUESTIONS

1. Name the comparator, which has highest magnification? Explain its construction and working. State its advantages and disadvantages. **(S-11,13; W-16)**
2. What is LVDT? With neat sketch, explain its principle of working. State, where it is used in practice. **(S.Q.P.)**
3. What is LVDT ? Explain its principle of working with neat sketch. **(W-14)**
4. With a neat sketch, explain the principle of working of LVDT. State its applications. **(S-16)**
5. Explain the (LVDT) electrical comparator with neat sketch. **(S-17)**

- Electrical comparator has the highest magnification amongst all the comparators.

LVDT is the most commonly used inductive transducer to translate linear motion into electrical signal (displacement).

Here,

L = Linear motion (displacement)
V = Variable inductance
D = Differential, which means, 'Output is difference of two secondary outputs'
T = Transformer, because it functions as the former of primary and secondary windings.

Working Principle:

The position of iron core (magnetic core or armature) is responsible for varying the differential voltage across two secondary windings of transformer, which is a measure of linear displacement.

Construction:

- It consists of an insulating hollow cylinder made up of Bakelite or any insulating material.
- On the circumference of this insulating cylinder, one primary winding (P) and two secondary windings (S_1 and S_2) are wound.
- The primary winding is wound at the center of insulating cylinder.
- On either side of primary winding, two secondary windings (S_1 and S_2) are wounded in the directions exactly opposite to each other.
- Inside the hollow insulating cylinder, **magnetic core** is placed, which is free to move back and forth.
- This magnetic core is also called as soft iron core or armature core.
- The displacement to be measured is attached to the magnetic core.
- The magnetic core is made up of nickel iron, which gives high sensitivity and low null voltage. This core is slotted longitudinally to reduce eddy current losses.
- The whole assembly is placed in stainless steel housing.

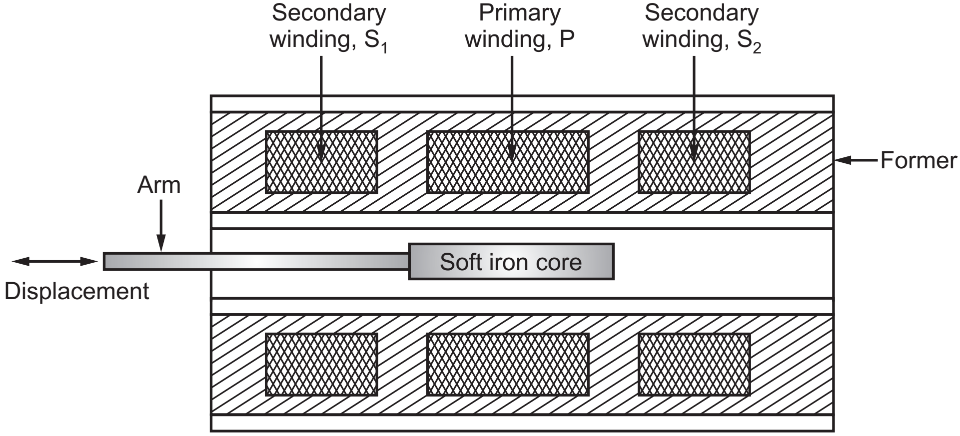
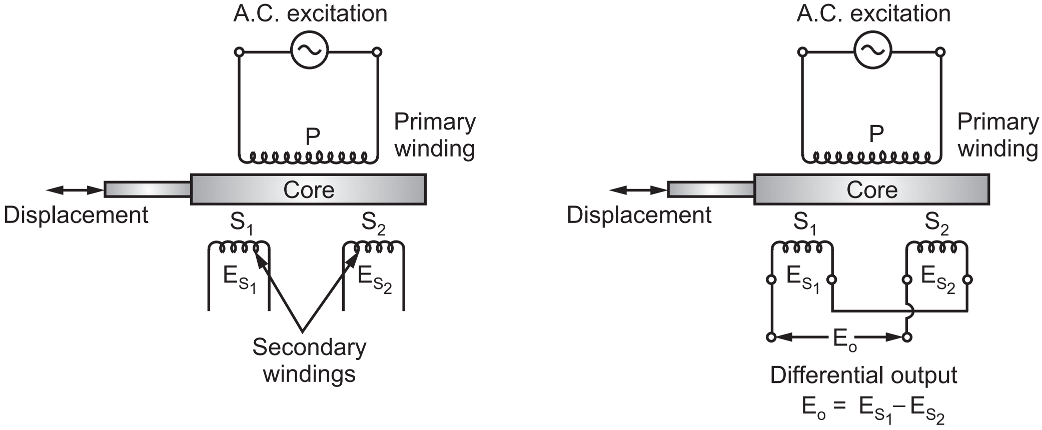


Fig. 2.9: LVDT

Working:

- When A.C. supply is given to the primary winding (P), it produces magnetic flux, which completes its path through S_1 and S_2.
- While completing the path, the flux produced by the primary winding is linked to the number of conductors of secondary windings.
- Therefore, according to Faraday's law of electromagnetic induction, an e.m.f. is produced in each secondary winding.
- Emfs produced in secondary coils S_1 and S_2 are shown by E_{S_1} and E_{S_2} respectively [Fig. 2.10 (a)].
- To convert two outputs of S_1 and S_2 into single voltage signal, S_1 and S_2 are connected in series as shown in Fig. 2.10 (b) with phase difference of 180° (wounded in opposite to each other).
- Thus, the output of transducer will be the difference of two emfs or voltages produced. Therefore, differential output voltage (E_o) is given by,

$$E_o = E_{S_1} - E_{S_2}$$



(a) **(b)**

Fig. 2.10: Electrical circuit of LVDT

Various Positions of Core and Corresponding Displacement Measurements:

(1) **When the core is at central position** of insulting cylinder, the magnetic flux linking to both S_1 and S_2 is equal and hence equal e.m.fs. are induced in S_1 and S_2.

Thus, $$E_{s_1} = E_{s_2}$$

Therefore, $$E_o = E_{s_1} - E_{s_2} = 0$$

This position of core is called as *normal (null) or zero position*. It concludes that, output voltage is zero at null position.

(2) **When core is moved towards left**, then flux linking to coil S_1 will increase and at the same time, flux linking to coil S_2 will decrease. Hence, e.m.f. induced in coil S_1 (E_{s_1}) is greater than emf induced in coil S_2 (E_{s_2}). As a result of which, output measurement between secondary terminals is *in phase* with primary voltage.

(3) **When core is moved towards right**, then flux linking to coil S_2 (E_{s_2}) will increase and at the same time flux linking to coil S_1 will decrease. Thus, e.m.f. induced in S_2 (E_{s_2}) is greater than e.m.f. induced in S_1 (E_{s_1}). As a result of which, output measurement between secondary terminals is *out of phase* with primary voltage.

- Thus, we can conclude that, the output voltage ($E_{s_1} - E_{s_2}$) measured between two secondary terminals of LVDT is directly proportional to the displacement of soft magnetic core.

2.19.1 Advantages of LVDT

1. High range for measurement of displacement.
2. Friction and electrical isolation.
3. Immunity (protection or exemption from obligation/penalty) against external effects.
4. High input and high sensitivity.
5. Ruggedness.
6. Low hysteresis, i.e. very small amount of current remains in electrical circuit.
7. Low power consumption.

2.19.2 Disadvantages of LVDT

1. Large displacement requirement. Therefore, not suitable for measurement of small displacements.
2. The frequency of carrier must be at least ten times the highest frequency component to be measured.
3. Temperature affects performance of the transducer.
4. Vibrations affect performance of the transducer.
5. Residual voltage problem.

2.19.3 Applications of LVDT

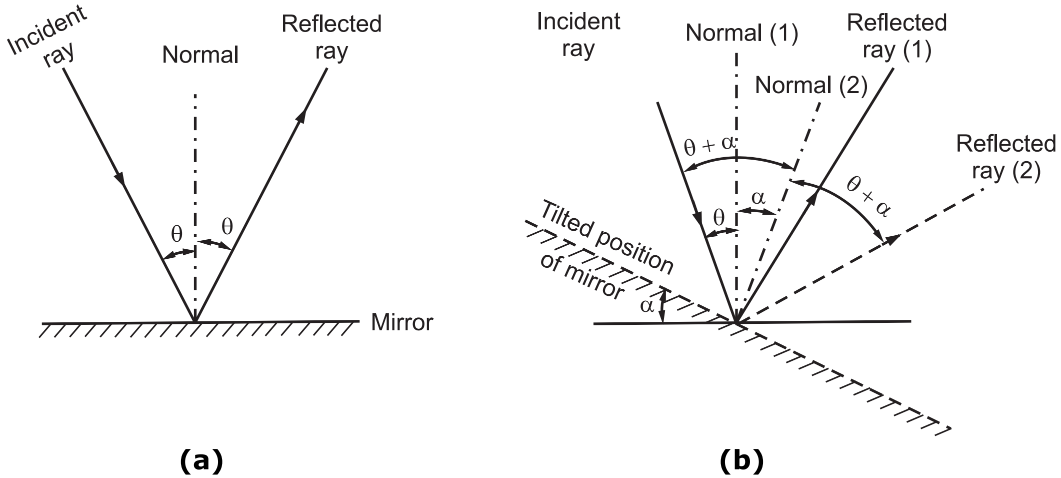
QUESTION

1. State the applications of LVDT. **(S-16)**

1. LVDT can be used for displacement measurement ranging from fraction of 1 mm to a few cm.
2. If it is installed in the measuring system as a secondary transducer, then it can be used to measure force, weight and pressure.
3. Useful for measurement of tension in rod, cord, cable.
4. Useful for measurement and control of thickness of metal sheet.

2.20 OPTICAL COMPARATORS

- Working principle of optical comparator is based on the laws of light reflection and refraction.
- According to the law of reflection, the angles of incidence and reflection are equal, when the reflection occurs on a plane surface (mirror), i.e. the angle between incident ray and normal (1) to the mirror surface (θ) is equal to angle of reflected ray and normal (1) to the mirror surface (θ). And total angle between incident ray and reflected ray is 2θ. Refer Fig. 2.11 (a).
- Now, if the reflecting surface (mirror) is tilted through an angle α, then normal (2) also moves through this angle α. Then, as shown in Fig. 2.11 (b), the angle between incident ray and normal (2) becomes (θ + α). According to law of reflection, the angle between reflected ray (2) and normal (2) should be equal to angle between incident ray and normal (2). Therefore, angle between reflected ray (2) and normal (2) should also be (θ + α). Thus, total angle between incident ray and reflected ray (2) will be 2 × (θ + α), i.e. (2θ + 2α). Thus, there is an increase of 2α in the total angle and double magnification is obtained.



(a) **(b)**

Fig. 2.11: Principle of reflection

Construction and Working:

- A beam of light passes through a graticule, which is engraved with a scale.
- The rays from monochromatic source of light are incident on movable mirror through condenser.
- These rays are passed to the fixed mirror by reflection, from where, they are again reflected to first (i.e. movable) mirror and then to the eyepiece. This double reflection gives magnification.
- If a standard/reference job is placed under plunger, the reference positions can be fixed.
- Now, if an undersize or oversize job is placed instead of standard/reference job under the plunger, then due to different size of job, the plunger movements will cause the movable mirror to deflect. Therefore, the variations can be measured by the graticule position through eyepiece.

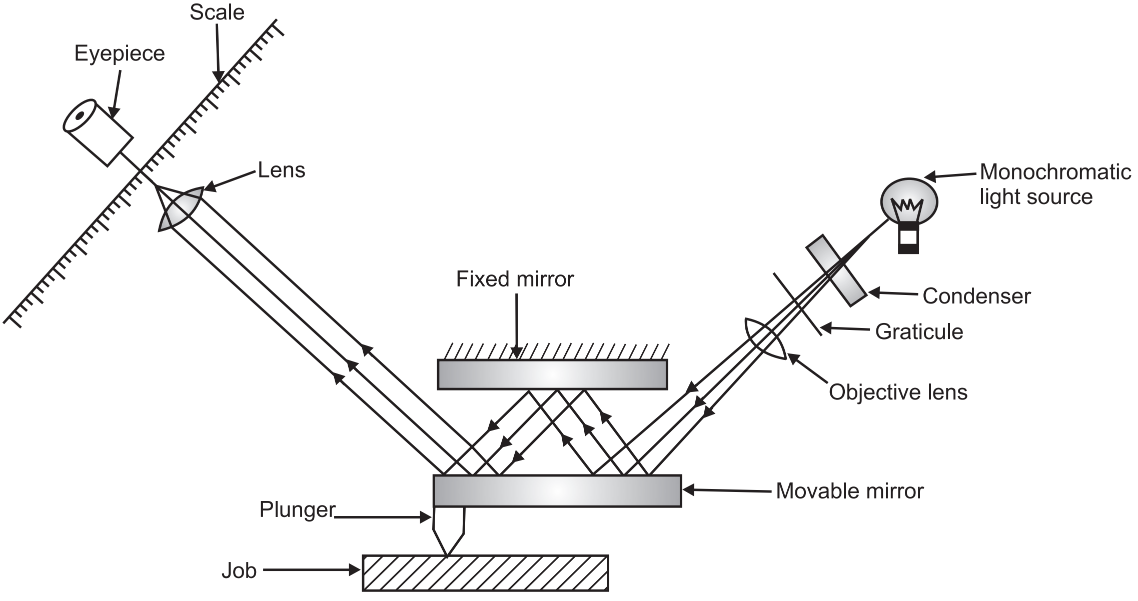


Fig. 2.12: Principle of optical comparator

2.20.1 Advantages of Optical Comparator

QUESTION

1. State the advantages and disadvantages of optical comparator. **(S-09, 10, 14; W-09)**

Advantages of Optical comparator are as follows:

1. These comparators have few moving linkages and hence, not subjected to wear and tear due to friction.
2. Wide range of measurement.
3. No parallax errors.
4. High magnification, so suitable for precision measurements.
5. It has self-illuminated scale. Hence, readings can be taken without influence of room lightings.

2.20.2 Disadvantages of Optical Comparator

Disadvantages of Optical comparator are as follows:

1. On need of high magnification, more heat from the source of light may cause the setting to drift.
2. An electric supply is necessary to operate the source of light.
3. Costly and bulky in design.
4. Instruments, on which, the scale is viewed through the eyepiece of a microscope, are not convenient for continuous use.

2.21 COMPARISON BETWEEN MECHANICAL AND PNEUMATIC COMPARATOR

Mechanical Comparator	Pneumatic Comparator
1. More moving parts, hence wear and tear is more.	1. Less moving parts, hence wear and tear is less.
2. Less accurate.	2. More accurate.
3. Limited range of magnification.	3. Wide range of magnification.
4. Does not require any external power source.	4. Needs external power supply.
5. Portable, compact and cheaper.	5. Large space is required and expensive.

2.22 COMPARISON BETWEEN MECHANICAL AND OPTICAL COMPARATOR

Mechanical Comparator	Optical Comparator
1. Does not require any external power source.	1. Requires external power source.
2. Cheaper.	2. Expensive.
3. Easy to handle.	3. Not easy to handle.
4. More number of moving parts.	4. Less number of moving parts.
5. Limited range of magnification.	5. Higher range of magnification.
6. Parallax error may occur.	6. No parallax error.
7. Robust, but compact.	7. Requires more space.

2.23 COMPARISON BETWEEN MECHANICAL AND ELECTRICAL COMPARATOR

Mechanical comparator	Electrical comparator
1. More moving parts, so more wear and tear. 2. Independent of power supply. 3. Less accuracy. 4. Limited range of magnification. 5. Inertia of moving parts may introduce errors in results.	1. Less moving parts, so less wear and tear. 2. Dependent on power supply. 3. More accuracy. 4. Wide range of magnification. 5. Voltage fluctuations may induce error in results.

2.24 COMPARISON BETWEEN COMPARATOR AND MEASURING INSTRUMENT

QUESTIONS

1. Differentiate between comparator and measuring instrument (at least 4 points). **(W-14)**
2. Differentiate between a comparator and a measuring instrument. **(S.Q.P.)**

Sr. No.	Comparative point	Comparator	Measuring Instrument
1.	**Purpose**	It is used to compare dimensions of parts with working standards and to measure difference between the sizes of parts manufactured and working standards.	It is used to measure the actual dimensions of manufactured parts.
2.	**Magnification**	Readings are magnified by suitable means.	No magnification system is provided.
3.	**Time required**	Measurements can be done rapidly and accurately, so it is suitable in mass production.	Measurement is time consuming, so not suitable in mass production.
4.	**Geometric forms**	Can be used to check geometric forms.	Can not be used to check geometric forms.
5.	**Errors**	No chances of errors due to incorrect contact pressure or deformation of work-piece.	Errors are caused due to misalignment of instrument or work-piece, incorrect contact pressure and deformation of instrument or work-piece.

Sr. No.	Comparative point	Comparator	Measuring Instrument
6.	**Accuracy**	Accuracy is independent of correct feel or operator skill.	Accuracy depends upon the correct feel and operator skill.
7.	**Human error**	It is subjected to parallax error.	It is subjected to observational error.
8.	**Remote controlling**	Remote operation is possible.	Remote controlling is not possible.

SOLVED PROBLEMS

Problem 2.1: *Prepare a stack of slip – gauges for Height 34.468 mm by using a normal Set of M45.* **(S-13)**

Solution: Height to be set up – 34.468 mm.

Set M45 is,

Range (mm)	Steps in (mm)	Number of pieces
1.001 to 1.009	0.001	9
1.01 to 1.09	0.01	9
1.1 to 1.9	0.1	9
1 to 9	1	9
10 to 90	10	9
	Total	45

To build 34.468 mm, the slip gauges from this set are used as,

$$\begin{array}{rl}
34.468 & \\
-\ \underline{\quad 1.008} & \quad \text{I}^{\text{st}}\text{ slip gauge} \\
33.460 & \\
-\ \underline{\quad 1.06} & \quad \text{II}^{\text{nd}}\text{ slip gauge} \\
32.4 & \\
-\ \underline{\quad 1.4} & \quad \text{III}^{\text{rd}}\text{ slip gauge} \\
31.0 & \\
-\ \underline{\quad 1.0} & \quad \text{IV}^{\text{th}}\text{ slip gauge} \\
30.0 & \\
-\ \underline{\quad 30.0} & \quad \text{V}^{\text{th}}\text{ slip gauge} \\
00.00 &
\end{array}$$

∴ Minimum number of slip gauges required are 5.

Problem 2.2: *List the minimum number of slip gauges to be brought together to produce an overall dimension of 73.975 mm, using a set of 87 pieces. The set contains* **(S-12, 15)**

Range (mm)	*Step (mm)*	*Pieces*
1.005	*–*	*1*
1.001 to 1.009	*0.001*	*9*
1.01 to 1.49	*0.01*	*49*
0.5 to 9.5	*0.5*	*19*
10 to 90	*10*	*9*
	Total	***87***

Solution: To built 73.975 mm height, the slip gauges from the given set are used as,

73.975 – 1.005	1st slip gauge
72.970 – 1.47	2nd slip gauge
71.50 – 1.5	3rd slip gauge
70.0 – 70.0	4th slip gauge
0	

∴ Minimum number of slip gauges required are 4.

Problem 2.3: *Prepare stack of slip gauges for height 58.975 mm using set M112.* **(W-12)**

Range (mm)	**Step (mm)**	**Pieces**
1.001 to 1.009	0.001	09
1.01 to 1.49	0.01	49
0.5 to 24.5	0.5	49
25, 50, 75, 100	25	04
1.005	–	01
	Total	**112**

Solution: To build a height of 58.975 mm, following slip gauges are required from the given M112 set.

58.975 – 1.005	Ist slip gauge
57.97 – 1.47	IInd slip gauge
56.5 – 6.5	IIIrd slip gauge
50.0 – 50.0	IVth slip gauge
0	

∴ Minimum 4 slip gauges are required to prepare stack of slip gauges.

Problem 2.4: *Develop the dimension 42.424 mm by using slip gauge set of M 112 for following conditions:*

1. *Without protection slips.*
2. *With protection slips of 2 mm each from both sides.*

Range (mm)	***Step (mm)***	***Pieces***
1.001 to 1.009	*0.001*	*9*
1.01 to 1.49	*0.01*	*49*
0.5 to 24.5	*0.5*	*49*
25, 50, 75, 100	*25*	*4*
1.005	*–*	*1*
	Total	***112***

Solution: Case – 1: Without protection slips:

To built **42.424 mm** height, the slip gauges from the given set are used as,

42.424 – 1.004	1st slip gauge
41.42 – 1.42	2nd slip gauge
40.00 – 15.00	3rd slip gauge
25.00 – 25.00	4th slip gauge
0	

Minimum number of slip gauges required are 4.

Case – 2: With protection slips of 2 mm each from both sides.

Net size = 42.424 – (2 × 2 mm)

∴ Net size = **38.424 mm**

38.424 – 1.004	1st slip gauge
37.42 – 1.42	2nd slip gauge
36.00 – 11.00	3rd slip gauge
25.0 – 25.0	4th slip gauge
0	

Minimum number of slip gauges required are 4.

Important Points

- Line standards are calibrated by comparing the given standard with a master scale in an optical comparator.
- *Line standards* and *End standards* are material standards, which are subjected to destruction and their dimensions vary with time.
- Slip gauges are used as standards of measurement for checking the accuracy of measuring instruments such as micrometers, calipers, snap gauges, dial indicators etc.

- *Wringing* is the process, when two clean and very accurately flat surfaces are slide together under pressure, they adhere firmly.
- Comparators are precision instruments used for comparison of manufactured parts as well as working gauges and instruments with reference to standard precision gauge blocks.
- Different types of Comparators: Mechanical comparators, Optical comparators, Pneumatic comparators, Electric and electronic comparators, Mechanical optical comparators.
- Pnemuatic comparators are most useful for measuring the roundness and taperness of cylinder bore.

Theory Questions for Practice

1. Define Standard. What are its types?
2. What is line standard? What are its characteristics?
3. What is end standard? Give its characteristics.
4. Write a short note on end bars.
5. Distinguish between Line standard and End standard.
6. Define wavelength standard. What are it's advantages?
7. Explain the process of wringing of slip gauges.
8. What are the precautions to be taken, while using slip gauges?
9. What is comparator? Give the advantages of comparator.
10. What are the essential requirements of a good comparator?
11. Enlist the applications of comparator.
12. Give classification of comparators. Explain any one mechanical comparator.
13. Enlist the applications of dial indicator.
14. Give advantages and disadvantages of dial indicator.
15. Explain sigma comparator.
16. Explain the working of pneumatic comparator.
17. What are the advantages and disadvantages of pneumatic comparators?
18. Explain the principle of working of optical comparators.
19. What are the advantages and disadvantages of optical comparator?
20. Differentiate between Comparator and Measuring Instrument.

Numerical Problems for Practice

1. The slip gauge set M38 consists of following gauge blocks.

Range (mm)	Steps (mm)	Pieces
1.005	-	1
1.01 - 1.09	0.01	9
1.1 - 1.9	0.1	9
1.0 - 9.0	1.0	9
10.0 - 100.0	10.0	10

Choose suitable slips to give following dimensions.

(a) 29.875 mm, (b) 15.09 mm, (c) 101.005 mm

Ans.

(a) Five slip gauges 20 mm, 6 mm, 1.8 mm, 1.07 mm and 1.005 mm.

(b) Three slip gauges 10 mm, 4 mm and 1.09 mm.

(c) Two slip gauges 100 mm and 1.005 mm.

---

2. Build up dimension of 46.635 mm using M87 slip gauge set.

Ans. We will use 4 slip gauges 40 mm, 4.5 mm, 1.13 mm and 1.005 mm.

---

3. Build up dimension of 29.758 mm using M87 slip gauge set.

Ans. We will use 4 slip gauges of 20 mm, 7.5 mm, 1.25 mm and 1.008 mm.

---

4. Enlist the slips to wring for an overall dimension of 52.325 mm using M45 set with protection slips of 1 mm each from both sides.

Ans. We will use 5 slip gauges 40 mm, 7 mm, 1.3 mm, 1.02 mm and 1.005 mm, in addition to two protection slips of 1 mm each.

---

5. Choose the suitable minimum number of slip gauges from M45 set to build up following dimensions.

(a) 43.716 mm, (b) 29.865 mm, (c) 24.095 mm, (d) 101.105 mm.

Ans. (a) We will use 4 slip gauges 40 mm, 1.7 mm, 1.01 mm and 1.006 mm.

(b) We will use 5 slip gauges 20 mm, 6 mm, 1.8 mm, 1.06 mm and 1.005 mm.

(c) We will use 4 slip gauges 20 mm, 2 mm, 1.09 mm and 1.005 mm.

(d) We will use 4 slip gauges 90 mm, 9 mm, 1.1 mm and 1.005 mm.

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2014

1. Draw labelled sketch of Sigma comparator. **(4M)**

Ans. Refer Article 2.15.2.

2. Differentiate between comparator and a measuring instrument (atleast 4 points). **(4M)**

Ans. Refer Article 2.24.

3. Differentiate between line and end standard (atleast 4 points). **(4M)**

Ans. Refer Article 2.4.

4. What is LVDT ? Explain its principle of working with neat sketch. **(4M)**

Ans. Refer Article 2.19.

Summer 2015

1. Draw a labelled diagram showing the working mechanism of dial indicator. **(6M)**

Ans. Refer Article 2.15.1.

2. List the minimum number of slip gauges to be wrung together to produce an overall dimension of 73.975 mm using a set of 87 pieces. The set contains **(4M)**

Range (mm)	Step	Pieces
1.005	–	1
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9

Ans. Refer Problem 2.2.

3. Discuss the characteristics of line standard and end standard. **(4M)**

Ans. Refer Articles 2.2 and 2.3.

4. Explain with neat sketch, construction and working of pneumatic comparator. **(8M)**

Ans. Refer Article 2.17.

Winter 2015

1. Define line standard and end standard. Give one application of each. **(4M)**

Ans. Refer Articles 2.2 and 2.3.

2. State the advantages and limitations of mechanical comparator. **(4M)**

Ans. Refer Article 2.16.

3. Differentiate between line standard and end standard. **(4M)**

Ans. Refer Article 2.3.

Summer 2016

1. Differentiate 'line standard', 'end standard' and 'wavelength standard'. (Give one application of each of them). **(6M)**

Ans. Refer Article 2.6.2.

2. Draw a labelled diagram showing the working mechanism of a dial indicator. **(4M)**

Ans. Refer Article 2.15.1.

3. Define the term 'comparator'. State the characteristics of a good comparator. **(4M)**

Ans. Refer Articles 2.14 and 2.14.2.

4. With a neat sketch, explain the principle of working of LVDT. State its applications. **(4M)**

Ans. Refer Articles 2.19, 2.19.3.

Winter 2016

1. Name the comparator, which has highest magnification. Explain its working and state its advantages and disadvantages. **(6M)**

Ans. Refer Article 2.19.

2. Discuss the characteristics of line standard and end standards. **(4M)**

Ans. Refer Articles 2.2.1 and 2.3.1.

3. Explain the construction and working of sigma comparator with neat sketch. **(4M)**

Ans. Refer Article 2.15.2.

Summer 2017

1. State the advantages of wavelength standards over the material standards. **(4M)**

Ans. Refer Article 2.6.1.

2. State the need and uses of the comparators. **(4M)**

Ans. Refer Articles 2.14.1 and 2.14.3.

3. Explain the (LVDT) electrical comparator with neat sketch. **(4M)**

Ans. Refer Article 2.19.

4. State the characteristics of the end standards. **(4M)**

Ans. Refer Article 2.3.1.

5. State the essential characteristics of the good comparator (any eight). **(4M)**

Ans. Refer Article 2.14.2.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 3

LIMITS, FITS, TOLERANCES AND GAUGES

About This Chapter ...

This chapter has a weightage of 8 marks and assigned duration is 6 hours. In this chapter, we learn about Limits, Fits, Tolerances and Gauges. We also learn about interchangeability, Selective assembly, Hole and Shaft basis system, Taylor's Principle, plug and ring gauges, IS 919-1993 standards and Concept of Multi-gauging and inspection.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	04 Marks	S-09	04 Marks
W-09	04 Marks	S-10	06 Marks
W-10	10 Marks	S-11	08 Marks
W-11	08 Marks	S-12	18 Marks
W-12	10 Marks	S-13	10 Marks
W-13	06 Marks	S-14	16 Marks
W-14	12 Marks	S-15	12 Marks
W-15	12 Marks	S-16	12 Marks
W-16	12 Marks	S-17	12 Marks

3.1 TERMINOLOGY

QUESTION

1. Draw conventional diagram of limits and fits and define the terms: **(W-14)**
   (i) Basic size, (ii) Fundamental Deviation.

Basic size:

- It is the specified standard size of a part, with reference to which, all the limits of variations of size are determined. It is same for both hole and its corresponding matting member i.e. shaft. As basic size is specified before the production or inspection, it is also called as **true value**.

Actual size:

- It is the actual measured value of manufactured job after measurement. Therefore, it is also called as **measured value**.

Zero line:

- Line corresponding to *basic size* is called as *zero line*. It is the line of *zero deviation*.
- In the graphical representation of limits and fits, all the deviations are shown w.r.to the zero line (or basic size) i.e. positive deviations above the zero line and negative deviations below the zero line.

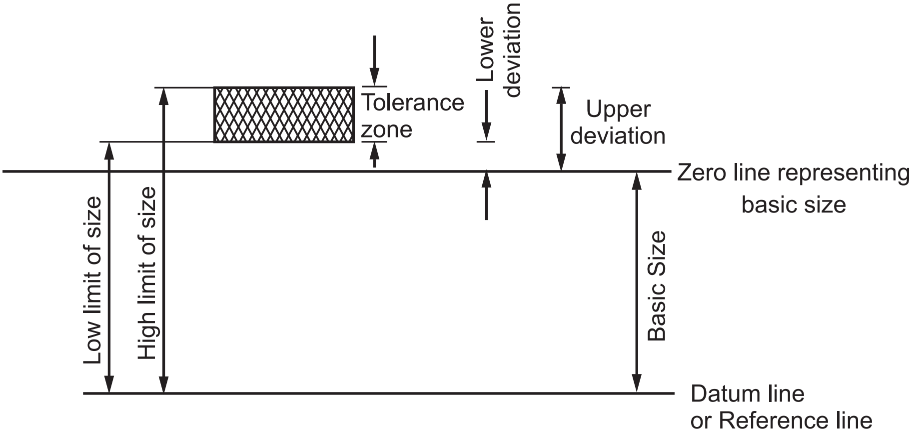


Fig. 3.1: Tolerance

Hole: It is a term used to **specify internal** features of part.

Shaft: It is a term used to **specify external** features of part.

3.2 TOLERANCE

- Tolerance is the algebraic difference between the maximum limit and minimum limit of a hole or shaft.
- It is also defined as 'difference between upper deviation and lower deviation'. It has an absolute value without algebraic sign. (Neither plus or minus).

3.2.2 Need of Tolerance

- In actual practice, it is never possible to make a part or component exactly same as per the given specified size (dimension). Simultaneously, no measuring instrument or method of measurement is available, which will show accurate size of component manufactured.
- Therefore, it is difficult, rather impossible, to produce a part to an exact size due to,
  1. Variations in the properties of raw material being machined.
  2. The production machines may themselves have some inherent inaccuracies.
  3. Operator error (how skilled the operator is ?)

- An attempt to entirely overcome the above three factors would result into very high costs. Therefore, if some variation to specified size does not affect the functional requirement of that component, then some tolerance can be given to basic size. By doing so, number of products falling inside the limits will be more and products falled outside the limits will automatically reduce. This leads to reduced cost of manufacturing component.
- But, the component can only be marked to lie between two limits, *maximum* and *minimum*. The difference between these two limits is called as **tolerance**.
- Tolerance on a dimension is the difference between the higher and the lower limit of a size. In other words, tolerance is the tolerable or allowable variation in size to overcome imperfections in workmanship and variations amongst the grades of work according to the requirements.
- Tolerance zone is defined as, "the difference between higher and lower limits of a dimension". It represents the margin for variation in workmanship.
- Tolerances should be selected so as to ensure reasonable and reliable operation of the manufactured parts during their normal service life. Extremely close tolerances [unnecessarily] will increase the manufacturing cost of part.
- **Tolerance** can also be specified/defined as, "the amount, by which, the job is allowed to go away from accuracy and perfectness without causing any functional trouble, when assembled with mating part and the assembly is put into actual services".
- A shaft of dimension $25^{\pm\ 0.02}$ indicates that, Upper limit = 25.02 mm and Lower limit = 24.98 mm. Therefore, Tolerance zone = 25.02 – 24.98 = 0.04 mm.

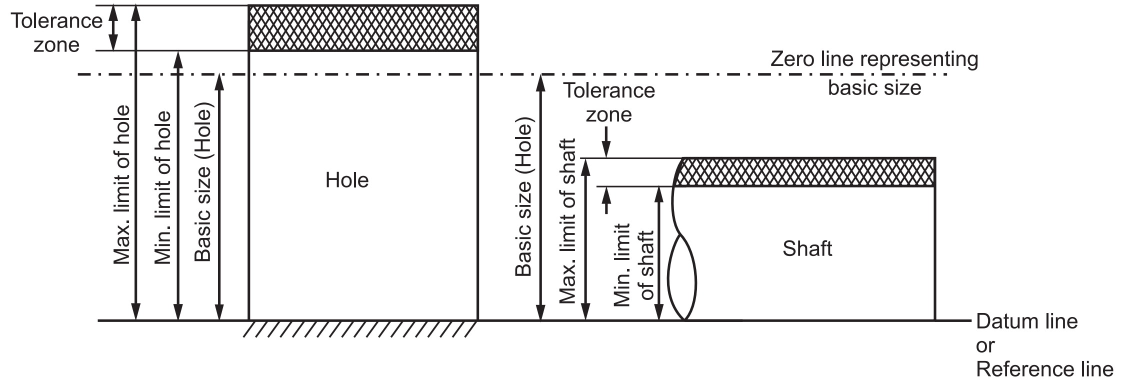


Fig. 3.2: Need of Tolerance

3.3 SYSTEMS OF TOLERANCE

QUESTION

1. What are the advantages of unilateral tolerance system in hole basis? **(S-11)**

- Tolerance for a particular dimension may be allowed to vary (change) either on one side of basic size or both sides of basic size.
- There are two systems of specifying the tolerance of a component.

(a) Unilateral System:

- If dimension of a part is permitted to vary only on one side of the basic size, the system of tolerance is said to be *unilateral*. It means that, tolerance will lie on one side of basic size, either upper or below it.

- $25^{+0.02}_{+0.01}$, $25^{0.02}$, $25^{-0.02}$ and $25^{-0.04}_{-0.05}$ are the examples of unilateral tolerance. Here, dimension of part is allowed to vary (change) only on one side of basic dimension or size.

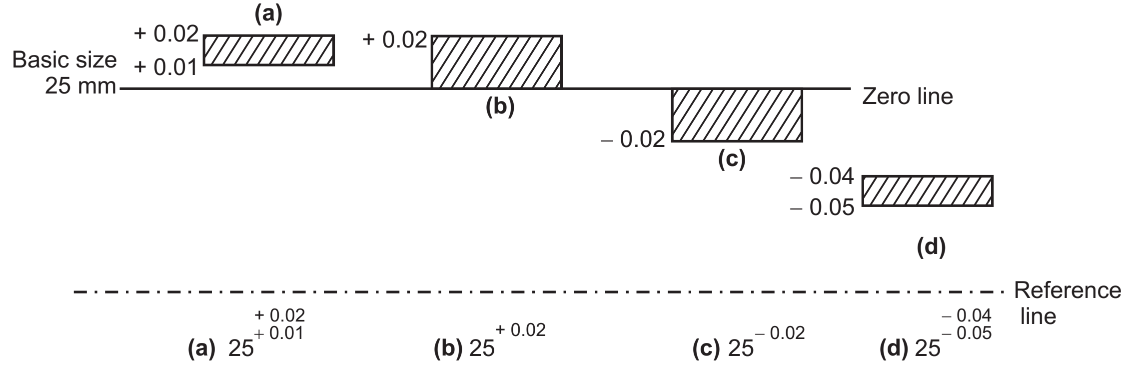


Fig. 3.3: Unilateral tolerance

Advantages of Unilateral System:

(i) Unilateral system is preferred in interchangeable manufactured parts, especially where precision fits are required, because it is easy and simpler to determine deviations.

(ii) Go gauge ends can be standardized as the holes of different tolerance grades have the same lower limit and all the shafts have same upper limit.

(b) Bilateral System:

- If dimension of a part is permitted to vary (change) on both sides of the basic size, the system of tolerance is said to be *bilateral system*. It means that, limits of tolerance will lie on either side of basic size; but it is not necessary to vary tolerance of equal amounts on both sides of basic size.
- For example, $25^{+0.02}_{-0.01}$ is an example of bilateral tolerance. Therefore, +0.02 and –0.01 denote permissible higher and lower deviations respectively.

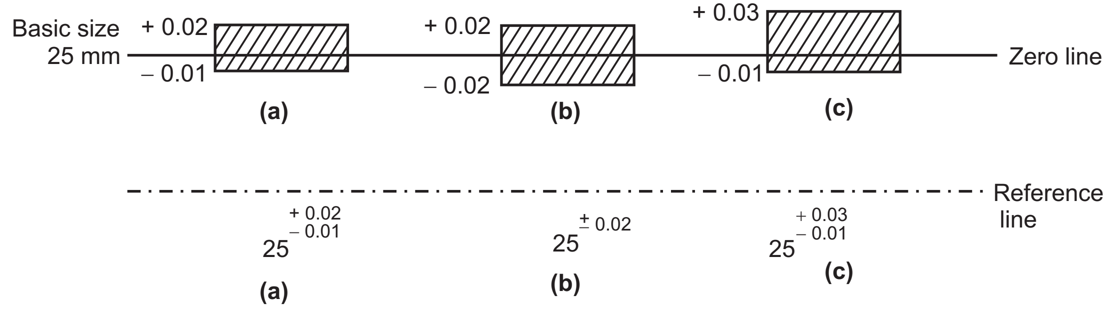


Fig. 3.4: Bilateral tolerance

- In this system, it is not possible to retain the same fit, when tolerance is varied. Therefore, limits of one or both mating parts will also be required to vary (change).

Advantages of Bilateral System:

(i) Bilateral system is preferred for manufacturing large sized components.

(ii) It makes procedure of machine setting, very easy and simple.

3.3.1 Difference between Unilateral and Bilateral System

QUESTION

1. Differentiate between unilateral system and bilateral system of tolerances on any four parameters. **(S-13; W-16)**

Unilateral System	Bilateral System
1. Dimension of a part is allowed to vary only on one side of basic size.	1. Dimension of a part is allowed to vary on both sides of basic size.
2. Tolerance zone lies on one side of basic size.	2. Tolerance zone lies on either side of basic size.
3. Preferred in interchangeable manufacture, i.e. mass production.	3. Used in manufacturing of large sized parts. Also helpful in machine setting.
4. e.g. $25^{+0.02}_{+0.01}$, $25^{+0.00}_{-0.02}$	4. e.g. $25^{+0.02}_{-0.01}$, $25^{\pm 0.02}$

3.4 LIMITS OF SIZE

QUESTION

1. Define limits. State their types. **(S.Q.P.)**

- Every production process is a combination of three elements - man, machines and materials. A change in any of these 3 elements will change the sizes of the manufactured parts. The incorrect size relationships between the manufactured parts affect their life and proper functioning.
- In mass production, where number of parts is to be manufactured, it is not possible to make all parts exactly alike and to exact dimensions. Also, perfect size is not only a difficult, but a costly matter. Therefore, the ranges of permissible difference in dimensions have been standardized under the concept of "*limits*".
- Limits of size of a dimension of a part are two extreme permissible sizes, between which, the actual size of manufactured part should lie. Limits are fixed with reference to the basic size of that dimension.
- For example, a shaft of 25 mm basic size with tolerance ± 0.02 may be written as $25^{\pm 0.02}$. Higher limit for the dimension is 25.02 mm and lower limit for the dimension is 24.98 mm.
- **Limits** are defined as, *"two extreme permissible sizes for a dimension, there being a higher limit and a lower limit"*. The greater of these two sizes is called as maximum limit or high limit of size, while the smaller size is called as minimum limit or low limit of size.

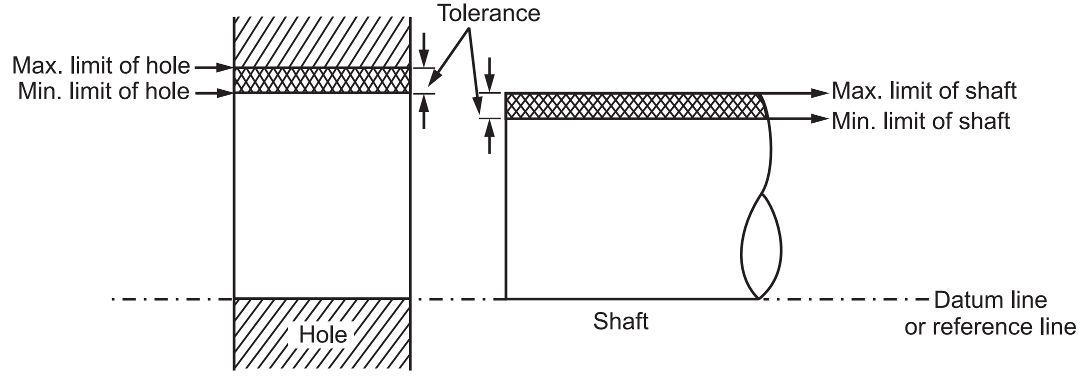


Fig. 3.5: Limits of size

3.5 DEVIATION

QUESTION

1. Draw the conventional diagram of limits and fits and define the terms :

   (i) Basic size, (ii) Fundamental Deviation **(W-14)**

- **Deviation** is the amount, by which, the actual size of a manufactured part deviates from its basic size. Thus, *deviation* is the algebraic difference between actual size and basic size.
- The straight line corresponding to the basic size is called as *zero line* (i.e. the line of zero deviation).

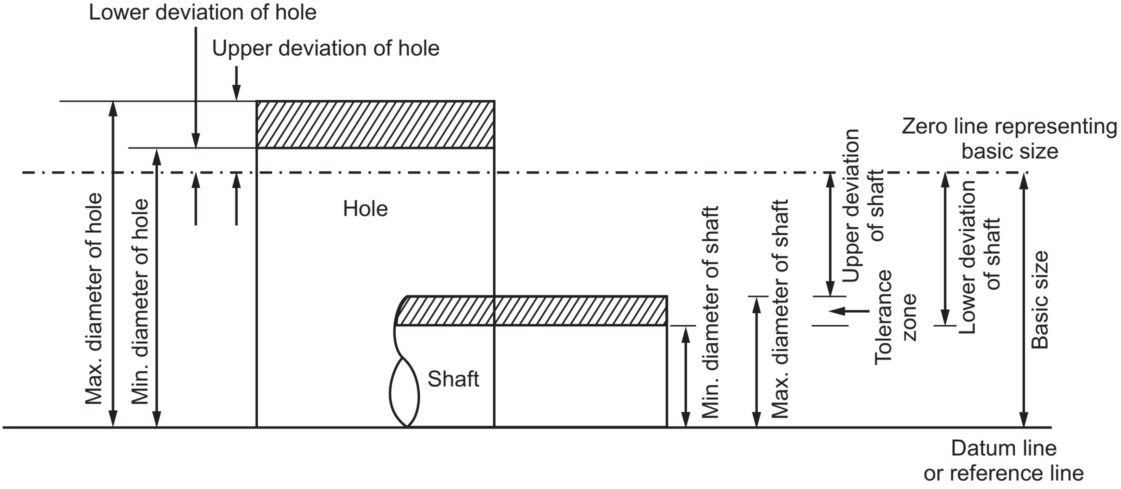


Fig. 3.6: Deviation

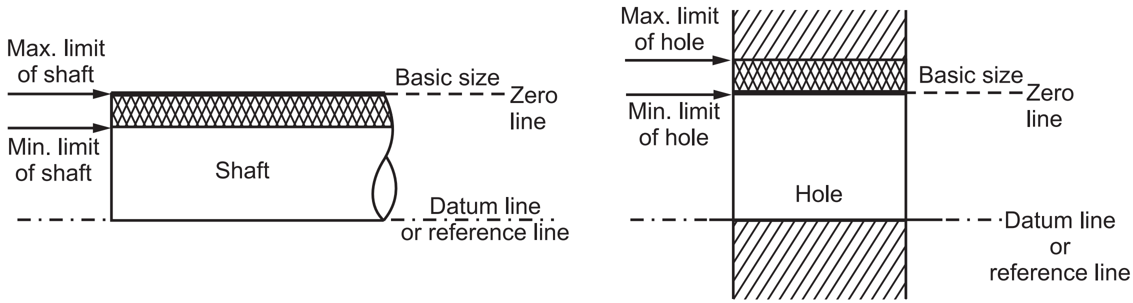
- **Upper deviation** is the difference between *maximum limit* and basic size.
- **Lower deviation** is the difference between *minimum limit* and basic size.
- **Mean deviation** is the arithmetic mean (average) of upper deviation and lower deviation.

- **Fundamental deviation** is either upper deviation or lower deviation, which is conventionally chosen to define the position of tolerance zone in relation to the zero line.
- In fact, it is the upper or lower deviation, which is nearest to zero line, either for shaft or a hole.

Sr. No.	Part	Fundamental deviation
1.	Hole	Lower deviation
2.	Shaft	Upper deviation

3.6 BASIC SHAFT AND BASIC HOLE

- **Basic shaft:** It is the shaft, whose fundamental deviation, i.e. upper deviation is zero or whose maximum limit of size is equal to basic size.
- **Basic hole:** It is the hole, whose fundamental deviation, i.e. lower deviation is zero or whose minimum limit of size is equal to basic size.

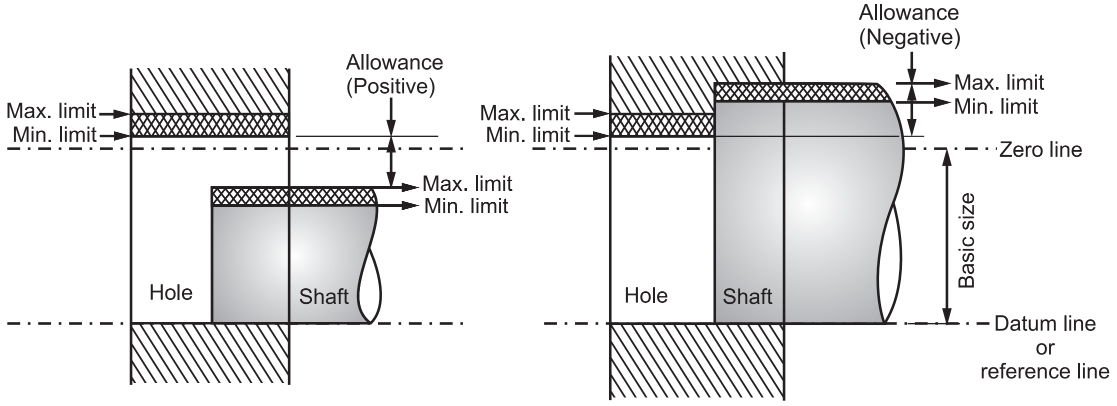


(a) Basic shaft **(b) Basic hole**

Fig. 3.7: Basic shaft and Basic hole

3.7 ALLOWANCE

- *Allowance* is an intentional difference kept between lower limit of the hole and higher limit of the shaft.
- *Allowance* is defined as, "the prescribed difference between the hole dimension and shaft dimension to obtain desired type of fit".
- Therefore, an allowance can be either positive (+) or negative (–), which is decided on the basis of the type of fit required. If the limits provided to both mating members are such that, the shaft diameter will be always smaller than the hole diameter, we say that, there is **positive allowance**. But, if the shaft diameter is larger than the hole diameter, we say that, there is **negative allowance**.
- Positive allowance is called *clearance*, while negative allowance is called *interference*.
- In **clearance fit**, allowance is the **minimum clearance**, i.e. difference between minimum size of hole and maximum size of shaft. It is referred as **positive allowance**. [Ref. Fig. 3.8(a)].
- In **interference fit**, allowance is the **maximum interference**, i.e. difference between minimum size of hole and maximum size of shaft. It is referred as **negative allowance**. [Ref. Fig. 3.8(b)].



(a) Positive allowance (Clearance) **(b) Negative allowance (Interference)**

Fig. 3.8: Allowance

3.8 DIFFERENCE BETWEEN TOLERANCE AND ALLOWANCE

Tolerance	Allowance
1. It is the permissible variation in any dimension of a part (either hole or shaft).	1. It is the prescribed difference between the dimensions of two mating parts (hole and shaft) to obtain required type of fit.
2. It is the difference between higher and lower limits of a dimension of a part.	2. It is the prescribed difference intentionally kept between the lower limit of hole and higher limit of shaft to obtain required type of fit.
3. Tolerance is to be provided on a dimension of part, as it is not possible to make a part of exact specified dimensions.	3. Allowance is to be provided between dimensions of mating parts to obtain required type of fit.
4. It has an absolute value without algebraic sign. (Neither positive nor negative)	4. Allowance may be positive (clearance) or negative (interference).

3.9 FITS

QUESTIONS

1. What do you understand by fit? What are type of fits? Draw neat sketches stating the practical examples of each. **(S-14)**
2. Define fits. State their types. **(S.Q.P.)**

- **Fit** is defined as, "the relation between the two mating parts, where one is inserted into the other with a certain degree of tightness or looseness".
- In simple words, when two mating parts are to be assembled, the relation obtained due to the difference between their sizes before assembly is called as *fit*.
- **Fit** is the degree of tightness or looseness between two mating parts to perform a definite function.

- Various kinds of engagement (fit) between hole and shaft can be obtained by varying the difference amongst their average sizes.
- Depending upon the actual sizes of hole or shaft, fits may be classified as: (a) Clearance fit, (b) Transition fit, (c) Interference fit.

Classification of Fits

Clearance fit

(a) Slide fit
(b) Running fit
(c) Loose running fit
(d) Slack running fit
(e) Easy slide fit

Transition fit

(a) Wringing fit
(b) Push fit

Interference fit

(a) Heavy force and shrink fit
(b) Force fit
(c) Tight fit

3.10 CLEARANCE FIT (S-14)

- In this type of fit, diameter of largest shaft is smaller than diameter of smallest hole, so that, the shaft can rotate or slide through, with different degrees of freedom according to the purpose of the mating members.

$\therefore$ For clearance fit : Largest shaft diameter < Smallest hole diameter

- Clearance fit denotes the condition of assembly of two mating parts, in which, the limits of size of these parts are so chosen that, **'positive allowance'** i.e. **'clearance'** will always occur. It can be classified into following types.

(i) Maximum clearance = Difference between maximum limit of hole and minimum limit of shaft.

(ii) Minimum clearance = Difference between minimum limit of hole and maximum limit of shaft.

(iii) *Mean clearance* = Arithmetic mean OR Average value of maximum and minimum clearances.

- For example: Sliding fit, running fit, loose running fit, slack running fit, easy slide fit etc.

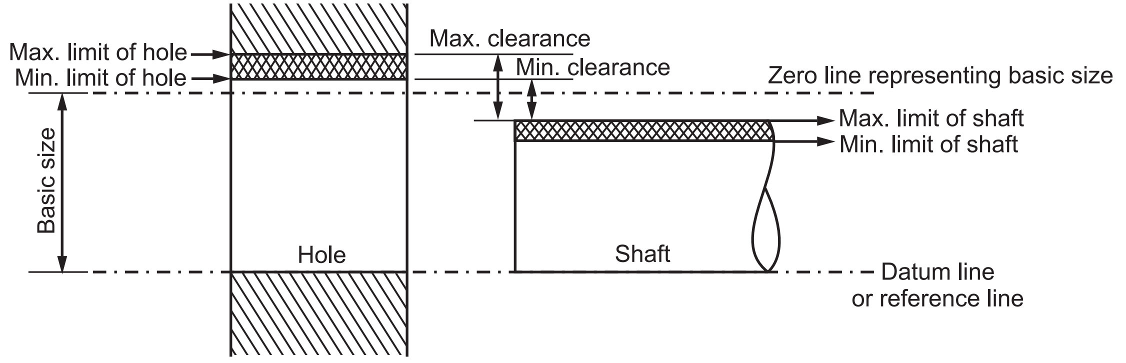


Fig. 3.9: Clearance fit

Note:

(a) Slide fit: It has very small clearance between mating parts. It is employed when the mating parts are required to move slowly in relation to each other. For example: Tail stock spindle of lathe.

(b) Running fit: It has a appreciable clearance between mating parts. It is employed for rotation at moderate speed.

For example: Gearbox bearings, crank shafts in their main bearings, shaft pulleys etc.

(c) Loose running fit: It is employed for rotation at high speeds.

For example: Idle pulley on shafts, in quick return mechanism of shaper.

3.11 TRANSITION FIT (S-14)

- In this type of fit, the sizes of limits of mating parts (shaft and hole) are so selected that, either clearance or interference may occur depending upon the actual size of parts.
- Here, diameter of largest allowable hole is greater than diameter of smallest shaft, but diameter of smallest hole is smaller than diameter of largest shaft, so that, small positive or negative allowance between diameters of mating parts (shaft and hole) is permissible.

  ∴ For transition fit,

  (i) Largest hole diameter > Smallest shaft diameter

  (ii) Largest shaft diameter > Smallest hole diameter
- Examples: Push fit and light keying fit, Spigot in mating holes, Coupling rings and recesses.
- Types: (i) Wringing fit and (ii) Push fit.

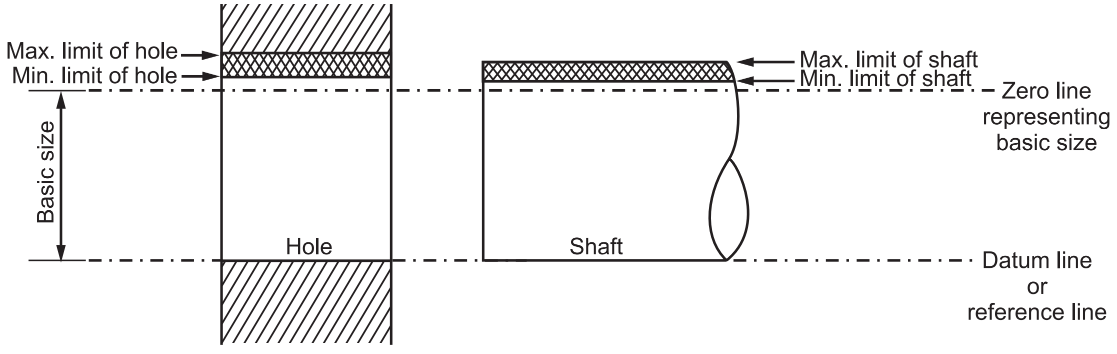


Fig. 3.10: Transition fit

Note:

(a) Wringing fit: It provides either zero interference or a clearance. It is employed, where parts can be replaced without difficulty during minor repairs.

(b) Push fit: It provides small clearance. It is employed for parts that must be dis-assembled during operation of a machine.

For example: Changing gears etc.

3.12 INTERFERENCE FIT **(S-14)**

QUESTION

1. Define maximum clearance and minimum interference. Draw suitable sketch. **(W-15)**

- In this type of fit, sizes of mating parts (hole and shaft) are so selected that, interference or negative allowance will always occur.
  Therefore, for Interference fit : Smallest shaft diameter > Largest hole diameter.
- In this type of fit, diameter of minimum allowable shaft is greater than that of maximum allowable hole.

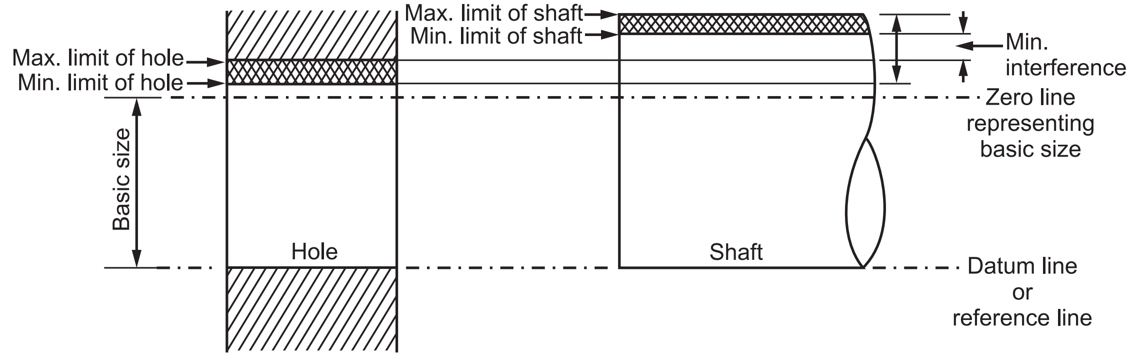


Fig. 3.11: Interference fit

Interference can be classified into following types:

(i) **Maximum interference** is the negative difference between the maximum limit size of the shaft and the minimum limit size of the hole.

(ii) **Minimum interference** is the negative difference between minimum limit size of the shaft and the maximum limit size of the hole.

(iii) **Mean interference:** Arithmetic mean or Average value of maximum and minimum interferences.

- For example: Press fit, driving fit, shrink fit etc.
- Types: (i) Force fit, (ii) Tight fit, and (iii) Heavy force and shrink fit.

Note:

(a) **Force fit:** It has considerable interference between mating parts. It is employed, when mating parts are not required to be disassembled during their total service life. Here, assembly of mating parts is only obtained, if high pressure is applied. For example: Gears on the shaft of concrete mixture, Forging machine etc.

(b) **Tight fit:** It has less interference than force fit. It is employed for the mating parts, that may be replaced while overhauling/maintenance of the machine. For example: Stepped pulley on the drive shaft of a conveyor, cylindrical grinding machine etc.

(c) **Heavy force and shrink fit:** It has maximum interference between mating parts. Therefore, to obtain the required fit, considerable amount of force is applied.

3.13 DESIGNATION OF FITS

QUESTION

1. Explain the meaning of H_7f_8 with respect to fit and basis of system. **(S-11)**

- To describe completely a hole or a shaft, its basic size followed by appropriate letter and the number of tolerance grade is given.
- A hole is designated by capital letter, while shaft by small letter.
  For example: 20 mm hole 'H' with tolerance grade IT_7 is designated as $20H_7$ and 20 mm 'f' shaft with tolerance grade IT_8 is designated as $20f_8$.
- A fit is indicated by its basic size, followed by symbols representing the limits of two mating parts, the hole being quoted first.
- For example: $20H_7f_8$ or $20\,\frac{H_7}{f_8}$ means that, 20 mm is basic size, H_7 indicates hole of tolerance grade IT_7 and f_8 indicates shaft of tolerance grade IT_8.
- **Note:** In order to determine the type of fit, observe the label (alphabet) of shaft.

For shafts	a to h	Clearance fit
For shafts	j to n	Transition fit
For shafts	p to z	Interference fit

- In the above example of 20 H_7f_8, shaft is represented with small letter 'f'. Since the alphabet 'f' lies in the category of 'a' to 'h', the type of fit is **clearance fit**. Type of fit system is always hole basis.

3.13.1 Interpretation of Designated Fit

QUESTIONS

1. Interpret meaning of 35 H_8f_7 w.r.t. fit and basis of system. State meaning of each term. **(S-15)**
2. Interpret the meaning of 27 H_5f_6 with respect to fit and basis system. **(W-14)**
3. Interpret the meaning of $25H_8s_6$ with respect to fit and basis of system. **(W-16)**

Interpret the meanings of:

(i) 25 H_8s_6: **(W-16)**

- 25 mm is the basic size.
- A hole is always designated by capital letter, and shaft is always designated by small letter.
- **$25H_8$:** It means H-hole of basic size 25 mm having tolerance grade IT_8. Capital letter "H" represents a basic hole, whose fundamental deviation, i.e. lower deviation is zero.
- **$25s_6$:** It means s-shaft of basic size 25 mm having a tolerance grade IT_6. Small letter "s" represents a basic shaft, whose fundamental deviation, i.e. upper deviation is zero.
- **$25H_8S_6$:**
  (a) It means a fit indicated by its basic size (25 mm), followed by symbols representing the limits of hole (H_8) and shaft (s_6), the hole being quoted first.
  (b) Since, shaft is designated by small letter "s", which lies inbetween the alphabets "p" to "z", the type of fit is "interference fit".

(ii) 27 H_5f_6:

- 27 H_5 means a H-hole of basic size 27 mm having tolerance grade IT_5.
- 27 f_6 means a f-shaft of basic size 27 mm having tolerance grade IT_6.
- 27 H_5f_6 is a fit indicated by its basic size (27 mm), followed by symbols representing the limits of hole (H_5) and shaft (f_6), the hole being quoted first. The type of fit system is hole basis system and obtained type of fit is transition fit.

(iii) 35 H_8f_7:

- 35H_8f_7 is a fit indicated by its basic size 35 mm, followed by symbols representing the hole H_8 i.e. hole having basic size 35 mm with tolerance grade IT_8 and shaft f_7 i.e. shaft having basic size 35 mm with tolerance grade IT_7.
- Type of fit system is hole basis system and obtained type of fit is *transition fit*.

3.14 INTERCHANGEABILITY

QUESTIONS

1. What is interchangeability? State its advantages. **(S-12)**
2. What is interchangeability? State its need and importance or relevance in mass production industries like automobile engine components. **(S.Q.P., S-16)**
3. What is interchangeability ? State its importance in mass production. **(W-15)**

- In olden days, production was limited to small number of parts to be produced. The same worker used to produce the parts and asked to assemble the mating parts to obtain necessary fits.
- But, today in the era of mass production, parts are manufactured by different workers in different plants and assembled in another plant. Under such conditions, dimensions of the various mating parts must strictly lie within certain variations; so that, any one part selected randomly will get assembled correctly with any other mating part that too selected randomly. Such system is called as *interchangeable system*.
- An interchangeable part can substitute any other part manufactured according to same drawing and same specifications.
- Interchangeability is possible only, when certain standards are strictly followed in various manufacturing units.
- For universal interchangeability, International standards should be followed.
- When all the parts to be assembled are manufactured in a single unit, then local standards may be followed.

3.14.1 Advantages of Interchangeability

QUESTIONS

1. What is interchangeability? State its advantages. **(S-12)**
2. What is interchangeability ? State its importance in mass production. **(W-15)**

(i) Mass production: Since interchangeability is achieved, if the parts are manufactured with small/close tolerances. Therefore, concept of interchangeability is practically used for mass production.

(ii) **Increase in productivity:** In mass production, different workers manufacture similar type of products on various machines. Therefore, number of products manufactured per day will increase, because each worker is assigned same work throughout the day. Therefore, rate of production increases. In other words, productivity of company increases and it can easily supply products as per increasing demand.

(iii) **Low production cost:** Different components can be manufactured in different parts of country, depending upon the availability of raw material, skilled labour and other facilities. This reduces cost of production considerably.

(iv) **Low maintenance cost:** Easy replacement and repairs of worn out or defective parts, therefore maintenance cost is very much reduced.

(v) **Improved quality:** Similar type of work is assigned to a worker, so he can easily specialize himself in that work. This results in improved quality of work.

(vi) **Less time consuming:** Due to small tolerances specified for manufacturing mating members, hence achieving interchangeability, assembly work of mating members requires small time.

3.15 SELECTIVE ASSEMBLY

QUESTIONS

1. Explain the term, 'selective assembly'. **(W-14)**
2. State the meaning of 'selective assembly'. State its relation with the concept of interchangeability in mass production. **(S.T.P.-I)**

- To achieve interchangeability, mating parts are given very close tolerances. In such cases, most of the manufactured parts are likely to be rejected because their actual dimension will fall outside permissible limits.
- Whereas, in selective assembly, manufactured parts of any one part are categorized into several groups according to their actual sizes. Similarly, their mating parts manufactured are also categorized in same number of groups.
- This is done to ensure that, part chosen randomly from any group can be assembled to mating part chosen randomly from the corresponding group.
- Therefore, desired type of fit can be obtained after their assembly, without further machining.
- In some cases, we may find difficulty to obtain desired type of fit. In such cases, little machining of a part can solve the difficulty in saving cost and time of assembly.

Advantages of Selective Assembly over Interchangeability:

(i) **No need of close tolerances:** In selective assembly, both mating parts can be manufactured with wider tolerances and then they can be categorized or separated into number of groups according to their actual sizes. During assembly, a part selected from a group can be assembled with its mating part selected from corresponding group.

(ii) Decrease in loss of company due to reduced number of scraps/wastage.

(iii) Reduced cost of production without affecting the quality of the product.

- **Applications:** Air craft, Automobile industries, Ball and Roller bearing industries.

3.16 HOLE BASIS AND SHAFT BASIS SYSTEM

- In a general limit system, it is necessary to decide on what basis, the limits are to be found to give the desired fit.
- Limit and fit system is defined as, "a system of series of standard allowances and tolerances to suit specific ranges of basic size, which, when properly selected and assigned to mating parts ensure specific classes of fit".
- There are two distinct systems for varying the sizes of parts known as *hole basis system* and *shaft basis system* of limits and fits.

3.16.1 Hole Basis System

QUESTIONS

1. Describe with sketches, hole basis system and shaft basis system. **(W-08, S-12)**
2. Draw the sketch of hole basis system and explain. **(W-12)**
3. Draw the sketch of hole basis system. Explain why it is preferred? **(W-13)**
4. Define with simple sketch, hole and shaft basis system. **(S.T.P.-I)**
5. Explain hole basis system. Why it is preferred ? **(W-15)**

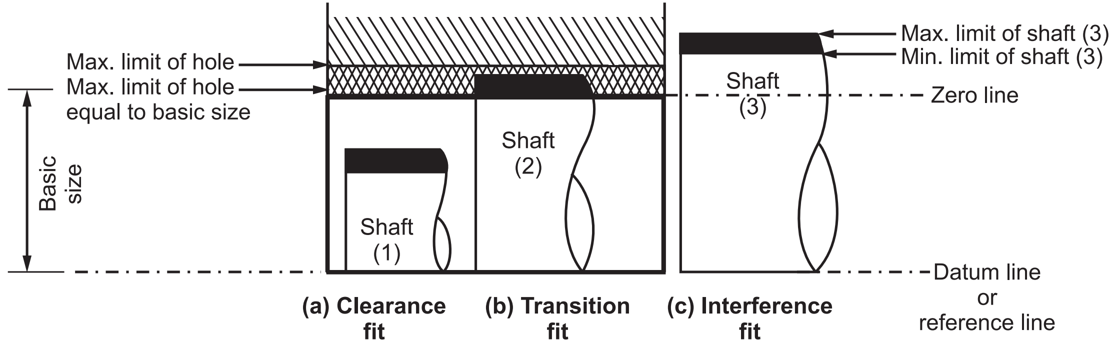
- In this system, the design size of hole, whose lower deviation (fundamental deviation) is zero, is assumed as basic size and different clearances or interferences are obtained by varying the limits of mating part i.e. shaft to have different class of fit.
- In other words, limits of hole are kept constant and limits of shaft are varied, so as to obtain the necessary type of fit.
- In this system, the hole has constant high and low limits for all fits of same accuracy grade and for same basic size.

Advantages of Hole Basis System:

(i) As hole basis system is very easy, convenient and less costly to make holes of correct sizes by using drills, reamers etc., therefore, hole basis system is preferred and used by almost all industrial companies.

(ii) It is also much easier to vary shaft sizes according to the fit required, by suitable methods such as turning and grinding.

(iii) Also, inspection of shafts can be done easily and rapidly with the help of adjustable gauges. Direct external measurement (such as shaft) is easier than internal measurement (such as hole).



(a) Clearance fit (b) Transition fit (c) Interference fit

Fig. 3.12: Hole basis system

3.16.2 Shaft Basis System

- In this system, the design size of a shaft, whose upper deviation (fundamental deviation) is zero, is assumed as basic size and different clearances or interferences are obtained by varying the limits of hole to have different types of fit.
- In other words, limits of shaft are kept constant and limits of holes are varied to obtain the necessary type of fit.

Advantage of Shaft Basis System:

(i) It is preferred, when different accessories with different fits such as pulley, bearings, gears etc. are mounted on a single large shaft.

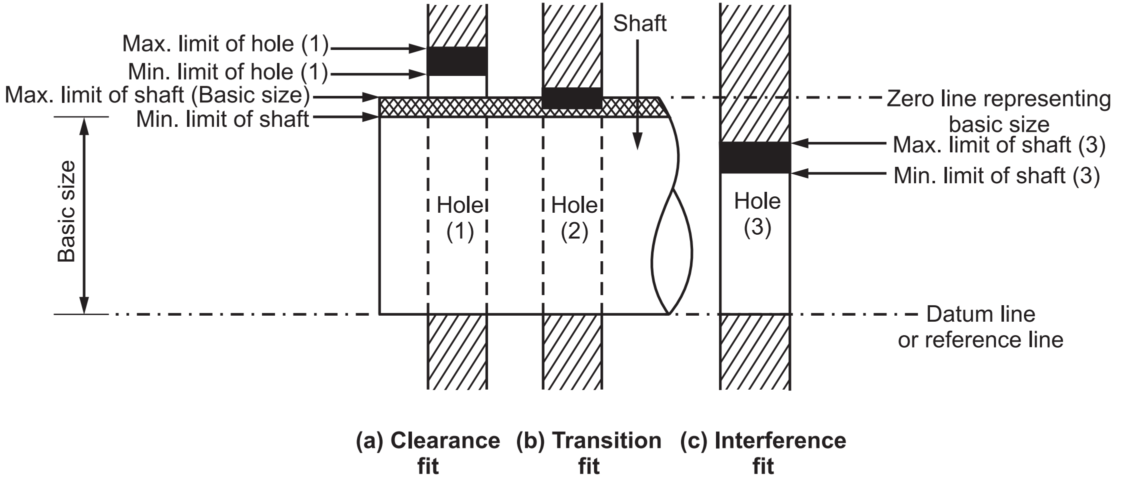
Disadvantages of Shaft Basis System:

(i) In mass production, use of this system will need large amount of capital and storage space for the large number of tools (drills, reamers, broaches, punches etc.) required to produce holes of different sizes. So, this method is not preferred in mass production.

(ii) As limits of holes are varied to obtain the necessary type of it, therefore it becomes compulsory to measure inside diameter of holes. Internal measurements are always difficult, because of complex construction of measuring instruments used.

(iii) Internal measurements are time consuming.

(iv) Accuracy is measured value depends upon the skill of operator. Therefore, cost of inspection increases due to high wages paid to skilled labours.



(a) Clearance fit **(b) Transition fit** **(c) Interference fit**

Fig. 3.13: Shaft basis system

Q. Why hole basis system is preferred over shaft basis system? **(W-13, 15)**

Ans.: • All modern systems employ the hole basis system, the main reason being that, it is easier to vary the size of the shaft than that of the hole.

- The majority of holes in engineering works are produced with drill and reamer or some similar tool.
- Therefore, it becomes necessary to use very large number of tools of varying sizes to vary the size of holes.
- However, in some cases, the shaft basis system proves to be more advantageous than the hole basis system.
- For example: Manufacturing of large sized parts.

3.16.3 Difference Between Hole Basis System and Shaft Basis System

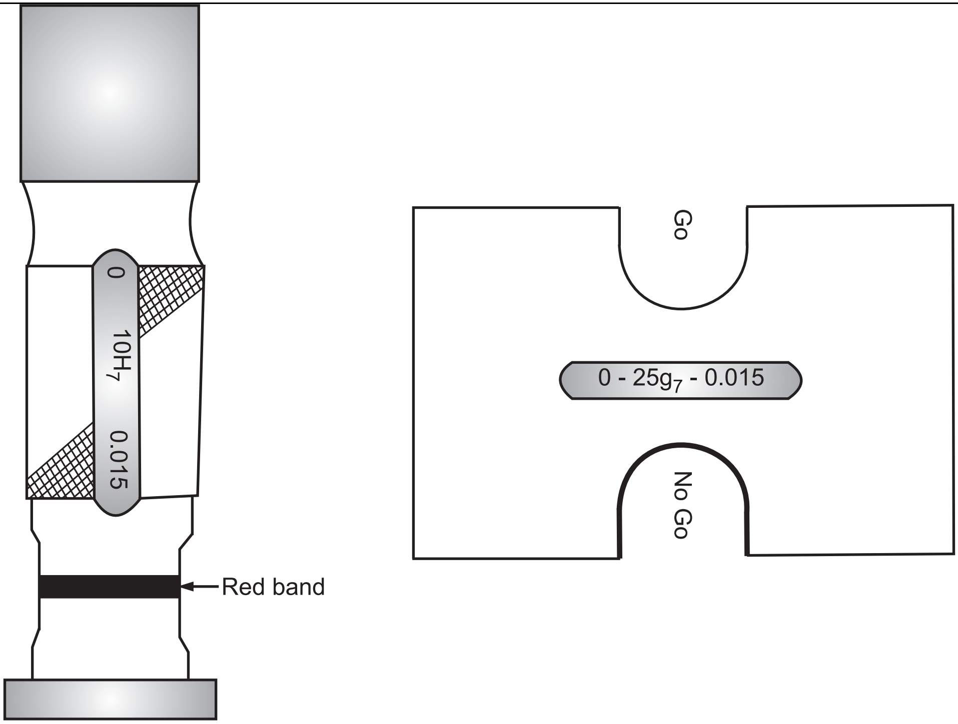
QUESTIONS

1. Differentiate between hole basis system and shaft basis system. **(W-09, 16; S-14, 15)**
2. Differentiate between hole basis system and shaft basis system. **(W-16)**

Hole Basis System	Shaft Basis System
1. Lower deviation of hole (fundamental deviation) is zero.	1. Upper deviation of shaft (fundamental deviation) is zero.
2. Limits on the hole are kept constant and those of the shaft are varied to obtain desired type of fit.	2. Limits on the shaft are kept constant and those of hole are varied to obtain desired type of fit.
3. System is preferred in mass production, because it is easy, convenient and economically cheaper i.e. less costly to make a hole of correct size.	3. System is not suitable in mass production, because it is not easy and convenient to make shaft of correct (True or specified dimension) size. Also, production cost and inspection cost, both will increase in manufacturing shaft of accurate size and accurate measurement of shaft manufactured, respectively.
4. It is much easy to vary (or change) the shaft sizes according to the fit required.	4. It is rather difficult to vary (or change) the hole sizes according to the fit required.
5. Less capital cost and small storage space is needed to produce shafts of different sizes.	5. Large capital cost and large storage space is needed for tools storage, because large number of tools of different sizes are necessary to produce holes of different sizes.
6. Gauging of shafts can be easily done with the help of Go and NO-GO adjustable gap gauges. Gauging means, to find out whether size of component (shaft or hole) manufactured is within specified limits or not?	6. Being internal measurement, gauging of holes is a difficult process.

3.17 "GO" AND "NO GO" LIMIT GAUGES

- Manufactured parts must be checked to determine, whether they lie between the given limits of size. In mass production, it will be very time consuming to measure the dimensions of each part, therefore instead of measuring actual dimensions of each part, the conformance of part produced with tolerance specifications can be checked by gauges.



(a) Plug gauge for checking hole **(b) Snap gauge for checking shaft**

Fig. 3.14

- Gauges are scaleless inspection tools of rigid design, which are used to check dimensions, form and relative positions of the surface of parts.
- They do not determine the actual size of part, but define whether deviations in the actual size or dimension of part produced are within the specified limits or not?
- They check whether the actual dimension of part produced lies between the two permissible limits of its size. Therefore, gauges consist of two sizes corresponding to their maximum and minimum limits.
- These limit gauges used for checking holes or shafts have two ends, labelled as 'GO' end and 'NO GO' end.
- End, which can be easily inserted in or around the component to be gauged (checked) is called as 'GO End'.
- And the other end, which cannot be inserted in or around the component to be gauged (checked), is called as 'NO GO' end.
- During gauging of component produced (either hole or shaft), if 'GO' end of the gauge goes and the 'NO GO' end does not go, then we conclude that, actual size

or dimension of component manufactured lies within the specified permissible limits of size and it is suitable for assembly and use.

- Limit gauges (GO and NO GO) are widely used in engineering industries, due to their advantages prescribed below.
  (i) Very ease to use.
  (ii) No need of skilled labour to operate them. Therefore, semi-skilled labour can be employed.
  (iii) Reduced inspection cost.
  (iv) Very quick and less time consuming.
  (v) No need of adjustments while using them.
  (vi) No need of calculations to find variations in size of component produced.

3.17.1 Principle of GO and NO GO Gauges

QUESTION

1. Explain principle of GO NO-GO gauging. **(S-09; W-11)**

- For checking the dimensions of work-piece, limit gauges usually have two working sizes; one corresponding to the low limit size and other to the high limit size of that dimension. These are known as GO and NO-GO gauges.
- The difference between the sizes of these two gauges is equal to the tolerance on the work-piece.
- Go gauge corresponds to low limit of size, whereas NO-GO gauge corresponds to high limit of size in case of hole.
- Go gauge corresponds to high limit of size, whereas NO-GO gauge corresponds to low limit of size in case of shaft.
- A part is considered to be good, if GO gauge enters it and NO-GO gauge does not enter it. This indicates that, the actual dimensions of part are within the specified limits.
- In case of hole, if both gauges fail to enter, it indicates that, hole is undersize, and in case of shaft, if both gauges fail to enter, it indicates that, shaft is oversize.

3.18 CLASSIFICATION OF GAUGES

Gauges are classified as,

1. **According to their type:**
   (a) Standard and limit gauges
   (b) Limit gauges
2. **According to form of surface to be tested:**
   (a) Plug gauges for checking holes
   (b) Snap and ring gauges for checking shafts
3. **According to their purpose:**
   (a) Workshop gauges
   (b) Inspection gauges
   (c) Reference or master gauges
4. **According to design:**
   (a) Single limit and double limit gauges
   (b) Single ended and double ended gauges
   (c) Fixed and adjustable gauges

3.19 TAYLOR'S PRINCIPLE

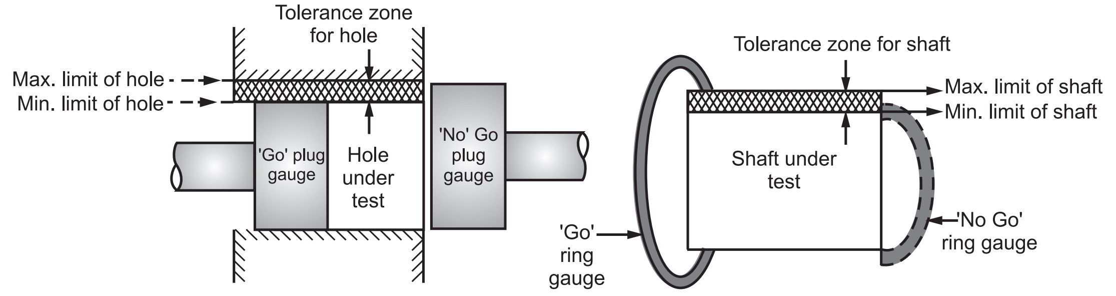
QUESTIONS

1. What is Taylor's Principle as applied to design of limit gauges? **(S-10, 12; W-10)**
2. State Taylor's principle of Gauge design and draw labelled sketch of GO and NO GO plug gauge. State the significance of Taylor's design. **(S-12)**
3. State Taylor's principle of gauge design. **(W-12; S-15, 16)**
4. Describe Taylor's principle for design of limit gauges. **(S-14)**
5. Explain the Taylor's principle of gauge design. **(S-17)**

According to Taylor's principle, 'GO' and 'NO GO' gauges should be designed to check **maximum and minimum material conditions** as below:

'GO' Limit	This designation is applied to *'maximum material conditions'* i.e. upper limit of shaft and lower limit of hole.
'NO GO' Limit	This designation is applied to *'minimum material conditions'* i.e. lower limit of shaft and upper limit of hole.

- 'GO' and 'NO GO' plug gauges are used for checking holes.
  - (i) 'GO' for plug gauge: Size of minimum limit of hole, and
  - (ii) 'NO GO' for plug gauge: Size of maximum limit of hole.
- 'GO' and 'NO GO' snap or ring gauges are used for checking shafts.
  - (i) 'GO' for snap or ring gauge: Size of maximum limit of shaft, and
  - (ii) 'NO GO' for snap or ring gauge: Size of minimum limit of shaft.
- **Taylor's principle** states that, GO gauges should be of full form, such that, 'GO' gauge should check all possible elements of dimension at a time (such as roundness, taper, location etc.), whereas 'NO GO' gauge should check only one dimension at a time.
- As GO gauge assembles with mating component, it should check number of dimensions, including errors of form such as straightness, roundness, squareness etc., which are outside the maximum metal limit.
- NO-GO gauge can check only one dimension of part at a time in order to find out any dimensions, which are outside the minimum metal limit.



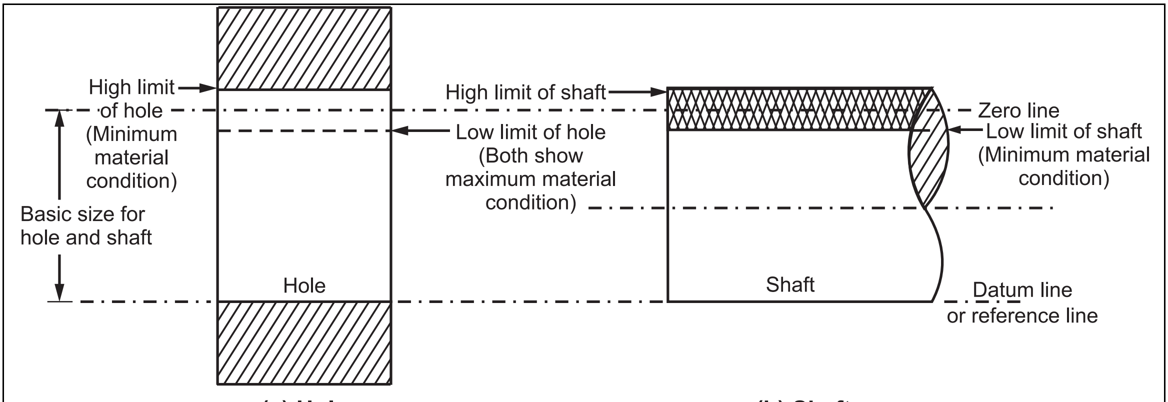
(a) For checking hole **(b) For checking shaft**

Fig. 3.15: Taylor's principle of gauge design

Maximum Material (Metal) Conditions and Minimum Material (Metal) conditions:

To understand this concept, let us take one shaft and one hole both having specified dimension $40^{\pm 0.05}$ mm.

Maximum material (metal) conditions	**Minimum material (metal) conditions**
For shaft, highest diameter possible is, Upper limit of shaft = 40 + 0.05 = 40.05 mm	For shaft, lowest diameter possible is, Lower limit of shaft = 40 − 0.05 = 39.95 mm.
For hole, lowest diameter permissible is, Lower limit of hole = 40 − 0.05 = 39.95 mm	For hole, highest diameter possible is Upper limit of hole = 40 + 0.05 = 40.05 mm



(a) Hole (b) Shaft

Type of Condition	**For Hole**	**For Shaft**
Maximum material condition	Low limit of hole	High limit of shaft
Minimum material condition	Upper/High limit of hole	Low limit of shaft.

Fig. 3.16

3.20 INDIAN STANDARDS DESIGN OF GAUGES

Important Points for Design of gauges:

1. Shape of 'GO' gauge should exactly coincide with mating parts.
2. 'GO' gauge enables several dimensions to be checked simultaneously.
3. Inspection 'GO' gauges must always be put into conditions of maximum impossibility.
4. 'NO GO' gauges are used for checking single element of component.
5. Inspection 'NO GO' gauges must always be put into conditions of maximum possibility.

- For example, if a hole of size less than 63 mm is to be checked, the double ended plug gauge can be used.
- Double ended plug gauge forms GO gauge side on one end and NO GO side on another end. Refer Fig. 3.16.

- While checking or gauging a hole produced, both ends of double ended plug gauge are made to insert into the hole produced, one by one.
- If the hole produced is undersized, then, both 'GO' and 'NO GO' ends of plug gauge will not enter inside hole. But, if the hole produced is oversized, then both 'GO' end and 'NO GO' ends of plug gauge will enter inside hole.
- If the dimension of hole produced is correct (it means, dimension of hole produced lies between high limit and low limit of size), then end of plug gauge corresponding to lower limit will enter into the hole and another end of plug gauge corresponding to upper (high) limit will not insert into hole produced.
- Therefore, end of plug gauge corresponding to low limit of size is 'GO end', whereas another end of plug gauge corresponding to high limit of size is 'NO GO' end.
- Therefore, we conclude that, in case of plug gauge used for gauging or checking dimension of hole, the end corresponding to low limit is GO end and the end corresponding to high limit is NO GO end.
- Similarly, we can observe that, in case of ring gauges or snap gauges used for gauging or checking dimension of shaft, one ring corresponding to high limit is GO ring gauge and another ring corresponding to low limit is NO GO ring gauge.
- In case of plug gauges, 'NO GO' end is made shorter in length than 'GO' end, because it never enters the hole and need not have provisions to account for wear or prevent jamming as in case of 'GO' end. Whereas, 'GO' end is made larger in length due to following advantages.
  (i) To check all possible dimensions of hole at a time, such as, roundness, taper, straightness after inserting it into hole thoroughly.
  (ii) Longer end of double ended plug gauge is GO end, whereas, shorter end is NO GO end. Thus, GO end and NO GO end of double ended plug gauge can be distinguished very easily.
  (iii) Longer GO end provides good support, while checking/gauge the dimension.

3.21 PLAIN PLUG GAUGES

QUESTION

1. Draw neat sketch of plug gauge showing GO and NO GO end. **(S-12)**

- **Plain plug gauges** are used to *check* whether the *dimensions of hole* lie within the specified limit or not.
- They are made up of suitable wear resisting steel and the gauging surfaces are suitably hardened.
- The gauging surfaces are first suitably *stabilized* using proper *heat treatment* process and then ground and lapped.
- They are provided with suitable *anti-corrosive coating* to prevent against corrosion.
- They are of two types:
  a) **Double ended type**, for sizes upto 63 mm.
  b) **Single ended type**, for sizes above 63 mm.
- They are designated with following parameters marked on handle.
  - Nominal size.
  - Class of tolerance.
  - Actual values of tolerance.
  - The word 'GO' on GO side.
  - The word 'NO GO' on NO GO side.
  - Some other standards.

- The 'NO GO' side is always painted with red band.
- Example: GO and NO GO plain plug gauge $25H_7$, IS: 3484.

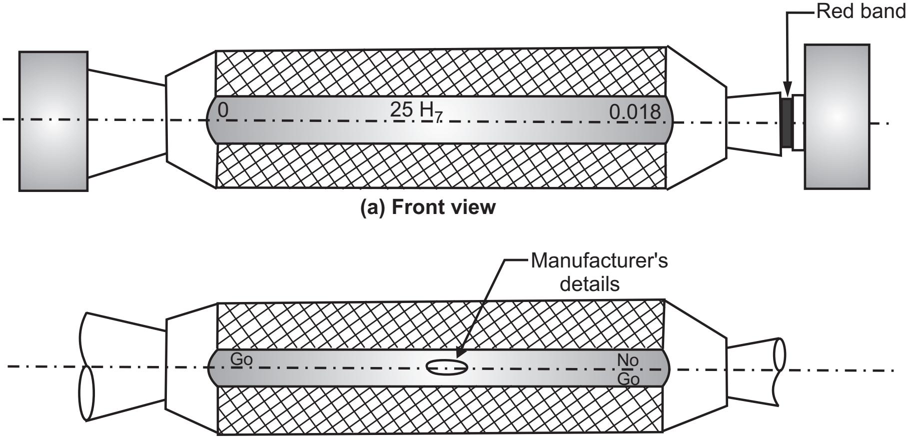


Fig. 3.17: Plain plug gauge

3.22 PLAIN RING GAUGES

- **Plain ring gauges** are used to check whether, the obtained **dimension of shaft** lies within the specified limit or not.
- They are made up of suitable *wear resisting steel* and the gauging surfaces (contact surfaces) are suitably *hardened*.
- Gauging surfaces are first suitably *stabilized* using proper *heat treatment* process and then ground (using grinder) and lapped.
- An anti-corrosive coating is provided on the gauging or contact surfaces, to prevent against corrosion.
- Double ended type ring gauges are not found. Only single ended ring gauges are available in two designs, a) GO ring gauges, b) NO GO ring gauges.
- They are available in two ranges, (i) 3 to 70 mm in 10 steps and (ii) 70 to 250 mm in 17 steps.

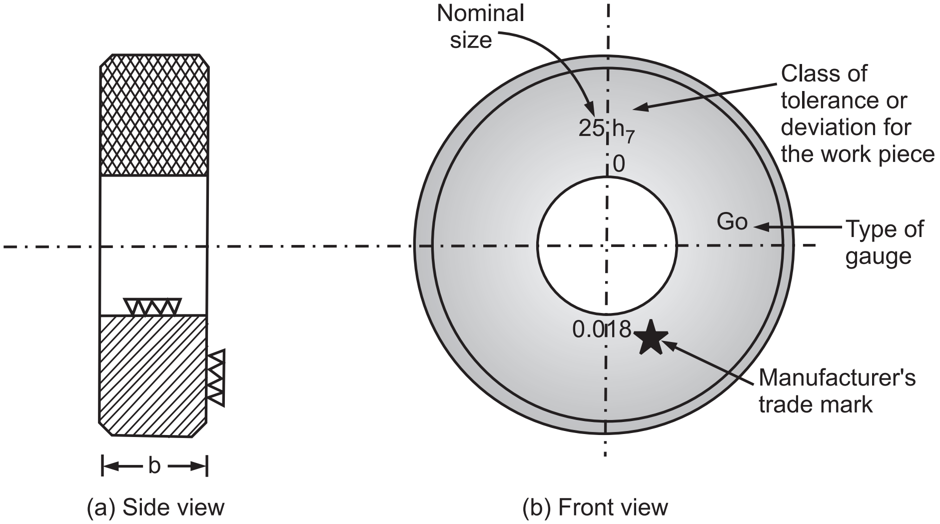


Fig. 3.18: 'GO' type of plain ring gauge (single ended)

- Figure 3.18 shows 'GO' type of ring gauge (single ended), used to check diameter of shaft. A shaft is treated as acceptable, if it enters into hole of ring gauge. Similarly, we can draw a NO GO type planning gauge (single ended) to check diameter of same shaft. Only difference found in NO GO ring gauge is slight decrease in its hole diameter. A shaft is treated as acceptable if shaft does not enter into hole of NO GO ring gauge.
- They are designated with following parameters marked on handle.
    - Nominal size.
    - Class of tolerance.
    - Actual values of tolerance.
    - The word 'GO' on GO side.
    - The word 'NO GO' on NO GO side.
    - Some other standards.
    - Manufacturer's trademark.
- Example: GO and NO GO plain ring gauge $25h_7$, IS : 3484.

3.23 SNAP GAUGE

- **Snap gauges** are used to check, whether the obtained or produced dimension of shaft lies within the specified limit or not.
- They are made up of suitable *wear resisting steel* and the gauging surfaces are hardened to a hardness value of about 750.
- The gauging surfaces are first suitably *stabilized* using proper *heat treatment* process and then ground and lapped.
- They are provided with suitable *anti-corrosive coating* to prevent against corrosion.
- They are available in two designs, (a) Rib type, (b) Plate type snap gauges.
- According to dimension of shaft to be checked, two types of snap gauges are made available in market.
    (i) Double ended snap gauges: Used to check shaft having diameter in the range of 3 mm to 100 mm.
    (ii) Single ended snap gauges: Used to check shaft having diameter in the range of 100 mm and 250 mm.
- They are designated with following parameters marked on handle.
    - Nominal size.
    - Class of tolerance.
    - Actual values of tolerance.
    - The word 'GO' on GO side.
    - The word 'NO GO' on NO GO side.
    - Some other standards.
- The 'NO GO' side is always painted with red band.
- Example: GO and NO GO snap gauge $25h_7$, IS: 3484.

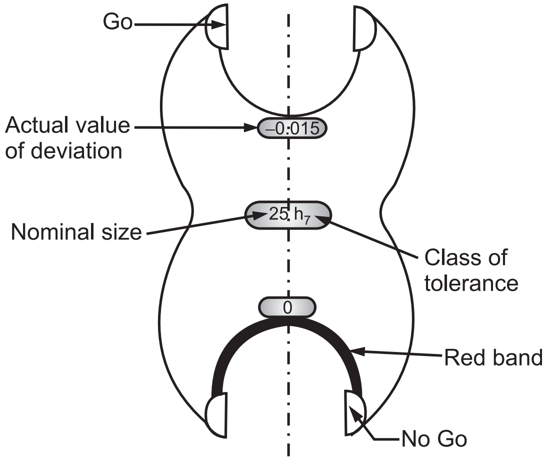


Fig. 3.19: Rib type snap gauge (Double ended)

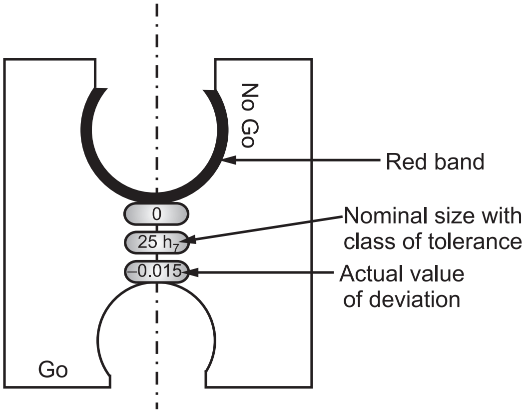


Fig. 3.20: Plate type snap gauge (Double ended)

3.24 ADVANTAGES OF GAUGES

QUESTION

1. State advantages and disadvantages of gauges over measuring instrument. **(S-08)**

Advantages of Gauges are as below:

1. No other auxiliary equipment is needed.
2. Give quick result about conformance or non-conformance of the part produced.
3. No need of adjustment is required while using them.
4. No need of any calculation.
5. No need of external power supply.
6. No need of skilled workers. Gauges can be easily used by unskilled workers too.
7. Low inspection cost.
8. Less time consuming.
9. Preferred in mass production.

3.25 DISADVANTAGES OF GAUGES

Disadvantages of Gauges are as below:

1. Gauges cannot measure the dimension/size of component produced. Therefore, inspection by gauges does not provide detailed information about the parts produced.

2. Their use is limited to particular jobs only. For example: Hole and shafts produced in mass production. Gauges cannot be used for inspection of costly items like diamonds.
3. It is very un-economical to manufacture gauges in small quantity, because of high capital cost and running cost involved in gauge maker industries. Therefore, gauges should be manufactured in sufficiently large quantity, to reduce production cost per gauge.

3.26 DIFFERENCE BETWEEN PRECISION MEASURING INSTRUMENT AND GAUGES

QUESTION

1. Distinguish between precision measuring instrument and gauges. **(W-10; S-13)**

Precision Measuring Instruments	Gauges
1. These are measuring tools carrying scales.	1. These are inspection tools without calibrated scales.
2. These are used to measure the actual dimension of parts.	2. These are used to determine, 'whether the dimensions of part produced are within the specified limits'.
3. Measurement by instruments is time consuming, so they are not suitable for mass production.	3. Measurement by gauges is easy and quick, so they are suitable in mass production.
4. The instruments are required to be handled by skilled workers.	4. The gauges can be easily handled by unskilled workers.
5. Use of precision measuring instruments in mass production increases the production cost.	5. Use of gauges in mass production decreases the production cost of part.

3.27 DIFFERENCE BETWEEN COMPARATOR AND GAUGE

QUESTION

1. Differentiate between comparator and gauge. **(W-15)**

Comparator	Gauge
1. Used to compare the actual dimensions of parts produced with working standards.	1. Used to determine, whether the actual dimensions of part manufactured lie within the given limits of size.
2. Determines the difference between actual sizes of part manufactured with standard value.	2. Determines the deviation from the actual dimensions or form (shape) of part.
3. Magnification and indicating systems are provided.	3. No magnification and indicating systems are provided.

Comparator	Gauge
4. Less wear or even no wear as in case of electrical, optical comparators.	4. Surface of GO gauge wears during its continuous use, to check holes (Plug gauge) and shafts (Ring gauge/Snap gauge).
5. Can be used to compare dimensions of larger and thin walled parts.	5. Can not be used to gauge the dimensions of larger and thin walled parts.

3.28 DIFFERENCE BETWEEN MEASURING INSTRUMENT, COMPARATOR AND GAUGES

Measuring Instrument	Comparator	Gauges
1. Used to measure actual dimensions of the manufactured parts.	1. Used to compare dimensions with working standards and to measure difference between sizes of parts and working standards.	1. Used to determine whether dimensions of parts lie within the specified limits or not.
2. Accuracy depends on correct feel and skill of operator.	2. Accuracy is independent of correct feel and skill of operator.	2. Accuracy is independent of skill of operator.
3. Errors are caused due to, (i) misalignment of measuring instrument with the workpiece, whose dimension is to be measured, and (ii) incorrect contact pressure causing deformation of workpiece.	3. No chances of errors due to incorrect contact pressure.	3. No possibility of errors.
4. Cannot be used to check geometric forms.	4. Can be used to check dimensions as well as geometric forms.	4. They are used to check geometric forms.
5. No magnification system is provided.	5. Magnification system can be employed using suitable arrangements.	5. No magnification system can be employed.
6. Not suitable for mass production, as measurement is time consuming.	6. Suitable for mass production due to quick and accurate measurements.	6. Preferred in mass production due to easy and rapid measurements.

3.29 MATERIAL FOR GAUGES

- High Carbon Steel is a relatively inexpensive and suitable material for gauges.
- The material used for gauges should have good hardness. For this purpose, gauges are heat treated before their practical use.
- Heat treatment consists of hardening the steel by heating to 730°C followed by quenching in water.
- After heat treatment, the gauges are stabilized by maintaining them at a tempering temperature of 200°C for 8-10 hours.
- Materials used: High carbon steel, Mild steel, Oil hardened steel, cast iron etc.
- Desirable properties of material used for gauges:
  (i) Hardness to resist wear.
  (ii) Corrosion resistant.
  (iii) Stability to maintain size and form.
  (iv) Machinability.
  (v) Low coefficient of thermal expansion.

3.30 IS 919 - 1993

- The aim of establishing standard system of fits and limits is to guide the user in,
  - (a) selecting basic functional clearances and interferences for given application to obtain necessary fit.
  - (b) establishing tolerances, providing a reasonable and economical balance between fits, consistency and cost.
- Every country has its own standards for engineering limits and fits. But to have universal interchangeability, following international standards are followed throughout the world.
  - (a) British Standard BS: 4500-1969.
  - (b) The International Standard ISO: 286-1988.
- India has developed our own National standards for engineering limits and fits, called as Indian Standard IS-919.
- IS-919 system is a suitable combination of 18 grades of tolerances and 25 types of fundamental deviations, indicated by letter symbols for both holes and shafts (capital letters A to Z_c for holes and small letters a to z_c for shafts) in diameter steps upto 500 mm.
- The 18 grades of tolerance are designated as IT 01, IT 0 and IT 1 to IT 16. These are standard tolerances and from IT 5 to IT 16 are multiples of the 'fundamental tolerance' unit i (0,0), where,

$$i \text{ (microns)} = 0.45 \sqrt[3]{D} + 0.001 D$$

- Where, D = Geometric mean of diameter steps involved and expressed in mm.
- The relative magnitude of each grade is given in Table 3.1. The complete series of diameter steps associated with the standard tolerance for each of the 18 tolerance qualities is given in Table 3.1.
- Number of fits ranging from extreme clearance to those of extreme interference can be obtained by a suitable combination of fundamental deviations. Each of 25 holes has a choice of 18 tolerances.
- A **hole** is described by the appropriate capital letter followed by a suffix number denoting the tolerance grade, for example, H_8.
- A **shaft** is described by a small letter followed by a suffix number denoting the tolerance grade, for example, g_7.
- A **fit** is indicated by the basic size common to both components, followed by symbols corresponding to each components, hole being quoted first.

$$\text{for example, } 45\ H_8/g_7 \text{ or } 45\ H_8g_7 \text{ or } 45\ \frac{H_8}{g_7}$$

- Positions of limits nearest to the basic size are indicated by letters given below.

  For Holes: A B C D E F G H J_s J K M N P R S T U V X Y Z Z_A Z_B Z_C.

  For Shafts: a b c d e f g h j_s j k m n p r s t u v x y z z_a z_b z_c.
- If a unilateral hole basis is chosen, then the H hole is basic, while for a unilateral shaft basis, the h shaft is basic. In either case, the fundamental deviation is zero.
- For shafts 'a' to 'h', the upper deviation is below zero line and for shafts 'j' to 'z_c', it is above zero line.
- For holes 'A' to 'H', the lower deviation is above the zero line and for holes 'J' to 'Z_c', it is below the zero line.

Table 3.1: Grades of Tolerances

Sr. No.	Grade	Value
1.	IT 01	0.3 + 0.08 D
2.	IT 0	0.5 + 0.12 D
3.	IT 1	0.8 + 0.02 D
4.	IT 5	7i
5.	IT 6	10i
6.	IT 7	16i
7.	IT 8	25i
8.	IT 9	40i
9.	IT 10	64i
10.	IT 11	100i
11.	IT 12	160i
12.	IT 13	250i
13.	IT 14	400i
14.	IT 15	640i
15.	IT 16	1,000i

Note:

(1) Values of three grades IT 2, IT 3 and IT 4 are geometrically between the values IT 1 and IT 5.

(2) Above IT 6, the tolerance magnitude is multiplied by 10 at each fifth step. This rule would be applied to any future extension beyond IT 16.

3.31 MULTI GAUGING MACHINE

Use/Purpose of Multi Gauging Machine:

- It is very useful for measurement of number of dimensions at a time.

Principle of Working:

- Multiple number of dimensions of a manufactured component can be compared with the corresponding accurate dimensions of a setting standard. A mechanical comparator, such as, dial gauge indicator is used to find out and record the deviation (If any).

QUESTION

1. Explain the multigauging machine with neat sketch. State its any two advantages. **(S-17)**

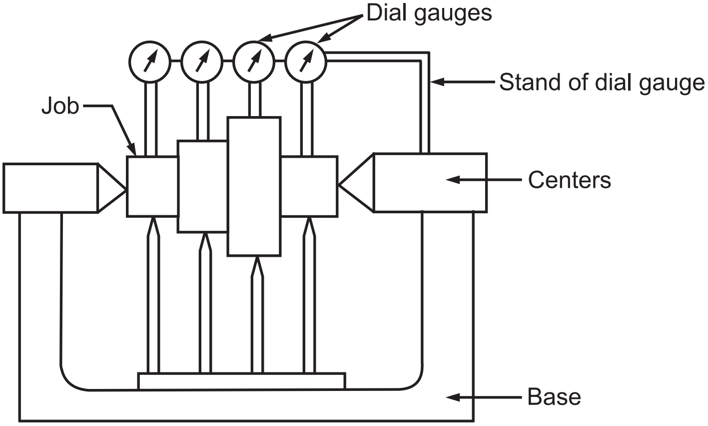


Fig. 3.21: Multi gauging machine

Working :

(1) Initial Set up:

- Initially, a master specimen or a standard setting component is held between two centres of machine.
- Fig. 21 shows a master specimen or standard setting component, for which, 4 dimensions are to be inspected.
- For this, equal number (4) of dial indicators are provided.
- Plunger of each dial indicator is made to touch the respective dimension.
- At this condition, dial gauge indicators are so adjusted that, pointer of each dial gauge indicator reads zero position, i.e. pointer is resting on zero reading.
- In simple words, all the dial gauge indictors in contact with dimensions to be checked are adjusted to their zero positions for different dimensions.
- After this set up, the master specimen or setting standard held in between two centres, is removed.

(2) Inspection of various dimensions of a manufactured component or part:

- Now, a manufactured component, whose actual dimensions are to be inspected, is fixed between centres in place of master specimen or setting standard, and the readings of dial indicators are recorded.
- Readings of dial gauge indictors are called as "deviations from standard dimensions".
- After holding the manufactured part in between centres,
    1. If there is no variation in zero reading of any dial gauge indicator, then it is concluded that, all the dimensions of manufactured component are same as setting standard.
    2. But, if pointer of any dial gauge indicator gets deflected, moves over the circular scale and shows some reading other than zero, then, we conclude that, there is some variation in dimensions of manufactured component.

Advantages of Multi Gauging Machine:

(i) Less time required for inspection.

(ii) Low cost of inspection.

(iii) Number of dimensions can be measured at a time.

Factors to be Considered While Designing a Multi Gauging Machine:

(a) Initial cost.

(b) Dimensional tolerances of the features to be measured.

(c) Complexity of the component.

(d) Complexity of the features to be measured.

(e) Number of features to be measured.

(f) Skill of the operator or user.

SOLVED PROBLEMS ON DESIGN OF GAUGES

Problem 3.1: *Design a general type plug gauge for checking a hole dimension* $30^{+0.05}_{-0.03}$*. Consider both wear allowance and gauge tolerance as 10% of work tolerance.* **(S-16, 17)**

Solution: Given data: Basic size of hole = 30 mm

Tolerance zone = −0.03 to 0.05 mm

Gauge maker tolerance = 10% of work tolerance

Procedure: (i) To calculate work tolerance:

From the data given above, we can write,

Upper limit of hole = 30 + 0.05 = **30.05 mm**

Lower limit of hole = 30 − 0.03 = **29.97 mm**

∴ Work tolerance = Upper limit of hole − Lower limit of hole

= 30.05 − 29.97 = **0.08 mm**

(ii) To calculate gauge maker tolerance:

It is given that,

Gauge maker tolerance = 10% of work tolerance

$$= \left(\frac{10}{100}\right) \times 0.08 = \mathbf{0.008\ mm}$$

(iii) To calculate wear allowance:

In the numerical problem (Question), it is given that,

Wear allowance = 10% of work tolerance

But, **as per the guidelines for gauge design**, it should be,

Wear allowance = 10% of gauge maker tolerance

$$\therefore \text{Wear allowance} = \left(\frac{10}{100}\right) \times (0.008)$$

= **0.0008 mm**

(iv) We calculate the sizes of gauges in the following way,

(a) **Size of Go gauge** = Lower limit of hole + Wear allowance

= 29.97 + 0.0008

= **29.9708 mm**

(b) **Size of No Go gauge:**

For No Go gauges, there is **no need to consider** wear allowance.

Therefore, **size of No Go gauge** = Upper limit of hole

= **30.05 mm**

(v) Design values of plug gauges:

(a) Limits of Go gauge = $\mathbf{29.9708^{+0.008}_{-0.000}}$

(b) Limits for No Go gauge = $\mathbf{30.05^{+0.008}_{-0.000}}$

Important Points

- *Basic size* is same for both hole and its shaft.
- *Actual size* is the measured size of job produced.
- *Zero line* is the line corresponding to basic size.
- *Tolerance* is defined as 'difference between upper and lower deviation and has an absolute value without sign'.
- Types of Specifying Tolerance:
  (i) Unilateral System of Tolerance
  (ii) Bilateral System of Tolerance
- *Limits* are two extreme permissible sizes for a dimension, known as higher limit and lower limit. The greater of these two sizes is called maximum limit or high limit of size, while the smaller size is the minimum limit or low limit of size.
- *Deviation* is the algebraic difference between actual size and basic size.
- The straight line corresponding to basic dimension is called as *zero line* (i.e. the line of zero deviation).
- *Fundamental deviation* is either upper deviation or lower deviation, which is conventionally chosen to define the position of tolerance zone in relation to the zero line.
- In Basic shaft, upper deviation is zero i.e. maximum limit of size is equal to basic size.
- In Basic hole, lower deviation is zero i.e. minimum limit of size is equal to basic size.
- *Allowance* is the prescribed difference between the hole dimension and shaft dimension specified to obtain desired type of fit.
- Relation between the two parts, where one part is inserted into the other with a certain degree of tightness or looseness is known as *fit*.

  Types of Fit: (i) Clearance fit, (ii) Transition fit, (iii) Interference fit.
- Plain plug gauges are used to check whether the dimensions of hole lie within the specified limit or not.
- Plain ring gauges or snap gauges are used to check whether the dimensions of shaft lie within the specified limit or not.
- High Carbon Steel is a relatively inexpensive and suitable material for manufacturing gauges.
- Multigauging machine is used to measure a number of dimensions simultaneously.

Theory Questions for Practice

1. Define tolerance. What is its need?
2. Differentiate between unilateral system and bilateral system.
3. Define (i) limits of size, and (ii) deviation.
4. Define basic shaft and basic hole.
5. What is allowance?
6. Differentiate between tolerance and allowance.
7. Define fits. Enlist the types of fits.
8. What is clearance fit? Illustrate with neat sketch.
9. Draw the sketches illustrating transition fit and interference fit.
10. How will you designate a fit?
11. What is interchangeability? What are its advantages?
12. Write a short note on "Selective assembly".
13. Differentiate between hole basis system and shaft basis system.
14. Give the classification of gauges.
15. What is taylor's principle applied to gauges?
16. Write a short note on "Plain plug gauges".
17. What are the advantages and disadvantages of gauges?
18. Differentiate between precision measuring instrument and gauges.
19. Write a short note on "Gauge maker tolerance and Wear allowance".
20. Enlist the materials used for gauges.
21. What is the concept of multi-gauging and inspection?

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2014

1. Explain the term selective assembly. **(4M)**

Ans. Refer Article 3.15.

2. Draw the conventional diagram of limits and fits and define the terms : **(4M)**
   (i) Basic size
   (ii) Fundamental Deviation

Ans. Refer Articles 3.1 and 3.5.

3. Interpret the meaning of 27 H_5f_6 with respect to fit and basis system. **(4M)**

Ans. Refer Article 3.13.1.

Summer 2015

1. What is the meaning of $35H_8f_8$? State meaning of each term. **(4M)**

Ans. Refer Article 3.13.1.

2. State the Taylor's principle of gauge design. **(4M)**

Ans. Refer Article 3.19.

3. Differentiate between Hole Basis System and Shaft Basis System. **(4M)**

Ans. Refer Article 3.16.3.

Winter 2015

1. Differentiate between gauge and comparator. **(4M)**

Ans. Refer Article 3.27.

2. Define maximum clearance and minimum interference. Draw suitable sketch. **(4M)**

Ans. Refer Article 3.12.

3. Explain hole basis system. Why it is preferred ? **(4M)**

Ans. Refer Article 3.16.1.

4. What is interchangeability ? State its importance in mass production. **(4M)**

Ans. Refer Article 3.14 and 3.14.1.

Summer 2016

1. State the Taylor's principle of gauge design. **(4M)**

Ans. Refer Article 3.19.

2. What is 'interchangeability'? State its need and relevance in mass-production industries. **(4M)**

Ans. Refer Articles 3.14 and 3.14.1.

Winter 2016

1. Differentiate between hole basis system and shaft basis system. **(4M)**

Ans. Refer Article 3.16.3.

2. Differentiate between unilateral system and bilateral system of tolerances on any four parameters. **(4M)**

Ans. Refer Article 3.3.1.

3. Interpret the meaning of $25H_8s_6$ with respect to fit and basis of system. **(4M)**

Ans. Refer Article 3.13.1.

Summer 2017

1. Explain the Taylor's principle of gauge design. **(4M)**

Ans. Refer Article 3.19.

2. Design the 'Workshop' and 'General Purpose' types of GO and NO-GO plug gauges for checking the hole of $30^{+0.05}_{-0.03}$ mm. Assume each of the wear allowance and gauge allowance as 10% of work tolerance. **(4M)**

Ans. Refer Problem 3.1

3. Explain the multi-gauging machine with neat sketch. State it's any two advantages. **(4M)**

Ans. Refer Article 3.31.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 4

ANGULAR MEASUREMENT

About This Chapter ...

This chapter has a weightage of 8 marks and assigned duration is 4 hours. In this, we learn various instruments and methods for angular measurements such as spirit level, sine bar, universal bevel protector and clinometers.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	10 Marks	S-10	12 Marks
W-10	08 Marks	S-12	08 Marks
W-12	08 Marks	S-13	08 Marks
W-13	12 Marks	S-14	07 Marks
W-14	14 Marks	S-15	12 Marks
W-15	12 Marks	S-16	12 Marks
W-16	12 Marks	S-17	12 Marks

4.1 INTRODUCTION

- Angular measurements are often necessary in engineering production and inspection works. The units of angular measurements are Degree (°), Minute (') and Second (").
- In mathematical calculations, however, 'Radian' is the most commonly used unit for angular measurement.

4.2 INSTRUMENTS FOR ANGULAR MEASUREMENTS

QUESTIONS

1. List down different instruments used for angular measurements. **(W-08) (S.T.P.-I)**
2. List the four instruments used in angular measurements. **(W-13)**

- There are many instruments, which can be used for measuring angles depending upon the component and the accuracy of the measurement required.

  The following are the instruments for angular measurements:

1. Universal bevel protractor.
2. Spirit level.
3. Sine bars.
4. Angle dekkor.
5. Clinometer.
6. Auto-collimator.
7. Angle gauges.

4.3 UNIVERSAL VERNIER BEVEL PROTRACTOR

QUESTION

1. Draw neat sketch of "Universal Bevel Protractor" and write the procedure for measuring "Angle of workpiece". **(W-12)**
2. Draw a labelled diagram of bevel protractor. State its uses. **(S.Q.P.)**
3. Draw a lebelled diagram of universal bevel protractor. State its uses. **(S-15, W-15)**

The vernier bevel protractor with acute angle attachment is shown in Fig. 4.1, which is the simplest angle measuring and testing instrument.

Construction:

- It consists of following parts:
  - **(i) Base plate:** It has high quality surface finish and degree of flatness. Base plate is also called as stock. It is placed on the workpiece surface, whose angle is to be measured.
  - **(ii) Adjustable blade:** It is attached to a circular dial and it is made to coincide with the angular surface. It can be swiveled (rotated) along the turret to required angle and can be locked at a suitable position, where reading of circular scale (mounted on the dial) can be noted down accurately.
  - **(iii) Main scale:** It is graduated in degrees. It can be rotated with the rotation of adjustable blade.
  - **(iv) Vernier scale:** It is a stationery scale mounted very close to the circular dial. Vernier scale enables the protractor to measure very small angles, to least count of 5'.
  - **(v) Acute angle measurement:** It is required for the measurement of acute angles.

Working:

- One surface of the component, whose angle is to be measured, is placed on the working edge of acute angle attachment.
- The adjustable blade is moved such that, its lower edge is coinciding with the angular surface (inclined surface) of component. Refer Fig. 4.1 (b).
- Now the adjustable blade is locked into the position to get accurate measurement.
- Value of angle measured can be obtained from main scale reading and vernier scale reading.

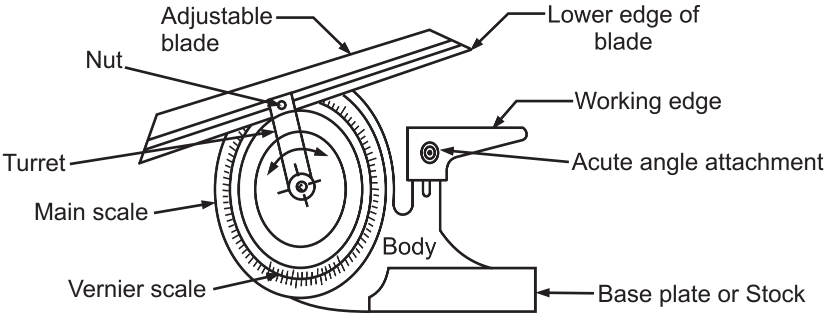


Fig. 4.1: (a) Construction of Universal Bevel Protractor

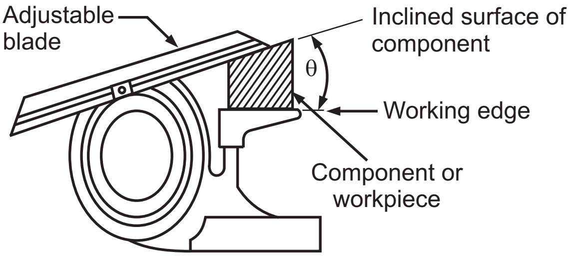


Fig. 4.1: (b) Measurement of angle

Procedure to take readings:

- Main scale on circular dial is divided into four quadrants, each being 90°. One division of main scale is equal to 1°. Degrees are numbered from 0 to 90° on either side of its zero position.
- Vernier scale is graduated in minutes. To represent 60 minutes on vernier scale on either side of zero position, 12 divisions are marked. It means that, one vernier division is equal to $\frac{1}{12}^{\text{th}}$ part of 60 minutes.

  $\therefore$ Each vernier division = $\frac{1}{12} \times 60$ minutes = 5 minutes.

  $\therefore$ L.C. of vernier scale = 5'.

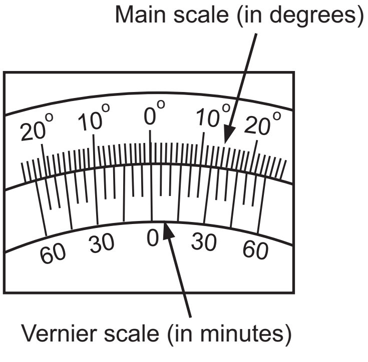


Fig. 4.2: (a) Divisions of Vernier scale

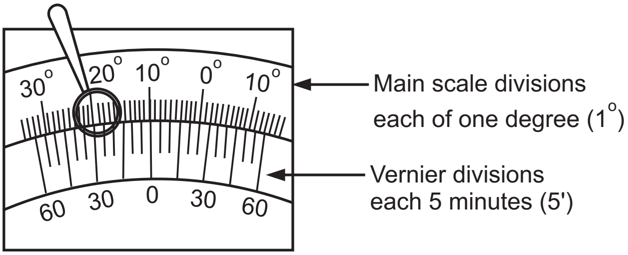


Fig. 4.2: (b) Reading the Vernier scale

- If angle of a component is to be determined, observe the divisions of main scale as well as Vernier scale, as shown in Fig. 4.2 (b).
- We observe that Zeroth division of vernier scale is just part to 10° on main scale (i.e. 10^{th} division of main scale).
- In the same way, try to find out any vernier division, which concides with main scale division.
- Here, 7^{th} division of vernier scale (from its Zeroth position towards left hand side) is coinciding with a division of main scale.
- Since 1 division of vernier scale is equal to 5', 7^{th} division of vernier corresponds to 35'. Therefore, the angle of component will be 10° 35'.
- This can also be proved or calculated by adopting following method.

We have, M.S.R. = 10°

Vernier scale division coinciding main scale division = 7.

Least count of vernier scale = 5'.

$$\therefore \quad \text{Angle measured} = \text{MSR} + (\text{VSD} \times \text{L.C.})$$

$$= 50° + (7 \times 5') = 10° 35'$$

Uses of Vernier Bevel Protractor:

1. For checking inside beveled face of a ground surface.
2. Used for measuring and laying out of angle accurately and precisely, within the accuracy of 5 minutes.
3. Used for checking 'V' block.
4. Used for measuring acute angles.

4.4 SPIRIT LEVEL

Spirit level is used to measure small angles or inclinations and to test straightness and flatness of surfaces.

Construction:

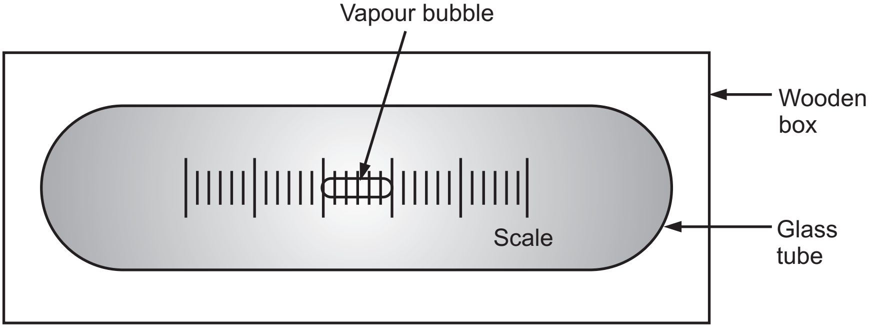


Fig. 4.3: Sealed glass tube

- Spirit level consists of a sealed and transparent glass tube, which is also called as glass vial.
- The inside surface of the glass tube is ground to a convex barrel shape having large radius. The precision of the level depends on the accuracy of this radius of the glass tube.

- A scale is engraved on the top of the glass tube. The glass tube is nearly filled with ether or alcohol, except a small bubble of vapour on it. It is carried in a metallic body having flat base.

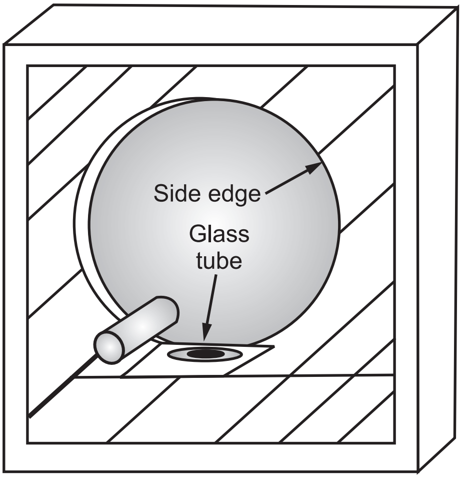


Fig. 4.4: Spirit level instrument

Working Principle:

- Spirit level instruments works on the principle that vapour bubble has a tendency to remain always at the highest point of the glass tube. If the base of spirit level is horizontal, and truly flat, then the centre point is the highest point of the glass tube. Therefore, the vapour bubble is at centre of scale due to flat base of body.
- Refer Fig. 4.5, where the base of spirit level instrument is resting on a horizontal and flat surface OA_1, the bubble occupies the central position denoted by B_1.
- But, if the flat base of spirit level is kept on an inclined surface such as OA_2, then the bubble will move relative to glass tube and will occupy new position, shown by B_2 on the engraved scale of glass tube.
- If inclination of surface OA_2 with respect to horizontal is Q, when 'l' be the distance travelled by the bubble along the glass tube and 'h' be the vertical difference in heights between the ends of the base of spirit level,
- Considering Δ OA_1A_2, we can write,

$$\tan \theta = \frac{h}{L} \qquad \ldots(i)$$

- Therefore, considering Δ OB_1B_2, we can write,

$$\tan \theta = \frac{l}{R} \qquad \ldots(ii)$$

  As angle θ is very very small, consider the arc distance 'l' as the horizontal distance between B_1 and B_2).
- Since the value of angle 'θ' is very very small, and tan (0°) = 0, we conclude that, the value of $\tan \theta$ will also be very small.

  So we can write,

$\tan(\theta°) = \theta$

Hence, equations (i) and (ii) can be written as,

$$\theta = \frac{h}{L} \text{ and } \theta = \frac{l}{R} \text{ respectively.}$$

where, R = Radius of curvature of the glass tube,

L = Length of the base

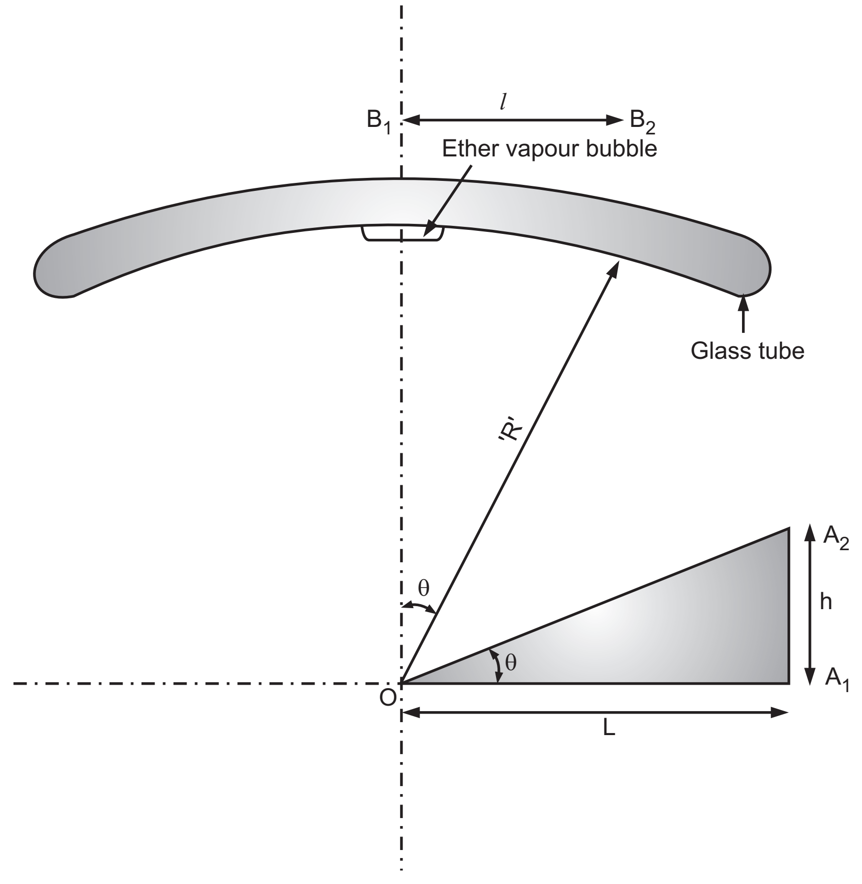


Fig. 4.5: Working principle of spirit level

- Sensitivity of spirit level can be defined as, "the angle of tilting surface, which makes the bubble to move through 1 division on engraved scale of glass tube". Here, the angle is expressed in seconds.
  - **(i) Sensitivity is 10 seconds:** It means that if the base of spirit level gets tilted by an angle of 10 seconds with respect to horizontal, the bubble inside the glass will be shifted to 1 division from zero position, or centre of scale.
  - **(ii) Sensitivity is 0.05 mm/m:** It means that, if base of spirit level instrument is placed on a straight horizontal surface of length 1 metre and if one end of surface is vertically raised by 0.05 rpm, then the bubble inside glass tube will be shifted to an 1 division from zero position or centre of scale.

4.4.1 Uses of Spirit Level

(a) To measure small angles.
(b) To check straightness and flatness of surfaces.
(c) To establish a horizontal datum for reference purpose i.e. reference line.
(d) To determine the small inclinations of surface with respect to the horizontal position.

4.4.2 Errors in the Use of Spirit Level

(a) Errors inherent in the instrument: Inherent errors are the constructional faults, which include faults in the glass tube, such as non-uniform radius of curvature poor calibration of engraved scale on glass tube, or both.

(b) Incorrect use: Errors due to its use in conjunction with faulty workpiece, precautions while handling.

(c) Temperature variations: Errors arised due to its exposure to direct sunlight, while taking measurements.

(d) Consistent use: Due to continuous use, the errors may be introduced in the measurements after certain period. Therefore, it must be re-calibrated at regular intervals (periodic calibration).

4.5 SINE BAR

QUESTION

1. Explain with neat sketch, construction and working principle of “SINE BAR”. **(W-08)**

Sine bar is a simple instrument, which utilizes the high degree of accuracy available for linear measurement. It is used along with slip gauges for accurate angle measurements or angle setting.

Construction:

- It consists of a steel bar and two rollers. The bar is made of high carbon, high chromium corrosion resistant steel, suitably hardened stabilized and precision ground. The rollers are of accurate and equal diameters. They are attached to the bar at each end and also to the upper surface of the bar.
- The nominal distance between the axes of two rollers is exactly 100 mm, 200 mm or 300 mm. A sine bar is specified by this distance as 100 mm, 200 mm and 300 mm sine bar.
- When the rollers are brought in contact with a flat surface, the top surface of the bar is parallel to the flat surface. All the working faces of the bar and cylindrical surfaces of rollers have surface finish of 0.2 µm R_a value or better.
- Depending upon the accuracy of the centre distance, sine bars are graded as A grade or B grade. Grade A sine bars are more accurate.

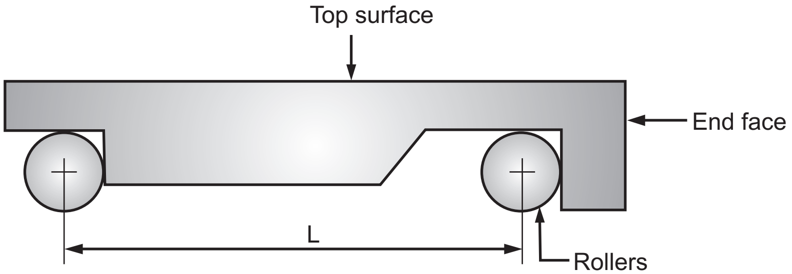


Fig. 4.6: Sine bar

Working:

- Working principle of sine bar is based on the laws of geometry and trignometry. To set a given angle, one roller of the bar is placed on the surface plate and combination of slip gauges is inserted under the second roller.

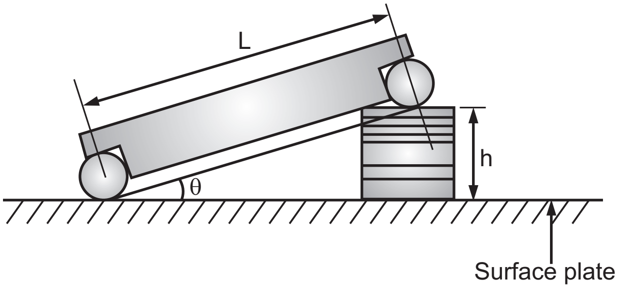


Fig. 4.7: Working principle of sine bar

- If 'h' is the height of the combination of slip gauges and 'L' is the distance between the roller centers, then,

$$\sin\theta = \frac{h}{L}$$

$$\therefore \qquad \theta = \sin^{-1}\left(\frac{h}{L}\right)$$

- Thus, the angle to be measured or to be set is determined by indirect method, using a function of sine. For this reason, the device used is called as **sine bar**.

Applications:

1. To measure taper plug gauge.
2. To set any work-piece to a given angle.
3. To measure and check the lathe angle.

4.5.1 Uses of Sine Bar to Measure Angle of Component

(a) When component is of small size:

- For checking the angle of component, of small size, the component is placed and clamped over the top surface of sine bar, resting on surface plate.
- Now, the slip gauges are inserted below one roller of sine bar, so that, sine bar can be lifted and set to an angle approximately equal to angle of component, which is to be measured.
- The slip gauges are inserted, till the upper surface of component becomes parallel to the surface plate as shown in Fig. 4.8.
- A dial gauger indicator is brought in contact with upper surface of component at end end.

- Now the dial gauge indicator is moved towards the other end of component in a straight line. If dial gauge indicator does not deviate from zero reading during this travel, then it indicates that, component is perfectly horizontal and truly parallel to surface plate. The angle of component can be obtained from the geometry of figure.
- The angle of component = $\theta = \sin^{-1}\left(\frac{h}{L}\right)$.
- But if, there are some deviations or variations in the dial gauge indicator reading during its travel over the component, then adjustments in the height of slip gauges is necessary to ensure that, component's upper surface is horizontal.
- But, this perfect adjustment of slip gauges combination requires too much time. Therefore, instead of adjusting slip gauges due to minor variations in reading, an alternative method can be used. In this method, the dial gauge indicator readings during its movement from one end to another end (say distance 'x') is noted down.
- If 'dx' is the variation in parallelism over the traveled distance 'x', then corresponding angular variation (dθ) is,

$$d\theta = \sin^{-1}\left(\frac{dx}{x}\right)$$

$$\therefore \text{ Actual angle of component } = \theta \pm d\theta = \sin^{-1}\left(\frac{h}{L}\right) + \sin^{-1}\left(\frac{dx}{x}\right)$$

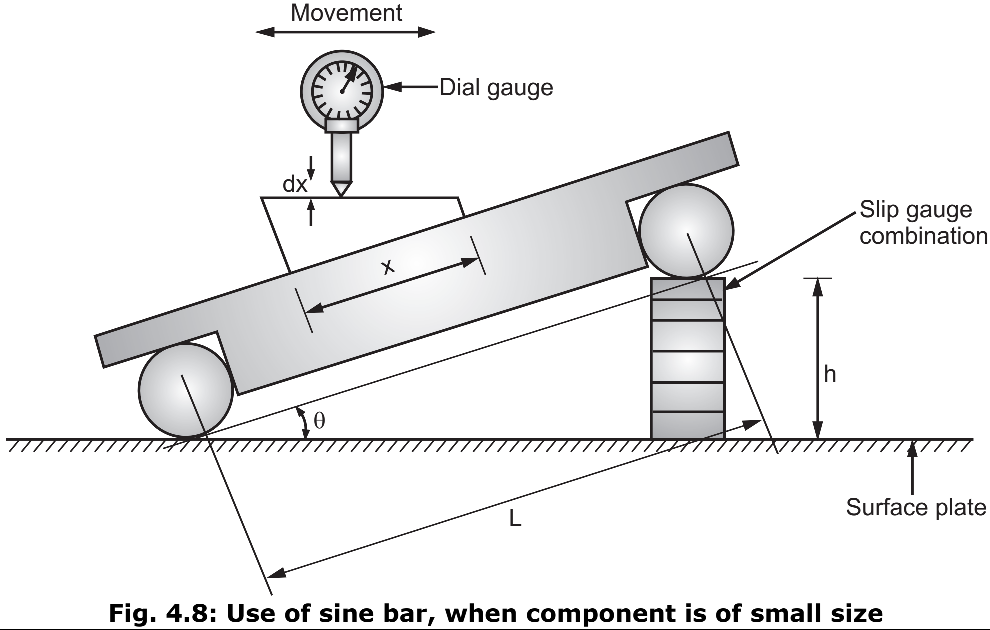


Fig. 4.8: Use of sine bar, when component is of small size

Note for students: Shape of sine bar is simplified from Fig. 4.8 onwards, which you can draw in minimum time.

(b) When component size is large:

- Due to large size, the component is placed over the surface plate and the sine bar is placed over the top surface of component.
- A vernier height gauge is mounted on the surface plate. A dial gauge mounted on the vernier height gauge is used to measure vertical height over each roller from the surface plate.

- If 'h' is the difference in the heights and 'L' is the distance between the roller centres of the sine bar, then, $\theta = \sin^{-1}\left(\frac{h}{L}\right)$. Refer Fig. 4.9.

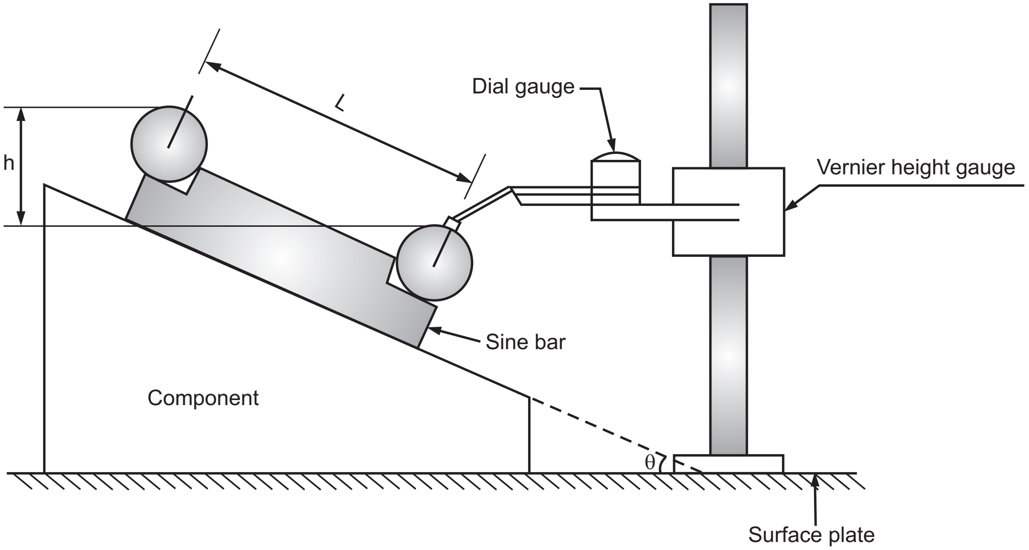


Fig. 4.9: Use of sine bar, when component size is large

- Another method of determining angle of large sized parts is shown in Fig. 4.10. The component is placed over a surface plate and sine bar is set up at approximate angle on the surface plate.
- A dial gauge is moved along the top surface of the sine bar to note down the variation in parallelism.
- If 'h' is height of the combination of the slip gauges and 'dh' the variation in parallelism over distance 'L', then, $\theta = \sin^{-1}\left(\frac{h \pm dh}{L}\right)$.

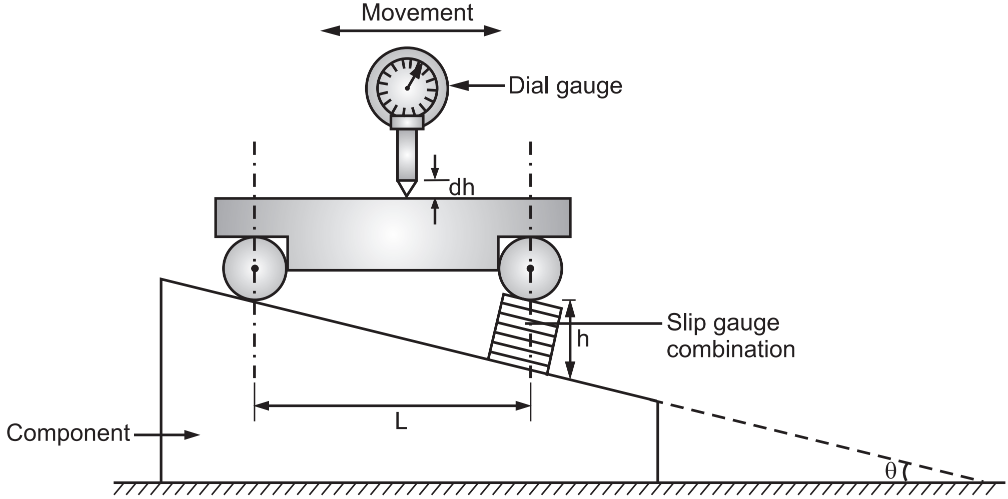


Fig. 4.10

4.5.2 Sources of Errors in Angular Measurement by Sine Bar

The different sources of errors in angular measurement by a sine bar are listed below:

(a) Errors in distance between roller centres.
(b) Errors in equality in size of roller and cylindrical accuracy in the form of the rollers.
(c) Errors in parallelism of roller axes with each other.
(d) Errors in parallelism between the gauging surface and plane of roller axes.
(e) Errors in flatness of the top (upper) surface of the bar.
(f) Errors in slip gauge combination used for angle setting.

4.5.3 Factors Affecting Accuracy of a Sine Bar

a) Equality of size of rollers.
b) Cylindrical accuracy of rollers.
c) Centre distance of rollers, because 'longer the sine bar, measurement will be accurate.
d) Parallelism of roller axes with each other.

4.5.4 Features of Sine Bar, which Have Tolerances for Accuracy

Following features of the sine bar have tolerance for accuracy:

(a) Upper and lower surfaces: Flatness and parallelism with respect to datum surface.
(b) Side faces: Flatness, squareness to top (upper) surface, squareness to the axes of rollers.
(c) End faces: Flatness, squareness to top upper surface, parallelism to the axes of rollers.
(d) Rollers: Straightness, cylindrical accuracy.
(e) Roller axes: Centre distance, parallelism with each other, and parallelism with top (upper) surface.

4.5.5 Precautions in Use of Sine Bars

1. Accuracy of sine bar should be ensured.
2. It should not be used for measurement of angle greater than 45°.
3. Larger sine bar should be used to reduce many errors.
4. Sine bars and component must be clamped against an angle plate. This prevents misalignment of the work-piece with sine bar while taking measurements.

4.5.6 Justification "Why it is Not Preferred to Use Sine Bar for Measuring Angles Greater than 45°"

QUESTIONS

1. Why it is not preferred for measuring angle more than 45°? **(W-08, S-13)**
2. Explain why sine bar is not used for angle greater than 45°, if accuracy in angle measurement is required? **(W-13, 16)**

- The accuracy of the angle set by a sine bar depends upon the errors in its important dimensions such as error in distance between roller centres, error in combination of slip gauges used for setting, error in parallelism between the mating surfaces and plane of roller axes etc.

- The slip gauge combination (h) required to set angle (θ) is given by,

$$h = L \sin \theta \qquad \text{... (i)}$$

- The effect of Error in spacing of *roller centres* (dL) or Errors in combination of *slip gauges (dh)* can be obtained by partial differentiation of the above equation.

$$\therefore \quad \frac{dh}{d\theta} = \sin\theta \frac{dL}{d\theta} + L \cos\theta$$

$$\therefore \quad dh = \sin\theta\, dL + L\cos\theta\, d\theta$$

$$\therefore \quad d\theta = \frac{dh}{L\cos\theta} - \frac{\sin\theta\, dL}{L\cos\theta}$$

$$= \tan\theta\left(\frac{dh}{L\cos\theta.\tan\theta} - \frac{dL}{L}\right)$$

$$= \tan\theta\left(\frac{dh}{L\sin\theta} - \frac{dL}{L}\right)$$

$$\text{But,} \quad L\sin\theta = h$$

$$\therefore \quad d\theta = \tan\theta \times \left(\frac{dh}{h} - \frac{dL}{L}\right)$$

- This term 'dθ' is called as error in the angle (θ) either measured or set using sine bar.
- From the above equation, we can see that, the effect of error in roller spacing (dL) or slip gauge combination (dh) is a function of angle θ. When the angle (θ) to be measured or set increases, value of tan θ will also increase. Therefore, equation (ii), we find the value of (dθ) is also increasing. dθ is the error in angle measurement. Therefore, angle to be measured or set (θ) should be small. The value of tan (45°) is 1 and it goes of increasing progressively if value of θ is more than 45°. Therefore, sine bars are not preferred for accurate measurements above 45°.
- **Note:** Sine bars provide the most reliable measurements for angles less than 15°.

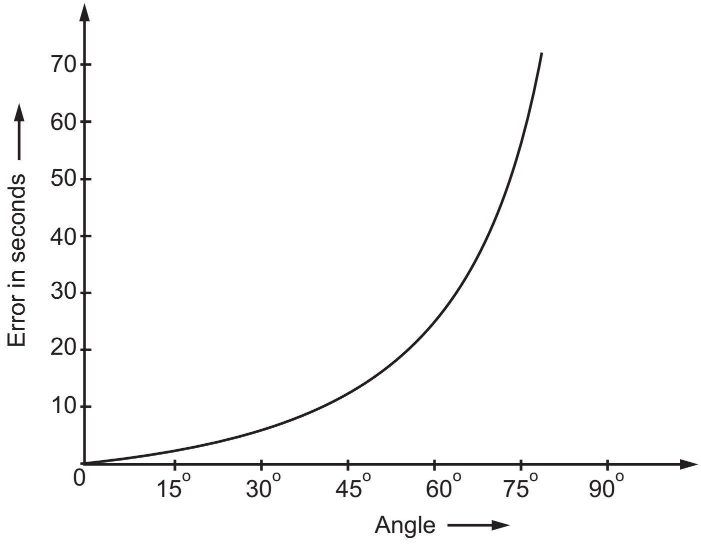


Fig. 4.11: Error with sine bar versus angle to be measured

4.5.7 Measurement of Angle of a Taper Plug Gauge with the Help of a Sine Bar

QUESTION

1. How will you measure the angle of taper plug gauge with the help of sine bar? Explain with a neat sketch. State any two limitations of sine bar. **(W-10, S-12)**

- Fig. 4.12 shows the use of sine bar for measurement of angle of a taper plug gauge.
- The sine bar is set up on surface plate with an angle approximately equal the **nominal angle** of the taper plug gauge.
- Taper plug gauge is placed on the sine bar and is prevented from sliding down with the help of a stop plate.
- The axis of the taper plug gauge is aligned with the axis of sine bar.

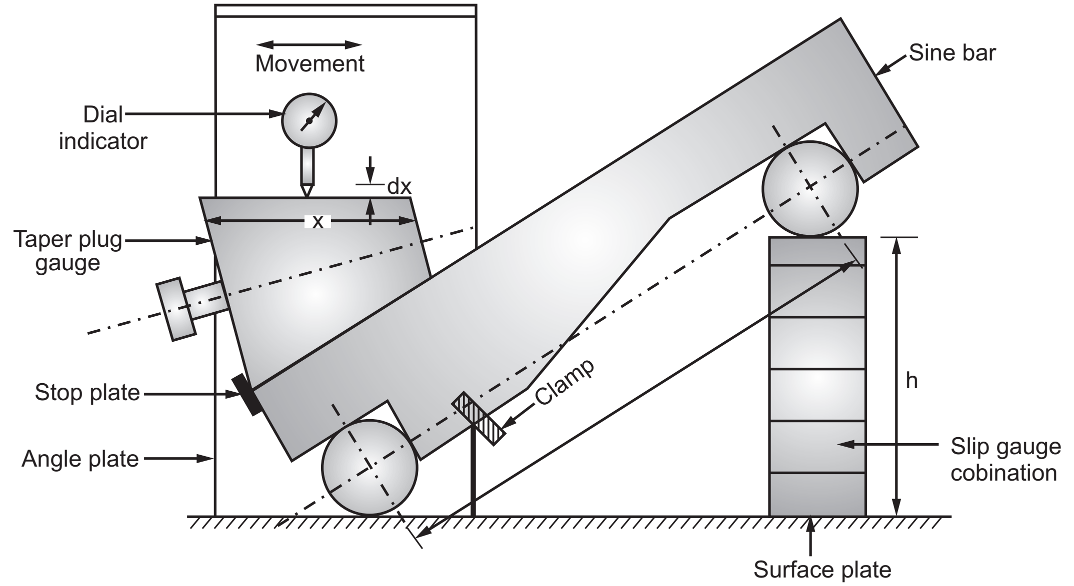


Fig. 4.12: Measurement of angle of taper plug gauge

- Let ‘dx’ be the difference in the readings of the dial gauge over a distance ‘x’, ‘h’ be the height of combination of the slip gauges used and ‘L’ be the distance between the roller centres, then,

$$\text{Nominal angle, } \theta = \sin^{-1}\left(\frac{h}{L}\right)$$

and error in angle measured,

$$d\theta = \sin^{-1}\left(\frac{dx}{x}\right)$$

∴ Actual angle of the taper plug gauge,

$$= \theta \pm d\theta$$

$$= \sin^{-1}\left(\frac{h}{L}\right) \pm \sin^{-1}\left(\frac{dx}{x}\right)$$

4.5.8 Limitations of Sine Bar

1. It is impractical to use sine bars for angle measurement above 45°.
2. It is difficult to hold taper plug gauge in desired position steadily for long time.
3. A small error in sine bar causes large error, in the angle measured.
4. Components of very large sizes cannot be inspected by sine bars.

4.6 CLINOMETER

QUESTION

1. What is Clinometer? Explain how it can be used for measurement and settings? Illustrate your answer with sketches. **(S-10)**
2. Explain with neat sketch, how angle is measured using clinometer. **(W-14)**
3. Explain with neat sketch, principle of working of clinometer. **(S.T.P.-I)**
4. What is Clinometer? Explain its use with suitable figure. **(W-16; S-17**

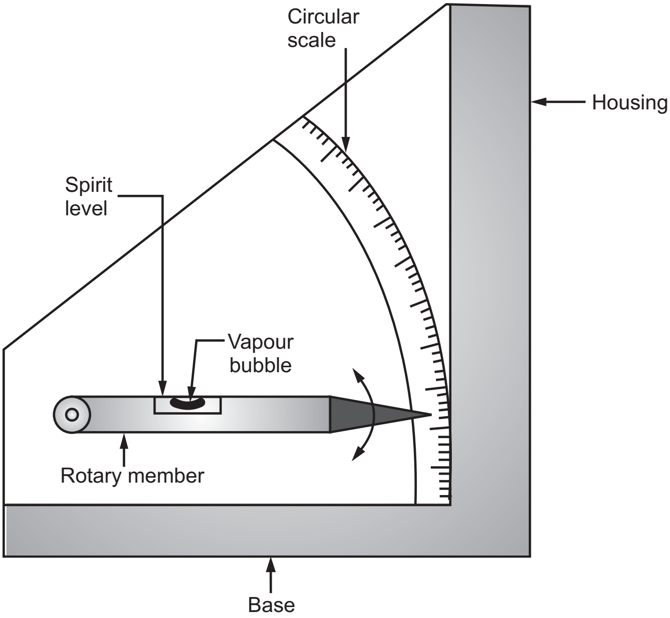


Fig. 4.13: Clinometer

- Clinometer is a special application of spirit level.
- In Clinometer, the spirit level is mounted on a rotary member carried in a housing. One face of housing forms the base of the instrument. When the rotary member is exactly parallel to base, then spirit level shows vapour bubble at centre of scale, i.e. zero reading.
- On the housing, there is a circular scale. The angle of inclination of the rotary member carrying spirit level relative to its base can be measured by this circular scale.
- Clinometer is mainly used to determine the included angle of two adjacent faces of a workpiece.
- For this purpose, the instrument base is placed on one of the surfaces and the rotary member is so adjusted, till zero reading of the bubble is obtained.
- A second reading is then taken in similar way by keeping the instrument on other surface.

- The included angle between the faces is then the difference between the two readings.

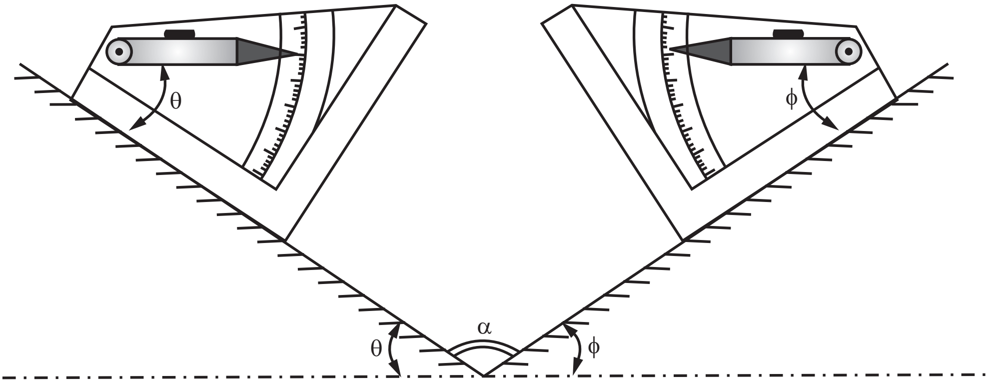


Fig. 4.14: Use of clinometer

- If θ and ϕ are readings of the instrument, the included angle between the surfaces is calculated as,
- Included angle between two surfaces,

$$\alpha = 180 - (\theta + \phi)$$

4.6.1 Uses of Clinometers

(W-16)

1. For measuring large angles between inclined surfaces.
2. For checking angular faces and relief angles on large cutting tools.
3. For setting inclinable table on jig boring machines.
4. For setting angular work on grinding machines.

4.7 ANGULAR STANDARDS OR ANGLE GAUGES

QUESTION

1. What are angle gauges? State procedure to set the gauges. **(S.Q.P.)**

- Angle gauges are used as angular standards to build up an angle between two surfaces. They are pieces of hardened and stabilized steel. Their measuring faces are lapped and polished to high degree of accuracy and flatness.
- For engineering purposes, the angular units are divided in a system as degrees, minutes and seconds.
- Angle gauges of length 75 mm and width 16 mm are available in two sets. One set consists of **12 pieces and a square block**, in three series of values of angle viz.

  1°, 3°, 9° , 27°, and 41°.
  1′, 3′, 9′ and 27′ and
  6′′, 18′′ and 30′′.

- Another set contains **13 pieces and a square block**.

  1°, 3° , 9°, 27° and 41°
  1′, 3′, 9′, 27′ and
  3′′, 6′′, 18′′ and 30′′.

- Accuracy of each angle gauge is accurate to within one second. Angle gauges are marked with engraved “V”, which indicates the direction of the included angle.

These gauges, together with square block can be so wrung that, any angle between 0° to 360° can be set.

- This is possible because the gauges in combination can be added or subtracted as required. Refer Figure 4.15 (b) and (c).

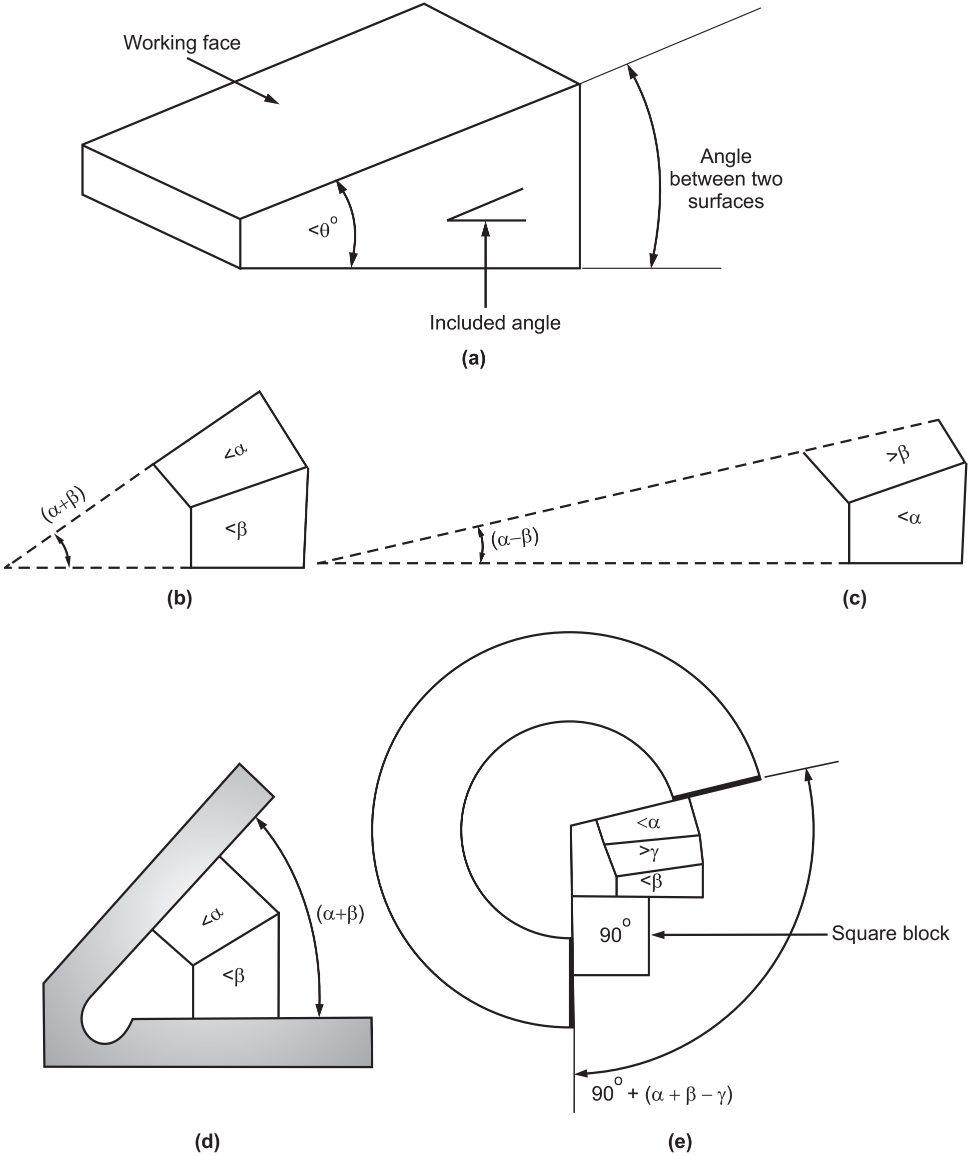


Fig. 4.15: Angle gauges

4.7.1 Applications of Angle Gauges

(i) Angle gauges are used for measurement and calibration purposes in tool rooms.

(ii) Angle gauges are also used in machine shops for setting up a machine. For example: revolving centre of magnetic chuck.

(iii) They are setting standards for angular measurements, like slip gauges used for linear measurements.

(iv) They reduce the set up time and minimize error in measurements.

4.7.2 Difference between Angle Gauges and Slip Gauges

QUESTION

1. Differentiate between angle gauges and slip gauges (at least four points) **(S-09, 14, 15; W-09, 11)**

Angle Gauges	Slip Gauges
1. They are used to measure or set up angles in the workshops.	1. They are used as height standards for the measurement of parts.
2. They are used in conjuction with angle measuring devices such as bevel protractor and autocollimator.	2. They are used in conjuction with sine bar to set up or measure an angle.
3. Length and width of angle gauges are 75 mm and 16 mm respectively. But heights vary for each angle gauge due to their inclined or sloping measuring faces.	3. Length and width of slip gauges are 30 mm × 10 mm respectively. But, the vary for each slip gauge.
4. They are available in only one grade.	4. They are available in 5 grades such as Grade II, Grade I, Grade 0, Grade 00 and Calibration grade.
5. Two sets of angle gauges are available, i.e. one set containing a square block with 12 angle gauges and other containing a square block and 3 angle gauges.	5. They are available as in many sets and each gets designated by letter 'M' followed by a number representing total number of slip gauges available in that particular set. For example: M45, M87, M105 etc.
6. Angle gauges can be added or subtracted.	6. Slip gauges can be only added.

4.8 ANGLE DEKKOR

QUESTIONS

1. Explain with neat sketch, how angle of a workpiece is measured with the help of angle dekkor? **(W-14)**
2. Explain the working principle of angle dekkor with neat sketch. **(S-17)**

- It is an angular comparator or auto-collimator telescope, which can simultaneously measure vertical and horizontal angular displacements of more than 60' × 40'.

Construction:

- It consists of a microscope, collimating (objective) lens and two scales engraved on a glass screen, placed in the focal plane of objective lens.

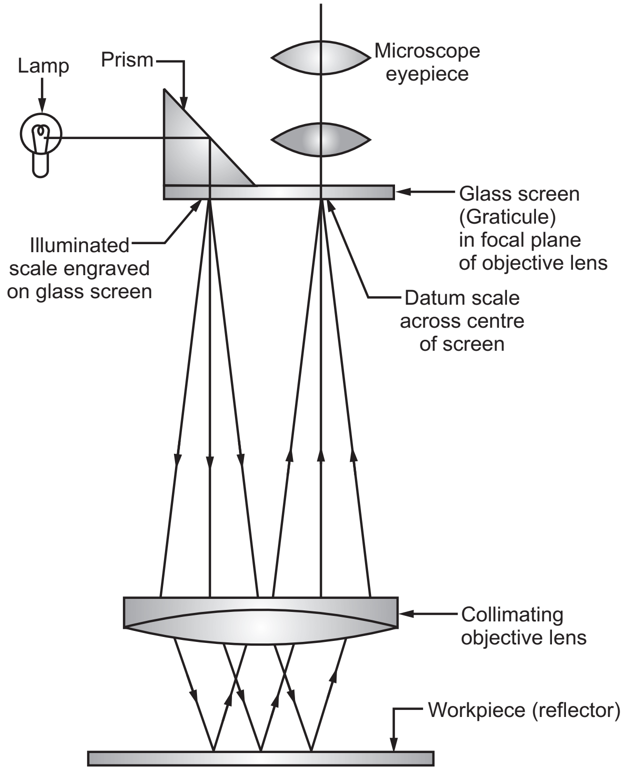
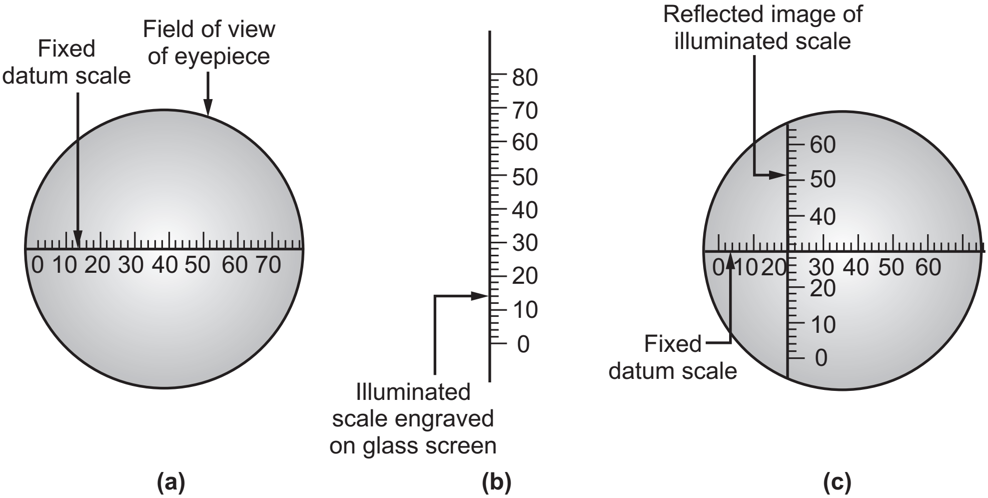


Fig. 4.16: Angle dekkor

- One scale is horizontal datum scale fixed across the centre of the screen and is always visible in the microscope eye-piece.
- Another scale is an illuminated vertical scale, which in normal position, is outside the view of eyepiece and only its reflected image is visible. The illuminated scale is projected as parallel beam by collimating lens, which after striking the reflector (workpiece) below the instrument is refocused on the lens in the field of view of eyepiece.
- The reflected image is illuminated and is received at right angles to the fixed scale.
- In this position, the two scales, horizontal and vertical intersect each other. Thus, the reading on the illuminated scale measures the vertical and horizontal angular deviations simultaneously.
- In other words, changes in angular position of reflector in two planes are indicated by changes in the intersection of two scales.



(a) (b) (c)

Fig. 4.17: Eyepiece view of angle dekkor

Working:

- Angle dekkor is capable of measuring small variations in the angular setting i.e. determining the angular tilt.
- For measuring the angle of a component, the working principle is the method of measurement by comparison.
- Thus, first of all, the angle gauge combination is set up to the nearest angle of component and the angle dekkor is set, such that, zero reading is obtained on the illuminating scale.
- The angle gauge build up is then removed and replaced by the component under test. A straight edge is used to ensure that, there is no change in lateral positions.
- The new positions of reflected (illuminated) scale with respect to fixed scale gives the angular tilt of the component from set angle.

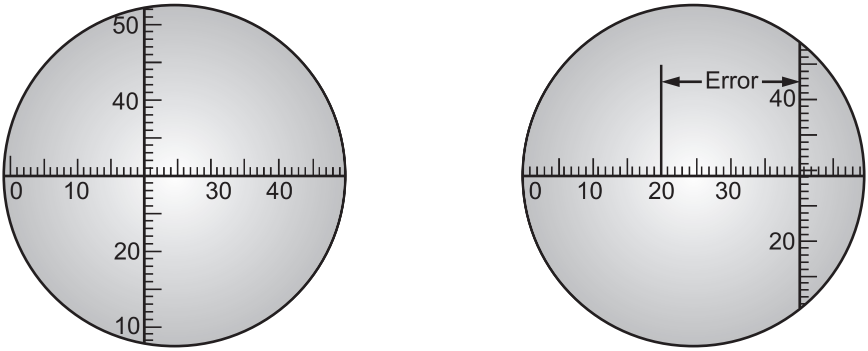


Fig. 4.18: Final positions of vertical illuminated scale showing horizontal and vertical angular displacement

Applications of Angle Dekkor:

In combination with angle gauges, it is used in:

(a) Measuring angle of a component.

(b) Angular setting of machines.

(c) Checking slope angles of V-blocks.

(d) Measuring angle of taper gauge.

SOLVED PROBLEMS ON ANGULAR MEASUREMENT

Problem 4.1: *An angle of value 33° 10′ 12″ is to be measured and to be set with the help of following standard angle gauges.*

[1°, 3°, 9°, 27°, 41°], [1′, 3′, 9′, 27′], [3″, 6″, 18″, 30″]. Show the arrangement to set up angle gauges with a sketch. Select minimum number of gauges.

Solution:

Degree	***Minutes***	***Seconds***
33° ⇒ 41°	*10′ ⇒ 9′*	*12″ ⇒ 18″*
– 9°	*+ 1′*	*– 6″*
32°	*10′*	*12″*
+ 1°		
33°		
[41°, 9°, 1°]	*[9′, 1′]*	*[18″, 6″]*

We will use [41°, 9°, 1°, 9′, 1′, 18″, 6″]

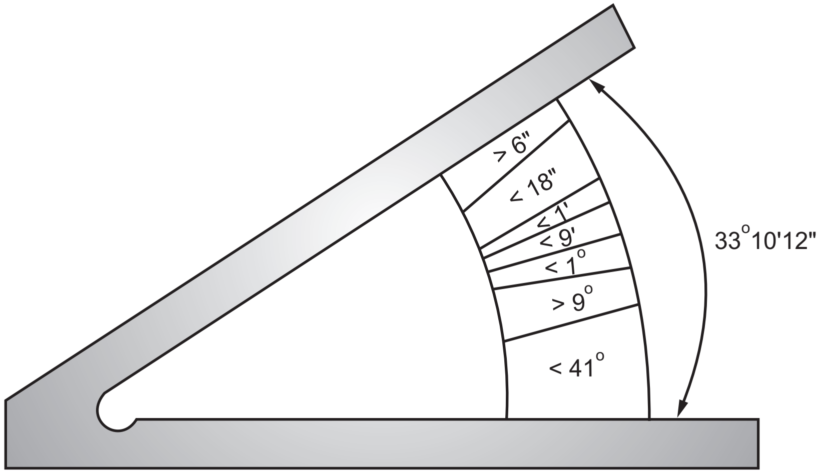


Fig. 4.19

Problem 4.2: *An angle of 139° 30′ 27″ is to be developed using following standard set of an angle gauges* **(S-15; W-16)**

[1°, 3°, 9°, 27°, 41°], [1′, 3′, 9′, 27′], [3″, 6″, 18″, 30″] and square block.

Solution:

Given angle = 139° 30′ 27″

Given set = [1°, 3°, 9°, 27°, 41°], [1′, 3′, 9′, 27′], [3″, 6″, 18″, 30″]

As the given angle is more than 90°, we will use a square block (90°).

Degree	Minutes	Seconds
139° ⇒ 90°	27′	30″
+ 41°	+ 3′	– 3″
131°	30′	27″
+ 9°		
140°		
– 1°		
139°		
[41°, 9°, 1°]	[27′, 3′]	[30″, 3″]

Therefore, we will use square block with [41°, 9°, 1°, 27′, 3′, 30″, 3″].

Problem 4.3: *An angle of 98° 27′ 15″ is to be developed using angle gauge set of [1°, 3°, 9°, 27°, 41°], [1′, 3′, 9′, 27′], [3″, 6″, 18″, 30″] and a right angle (square block).* **(W-11, 13)**

Show arrangement of using sketch.

Solution:

Given angle = 98° 27′ 15″

Given set = [1°, 3°, 9°, 27°, 41°], [1′, 3′, 9′, 27′], [3″, 6″, 18″, 30″]

As the given angle is more than 90°, we will use a square block (90°) i.e. right angle.

Degree	Minutes	Seconds
98° ⇒ 90°	27′ ⇒ 27′	15″ ⇒ 18″
+ 9°		– 3″
99°		15″
– 1°		
98°		
[9°, 1°]	[27′]	[18″, 3″]

We will use square block with [9°, 1°, 27′, 18″, 3″]

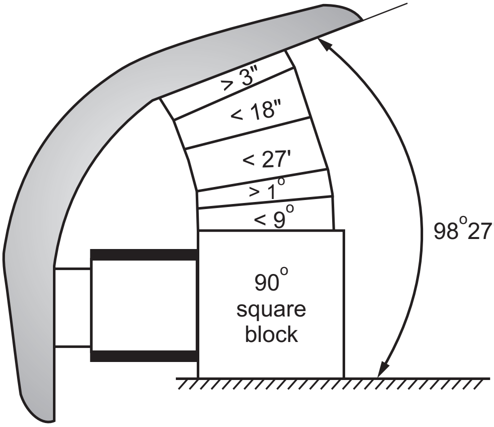


Fig. 4.20

Problem 4.4: *An angle of 117° 8′ 42″ is to be developed using angle gauge set of [1°, 3°, 9°, 27°, 41°], [1′, 3′, 9′, 27′], [3″, 6″, 18″, 30″] and a right angle (square block).*

Solution:

Given angle = 117° 8′ 42″

Given set = [1°, 3°, 9°, 27°, 41°], [1′, 3′, 9′, 27′], [3″, 6″, 18″, 30″]

As the given angle is more than 90°, we will use a square block (90°) i.e. right angle.

Degree	Minutes	Seconds
Square block ⇒ 90°	8′ ⇒ 9′	42″ ⇒ 30″
+ 27°	− 1	+ 18″
117°	8'	48″
− 1°		− 6"
98°		42"
[90°, 27°]	[9', 1']	[30", 18", 6"]

We will use square block with [27°, 9', 1′, 30", 18", 6"]

Problem 4.5: *An angle of 49° 29′ 18″ is to be developed using standard angle gauge set of 13 pieces. Calculate the angle gauges required.*

Solution:

Given angle = 49° 29′ 19″

Given set = [1°, 3°, 9°, 27°, 41°], [1′, 3′, 9′, 27′], [3″, 6″, 18″, 30″]

Degree	Minutes	Seconds
49° ⇒ 41°	29′ ⇒ 27′	18″
+ 9°	+ 3′	
50°	30′	
− 1°	− 1'	
49°	29'	
[41°, 9°, 1°]	[27′, 3′, 1′]	[18″]

We will use [41°, 9°, 1°, 27', 3', 1', 18"]

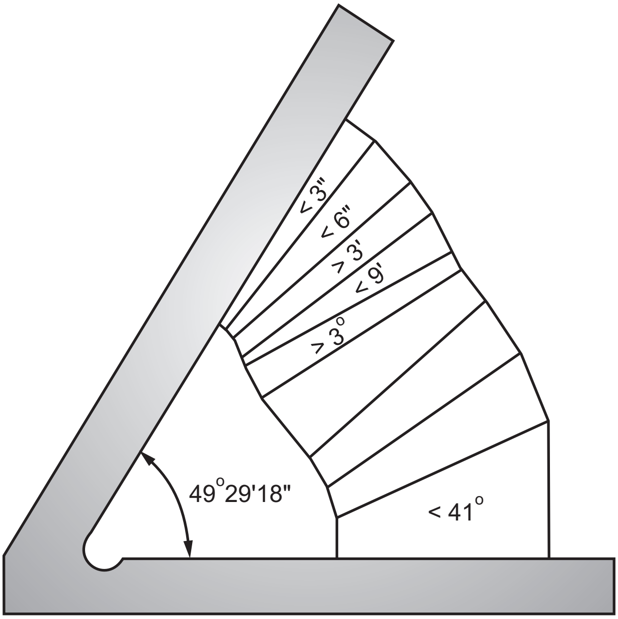


Fig. 4.21

Problem 4.6: *Construct an angle of 33° 19' 15" using minimum number of angle gauges using standard gauge set. Draw the sketch of arrangement.* **(W-14)**

Solution:

Degree	*Minutes*	*Seconds*
33° ⇒ 41°	*19′ ⇒ 27′*	*15″ ⇒ 18″*
− 9°	*− 9′*	*− 3″*
32°	*18′*	*15″*
+ 1°	*+ 1'*	
33°	*19'*	
[41°, 9°, 1°]	*[27', 9′, 1′]*	*[18″, 3′]*

We will use [41°, 9°, 1°, 27', 9', 1', 18", 3"]

Note: For arrangement, refer previous problem 4.4.

Problem 4.7: *Explain how you will use the angle gauge block for obtaining the angle 32°50' 54".* **(S-11)**

Solution: Given angle = 32° 50' 54"

Set available = [1° 3° 9° 27° 41°] [1' 3' 9' 27'] [3" 6" 18" 30"]

Degrees and minutes	Seconds
27° + 9° 36° − 3° 33° − 9' 32° 51' − 1' 32° 50' [27° 9° 3° 9' 1']	30" + 18" 48" + 6" 54" [30" 18" 6"]

Therefore, we will use [27° 9° 3° 9' 1' 30" 18" 6"].

Problem 4.8: *A 100 mm sine bar is to be set up to an angle of 33°, determine the slip gauges needed from 87 pieces set.*

Solution: Given data:

$\theta = 33°$

$L = 100$ mm (L = distance between roller centers)

Procedure:

For sine bar, we have, $h = L \sin \theta$

$h = 100 \times \sin (33°)$

∴ $\mathbf{h = 54.464}$ **mm**

M-87 set contains:

Range (mm)	Step (mm)	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9
1.005	–	1
	Total pieces	**87**

To build up 54.464 mm height, the slip gauges from the given set are used as,

54.464 – 1.004	1st slip gauge
53.46 – 1.46	2nd slip gauge
52.00 – 2.00	3rd slip gauge
50.00 – 50.00	4th slip gauge
0	

Minimum number of slip gauges required are 4.

Problem 4.9: *A 200 mm sine bar is to be set to an angle of 32° 5' 6". Find the length of the slip gauge combination required.*

Solution: Given data: L = 200 mm

θ = 32° 5' 6"

Procedure: Given angle = 32° 5' 6"

We know that, 1° = 60'

and 1' = 60"

$\therefore$ Convert the 6" into degree as, $\frac{6}{60}$ = 0.1' (minutes) = $\frac{0.1'}{60}$ = 0.001667° (degrees)

Also, convert the 5' into degree as, $\frac{5}{60}$ = 0.0833° (degrees)

$\therefore$ Angle in degrees = θ = 32 + 0.001667 + 0.0833

θ = 32.085°

We know, for sine bar,

$$\sin\theta = \frac{h}{L}$$

$$\therefore \quad h = L \times \sin(\theta)$$

$$= 200 \times \sin(32.085°)$$

$$= \mathbf{106.235\ mm}$$

This is the required length of the built-up using slip gauges.

Problem 4.10: *If the length of sine bar is 100 mm and angle of 14° is to be developed, determine the height of slip gauges and size of slips using M-45 slips.*

(S-14, W-15)

Solution: Given data: L = 100 mm

θ = 14°

Procedure: For sine bar, we have,

$$h = L \sin\theta$$

$$\therefore \quad h = 100 \times \sin(14°) = 24.192 \text{ mm}$$

M-45 slip gauge set contains:

Range (mm)	Step (mm)	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.09	0.01	9
1.1 to 1.9	0.01	9
1 to 9	1	9
10 to 90	10	9
	Total pieces	**45**

To build up 24.192 mm height, the slip gauges from the given set are used as,

24.192 – 1.002	1st slip gauge
23.19 – 1.09	2nd slip gauge
22.1 – 1.1	3rd slip gauge
21.0 – 1	4th slip gauge
20 – 20	5th slip gauge
0	

Therefore, minimum number of slip gauges required to build up 24.192 mm height is 5.

Important Points

- The vernier bevel protractor with acute angle attachment is the simplest angle measuring and testing instrument.
- Spirit level is used to measure small angles or inclinations, to test straightness and flatness of surfaces.
- Sine bar is a simple instrument, which utilizes high degree of accuracy available for linear measurement.
- A Clinometer is a special case of the application of spirit level.

Theory Questions for Practice

1. Write a short note on universal vernier bevel protractor.
2. What is spirit level? What do you mean by its sensitivity?
3. What are angle gauges? Explain their use in brief.
4. What is sine bar? How will you use sine bar to measure angle of component?
5. What are the factors affecting accuracy of a sine bar?
6. "Why it is not preferred to use sine bar for measuring angles greater than 45°?" Justify the statement.
7. Explain the procedure of measurement of angle of a taper plug gauge with the help of a sine bar.
8. What is clinometer? Explain its use with suitable figure.
9. Enlist the instruments used for angular measurements.

Numerical Problems for Practice

1. A 200 mm sine bar is to be set up to an angle of 25°. Find the slip gauges needed from M87 set.

Ans. We will use 4 slip gauges of dimensions 80 mm, 2.5 mm, 1.02 mm and 1.003 mm to build up required height of 84.523 mm.

2. Set an angle of 8° 14' using angle gauges.

Ans. [9° 1°] [27' 9' 3' 1']

3. Set the following angles (a) and (b) by using set of angle gauges,

[1° 3° 9° 27° 41°] [1' 3' 9' 27'] [3" 6" 18" 30"]

(a) 39° 33' 30"

(b) 57° 38' 9"

Ans. (a) [41° 1°] [27'] [30"]

(b) [41° 27° 9° 3° 1°] [27' 9' 3' 1'] [6" 3"]

4. An angle of 49° 33' 21" is to be measured. Sketch the arrangement using minimum number of angle gauges.

Ans. [41° 9°] [27'] [18" 3"]

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2014

1. Explain with neat sketch, how angle of a workpiece is measured with the help of angle dekkor? **(6M)**

Ans. Refer Article 4.8.

2. Construct an angle of 30°19' 15" using minimum number of angle gauges using standard angle gauge set. Draw the sketch of the arrangement. **(4M)**

Ans. Refer Problem 4.5.

3. Explain with neat sketch, how angle is measured using clinometer. **(4M)**

Ans. Refer Article 4.6.1.

Summer 2015

(c) Draw a lebelled diagram of universal bevel protractor. State its uses. **(4M)**

Ans. Refer Article 4.3.

(c) Differentiate between angle gauges and slip gauges (atleast four points). **(4M)**

Ans. Refer Article 4.7.1.

(b) An angle of 139°30'27" is to be developed using angle gauge set of (1°3°9°27°41°) (1'3'9'27') (3"6"18"30") and square block. Show arrangement with neat sketch. **(4M)**

Ans. Refer Problem 4.2.

Winter 2015

1. Draw a labelled sketch of bevel protractor. State its uses. **(4M)**

Ans. Refer Article 4.3.

2. If length of sine bar is 100 mm, find the length of slip gauges required to build an angle of 14° by using M45 slip gauge set. **(4M)**

Ans. Refer Problem 4.9.

3. An angle of 49° 29' 18" is to be developed by using standard angle gauge set of 13 pieces. Calculate the gauges required and sketch the arrangement. **(4M)**

Ans. Refer similar Problem 4.1 or 4.4.

Summer 2016

1. Differentiate between 'angle gauges' and 'slip gauges' (four points). **(4M)**

Ans. Refer Article 4.7.1.

2. Draw a labelled diagram of a universal bevel-protractor. Show its specific application on diagram. **(4M)**

Ans. Refer Article 4.3.

3. An angle of 117° 8' 42' is to be set and measured with the help of standard angle gauges and square block. Select the minimum number of pieces and sketch the arrangement. **(4M)**

Ans. Refer similar Problem 4.3.

Winter 2016

1. Explain why sine bar is not used for measurement of angle greater than 45°, if accuracy in angle measurement is required. **(4M)**

Ans. Refer Article 4.5.6.

2. What is clinometer? Explain its use with suitable figure. **(4M)**

Ans. Refer Articles 4.6 and 4.6.1.

3. An angle of 139°30′27″is to be developed using angle gauge set of (1°,3°,9°, 27°, 41°) (1′,3′,9′, 27′) (3″,6″, 18″, 30″) and a square block. Show the arrangement with neat sketch.

Ans. Refer Problem 4.2. **(4M)**

Summer 2017

1. An angle of 33°-9'-15" is to be measured with the help of the 13 pieces standard set of angle gauges. Show the arrangement of angle gauges with a neat sketch by selecting minimum number of gauges. **(4M)**

Ans. Refer Similar Problem 4.1.

2. Explain the working principle of clinometer with neat sketch. **(4M)**

Ans. Refer Article 4.6.

3. Explain the working principle of angle dekkor with neat sketch. **(4M)**

Ans. Refer Article 4.8.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

***

Chapter 5

SCREW THREAD MEASUREMENTS

About This Chapter ...

This chapter has a weightage of 6 marks and assigned duration is 3 hours. Here we learn to measure different elements of screw thread such as Major diameter, Minor diameter, Effective diameter by using two wire method and three wire method, Thread gauge micrometer, Floating carriage dial micrometer.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	04 Marks	S-09	04 Marks
W-09	08 Marks	S-10	08 Marks
W-10	08 Marks	S-11	08 Marks
W-11	07 Marks	S-12	08 Marks
W-12	08 Marks	S-13	08 Marks
W-13	08 Marks	S-14	08 Marks
W-14	08 Marks	S-15	08 Marks
W-15	12 Marks	S-16	10 Marks
W-16	10 Marks	S-17	12 Marks

5.1 INTRODUCTION TO SCREW THREAD MEASUREMENT

Screw thread metrology deals with the measurements of screw thread profiles. These measurements find out the dimensional accuracy of screw threads, their strength, workability and nature of errors (if any).

Here, the object of dimensional control is to ensure mechanical strength, which depends upon the amount of flank contact with a threaded hole.

5.1.1 Uses of Threads

(a) Screw threads are used principally on *fasteners* such as machine bolts, stove bolts and wood screws. Threads of this nature are simple in design and easy to produce. The usual form is a 'V', although there are several slight variations to this form.

(b) Another function of a screw thread is to *transmit power*, lead screw on a lathe.

(c) Screw threads are employed for *measuring devices* such as micrometers.

5.2 TYPES OF SCREW THREADS

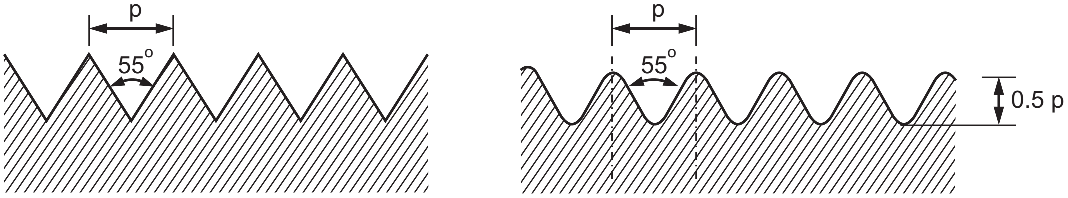
Screw threads have been standardized according to their cross-sectional form. The most commonly used screw threads are,

(a) V threads: All bolts and similar fasteners have V-shaped threads. V-threads with smaller pitch are used in automotive and aeronautical industries, since there are fewer tendencies for them to loosen because of vibrations.

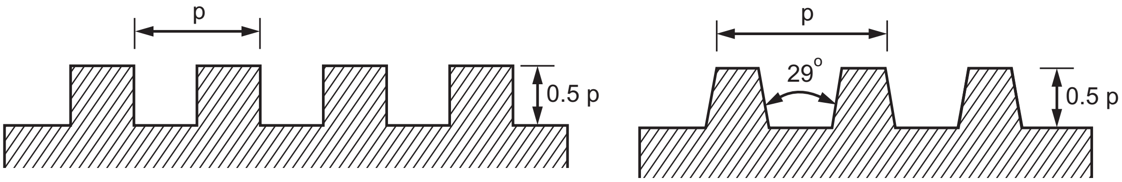
(b) Whitworth threads: Whitworth threads are better, because they have filleted at top and bottom and add strength by eliminating sharp corners and roots.

(c) Square threads: Square threads are widely used for power transmission due to maximum efficiency. In square threads, the sides of threads are parallel and bursting force on the nut vanishes and axial thrust is practically equal to normal pressure on the threads.

(d) Acme threads: Acme threads, though not as efficient as square threads, but are easier to cut and are stronger than square threads. They permit the use of a split nut, which can be used to take up the wear. Acme threads are cheaper to manufacture and can transmit the power in any direction.



(a) V threads **(b) Whitworth threads**



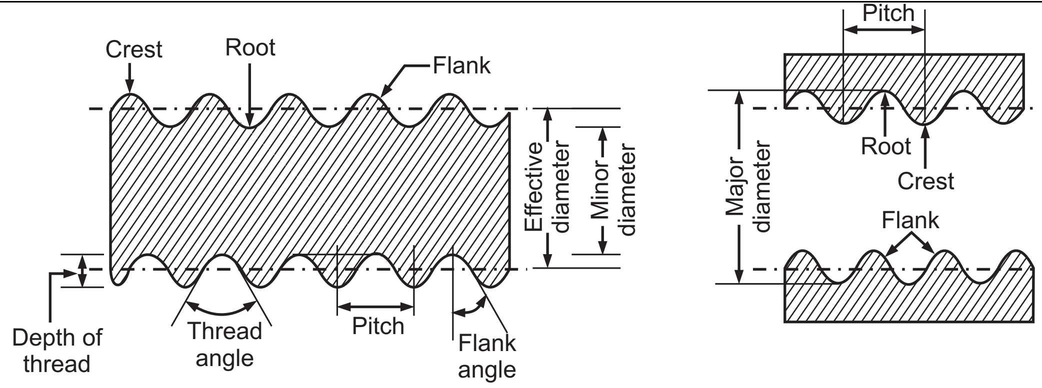
(c) Square threads **(d) Acme threads**

Fig. 5.1: Types of threads

5.2.1 External Threads and Internal Threads

(i) External threads: The threads formed on outside (exterior) of a work-piece re called as external threads. For example: Bolt or stud.

(ii) Internal thread: The threads formed on inside (interior) of a work-piece are called as internal threads. For example: Nut.



(a) External threads **(b) Internal threads**

Fig. 5.2: Types of threads

5.3 TERMINOLOGY OF SCREW THREADS

QUESTION

1. Draw a neat sketch of metric screw thread profile showing all the parameters. **(S-14)**

- A **parallel screw thread** is a continuous helical ridge of uniform section and uniform axial spacing formed on the exterior surface of a circular cylinder or on the interior face of a circular hole.

  Following are the definitions of some of the useful terms in screw threads.

  1. **Axis of a thread or Thread axis:** It is an imaginary line passing through the centre of screw along its length.
  2. **Form of thread:** It is the shape of contour of one complete thread as seen in an axial section.
  3. **Pitch:** Pitch of a screw thread is the axial distance measured parallel to axis, between the two corresponding points on adjacent thread forms in the same axial plane and on same side of axis. **Pitch is defined** as, *"the axial distance (measured parallel to thread axis) of one point on one thread to the corresponding point on adjacent or next or successive thread".*
  4. **Lead:** It is the axial distance travelled by the thread, when it completes one revolution.
  5. **Crest:** It is the prominent part of apex of ridge of thread. (Thread may be external or internal).
  6. **Root:** It is bottom of groove formed between two ridges (two flanks) of thread. (Thread may be external or internal).

7. **Flank:** It is straight edge, which connects a crest with root.
8. **Major diameter:** It is the diameter of an imaginary cylinder, which would touch all the crests of external thread or roots of an internal thread.
9. **Minor diameter:** It is the diameter of an imaginary cylinder, which would touch all the roots of external thread or crests of an internal thread.
10. **Effective diameter:** It is the diameter of an imaginary cylinder, which intersect, the flanks of threads in such a way that, both, 'width of threads' and 'width of spaces' between threads are same.
11. **Pitch diameter:** It is the diameter of pitch cylinder (imaginary cylinder), which is co-axial with the axis of screw, and intersects the flanks of threads in such a way that, both 'width of threads' and 'width of spaces' between the threads are equal.
    - Please note, *on straight threads, pitch diameter is same as effective diameter*.
12. **Included angle or thread angle:** It is the angle between the flanks of the thread measured in an axial plane.
13. **Flank angle:** It is the angle between the individual flank and perpendicular drawn to the axis of thread, measured in an axial plane. It is commonly termed as 'half the thread angle'.
14. **Helix angle:** It is defined as 'the angle made by helix of thread at the pitch line with the screw axis'. Helix angle is complementary to the lead angle.
15. **Lead angle:** It is defined as, "the angle made by the helix of thread at the pitch line, with a plane perpendicular to screw axis".
16. **Depth of thread:** It is the distance from crest of thread to root of the thread.

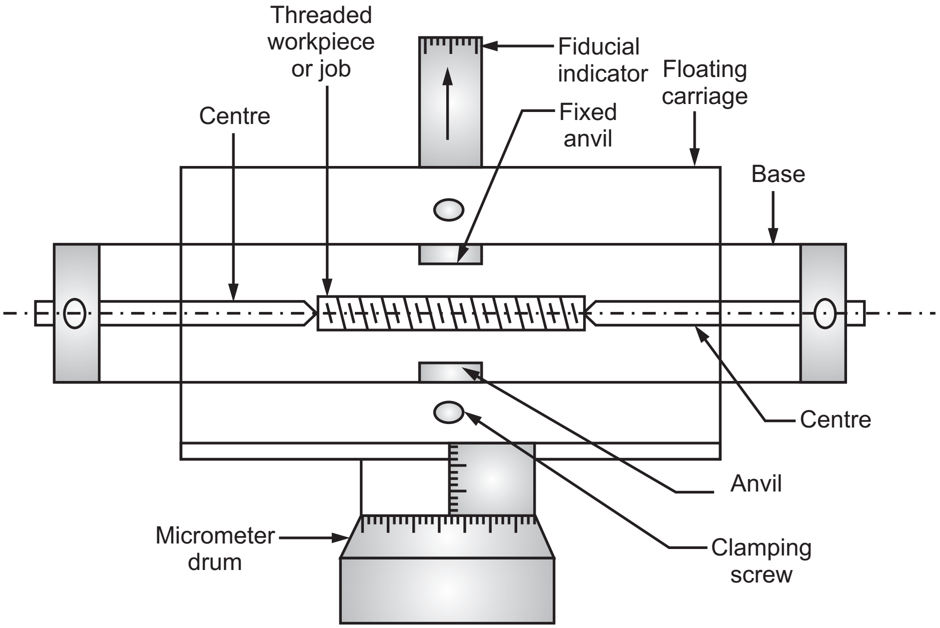


Fig. 5.3

17.Addendum:

- For an external thread, it is the radial distance between major cylinder and pitch cylinder.
- For an internal thread, it is the radial distance between minor cylinder and pitch cylinder.

18. Dedendum:

- For an external thread, it is the radial distance between minor cylinder and pitch cylinder.
- For an internal thread, it is the radial distance between major cylinder and pitch cylinder.

5.4 VARIOUS INSTRUMENTS USED TO MEASURE CHARACTERISTICS OF SCREW THREAD

QUESTIONS

1. Suggest the measuring instruments to measure the following parameters of an external thread and internal thread. (1) Major diameter, (2) Effective diameter, (3) Pitch, (4) Thread angle. **(S-10)**
2. Suggest the suitable instruments to measure external and internal threads. **(W-12, 13)**

For External Thread Measurement:

Characteristic	Measuring Instrument
1. Major diameter	Ordinary micrometer or Bench micrometer, Tool - maker's microscope, Profile projector.
2. Minor diameter	Bench micrometer, a floating carriage diameter measuring machine with V-pieces, optical projector or microscope.
3. Effective diameter	Screw thread micrometers. Floating carriage diameter measuring machines using wires.
4. Pitch	Pitch measuring machine, screw pitch gauge (profile gauge) and pitch error testing machines.
5. Thread angle and form (profile)	Optical projector.

For Internal Thread Measurement:

Characteristic	Measuring Instrument
1. Minor diameter	1. Bench micrometer using taper parallels or rollers. Thread measuring machine.
2. Effective diameter	2. Screw thread micrometer.

Characteristic	Measuring Instrument
3. Major diameter	3. Using cast of the thread. Once a cast is made, major diameter can be determined by using microscope or optical projector.
4. Pitch	4. Screw pitch gauge or profile gauge, microscope or pitch measuring machine.
5. Thread angle and form	5. Using cast of thread. Once a cast is made, thread angle and form can be determined using either a microscope or an optical projector.

5.5 CONSTRUCTION AND WORKING PRINCIPLE OF FLOATING CARRIAGE DIAL MICROMETER

QUESTIONS

1. Give the working principle of floating carriage dial micrometer with neat sketch. **(W-09, 10, 12, 13)**
2. Make a neat sketch of floating carriage dial micrometer and label the parts. Write any four applications of it. **(S-10)**

- Floating Carriage Dial Micrometer is also commonly known as "effective diameter measuring micrometer" or "floating carriage diameter measuring machine", working on micrometer principle (screw and nut).
- In fact, floating carriage diameter measuring is the bench micrometer mounted on a carriage machine.

Working Principle:

When drum of micrometer rotates by one revolution, it will move forward by a distance equal to pitch of an internal thread. This movement is measured by using number of divisions engraved on drum and main scale.

- This instrument is used for accurate measurement of 'Thread Plug Gauges'. Most important gauge dimensions such as Major diameter, Effective diameter, and Minor diameter are measured with the help of this instrument.
- All these dimensions have a vital role in the thread plug gauges, since the accuracy and interchangeability of the component depends on the gauges used. To reduce the effect of slight errors in the micrometer screws and measuring faces, this micrometer is basically used as comparator.

Construction:

- Features of Floating carriage diameter measuring machines are,
  (a) Robust or sturdy cast iron base.
  (b) Suitable for dimensional stability.
  (c) Internal ways ground (finished by grinding) to finest accuracy.
  (d) Micrometer least count of the order 0.002 mm with non-rotary spindle.

- The machine consists of three units,
  - (a) A base casting carries a pair of accurately mounted and aligned centers, on which the threaded workpiece is mounted i.e. *first carriage*.
  - (b) Second carriage known as lower carriage is mounted on the first carriage at exactly 90°. It is capable to move parallel to thread axis.
  - (c) Third carriage known as upper carriage is mounted on the second carriage/ lower carriage. This upper carriage is capable to move at 90° to the thread axis due to provision of V-ball slides.
- Upper carriage has micrometer thimble with graduated cylindrical scale at one end. Micrometer thimble can read upto 0.002 mm. On another end, a fiducial indicator is used in placed of fixed anvil, to perform all measurements at same pressure. Both, micrometer thimble and fiducial indicator have special exchangeable anvils made to suit the form of thread.

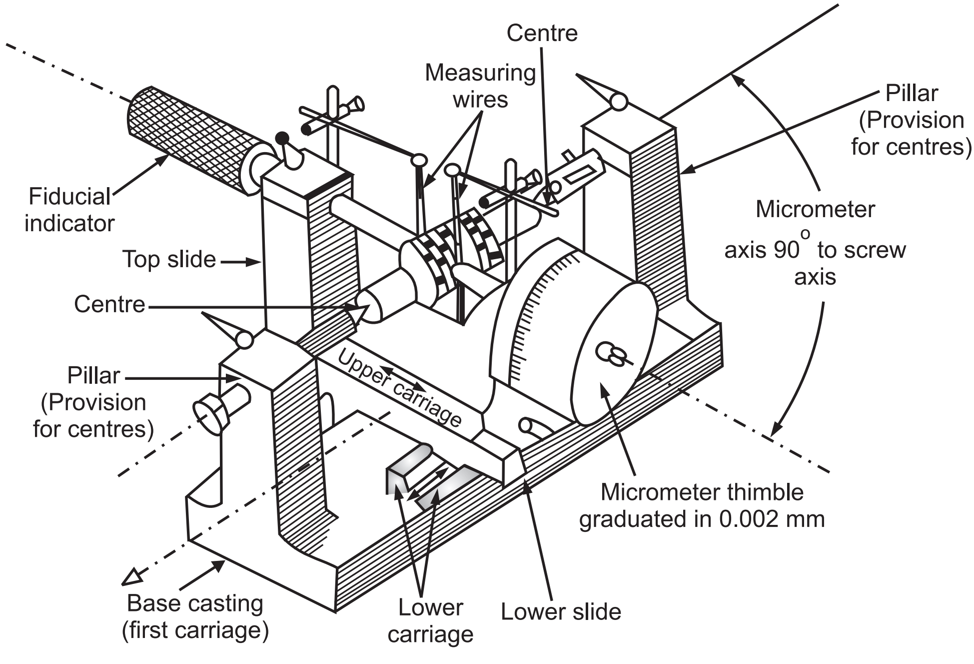


Fig. 5.4: Understanding view of floating carriage dial micrometer

Principle of Working:

- Threaded workpiece to be inspected is held between two centres, supported on two pillars of base.
- The distance between the two centres can be adjusted according to the length of threaded workpiece.
- After inserting the threaded workpiece between the centres, the lower carriage is moved or adjusted for correct positioning.

- Then, the anvil of micrometer and fixed anvil of fiducial indicator are adjusted in such a way that, they make point contact with the threaded screw, and fiducial indicator shows zero position.
- Now, it is obvious that, the axes of fiducial indicator and micrometer head spindle is same and perpendicular to line of two centres. Now, reading is obtained from the cylindrical scale provided on micrometer thimble.
- The fiducial indicator is specially designed and has only one index line, against which, its pointer is always to be set (i.e. zero position or set point). This ensures constant measuring pressure for all readings.
- In case of measurement of effective diameter, two supports are provided above the micrometer carriage for supporting the wires, V-pieces etc.

Note : 'The students are advised to draw fig. 5.4 in the examination.'

5.6 APPLICATIONS OF FLOATING CARRIAGE DIAL MICROMETER

(S-10)

(i) Measurement of pitch.
(ii) Measurement of external diameter.
(iii) Measurement of internal diameter.
(iv) Measurement of an angle.
(v) Measurement of effective diameter.

5.7 MEASUREMENT OF MAJOR DIAMETER OF EXTERNAL THREAD

QUESTION

1. How major diameter is measured using floating carriage micrometer ? **(W-09, 11; S-14, 15)**

Machine used: Floating carriage diameter measuring machine.

Construction:

- It consists of a sturdy cast iron base, having pillars.
- Two accurately aligned and adjustable centres are mounted on the pillars of base.
- In short, the machine comprises of three units,
  (a) A base casting carries a pair of accurately mounted and aligned centers, on which, the threaded workpiece is mounted i.e. first carriage.
  (b) Second carriage (known as lower carriage) is mounted at exactly 90°. This lower carriage is capable to move parallel to thread axis.
  (c) Third carriage (known as upper carriage) is mounted on the lower carriage. It is capable to move at 90° to the thread axis due to provision of V-ball slides.
- Upper carriage has micrometer anvil at one end. Micrometer has a thimble with graduated cylindrical scale, which can be read upto 0.002 mm. On another end, a fiducial indicator with a fixed anvil is used, so as, to perform all measurements at same measuring (contact) pressure.
- Both, micrometer thimble and fiducial indicator have special exchangeable anvils made to suit the form of thread.

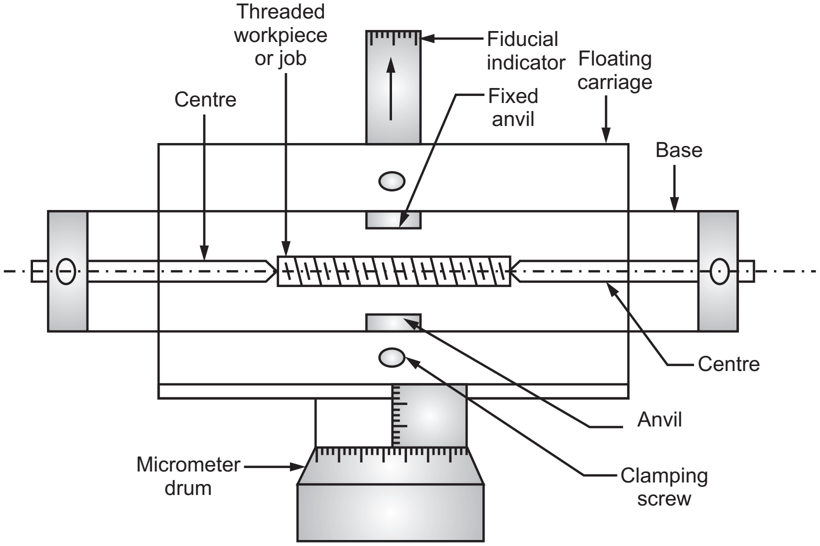


Fig. 5.5: Floating carriage diameter measuring machine

Working:

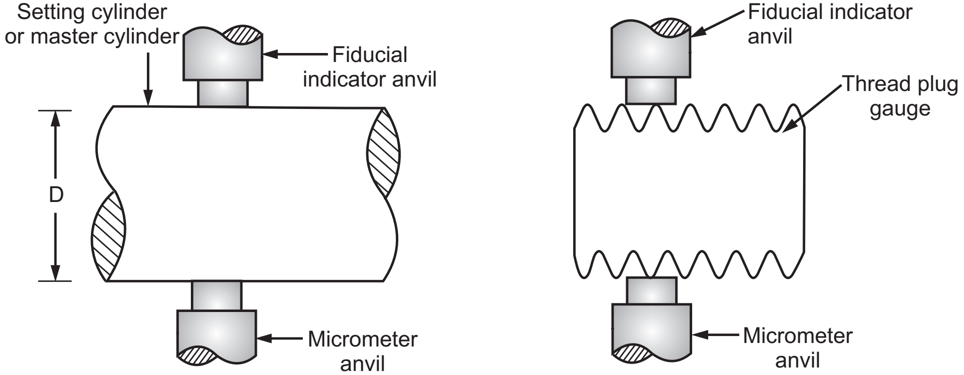
- For measurement, a calibrated setting cylinder having approximately same diameter as the major diameter of thread to be measured is used as setting standard.
- The setting cylinder is inserted in between two centres, supported on pillars of base carriage.
- With the fixed anvil of fiducial indicator showing zero position or set value, the anvil of micrometer is moved and in such a way that, both anvils (fixed anvil of fiducial indicator and moving anvil with micrometer) make point contact with the calibrated setting cylinder. Now, the reading of setting
- Now, the cylinder is replaced by thread plug gauge or threaded workpiece and again the same procedure (explained above for setting cylinder) is carried out and second reading of micrometer is taken for same reading of fiducial indicator.
- If D = Diameter of setting cylinder.

  R_1 = Reading of micrometer on Setting cylinder.

  R_2 = Reading of micrometer on threaded workpiece.

  Then,

  Major diameter = $D + (R_2 - R_1)$



(a) Reading 'R_1' is taken **(b) Reading 'R_2' is taken**

Fig. 5.6: Measurement of major diameter

The measurement is taken at two or three positions to determine the amount of taper (if any) along the length of screw and error of quality about thread axis.

5.8 MEASUREMENT OF MINOR DIAMETER OF EXTERNAL THREAD

Machine used: Floating carriage diameter measuring machine.

Construction:

- It consists of a sturdy cast iron base, having pillars.
- Two accurately aligned and adjustable centres are mounted on the pillars of base.
- In short, the machine comprises of three units,
  - (a) A base casting carries a pair of accurately mounted and aligned centers, on which, the threaded workpiece is mounted i.e. first carriage.
  - (b) Second carriage known as lower carriage is mounted at exactly 90°. This lower carriage is capable to move parallel to thread axis.
  - (c) Third carriage known as upper carriage is mounted on the lower carriage. It is capable to move at 90° to the thread axis due to provision of V-ball slides.
- Upper carriage has micrometer anvil at one end. Micrometer has a thimble with graduated cylindrical scales which can be read upto 0.002 mm. On another end, a fiducial indicator with a fixed anvil is used, so as, to perform all measurements at same measuring (contact) pressure.
- Both, micrometer thimble and fiducial indicator have special exchangeable anvils made to suit the form of thread.

Working:

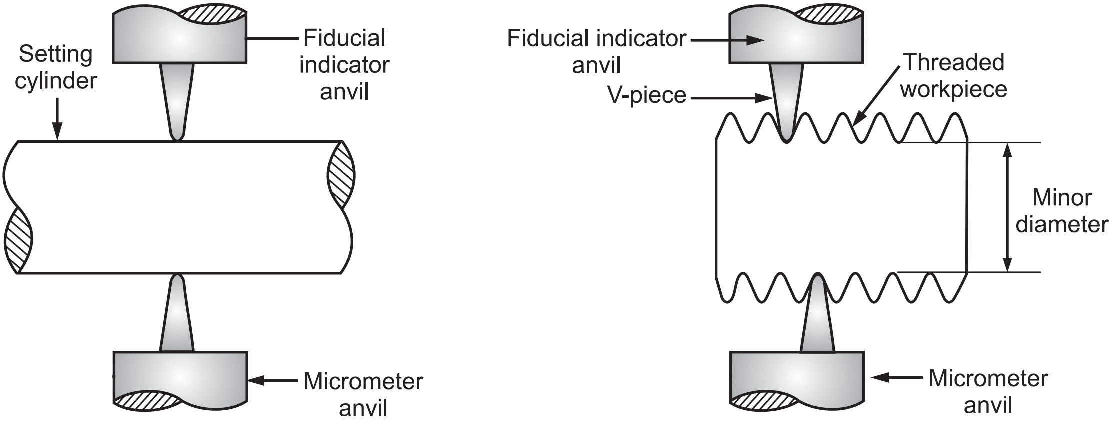
- For measurement, a calibrated setting cylinder having approximately same diameter as the minor diameter of threaded screw to be measured is used as setting standard.
- The setting cylinder is inserted in between two centres, supported on end pillars of base carriage.
- With the fixed anvil of fiducial indicator showing zero position or set value, the anvil of micrometer is moved and adjusted in such a way that, both anvils (i.e. fixed anvil of fiducial indicator and moving anvil with micrometer) make point contact with the calibrated setting cylinder. Now, the micrometer reading is taken (R_1).
- Now, the calibrated setting cylinder is replaced by threaded workpiece. Same procedure (as explained for setting cylinder) is carried out to get micrometer reading for the same reading of fiducial indicator.
- During measurement of minor diameter, the flat anvils of micrometer and fiducial indicator are unable to make the grooves. Therefore, small V-pieces are attached to the ends of both anvils. These V-pieces are available in various sizes. Included angle of V-piece should be less than thread angle, so that, V-pieces can be easily probe to the root of thread.
- If D = Diameter of setting cylinder.

  R_1 = Reading of micrometer on calibrated setting cylinder.

  R_2 = Reading of micrometer on threaded workpiece.

Then,

Minor diameter = D + $(R_2 - R_1)$



(a) Reading 'R_1' is taken **(b) Reading 'R_2' is taken**

Fig. 5.7: Measurement of minor diameter

5.9 MEASUREMENT OF EFFECTIVE DIAMETER OF EXTERNAL THREAD USING TWO WIRE METHOD (W-16; S-17)

QUESTIONS

1. Define effective diameter of screw threads. Explain two wire method of measuring effective diameter of screw plug gauge on floating carriage measuring machine. **(W-08; S-12)**
2. Explain in brief, the two wire method for thread measurement. **(W-10, 14; S-13)**

Machine Used: Floating carriage diameter measuring machine.

Construction:

- It consists of a sturdy cast iron base, having pillars.
- Two accurately aligned and adjustable centres are mounted on the pillars of base.
- In short, the machine comprises of three units,
  (a) A base casting carries a pair of accurately mounted and aligned centers, on which, the threaded workpiece is mounted i.e. first carriage.
  (b) Second carriage known as lower carriage is mounted at exactly 90°. This lower carriage is capable to move parallel to thread axis.
  (c) Third carriage known as upper carriage is mounted on the lower carriage. It is capable to move at 90° to the thread axis due to provision of V-ball slides.
- Upper carriage has micrometer anvil at one end. Micrometer has a thimble with graduated cylindrical scales which can be read upto 0.002 mm. On another end, a fiducial indicator with a fixed anvil is used, so as, to perform all measurements at same measuring (contact) pressure.
- Both, micrometer thimble and fiducial indicator have special exchangeable anvils made to suit the form of thread.

Working:

- For measurement, threaded workpiece is inserted in between two centres supported on end pillars of base carriage.

- Two wires or rods of identical diameters are placed between the flanks of thread.
- These wires are made up of hardened steel with high accurate smooth surface finish.
- With the anvil of fiducial indicator showing set value or zero position, the micrometer anvil is moved and adjusted in such a way that both anvil (i.e. fixed anvil of fiducial indicator and moving anvil of micrometer) make point contact over the wires inserted in the grooves.
- Now, the reading of micrometer is taken. The value obtained is the diameter measured (M) over the wires.
- Therefore, dimension under wires (T) can be calculated using,

  $$T = M - 2d$$

  where, d is the known diameter of wire.
- Let 'E' be the value of effective diameter to be measured. It can be calculated from the following formula:

  $$E = T + P$$

  where, value of 'P' is added to diameter under wires (T) to get effective diameter (E). Value of P depends upon diameter of wires used and pitch of threaded work-piece.
- Value of 'P' can be derived from the geometry of figure, if developed (given in next subarticle).
- It is given by, $P = 0.866\ p - d$

  where, p = pitch of thread

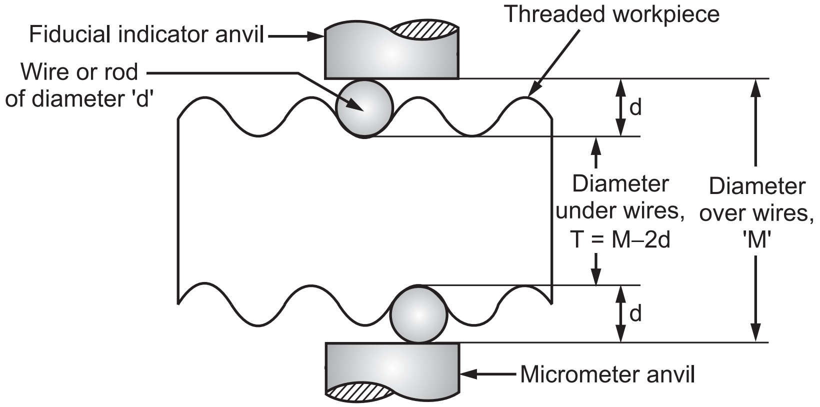


Fig. 5.8: Measurement of effective diameter using two wire method

5.9.1 Derivation of 'P' in Terms of Pitch (p) and Wire Diameter (d)

- From the previous article, we have measured, effective diameter of screw thread by relation, E = T + P.

- The value of P depends upon diameter of wire used and pitch of thread 'p'. Using the geometry developed as shown in Fig. 5.9, we see that,

$$HF = \frac{P}{2}$$

$$P = 2 \times HF$$

where, HF is the distance to be added due to one wire inserted on one side. For second wire inserted to other end, again one value of HF is added. Thus,

$$P = 2 \times HF$$

- If threaded or included angle is taken as '2θ'.

then θ = Half the included angle

(i) To calculate the value of distance 'HF':

Let us consider right angle triangle Δ GBO,

$$\sin\theta = \frac{OB}{OG}$$

$$\frac{1}{\sin\theta} = \frac{OG}{OB}$$

$$\therefore \quad \operatorname{cosec}\theta = \frac{OG}{OB}$$

$$\therefore \quad OG = OB \times \operatorname{cosec}\theta$$

$$\therefore \quad OG = \frac{d}{2} \cdot \operatorname{cosec}\theta \qquad \left[\because \ OB = \text{Radius of wire} = \frac{d}{2}\right] \ldots (5.1)$$

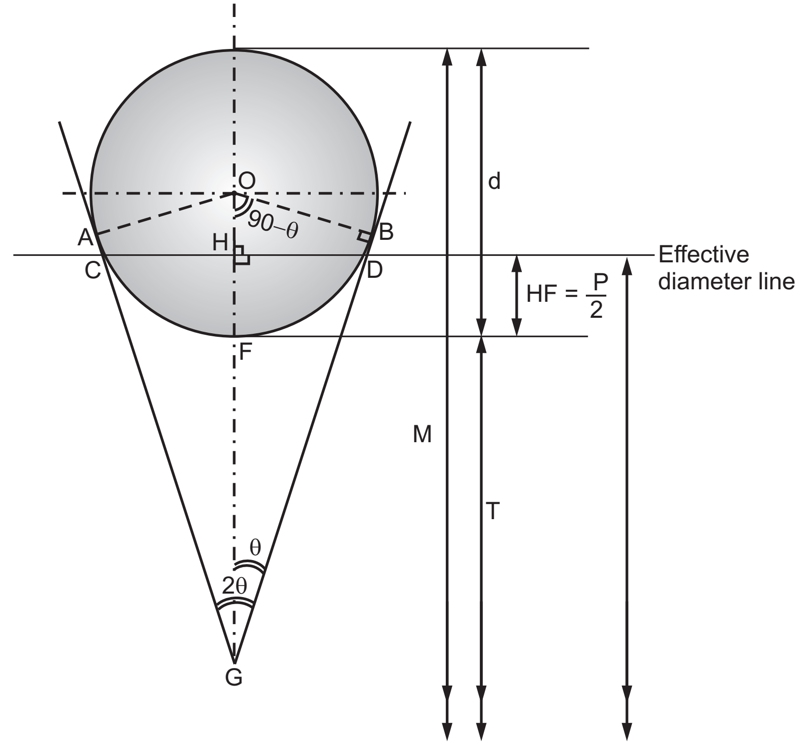


Fig. 5.9: Geometry developed to find 'P'

(ii) To calculate the value of line 'GH': Let us consider Δ GHO to calculate the distances of line GF, we can write,

$$GF = OG - OF$$

$$GF = \frac{d}{2} \text{cosec}\,\theta - \frac{d}{2} \qquad \text{[From equation (5.1)]}$$

$$= \frac{d}{2} (\text{cosec}\,\theta - 1) \qquad \dots (5.2)$$

We have, $$\tan\theta = \frac{HD}{GH}$$

$$\therefore \quad \frac{1}{\tan\theta} = \frac{GH}{HD}$$

$$\therefore \quad GH = HD \cdot \cot\theta \qquad \left[\because \cot\theta = \frac{1}{\tan\theta}\right] \dots (5.3)$$

(iii) To calculate the value of line 'HD':

By geometry, we have,

$$HD = \frac{1}{2} \times CD$$

$$\therefore \quad HD = \frac{1}{2} \times \frac{p}{2} \qquad [\because \text{ CD lies on effective diameter line,}$$

$$= \frac{p}{4} \qquad \text{it is equal to half of pitch of screw} = \frac{p}{2}\,]$$

Put this value of HD in equation (5.3), where, GH = HD · cot θ

$$GH = \frac{p}{4} \cdot \cot\theta \qquad \dots (5.4)$$

Also, we can write distance 'HF' as

$$HF = GH - GF$$

$$HF = \frac{p}{4} \cot\theta - \frac{d}{2} (\text{cosec}\,\theta - 1) \qquad \left[\begin{array}{c}\text{From equations (5.2)} \\ \text{and (5.4)}\end{array}\right]$$

We get, $$P = 2 \times HF = 2 \times \left\{\frac{p}{4} \cot\theta - \frac{d}{2} (\text{cosec}\,\theta - 1)\right\}$$

$$\therefore \quad P = \frac{p}{2} \cdot \cot\theta - d\,(\text{cosec}\,\theta - 1) \qquad \dots (5.5)$$

For Metric screw threads, we have, θ = Half included angle = $\frac{60°}{2}$ = 30°

$\therefore$ By putting θ = 30° in equation (5.5), we get,

$$P = \frac{p}{2} \cot(30°) - d\,[\text{cosec}\,(30°) - 1]$$

$$\therefore \quad \mathbf{P = 0.866\,p - d}$$

Thus, effective diameter of screw (E) can be calculated by adding value 'P' to dimension under wires (d) measured by micrometer of floating carriage measuring machine, E = T + P.

5.10 MEASUREMENT OF THE EFFECTIVE DIAMETER OF SCREW PLUG GAUGE USING 'THREE WIRE METHOD'

QUESTION

1. State principle of three wire method. Where it is used? **(S.Q.P.)**

Machine used: Floating carriage diameter measuring machine.

Construction:

- It consists of a sturdy cast iron base, having pillars.
- Two accurately aligned and adjustable centres are mounted on the pillars of base.
- In short, the machine comprises of three units,
  (a) A base casting carries a pair of accurately mounted and aligned centers, on which, the threaded workpiece is mounted i.e. first carriage.
  (b) Second carriage known as lower carriage is mounted at exactly 90°. This lower carriage is capable to move parallel to thread axis.
  (c) Third carriage known as upper carriage is mounted on the lower carriage. It is capable to move at 90° to the thread axis due to provision of V-ball slides.
- Upper carriage has micrometer anvil at one end. Micrometer has a thimble with graduated cylindrical scale, which can be read upto 0.002 mm. On another end, a fiducial indicator with a fixed anvil is used, so as, to perform all measurements at same measuring (contact) pressure.
- Both, micrometer thimble and fiducial indicator have special exchangeable anvils made to suit the form of thread.

Working:

- For measurement, threaded workpiece is inserted in between two centres, supported on end pillars of base carriage.
- Three wires or rods of identical diameters are placed between the flanks of thread, one on one side and two on other side.
- With the fixed anvil of fiducial indicator showing zero position or any set value, moving anvil of micrometer is moved in such a way that, both anvils make point contact with wires inserted between flanks. Micrometer reading is noted at this position.
- This method ensures the alignment of micrometer anvil parallel to axis of thread.
- Micrometer reading gives the measured dimension over the wires, denoted by M. To calculate the effective diameter of screw, we use,
- E = Effective Diameter = T + P

  where, M = Measured dimension over wires
  d = Diameter of wire
  P = A value depending upon diameter of wire and pitch of thread
  T = Dimension under wires = M – 2d
- Value 'P' is added to the diameter under wires (T) to give effective diameter (E), which can be derived in the same manner, as we have seen in previous article, while using two wire method.

  It is given by, $P = 0.866\, p - d$
  where, p = Pitch of threaded screw, and
  d = Diameter of wire

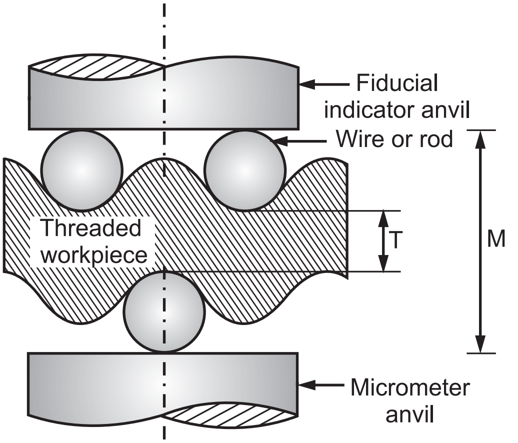


Fig. 5.10: Measurement of effective diameter using three wire method

5.11 BEST SIZE WIRE

QUESTION

1. What is 'best size of wire' ? State the expression for the same, indicating meaning of each term. **(W-14)**

- Best size wire is a wire of such diameter, that, it makes contact with the flanks of a thread on the effective diameter line or pitch line.
- While making measurements of effective diameter by two or three wire method, if best size wire is used, any error in the measurement occurring due to error in the thread form or thread angle can be minimized.

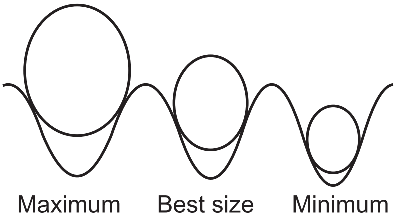


Fig. 5.11: Selection of best wire for effective diameter measurement

- Refer the figure 5.10, where OB is perpendicular to the flank of thread, and it is equal to radius of wire used. If 2θ is threaded angle, then $\angle$ OGB = $\frac{2\theta}{2} = \theta$.

  Let d_b be the best size wire diameter.

$$\therefore \quad d_b = 2 \times r_b$$

$$= 2 \times OB \qquad \text{... (i)}$$

To calculate the value of OB, consider right angled triangle Δ OHB,

$$\therefore \quad \sin(\angle BOA) = \frac{HB}{OB}$$

$$\text{or} \quad \sin(90 - \theta) = \frac{HB}{OB}$$

$$\therefore \quad OB = \frac{HB}{\sin(90 - \theta)} = \frac{HB}{\cos\theta}$$

$$\therefore \quad OB = HB \sec(\theta) \qquad \ldots (5.6)$$

To calculate the value of HB, take reference of geometry drawn in Fig. 5.12.

As HB lies on the pitch line, we can say that, HB is 1/4th of pitch of thread.

$$\therefore \quad HB = \frac{p}{4} \qquad [\because \text{ Pitch of thread} = p]$$

As

$$r_b = OB = HB \sec\theta$$

$$r_b = OB = \frac{p}{4} \sec\theta \qquad \ldots (5.7)$$

$$\therefore \text{ Diameter of best size wire,} \quad d_b = 2.r$$

$$\therefore \quad d_b = 2 \times \left(\frac{p}{4} \sec\theta\right) \qquad [\text{From equation (5.7)}]$$

$$\therefore \quad d_b = \frac{p}{2} \sec\theta$$

Therefore, the measurement of screw thread can be made accurate by using the wire having diameter d_b as calculated by above formula, where values of p and θ are known to us before measurement.

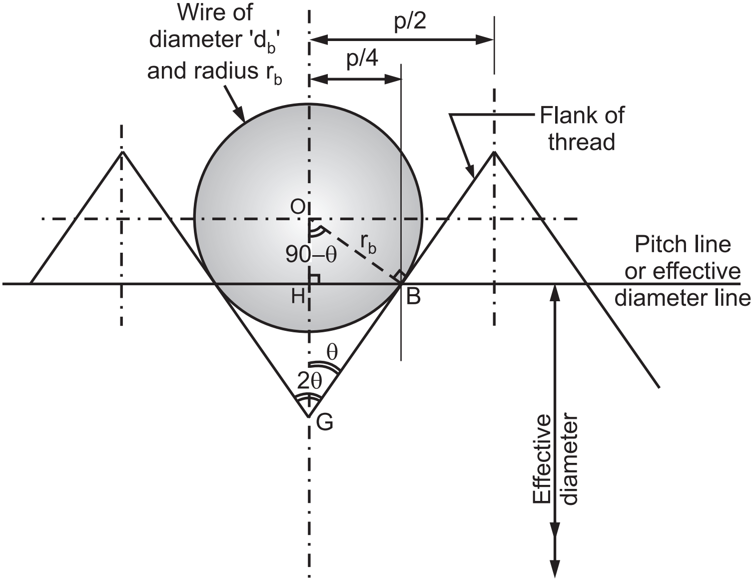


Fig. 5.12: Best size wire geometry

5.12 MEASUREMENT OF PITCH OF EXTERNAL THREAD

- Errors in the pitch of a nut or bolt have a serious effect on the accuracy of fit produced. The effect of pitch error on the effective diameter is approximately double, that is to say, if a bolt has a pitch error of 0.01 mm, then the actual effective diameter shows an error twice this value, i.e. 0.02 mm.
- Generally, two methods are used for the measurement of pitch and pitch errors:
  (a) Optical projection, and
  (b) Pitch measuring machine.

5.13 PITCH MEASUREMENT USING OPTICAL PROJECTION
OR
TOOL MAKER'S MICROSCOPE

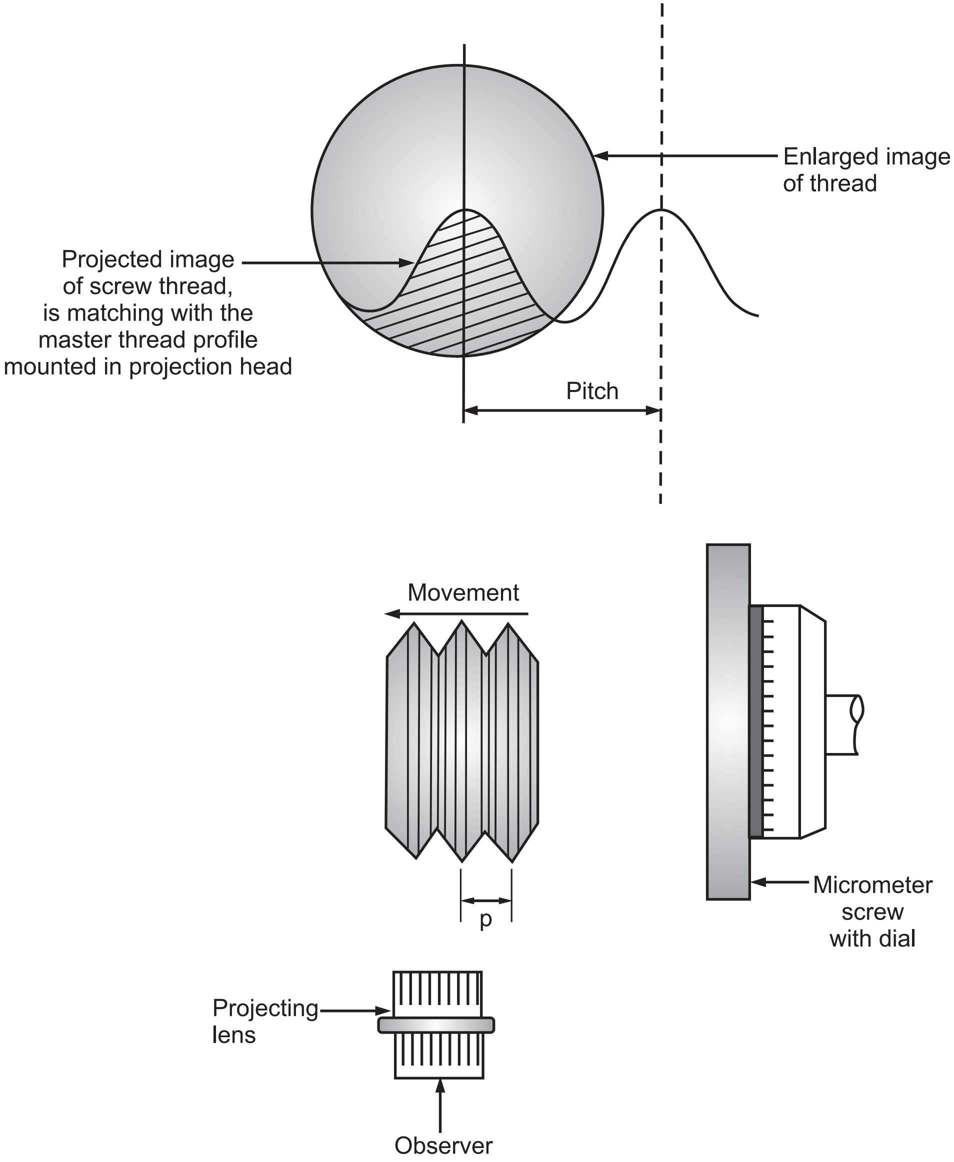


Fig. 5.13: Pitch measurement using optical projection

- A tool maker's microscope working on the principle of optical projection technique is used.
- The threaded screw is set between the centers on the microscope table. It is ensured that, the table is rotated by an angular amount, equivalent to the helix angle of the thread.
- A standard or master thread profile is mounted in the projection head. The screw thread can be mounted between the centres under the objective. Now the table is

moved in the longitudinal direction parallel to screw axis, until the magnified image of the next thread matches the master profile, and the final reading of longitudinal micrometer is taken.

- A sharp image of thread is projected on the screen to match with a motor thread profile mounted in the projection head, and initial reading is taken from the micrometer indexing dial, which controls table movement.
- It is also possible to check or measure both, depth of thread and flank angle, using this principle of optical projection.

5.14 PITCH MEASURING MACHINE (S-17)

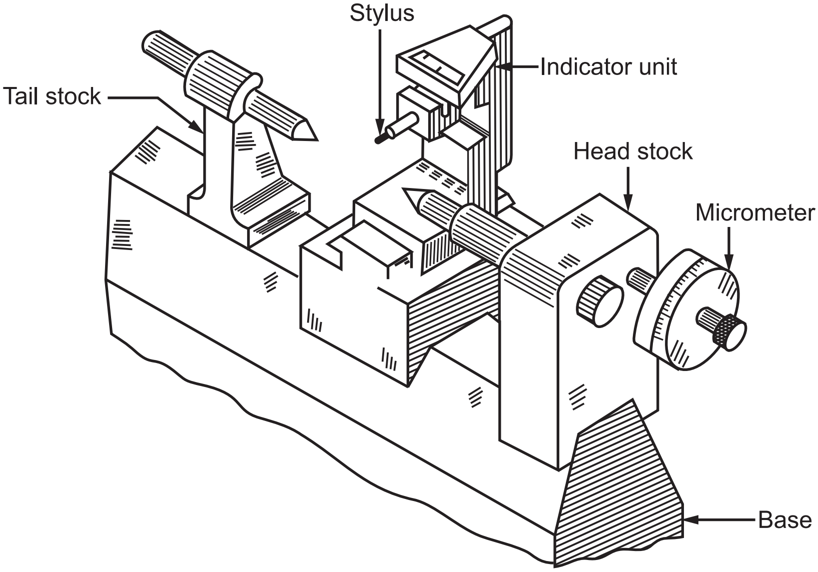
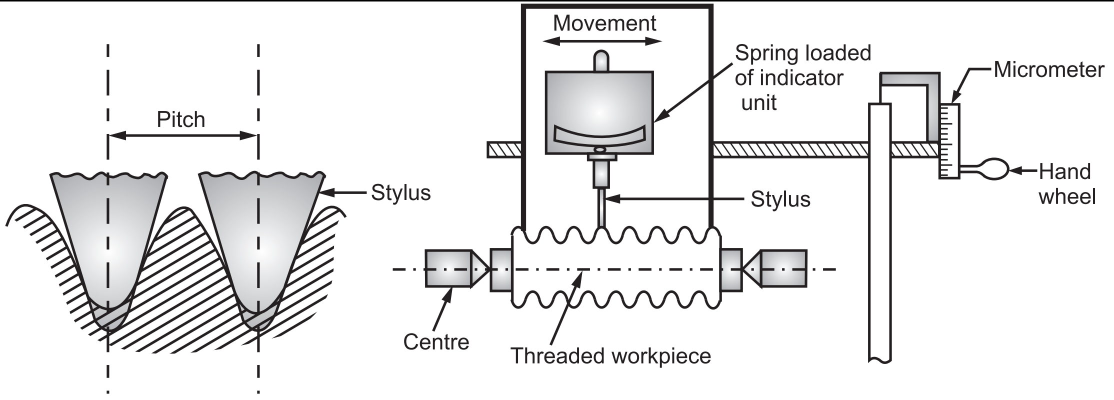


Fig. 5.14: Pitch measuring machine [3D view]

- Pitch measuring machine is used to measure the pitch error of individual threads accurately.
- The stylus of indicator unit is set in groove of thread, such that, indicator unit shows zero reading. Indicator unit is carried on a slide mounted on balls, so that, it can move along the thread axis.
- It employs various stylus points to suit the different forms and profiles of screw threads, which are to be checked. The screw under measurement is held stationary between centers on the machine, located at headstock and tailstock.
- The slide is actuated by means of a micrometer. When the micrometer spindle is rotated, the indicator unit along with its stylus resting in groove will move parallel to thread axis.
- During movement of indicator unit from one groove of thread to another groove of adjacent thread, the stylus will move in and out of each successive thread. When the stylus is moving over the flanks due to micrometer rotation, the indicator unit will show variations in reading.
- As soon as, the stylus tests in the groove of adjacent thread, the indicator unit should show zero reading.

- Micrometer reading is taken during this travel of indicator, unit along with stylus.
- The micrometer reading is taken each time, when stylus moves from groove of one thread to groove of next thread. If there are variations in the readings show the pitch error of each thread of the screw.
- Special graduated discs are provided to fit the micrometer to suit all pitches.
- The small handwheel below the micrometer screw serves the purpose of moving the indicator with its stylus in contact with each thread profile along the length of threaded screw. The total travel of the micrometer is 25 mm. This method is able to read the smallest pitch errors of order 0.002 mm.



(a) Position of stylus at roots of two adjacent threads **(b) Pitch measuring machine**

Fig. 5.15: Pitch measurement method

5.15 MEASUREMENT OF MAJOR DIAMETER OF INTERNAL THREAD (S-17)

- Instrument used: Thread comparator with ball ended stylus of radius less than radius of root of thread to be measured.

Construction:

- Here, one stylus is attached to floating head. The floating head is always kept in contact with plunger of dial indicator using pressure exterted by a spring constrained in the floating gauge.
- For different thread forms and dimensions, large range of styli are available.

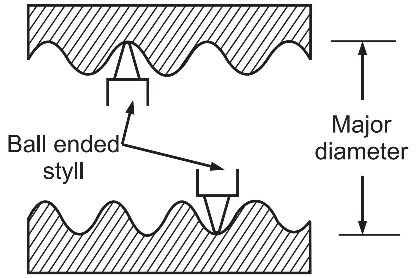


Fig. 5.16: Measurement of major diameter of an internal thread

Working:

- For measurement, a calibrated setting cylinder having approximately same diameter equal to major diameter of internal thread is used, as standard.
- Initially, instrument is set on this setting cylinder and corresponding reading of the dial indicator is noted.
- Now, floating head gauge mounted in comparator is retracted to engage the tips of the stylii at the root of the screw thread under spring pressure and reading of the dial indicator is noted.
- If D = Diameter of cylindrical reference standard or calibrated setting cylinder,

  R_1 = Reading of dial indicator on setting cylinder,

  R_2 = Reading of dial indicator on screw thread,

  Then, Major diameter of internal thread = $D + (R_2 - R_1)$

5.16 MEASUREMENT OF MINOR DIAMETER OF INTERNAL THREADS

- To measure minor diameter, two commonly used methods are,
  - (i) Using taper parallels
  - (ii) By using rollers and slip gauges.

5.16.1 Using Taper Parallels

- If screw diameter is less than 200 mm, taper parallels are used in conjunction or combination with micrometer.
- The taper parallels are pairs of wedges having parallel outer edges.
- The diameter across their outer edges can be changed by sliding them over each other as shown in Fig. 5.17.

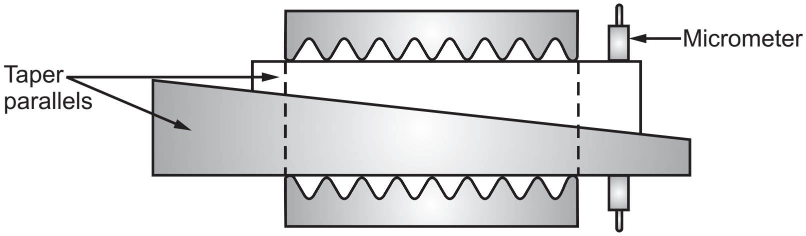


Fig. 5.17: Measurement of minor diameter of internal threads

- The taper parallels are inserted inside the thread and adjusted until, they are perfectly aligned with each other and a firm contact is established with the minor diameter.
- The diameter over the outer edges is measured with a micrometer, which is referred as **minor diameter**.

5.16.2 By Rollers and Slip Gauges

- If the mirror diameter of internal threads to be measured is large, then combination of two rollers of known diameter and a set of slip gauges is used to span the inner diameter (minor diameter).

  ∴ Minor diameter = $d_1 + d_2 + l$

  where, d_1 and d_2 are the roller diameters and length '*l*' is the length of slip gauge set.

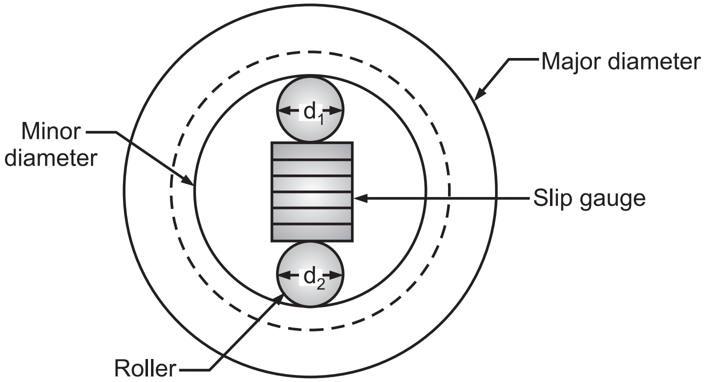


Fig. 5.18: Measurement of internal diameter with slip gauges and rollers

5.17 SCREW THREAD ERRORS

QUESTION

1. List the types of errors in threads. **(W-11; S-15)** **(S.T.P.-I)**

- During measurements of various parameters of screw thread, it is necessary to find out errors occurred in five basic elements like, major diameter, minor diameter, effective diameter pitch and angle of thread. These errors may lead to rejection of threads.
- Thread errors in each element are discussed in brief as under:

(a) Major and minor diameter errors:

- Error in the major diameter or minor diameter may cause interference between mating threads or a reduction in the flank contact. This may cause component weakness.
- Errors in major diameters or minor diameters of threads are generally caused by error in machine setting.

(b) Effective diameter error:

- Errors in effective diameter will cause either 'interference between the thread flanks' or 'general slackness of fit between mating parts'.
- If the major and minor diameters are at the maximum limit, and the effective diameter is below the minimum limit, then the thread will be thin on an external screw and thick on an internal screw.

(c) Pitch errors: (S-17)

QUESTION

1. Name the types of pitch errors. Sketch and label each type. (S-16)

- Pitch errors in threads include Periodic, Drunkenness, Progressive and Erratic or Irregular types of errors. These errors in pitch are described with sketches in the next article.
- Pitch error occurs, if the ratio of the linear velocity of tools and angular velocity of the work is not maintained constant and correct.
- The total Pitch Error in overall length of the thread is called as *Cumulative Pitch Error*.

5.17.1 Periodic Errors

- When the errors vary in magnitude and are recurring at regular intervals, (during measurement from thread to thread along the screw), they are known as periodic errors. This error repeats itself at regular intervals along the successive portions of thread being longer or shorter than the mean, i.e. the error is cyclic in nature.
- Pitch of the thread is not uniform and pitch increases to a maximum, then reduces through the normal value to a minimum value and so on.
- Therefore, the graph between the cumulative pitch error and length of threads of this error is sinusoidal.
- Please note that, cumulative pitch error means total pitch error in overall length of thread.
- Such errors are caused due to,

  (a) Non-uniform tool work velocity ratio.

  (b) Lack of lead screw squareness, while cutting the thread.

  (c) Eccentric mounting of the gears between the lead screw and spindle.

  (d) Error in the teeth of gears between the lead screw and spindle.

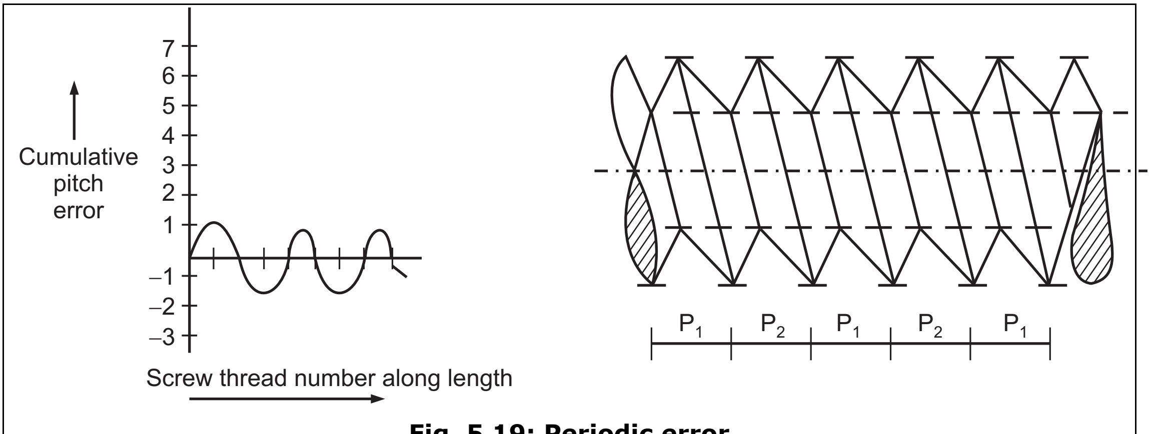


Fig. 5.19: Periodic error

5.17.2 Drunkenness or Drunken Thread Error

- Drunkenness is also known as drunken-thread. It is a particular case of periodic error.
- In this error, the pitch measured parallel to the thread axis will always be correct; the only error is that, the thread is not cut to true helix.
- If the screw thread be regarded as an inclined plane wound round a cylinder, and, if the thread be unwound from the cylinder (i.e. development of the thread be taken), then the drunkenness can be visualized. The profile of helix will be a curve in the case of drunken thread and not a straight line as shown in Fig. 5.20. Here, α is the helix angle.
- **Drunken thread** is the one having erratic pitch. Eratic pitch does not follow regular pattern. Here, the advance of helix is irregular in one complete revolution of the thread. The pitch of the thread is not uniform. It varies in magnitude over equal fractions of each turn of the thread, i.e. it is repeated once per turn of thread in drunken thread error.
- It is very difficult to determine such errors and moreover, they do not have any adverse effect on the working, unless the thread has a very large size.
- They may arise due to disturbances in the machine set up, variation in the cutting properties of material etc.

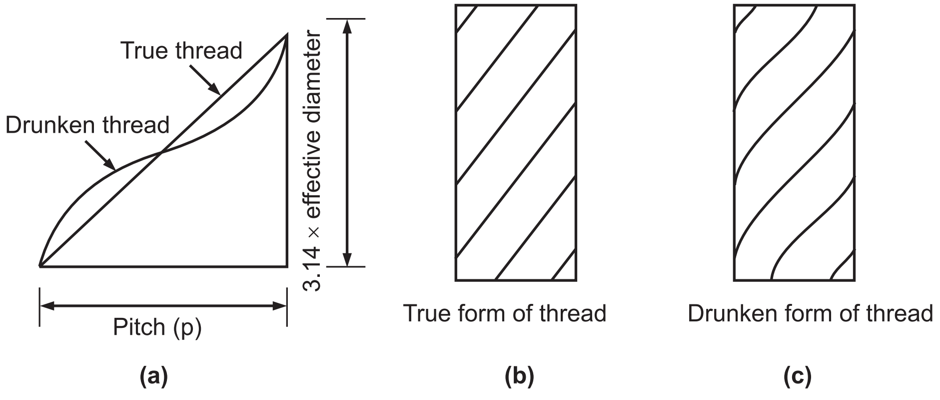


Fig. 5.20: Drunken thread error

5.17.3 Progressive Pitch Error

- Progressive pitch error is uniform and gradual, but giving pitch value either a greater or smaller than nominal value as shown in Fig. 5.18.
- The cumulative pitch error increases with the increase in length of thread.

- Such errors are caused due to,
  (a) Incorrect ratio of the linear velocity of tool and angular velocity of the work.
  (b) Pitch error in the lead screw of lathe or other machine used for thread cutting.
  (c) Use of incorrect gear or gear train between work and lead screw.

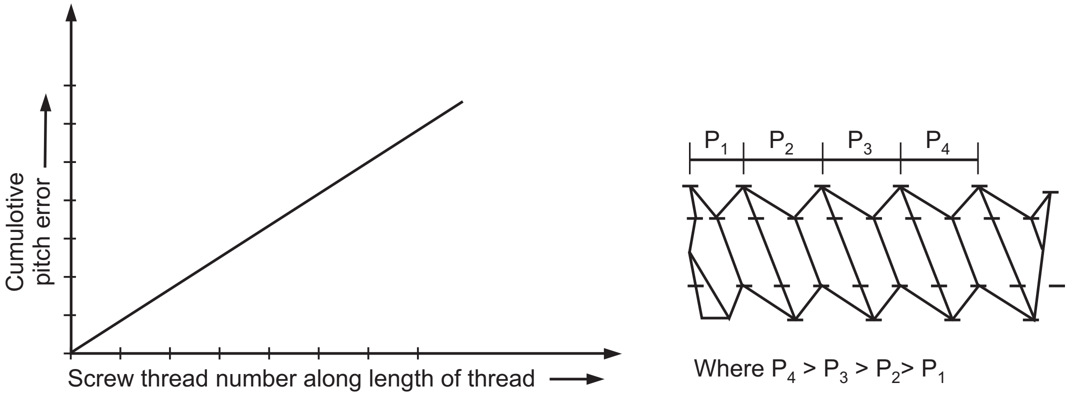


Fig. 5.21: Progressive error (A straight line graph)

5.17.4 Irregular or Erratic Errors

- When the pitch varies irregularly along the length of thread, the types of errors found are called as **irregular erratic pitch error.**
- They are caused due to,
  (a) Machine faults.
  (b) Disturbances in the machining set up,
  (c) Variations in the cutting properties of the material etc.
  (d) Irregular cutting action resulting from non-uniformity in the material of the screw.
- They have no specific characteristic and specific causes.
- Therefore, they cause eratic and irregular variations in pitch over different length of thread.

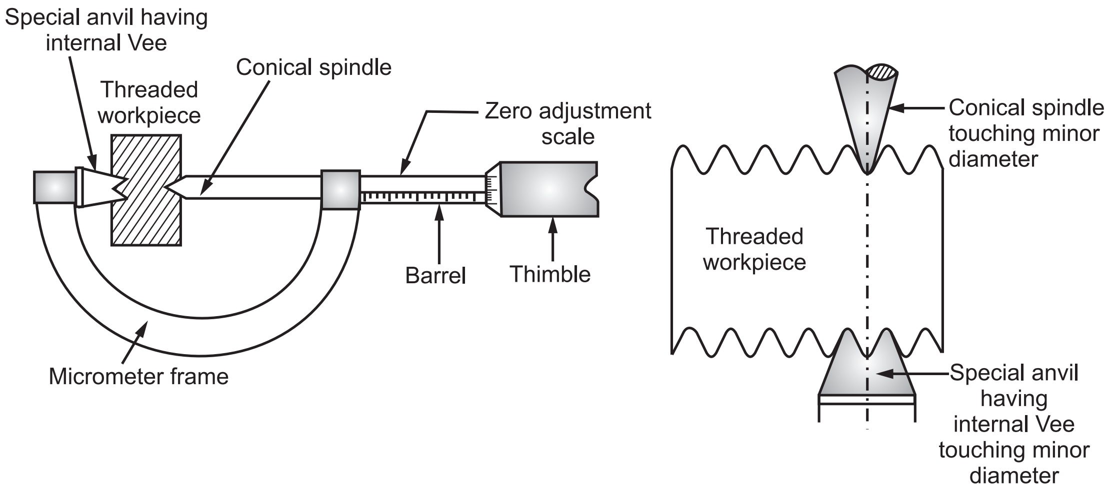
5.18 SCREW THREAD MICROMETER (S-17) (W-16)

QUESTIONS

1. Draw a neat labeled sketch of screw thread micrometer and state its principle of working. (S.Q.P.)
2. Draw a neat labelled sketch of screw thread micrometer. State its principle of working. (W-15)

- Screw thread micrometer is used to find pitch diameter of screw threads accurately.

- The screw thread micrometer is just like an ordinary micrometer, with the difference, that it is equipped with a special anvil and a conical spindle.
- The special anvil has an internal vee, which fits over the thread, as shown in Fig. 5.22 (a).
- Thus, internal vee of special anvil can adjust itself to the helix angle of the thread being measured.
- The conical spindle of micrometer can be slide backward or forward, so that, it can touch the root of a screw thread from one side.
- In screw thread micrometer, it is essential that, "when the conical spindle is brought into contact with internal vee of anvil, the micrometer should read zero".
- The end of spindle is pointed to 60° cone, and the internal vee of special anvil is also grooved for 60°, provided that threaded angle of screw thread is 60° (Metric threads). Therefore, angle of vee of special anvil and the angle of conical spindle, both corresponds to threaded angle of thread profile. Internal vee of special anvil is free to rotate so as to adjust itself to the helix angle of thread being measured.
- Sharp tip of spindle is grounded off.
- In other words, the internal value of special anvil is allowed to swivel in the micrometer frame.
- If correctly adjusted, this micrometer gives effective diameter.



(a) Screw thread micrometer **(b) Use of screw thread micrometer**

Fig. 5.22

- Different sets of anvils are provided for different type of threads and the contact point of micrometers are so designed that, some allowance for thread clearance is always made.

- In this method, actually the measurement is done between the major diameter on one side (special anvil) and minor diameter on other side (conical spindle). Therefore, the *actually measured dimension* is an **effective diameter**.
- When the threaded workpiece is held between the screw thread micrometer anvils, then the micrometer reading directly gives the value of effective diameter of screw threads.

Important Points

- Screw threads are used for measuring devices such as micrometers. Also, they find wide applications for fastening purpose.
- *Floating diameter measuring machines* are used to find minor diameter, major diameter and effective diameter of screw thread.
- The most commonly used screw threads are 'V' threads, Whitworth threads, Square threads, Acme threads, etc.
- *Best size wire* is a wire of such diameter that it makes contact with the flanks of a thread on the effective diameter or pitch line.
- *The errors* found in screw threads are major diameter error, minor diameter error, effective diameter error, pitch errors.
- Pitch errors include periodic, drunken, progressive and irregular errors.

Theory Questions for Practice

1. What are the types of screw threads?
2. Enlist the various instruments used to measure characteristics of screw thread.
3. Explain the working principle of floating carriage dial micrometer. Enlist its applications.
4. How will you measure major diameter of an external thread?
5. How will you measure minor diameter of an external thread?
6. How will you measure effective diameter of an external thread?
7. Explain the process of measurement of the effective diameter of screw plug gauge using three wire method.
8. What is best size wire?
9. How will you measure pitch of external thread?
10. Write a short note on "Pitch measuring machine".
11. What are the screw thread errors? Explain in brief.

MSBTE Questions and Answers (As per G - Scheme)

Winter 2014

1. Explain in brief, two wire method for thread measurement. **(4M)**

Ans. Refer Article 5.9.

2. What is 'best size of wire' ? State the expression for the same, indicating meaning of each term. **(4M)**

Ans. Refer Article 5.11.

Summer 2015

1. How major diameter is measured using floating carriage micrometer? **(4M)**

Ans. Refer Article 5.7.

2. List the types of errors in screw thread. **(4M)**

Ans. Refer Article 5.17.

Winter 2015

1. Draw a neat labelled sketch of screw thread micrometer. State its principle of working. **(4M)**

Ans. Refer Article 5.22.

2. Explain in brief, two wire method for thread measurement. **(4M)**

Ans. Refer Article 5.9.

Summer 2016

1. Write the procedure for measuring 'Effective diameter' of screw thread, by using 'two-wire method'. **(4M)**

Ans. Refer Article 5.9.

2. Name the types of pitch errors. Sketch and label each type. **(4M)**

Ans. Refer Articles 5.17 (c), 5.18, 5.19, 5.20, 5.21.

Winter 2016

1. Write the procedure for measuring ‘effective diameter of screw thread’ using two wire method. **(6M)**

Ans. Refer Article 5.9.

2. List the types of errors in threads and explain. **(4M)**

Ans. Refer Articles 5.17.

Summer 2017

1. Explain the two wire method of effective diameter measurement with neat sketch. **(4M)**

Ans. Refer Article 5.9.

2. Explain the measurement of the pitch for internal and external thread with neat sketch. **(4M)**

Ans. Refer Articles 5.14 and 5.15.

3. State and explain the various pitch errors in the screw threads. **(4M)**

Ans. Refer Articles 5.17.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 6

GEAR METROLOGY

About This Chapter ...

This chapter has a weightage of 4 marks and assigned duration is 3 hours. We learn about involute tooth profile, tooth thickness measurement by constant chord method and gear tooth vernier and errors in gears.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	08 Marks	S-09	08 Marks
W-09	08 Marks	S-10	08 Marks
W-10	04 Marks	S-11	04 Marks
W-11	12 Marks	S-12	08 Marks
W-12	08 Marks	S-13	08 Marks
W-13	08 Marks	S-14	04 Marks
W-14	14 Marks	S-15	14 Marks
W-15	12 Marks	S-16	12 Marks
W-16	12 Marks	S-17	12 Marks

6.1 INTRODUCTION TO GEARS

Gears drives are the most commonly used devices for the transmission of mechanical power. Due to positive drive in action, they are preferably used in clutch, belt and chain drives. The transmission efficiency of gears is about 99%; however, to obtain high efficiency, the gears produced must have high degree of accuracy of dimensions and geometric form.

6.2 GEAR TERMINOLOGY

Fig. 6.1 (a) and (b) shows all the important terms used in connection with the measurement or calculation of elements involved in the spur gears.

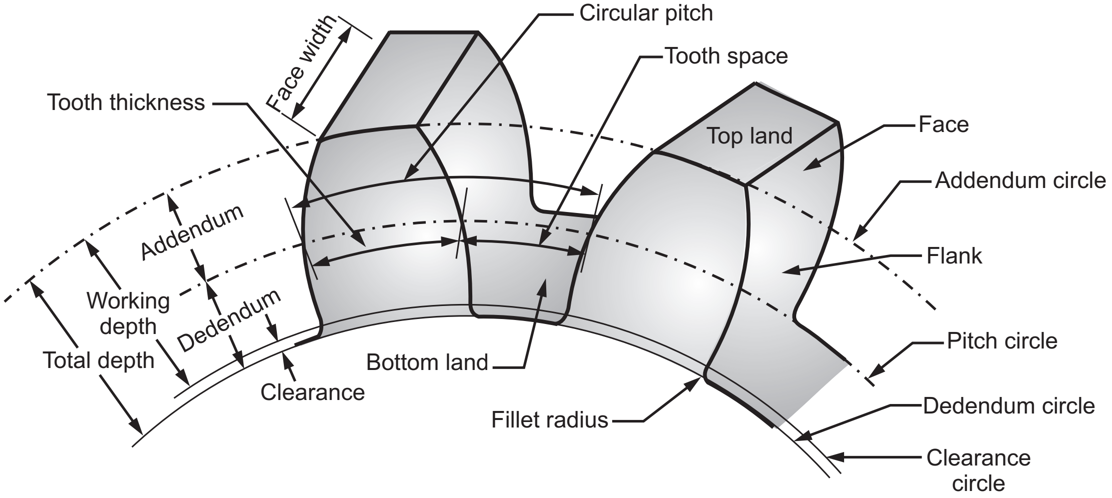


Fig. 6.1: (a) Various terms related to gear tooth

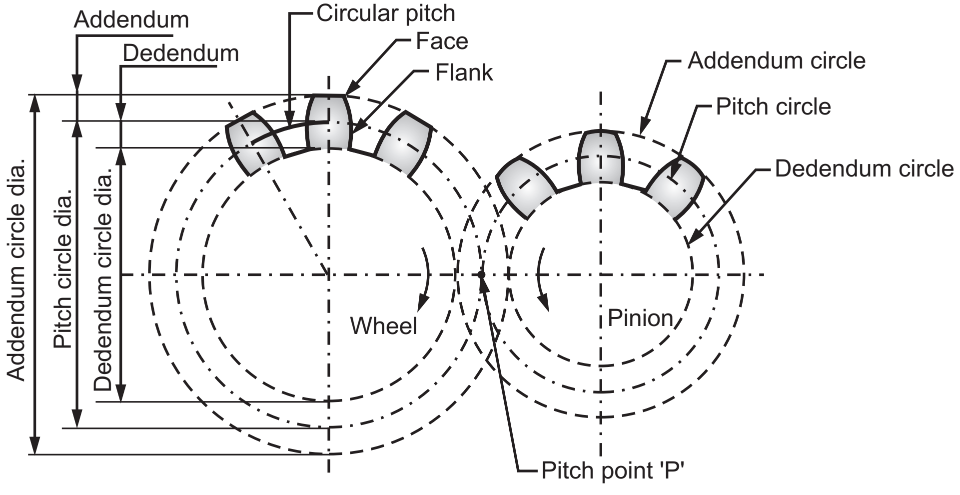


Fig. 6.1 (b): Externally meshed spur gear drive

(1) Base Circle: It is the circle, from which, involute form is generated. Only base circle on a gear is fixed and remains unchanged.

(2) Addendum Circle:

- It is the circle corresponding to maximum diameter of gear profile, upto which, the involute form is generated.

- It can be expressed as the circle passing through the top of gear teeth. It is concentric with the pitch circle.

(3) Dedendum Circle:

- It is the circle corresponding to minimum diameter of gear profile.
- It can be expressed as the circle passing through the bottom of gear teeth. It is concentric with the pitch circle.

(4) Pitch Circle:

- Pitch circle is an imaginary circle on gear, which pure rolling action produces the same motion as the actual gear.

(5) Pitch Circle Diameter:

- Diameter of pitch circle is called as pitch circle diameter. Generally the size of gear is specified by PCD. It is denoted by D.

(6) Module: It is defined as 'the ratio of pitch circle diameter to number of teeth'.

i.e, $$m = \frac{D}{N}$$

(7) Circular Pitch: It is defined as 'the distance measured along the pitch circle from a point on one tooth to a corresponding point on adjacent tooth'. Thus, the circular pitch denoted by 'p_c' for a spur gear of pitch circle diameter 'D' having the number of teeth 'N' can be expressed by,

$$p_c = \frac{\pi D}{N} = \pi \cdot m \qquad \text{(where, m is the module)}$$

(8) Addendum: It is defined as 'the radial distance from pitch circle to the top of tooth' (i.e. upto addendum circle). Its value is equal to module i.e. 'm'.

(9) Dedendum: It is defined as 'the radial distance from pitch circle to the bottom of tooth space'.

$$\text{Dedendum} = 1.157 \text{ m}$$

(10) Total Depth: It is the sum of addendum and dedendum.

Mathematically, Total depth = Addendum + Dedendum

$$= m + 1.57 \text{ m} = 2.57 \text{ m}$$

(11) Clearance: It is defined as 'the radial distance from top of tooth to bottom of a mating tooth space, when teeth are symmetrically engaged'.

(12) Working Depth: It is defined as 'the greatest depth to which a tooth of one gear extends into tooth space of its mating gear'. In short, it is given by,

$$\text{Working depth} = (\text{Addendum} + \text{Dedendum}) - \text{Clearance}$$

(13) Diametral Pitch: It is defined as 'the number of teeth of the gear per mm of pitch circle diameter'. Thus, the Diametral pitch denoted by 'p_d' is given by,

$$p_d = \frac{\text{Number of teeth}}{\text{Pitch circle diameter}} = \frac{N}{D} = \frac{1}{m} \qquad \left[\because\ m = \frac{D}{N}\right]$$

Thus, it is a reciprocal of module.

(14) Pitch Point: It is defined as 'the point of contact between pitch circles of two gears in mesh'.

(15) Blank Diameter: The diameter of a gear blank is equal to the pitch circle diameter plus twice addendum.

(16) Tooth Thickness: It is defined as, "actual distance (arc) measured along the pitch circle *'from its intercept with one flank to its intercept with the other flank'* of the same tooth". It can also be defined as, *'the arc between two flanks of same tooth'*. Tooth thickness is half of the circular pitch.

6.3 INVOLUTE TOOTH PROFILE

QUESTION

1. Explain how will you check the involute profile of a spur gear using involute measuring machine? **(S-10)**

Involute:

- Therefore, involute is the profile that would be produced, if a string is wounded tightly around a cylinder and then unwounded from the cylinder, keeping the string tight.
- An involute of a circle is defined as 'a plane curve generated/traced by a point on a tangent, which rolls on the circle without slipping'.
- Involute can also be defined as 'a path described by a point or locus of a point on a piece of string, when unwounded from a stationary cylinder'.
- Consider a string, which is initially wrapped around a circle, whose one end is fixed at some point Q on a base circle and other end (free end) P coincides with point R on the base circle.
- When the string is unwrapped/unwounded from free end upto point Q_1, then the free end will trace the curve PP_1.
- Similarly, when the string is unwrapped upto point Q_2, the free end will trace the curve further as PP_1P_2.
- This curve PP_1P_2 is called as *involute curve*.

- Now, draw a tangent 'TT' to point P_2. We observe that,
  - (a) Tangent TT to involute is perpendicular.
  - (b) Arc distance PQ_1 = Straight Distance P_1Q_1.
  - (c) Arc distance PQ_2 = Straight Distance P_2Q_2.
- Please note that, shape of involute depends upon the diameter of base circle, from which, it is generated.

Bass circle diameter $\propto$ Curvature of Involute

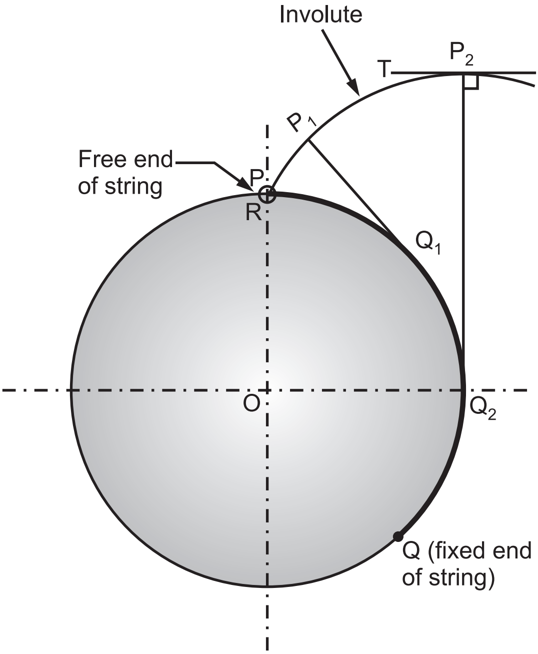


Fig. 6.2: Involute tooth profile

Involute Measuring Machine:

Working Principle:

It works on the principle that, 'if a straight edge is rolled around the base circle without slipping, the stylus of dial gauge would traverse a true involute'.

Procedure:

(a) The gear to be tested is mounted on a mandrel.

(b) A circular disc of same size as that of base circle diameter is also mounted on same mandrel, but at certain distance apart (behind the tooth profile).

(c) Involute measuring machine consists of a straight edge, which can be rolled around the circular disc.

(d) The arrangement is such that when the straight edge is rolling the circular disc without slipping, at the same, the measuring tip or stylus of dial gauge is in contact with the tooth profile. Refer Fig. 6.3 showing a tooth profile, to which, a dial indicator is attached.

(e) When the gear and the circular disc are given rotary motion, the straight edge moves over the circular disc without slip and the stylus/plunger of dial gauge moves under the tooth profile.

(f) If the tooth profile has some deviation from the true profile, then plunger of dial gauge will indicate the same. But, if the dial gauge indicator does not show any reading than zero, the tooth profile under measurement is said to be correct.

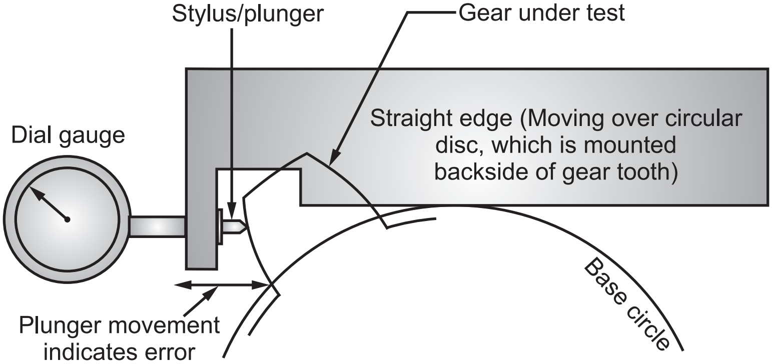


Fig 6.3

6.4 INSPECTION OF GEARS

- Inspection of gear is mainly of two types: (i) Analytical, and (ii) Functional.

(i) Analytical Inspection:

1. It is necessary to differentiate between the measurements of the individual parameters of gear, i.e. their individual errors.
2. To measure all the individual gear parameters and their errors, it is necessary to know the errors of gear cutting machine so that the gear production can be controlled and the machine can be reset.
3. The analytical inspection of gear involves in determination of following teeth elements, in which, the errors are caused due to manufacturing errors.

   (a) Tooth Profile, (b) Spacing, (c) Pitch, (d) Runout or eccentricity or concentricity, (e) Thickness of tooth, (f) Lead, (g) Backlash.
4. But, this inspection method is not preferred in industries, because it is very slow, complex and tedious method.
5. Also, the discrete error values of pitch, tooth profile etc. cannot give overall assessment regarding the accuracy of gear. It is not easy to assess accurately how these elemental values combine in practice to give a prescribed performance under operational conditions.

(ii) Functional Inspection:

1. The overall accuracy of gear may be determined by checking the combined effect of errors in the individual parameters.
2. It consists of carrying out the running test of a gear with master gear, to determine composite errors in vibrations, noise variations in action of gear.

- If a pair of gears work together at the designed speed and designed load with little noise, the gears are are considered to be satisfactory.
- If the drive is noisy, then analytical inspection is carried out to check individual elements.
- The various functional tests are rolling gear test, Parkinson gear test etc.

6.5 TOOTH THICKNESS MEASUREMENT (S-08)

- Tooth Thickness is defined as 'the arc distance measured along the pitch circle from its intercept with one flank to its intercept with other flank of same tooth'.

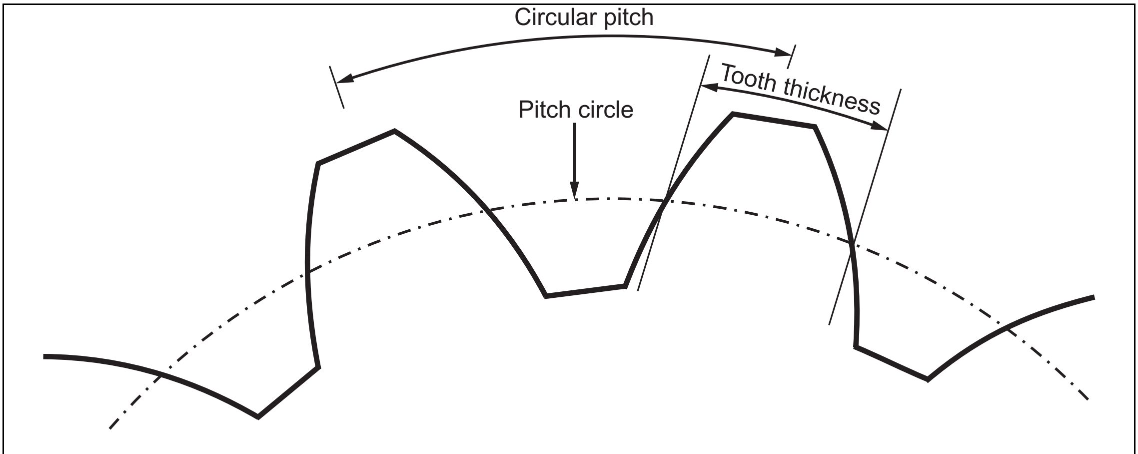


Fig. 6.4: Tooth thickness measurement

- With reference to Fig. 6.4, we find that,

$$\text{Tooth thickness} = \text{Arc distance AB} = \text{Arc distance BC}$$

$$\text{Circular pitch} = \text{Arc distance AB} + \text{Arc distance BC}$$

$$p_c = 2 \times \text{Arc distance AB}$$

$$p_c = 2 \times \text{Tooth thickness}$$

$$\text{Tooth thickness} = \frac{1}{2} p_c$$

- Following are the methods of measuring tooth thickness:
  - (a) Measurement of tooth thickness by gear tooth vernier caliper using chordal thickness method.
  - (b) Constant Chord Method.
  - (c) Base Tangent Method.
  - (d) Measurement over pins and balls.

6.5.1 Measurement of Tooth Thickness by Gear Tooth Vernier Caliper using Chordal Thickness Method

QUESTIONS

1. Describe with a neat sketch, the use of "Vernier gear tooth caliper" to measure the chordal thickness of gear tooth on the pitch circle. **(W-08)**
2. Explain the principle of measurement of tooth thickness by gear tooth vernier caliper. **(W-09, 11, 15; S-09,14, 17)**
3. Calculate the setting of a gear tooth vernier caliper for a straight spur having 30 teeth of module 5. **(S-11)**
4. Draw the neat sketch of gear tooth vernier caliper and write the procedure for measuring chordal tooth thickness. **(W-12, 14; S-15)**
5. Draw a neat labelled sketch of gear tooth vernier and name its different parts. **(S.T.P.-II)**
6. Explain the principle of measurement of a spur gear tooth thickness using a gear tooth vernier. State mathematical relations to compare chordal addendum and chordal tooth thickness. **(S-16)**

- Since tooth thickness is a length of arc, it cannot be measured directly. Therefore in most cases, it is sufficient to measure chordal thickness i.e. chord joining the intersection of tooth profile with pitch circle.
- To measure the chordal thickness, gear tooth vernier caliper is used.
- The gear tooth vernier caliper consists of two perpendicular vernier arms with vernier scale on each arm. One vernier arm (vertical) is used for setting the jaws at proper death 'd' from top of tooth, whereas, second arm (horizontal) is used for measuring tooth thickness.
- The caliper is so set that, it slides or resets on the top of gear tooth and lower ends of caliper jaws touch the flanks or sides of tooth at pitch circle.
- The reading on horizontal vernier scale gives the value of chordal thickness (w) reading on vertical vernier scale gives chordal addendum (d).
- These measured values by the gear tooth vernier caliper are compared with the theoretical values.

Theoretical values are calculated by using the following formula

$$w = N \cdot m \sin\left(\frac{90}{N}\right) \qquad \dots (1)$$

$$d = \frac{N \cdot m}{2}\left[1 + \frac{2}{N} - \cos\left(\frac{90}{N}\right)\right] \qquad \dots (2)$$

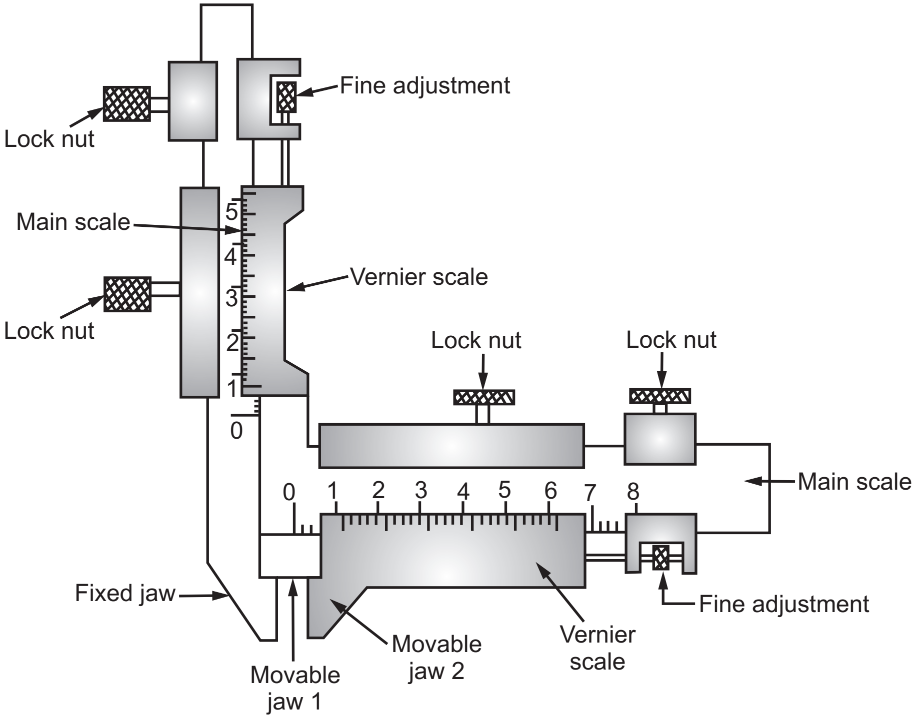


Fig. 6.5: Gear tooth vernier caliper

- Tooth thickness is specified by an arc distance AEB and 'w' is chord ADB and also distance 'd' is slightly greater than the addendum CE. Therefore 'w' is called as *chordal thickness* and 'd' is called *chordal addendum*.
- The above formulae of theoretical values can be derived in the following manner.

For Chordal Thickness:

We have, $w = AB = 2 \times AD = 2 \times AO \times \sin\theta \qquad \left[\because \sin\theta = \frac{AD}{AO}\right]$

$$= 2\,R \sin\theta \qquad \ldots (6.3)$$

Also, $\text{Angle } AOD = \theta = \frac{360}{4N}$

where, N is the number of teeth and OA = R = pitch circle radius.

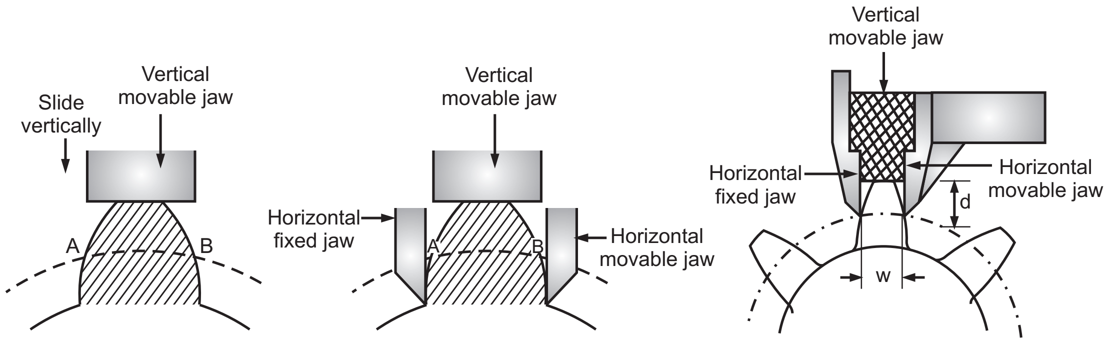
$\therefore$ Equation (6.3) is written as,

$$w = 2R \sin\left(\frac{360}{4N}\right) \qquad \ldots (6.4)$$

Also, $m = \frac{\text{P.C.D.}}{\text{No. of teeth}} = \frac{D}{N} = \frac{2R}{N}$ or $R = \frac{N.m}{2}$ or $2R = N.m$

Therefore, equation (6.2) is modified as,

$$w = N.m \sin\left(\frac{360}{4N}\right) \text{ or } w = N.m \sin\left(\frac{90}{N}\right) \qquad \ldots (6.5)$$



(i) (ii) (iii)

Fig. 6.6 (a): Use of Gear vernier caliper to measure chordal thickness and chordal addendum

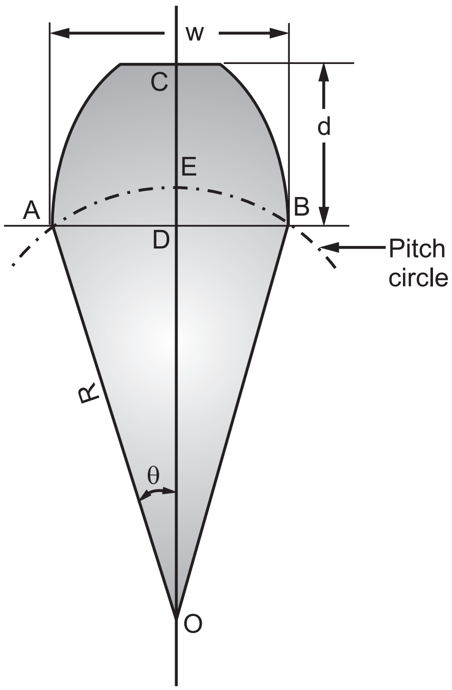


Fig. 6.6 (b): Geometry of gear tooth

Terms	Meaning
Curve AEB	Circular tooth thickness
Line ABD	Chordal tooth thickness
Line EC	Addendum
Line DC	Chordal addendum

For Chordal Addendum:

$$d = OC - OD \qquad \dots (6.6)$$

where, $OC = OE + CE \text{ (Addendum)} = R + m = \left[\frac{N.m}{2} + m\right] \qquad \left[\because R = \frac{N.m}{2}\right]$

Also, $\cos\theta = \frac{OD}{AO} = \frac{OD}{R}$;

$\therefore \qquad OD = R\cos\theta = \left[\frac{N.m}{2}\cos\left(\frac{90}{N}\right)\right] \qquad \left[\because \theta = \frac{90}{N}\right]$

$\left[\text{and } R = \frac{N \cdot m}{2}\right]$

Therefore, equation (6.6) is modified as,

$$d = \frac{N.m}{2} + m - \frac{N.m}{2}\cos\left(\frac{90}{N}\right)$$

$$= \frac{N.m}{2}\left[1 + \frac{2}{N} - \cos\left(\frac{90}{N}\right)\right] \qquad \dots (6.7)$$

6.5.1.1 Procedure to Calculate Theoretical Value of Chordal Thickness and Chordal Addendum

- If number of teeth = N = 30, and Module = 5 mm, then using equation (6.5), calculate theoretical value of chordal thickness as,

$$w = N \cdot m \sin\left(\frac{90}{N}\right)$$

$$= 30 \times 5 \times \sin\left(\frac{90}{30}\right)$$

$$= \mathbf{7.85\ mm}$$

- Similarly, using equation (6.5), we can calculate theoretical value of chordal addendum as,

$$d = \frac{N \cdot m}{2}\left[1 + \frac{2}{N} - \cos\left(\frac{90}{N}\right)\right]$$

$$= \frac{30 \times 5}{2} \times \left[1 + \frac{2}{30} - \cos\left(\frac{90}{30}\right)\right] \qquad [\because N = 30 \text{ and } m = 5]$$

$$\therefore \qquad d = \mathbf{5.102\ mm}$$

- These theoretical values are also called as required **setting** of gear tooth vernier caliper can be obtained. The above calculated theoretical values of chordal thickness and addendum are then compared with actually measured values by gear tooth vernier caliper, to find our error (if any).

6.5.1.2 Limitations/Demerits of Chordal Thickness Method

(a) The vernier scale itself is not reliable to accuracy closer than 0.05 mm.

(b) Measurement depends upon two vernier readings, each of which is a function of other.

(c) If measurement is made with an edge of measuring jaw, not its face, then it will lead to inaccurate measurement, again do not lead to accurate measurement.

(d) Separate calculations are required for gears having different number of teeth.

(e) Accuracy of using this method is limited to least count of vernier.

(f) As the measuring jaws are subjected to wear and tear due to continuous use, the scales of caliper are required to be calibrated on periodic basis for good accuracy.

6.5.2 Constant Chord Method

QUESTION

1. Explain constant chord method for measuring tooth thickness of gear. **(W-10)**
2. With neat sketch, explain measurement of tooth thickness by constant chord method. **(S.Q.P., W-15)**

- We have seen that, in gear tooth caliper method, both the chordal thickness and chordal addendum are dependent upon number of teeth. Now, if number of teeth on gears is different in a single set of gears to be measured, then number of teeth of every gear must be known to calculate the chordal thickness and chordal addendum.
- Thus, measurement of various parameters of different gears in a single set would involve separate calculations. Thus, the process becomes laborious and time consuming.
- Constant chord method eliminates these problems. Constant chord of a gear is measured, where the gear tooth flanks touch the flanks of basic rack.

Working Principle:

- Teeth of basic rack are straight and inclined to their pitch line at pressure angle (ϕ) as shown in Fig. 6.7. The gear tooth and rack are in contact in symmetrical position of all num at the point of contact. The distance AB remains constant. This distance 'AB' is referred as constant chord. Refer Fig. 6.7.
- If the gear relates and all teeth come in contact with the rack, the contact occurs only at point A and B. This, is the reason why, AB is called as constant chord.

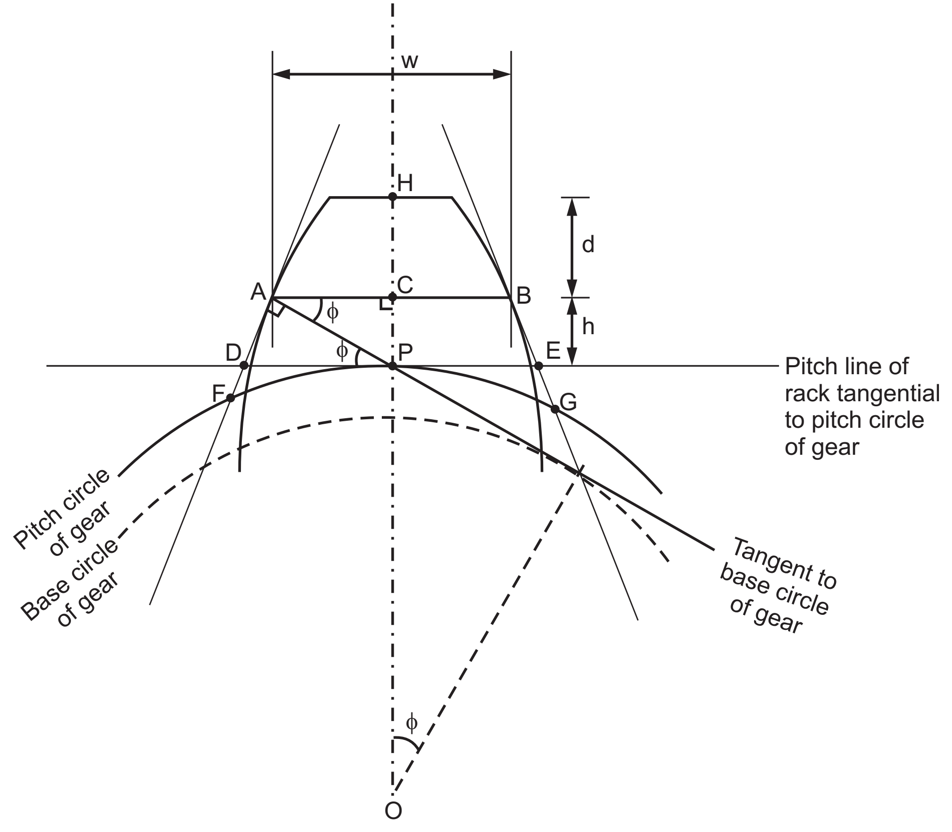


Fig. 6.7

- Also, we can see that 'd' is the vertical distance of chord 'AB' from top face of tooth. [Point 'H'].
- In constant chord method of tooth thickness measurement, it is essential that,

  (a) Pitch line of rack is tangent to pitch circle of gear

  (b) $\begin{bmatrix}\text{Tooth thickness of rack} \\ \text{measured along its pitch line}\end{bmatrix} = \begin{bmatrix}\text{Arc tooth thickness of gear tooth} \\ \text{measured along its pitch circle}\end{bmatrix}$

  ∴ Distance 'DE' = Arc distance 'FG'
- Constant chord 'AB' is measured, when the flanks of gear tooth touch the flanks of basic rack.
- **Definition of constant chord:** It is defined *as 'the chord joining those points located on opposite sides of faces of a gear tooth, which make, contact with the mating teeth of rack, when the pitch line of rack is tangent to pitch circle of gear'.*
- The values of distance AB ('w') and its depth (d) from top of tooth can be measured by suitable measuring instrument.
- These measured values are then compared and verified with their theoretical values.

- Theoretical values can be calculated by using following formulae,

  (a) Constant chord (AB) 'w' = $\frac{\pi}{2} \cdot m \cdot \cos^2\phi$

  (b) Depth, 'd' = $m \times \left[1 - \frac{\pi}{4} \cos\phi \sin\phi\right]$

  where, m = Module; and ϕ = Pressure angle.

Procedure to Evaluate Mathematical Formulae for calculating theoretical values of Constant Chord (AB) and Its Depth from Tip:

- Referring to the figure 6.7, we have $\angle$ CAP = ϕ i.e. pressure angle

(i) Calculation of constant chord, AB i.e. (w):

We can see, distance AB = w = 2 × AC ... (6.6)

Also, PD = PE = Arc distance PG

$$= \frac{1}{4} \times \text{Circular pitch}$$

$$\therefore \quad PD = \frac{1}{4} \times \left(\frac{\pi \times D}{N}\right)$$

$$\therefore \quad PD = \frac{1}{4} \times \pi \cdot m \qquad \left[\because \text{module, } m = \frac{\text{Pitch circle diameter}}{\text{Number of teeth}} = \frac{D}{N}\right]$$

Now consider ΔAPD,

$$\cos\phi = \frac{AP}{PD}$$

$$\therefore \quad AP = PD \cos\phi$$

$$\therefore \quad AP = \frac{1}{4} \cdot \pi \cdot m \cos\phi \qquad \text{... (6.7)}$$

Consider ΔACP,

$$\cos\phi = \frac{AC}{AP}$$

$$\therefore \quad AC = AP \cos\phi$$

$$AC = \left(\frac{1}{4} \cdot \pi \cdot m \cdot \cos\phi\right) \times \cos\phi \qquad \text{[From equation (6.7)]}$$

$$= \frac{\pi}{4} \cdot m \cdot \cos^2\phi$$

Put this value of AC in equation (6.6),

$$\therefore \quad w = 2 \times \frac{\pi}{4} \cdot m \cdot \cos^2\phi$$

$$\therefore \quad w = \frac{\pi}{2} \cdot m \cdot \cos^2\phi \qquad \text{... (6.8)}$$

(ii) Calculation of distance 'd':

We know, from ΔACP,

$$\sin\phi = \frac{CP}{AP}$$

$$\therefore \quad CP = AP \cdot \sin \phi$$

$$\therefore \quad CP = \frac{1}{4} \cdot \pi \cdot m \cos \phi \sin \phi \qquad \text{[From equation (6.7)]}$$

$$\therefore \quad CP = \frac{\pi}{4} \cdot m \cdot \cos \phi \sin \phi$$

Also, Distance, d = Addendum (PH) − Distance (CP)

$$= m - \frac{\pi}{4} \cdot m \cdot \cos \phi \cdot \sin \phi$$

$$= m \left[1 - \frac{\pi}{4} \cos \phi \sin \phi \right] \qquad \ldots (6.9)$$

6.5.2.1 Merits/Advantages of Constant Chord Method

1. Value of constant chord is same for all gears having any number of teeth of same module.
2. Less time consuming and convenient.

6.6 BASE TANGENT COMPARATOR METHOD / TANGENT MICROMETER

- Measurement of tooth thickness using the gear tooth vernier does not give very accurate
  - (i) the measurement depends upon two vernier readings, each of which, is a function of other and
  - (ii) the measurement is made the faces of its measuring jaws, which itself are the causes of inaccurate measurements.
  - (iii) comparatively more sensitive than chordal thickness method.
  - (iv) This method does not depend on number of teeth.
- These problems can be overcomed by measuring the span of selected (convenient) number of teeth. The span length is tangent to the base circle and therefore it is called as base tangent length.
- The base tangent method uses a single vernier caliper.
- The measuring instrument is known as base tangent comparator. It consists of two flanked anvils, one fixed and other moving.
- Moving anvil carries a micrometer having limited movement on either side of zero setting.

Procedure:

(a) Base tangent length (d) is calculated with the help of following formula,

$$d = N \cdot m \cos \phi \left[\tan \phi - \phi - \frac{\pi}{2N} + \frac{\pi S}{N} \right]$$

where,

N = Number of teeth

m = Module

S = Number of teeth between two anvils

ϕ = Pressure angle

- This theoretically calculated value of base tangent length (d) is then set in the tangent comparator using a suitable combination of slip gauges as shown in Fig. 6.8.
- This theoretically calculated value of base tangent length is set in between the anvils of comparator using a slip gauge combination.
- This becomes the standard for the comparator. Now, the gear span distance is checked practically with this tangent comparator and variation from the theoretical value can be read on micrometer dial provided on the device.

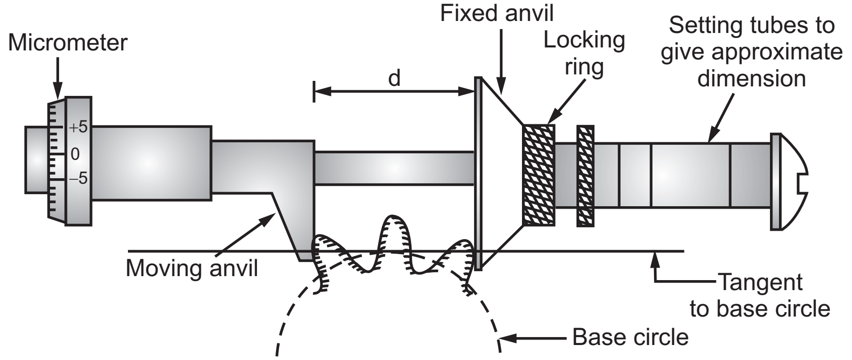


Fig. 6.8: Tangent micrometer/Gear tooth micrometer

6.6.1 Uses of Tangent Micrometer

- To compare thread parameter with standards.
- To measure the variation in the base tangent length (i.e. the line connecting the contact points of two different flanks placed same distance apart).
- For checking gear tooth parameters.

6.7 MASTER GEARS

- Master gears are made with sufficient accuracy, so that, they can be used as the basis for comparing the accuracy of gears under test.
- Most important purpose of master gear is to find out composite error in the gear under test.
- In case of gear rolling test, the master gear is close mesh with the gear under test. Both the gears are rotated by hand and deviations (if any) are not by a dial indicator attached to gear under test.
- Master gears are of two types,
  (i) Master Gear Type 'A' used for checking precision gears of accuracy grades upto 7 and
  (ii) Master Gear Type 'B' used for checking gears of accuracy grades from 8 to 12.

6.8 COMPOSITE METHOD OF GEAR CHECKING

- Composite testing of gears is used to measure the variation in centre to centre distance, when a gear under test is rotated in tight mesh with a master gear.

- Composite testing of gears, following two types of methods are adopted.
  - (i) Total composite variation.
  - (ii) Tooth to tooth composite variation.
- Composite method of gear checking has the advantage of determining all types of errors found in a gear under test.

Applications of Composite gear testing:

(i) It is specially preferred and suited for larger gears, as it ensures control over the tooth spacing.

(ii) It is much suitable for checking wornout gears.

6.9 PARKINSON GEAR TESTER

QUESTIONS

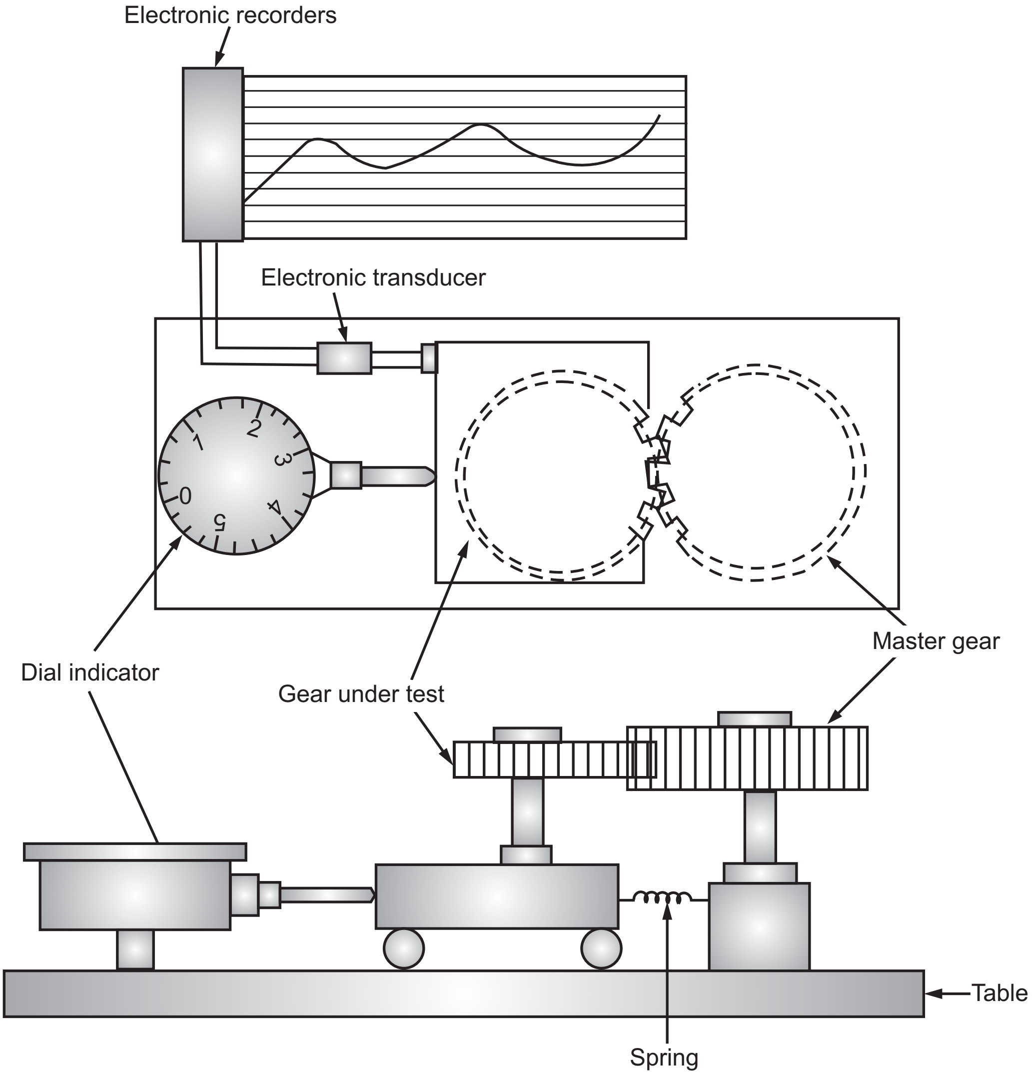
1. Describe with neat sketch, the working of "Parkinson Gear Tester". **(W-08,11, 16; S-12, 17)**
2. Draw labeled sketch of Parkinson gear tester. **(W-13)**
3. Explain Parkinson's Gear Tester'. **(W-14)**
4. Explain principle of measurement of Parkinson gear tester with a neat sketch. **(S-16)**

Principle:

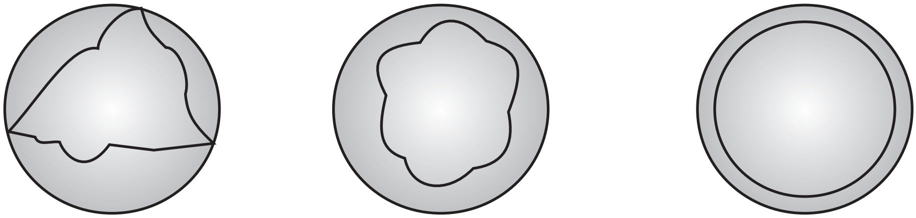
- Here, a standard or master gear is mounted on a fixed vertical spindle and the gear under test is mounted on another similar spindle, placed on a sliding carriage, and both the gears are maintained in mesh by spring pressure. A dial indicator is attached to the sliding carriage.
- When the gears are rotated, error (if any) in the gear under test will cause the gear to move away from the spindle of master gear movements of sliding carriage are observed by a dial indicator attached to it.
- If dial gauge indicator does not show any reading, it means that, the gear under test is manufactured as per the specifications. But, if variations are found in the dial gauge reading due to movements of sliding carriage, the gear under test is said to have certain irregularities. Sometimes, these variations can also be noted by a recorder in the form of waxed circular charts.

Working:

- Master gear is mounted on the right side spindle, which can be moved along the length of the table. This spindle can be clamped to any desired position.
- Gear under test is mounted on the left side, having a sliding carriage. A spring pressure is applied between the two carriages.
- Both the spindles are so adjusted that, their axial distance is equal to the desired gear centre.
- The dial indicator is in contact with the left end of sliding carriage and will determine any variations in the gear under test (For example: Errors in tooth form, pitch or concentricity of pitch line etc.
- Alternatively, a recorder in the form of waxed circular paper charts may be used as shown at top in the Fig. 6.9 (a). The movements of floating/sliding carriage. Fig. 6.9 (b) shows few typical charts recorded.



(a) Parkinson gear tester



Gear unsatisfactory **Gear moderate** **Gears fully satisfactory**

(b)

Fig. 6.9

Limitations of Parkinson's Gear Tester:

(a) Gears having diameter more than 400 mm cannot be tested.

(b) Minute movements of sliding carriage should be recorded, for which, sensitivity of recorder or dial indicator should be high.

(c) Errors are not differentiated or identified individually to know the type of error i.e. error in tooth thickness, pitch or concentricity of pitch line etc.

(d) This method is used for accepting or rejecting the gear, but not to find the causes in variations of gear.

(e) Measurements are dependent upon the form of master gear.

(f) Low movement in the movement of floating carriage and high sensitivity of sensing unit is important.

6.10 ROLLING GEAR TEST

QUESTION

1. Write the procedure of rolling gear test. **(S-12)**

- Composite errors such as errors in tooth form, pitch, concentricity of pitch line etc. can be checked by **rolling gear test**. This method is used to distinguish the two gears manufactured in two categories.

  (i) Acceptable, (ii) Rejectionable, before leading to assembly section.
- The system consists of two carriages (one fixed and other movable) mounted on a base.
- The fixed carriage is locked at one position. Master gear is mounted on the spindle of fixed carriage.
- The movable carriage is spring loaded and it is held towards the fixed carriage.
- Gear under test is mounted on the spindle of movable carriage, such that, master gear and gear under test, both are in mesh. A dial gauge indicator is made to rest against movable carriage.
- Now, the master gear and gear under test, in mesh, are rotated by hand and variations in the dial gauge readings are observed. If there is no variation seen in the dial gauge reading, then the gear under test is to be perfect. But, if variations in dial gauge readings are found and variations fall outside the permissible limits, then the gear is rejected.
- Only acceptable gears are sent for assembly, due to which, unnecessary expenses in assembly section can be saved.
- In addition to cost, great amount of trouble caused due to gears running with noise is avoided.

6.10.1 Advantages of Rolling Gear Test

(a) Most commonly used test under production conditions.

(b) Less time consuming.

(c) Accurate results.

(d) Composite error due to error in tooth form, pitch, concentricity of pitch line etc. can be determined.

6.11 SOURCES OF ERRORS IN MANUFACTURING GEAR

QUESTIONS

1. State and explain any four types of errors in gears. **(S-09, W-09)**
2. What are the sources of error in manufacturing gears? **(S-12)**

- The gears are manufactured by two methods:

  (i) Gear reproducing method and (ii) Gear generating method.

1. In gear reproducing method, a formed involute cutter is used to cut gear teeth. The various sources of errors are,
   (a) Errors in manufacture of cutter, i.e. incorrect profile of cutting tool.
   (b) Errors in positioning of cutter relative to gear blank.
   (c) Errors due to incorrect indexing of gear blank.

- In gear generating method, the cutting tool forms the profile of several teeth simultaneously during constant motion of tool and blank. The various sources of errors are,
  (a) Errors in manufacture of hob or cutting tool and gear blank.
  (b) Errors in positioning the hob or tool relative to work.
  (c) Errors in relative motion of tool and blank during cutting operation.

6.12 VARIOUS TYPES OF ERRORS IN GEARS

QUESTIONS

1. List the eight errors in gear tooth. **(W-13, 16)**
2. List down four types of errors in gear metrology. With suitable sketch, explain the measurement of any one. **(S-09, W-09, 11, 13, S.Q.P.)**
3. Explain various errors in gears. **(S-17)**

- Analytical inspection of gears is used for the measurement of following "teeth elements", in which, manufacturing errors may be present.
  (a) "Runout"
  (b) "Pitch" error
  (c) Error in "Profile"
  (d) Error in "Lead"
  (e) "Backlash"
  (f) "Tooth thickness" error
  (g) "Concentricity" error
  (h) "Alignment" error
  (i) "Axial runout"
  (j) "Cyclic error"
  (k) "Periodic error"

6.13 RUNOUT CHECKING

QUESTIONS

1. Explain the following errors in gears, (1) Backlash, (2) Runout. **(S-10)**
2. State and explain four types of errors in gears. **(S-09, 17; W-09, 11, 12)**

Runout:

- Runout is defined as *'the total variation of the distance between a surface of revolution and a reference surface measured perpendicular to the surface of revolution'.*
- Runout means 'the eccentricity in the pitch circle'.
- The runout is twice the *eccentricity*.
  (i) Eccentric gears tend to vibrate during each revolution.
  (ii) Badly eccentric gear may lead to sudden gear failure.

- Problems caused due to error in runout are,
  (i) Eccentric gears tend to vibrate during each revolution.
  (ii) Badly eccentric gear may lead to sudden gear failure.
- The runout in the gears is measured by means of gear eccentricity testers.
- Gear eccentricity tester consists of a dial gauge indicator, which has a special tip. The form of tip depends on the module of gear to be tested.
- To check the gear for runout error, the gear is mounted on a mandrel supported in the centres.
- This tip is inserted between the tooth spaces and gear is rotated tooth by tooth.
- The maximum variation is noted from dial indicator reading which specifies the amount of runout of gear.

6.14 LEAD CHECKING

- Lead is the axial advancement of a helix for one complete rotation about its own axis.
- In case of spur gears, lead tolerance is defined as the allowable deviation across the face-width of a tooth surface.
- Control of lead is necessary to ensure adequate contact across the face width, when gear and pinion are in mesh and properly mounted with parallel axes living in the same plane.
- Lead may be checked by lead checking instrument.
- Measuring pointer traces the tooth surface at pitch circle and parallel to axis of gear.
- Measuring pointer is connected to a dial gauge indicator, which continuously indicates the deviation.
- This measuring pointer is mounted on a sliding carriage, which travels parallel to the gear axis.
- The total deviation shown by dial indicator indicates the amount of displacement of gear tooth in the facewidth traversed.

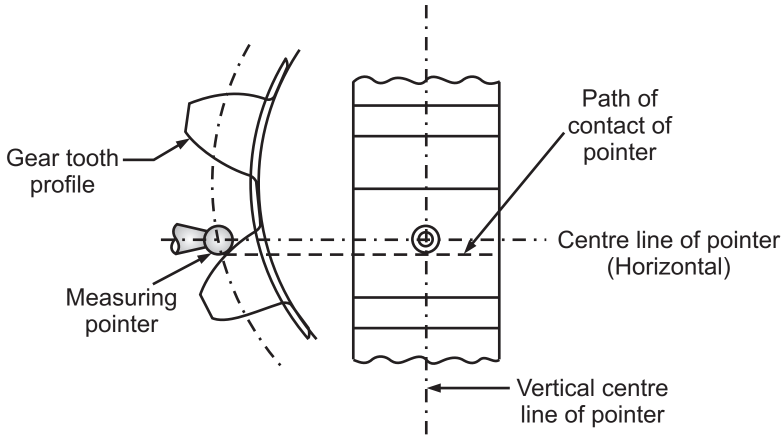


Fig. 6.10: Lead checking instrument

6.15 BACKLASH, ITS SIGNIFICANCE AND CHECKING (S-10)

QUESTION

1. Describe with neat sketch, the defect of Backlash in case of a gear. **(S.T.P.-II)**

Definition:

- Backlash in gears is a play between mating tooth surfaces.
- For the purpose of measurement and calculation, backlash is defined as *'the amount, by which, a tooth space exceeds the thickness of mating tooth'*.
- Backlash should be measured at the tighest point mesh.

Significance:

- If the two mating gears are produced such that, the tooth spaces are equal to tooth thickness at the pitch circle, then there will not be any clearance in between the mating teeth of two gears.
- Tight mesh leads to gear sound, increased power losses, overheating and rupture of lubricant film, overloaded bearing and premature gear failure.
- Therefore, a small clearance is provided by thinning the tooth profile uniformly. Refer Fig. 6. This results in a small play between the mating tooth surfaces, which is called as backlash.
- Thus, backlash is necessary to avoid tight mesh.

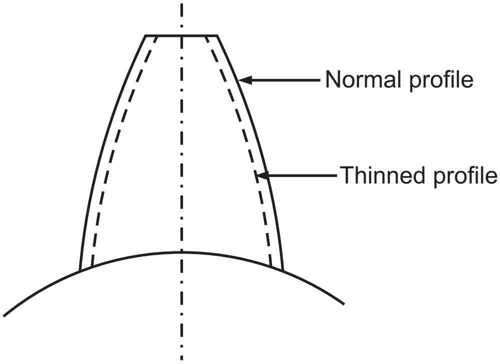


Fig. 6.11: (a) Thinning of tooth profile

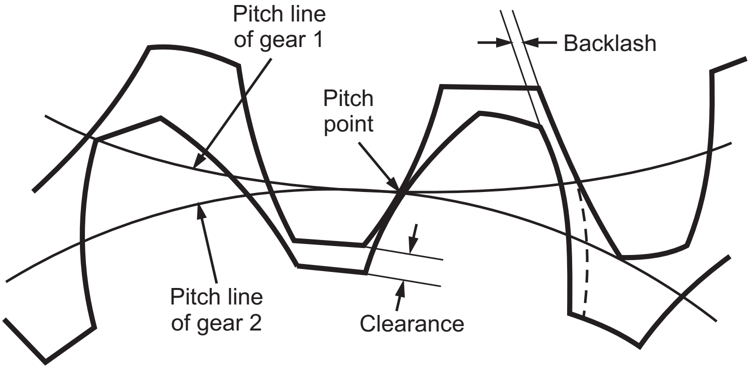


Fig. 6.11: (b) Significance of backlash

Checking:

- To check backlash, the gear and pinion are mounted in mating position. The pinion is held fixed and is not free to rotate.
- A rigidly mounted dial indicator is placed against the tooth of gear perpendicular to surface. Now, the gear is rotated backward and forward as far as possible, to note down the maximum displacement, recorded by dial indicator. It gives circular backlash.
- For spur gears, Normal backlash = Circular backlash × Cosine (Pressure angle)
- Backlash variation is measured by locating the points of maximum and minimum backlash in the pair and by obtaining the difference.
- Backlash should be measured at the tightest point of mesh, on the pitch circle, in a direction normal to the tooth surface.
- For precision gears, the variation in backlash should not exceed 0.02 mm to 0.03 mm.

6.16 CONCENTRICITY OF TEETH

- All the teeth on gear must be concentric with the pitch line of gear.
- If teeth are not concentric, then fluctuating velocity will be noticed on the pitch line circle while transmitting motion.
- Error in concentricity also leads to inaccuracy in gears produced, when being used for indexing purposes.
- Tooth concentricity can be checked by,
  (a) Mounting the gear between bench centres, placing a standard roller in each tooth space and then using a dial indicator.
  (b) Using a projector, in which, the teeth are brought against a stop and each image of tooth on screen should coincide with a line on screen.
  (c) Using a gear testing fixture fitted with a spring loaded slide and dial indicator, in which, the spring exerts a constant pressure on the mating teeth and movement of dial indicator gives the measure of concentricity of teeth.

6.17 OTHER ERRORS IN GEARS

Apart from backlash, runout and error in tooth form, the other possible errors in gears are,

(a) Pitch errors: It gives rise to gear noise and its intensity depends upon, how pitch errors are produced.

(i) Adjacent pitch error = Design pitch − Actual pitch.

(ii) Cummulative pitch error = $\left(\begin{array}{c}\text{Design length}\\\text{value}\end{array} - \begin{array}{c}\text{Actual length}\\\text{value}\end{array}\right)$ between corresponding flanks of teeth not adjacent to each other.

(b) Tooth thickness error: It is the difference between design tooth thickness the actual tooth thickness measured. This value indicates the deviation of actual tooth thickness from the design tooth thickness.

Important Points

- *Involute* is defined as "locus of a point on a piece of string, which is unwound on a stationery cylinder".
- *Different parameters* checked while carrying measurements of a spur gear are,

  (1) Runout
  (2) Pitch,
  (3) Profile,
  (4) Lead,
  (5) Backlash,
  (6) Tooth thickness,
  (7) Concentricity,
  (8) Alignment,
  (9) Composite errors.
- *Tooth Thickness* is defined as, "the arc distance measured along the pitch circle from its intercept with one flank to its intercept with other flank of same tooth".
- Tooth thickness is measured by gear tooth vernier caliper or tangent micrometer.

Theory Questions for Practice

1. What is involute tooth profile?
2. Explain the process of measurement of tooth thickness by gear tooth vernier caliper using chordal thickness method.
3. Explain constant chord method.
4. Enlist the uses of tangent micrometer.
5. Explain the working of parkinson gear tester.
6. Write a short note on "Run out checking".
7. What is backlash? State its significance.
8. Explain the process of rolling gear test.

Numerical Problems for Practice

1. Calculate the setting for a straight spur gear having 32 teeth of module 4 mm for a gear tooth vernier caliper. [**Ans.:** w = 6.28 mm, d = 4.077 mm]

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2014

1. Draw the neat sketch of Gear tooth vernier caliper and write the procedure for measuring chordal tooth thickness. **(6M)**

Ans. Refer Articles 6.5 and 6.5.1.

2. Explain 'Parkinson's Gear Tester'. **(8M)**

Ans. Refer Article 6.9.

Summer 2015

1. Describe with neat sketch, the working of "The Parkinson Gear Tester". **(6M)**

Ans. Refer Article 6.9.

2. Draw a neat sketch of vernier gear tooth caliper and write the procedure for measuring chordal tooth thickness. **(8M)**

Ans. Refer Articles 6.5 and 6.5.1.

Winter 2015

1. Explain the principle of measurement of gear tooth thickness using a gear tooth vernier.

Ans. Refer Article 6.5.1. **(4M)**

2. With a neat sketch, explain measurement of tooth thickness by constant chord method.

Ans. Refer Article 6.5.2. **(8M)**

Summer 2016

1. Explain principle of measurement of Parkinson gear tester with a neat sketch. **(4M)**

Ans. Refer Article 6.9.

2. Explain the principle of measurement of a spur gear tooth thickness using a gear tooth vernier. State mathematical relations to compare chordal addendum and chordal tooth thickness. **(8M)**

Ans. Refer Article 6.5.1.

Winter 2016

1. Explain 'Parkinson's gear tester' with neat sketch. **(4M)**

Ans. Refer Article 6.9.

2. Explain in detail errors in gears. **(8M)**

Ans. Refer Article 6.12.

Summer 2017

1. Explain various errors in gears. **(4M)**

Ans. Refer Articles 6.12, 6.13, 6.15 and 6.16.

2. Explain the method of gear tooth thickness measurement by Gear tooth vernier with neat sketch. **(4M)**

Ans. Refer Article 6.5.1.

3. Explain the working of Parkinson Gear Tester with neat sketch. **(4M)**

Ans. Refer Article 6.9.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 7

MEASUREMENT OF SURFACE FINISH

About This Chapter ...

This chapter has a weightage of 6 marks and assigned duration is 5 hours. Here, we learn importance of surface finish, primary texture, secondary texture, different terms and symbols used in surface finish. We also learn the various techniques of qualitative and quantative analysis of surface finish.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	04 Marks	S-09	08 Marks
W-09	08 Marks	S-10	04 Marks
W-10	08 Marks	S-11	08 Marks
W-11	24 Marks	S-12	08 Marks
W-12	12 Marks	S-13	14 Marks
W-13	18 Marks	S-14	16 Marks
W-14	10 Marks	S-15	08 Marks
W-15	12 Marks	S-16	08 Marks
W-16	12 Marks	S-17	08 Marks

7.1 IMPORTANCE OF SURFACE FINISH

- When a raw material is machined by cheap removal process, its external surface cannot be finished as perfectly smooth, due to deviation from the assumed ideal working conditions.
- Therefore, on any finished surface, imperfections or irregularities are bound to be there.
- These irregularities are in the form of successive hills and valleys, which vary in both, height and spacing. This is referred as **surface roughness**.
- If surface is too rough, then initial wear particles are large and act as **abrasives** and wear takes place continuously at a higher rate.
- **Surface finish** is expressed in terms of surface texture i.e. smooth or rough.
- **Surface texture** is defined as, *"the quality characteristic of an actual surface due to small departures or deviations from its general geometrical form, which is occurring (repeating) at regular or irregular (random) intervals, causing to form a pattern or texture on the surface"*.

- In short, the surface texture refers to **repetitive or random deviations from nominal surface, which forms the pattern of surface.**
- **Various factors affecting surface roughness:**
  - (a) Vibrations.
  - (b) Quality of material used for workpiece.
  - (c) Type of machining process.
  - (d) Rigidity of production system consisting of machine tool, fixture, cutting tool etc.
  - (e) Cutting parameters i.e. feed, speed and depth of cut.
  - (f) Type of coolant used.
- Modern developments and techniques in the field of grinding, honing, lapping have improved the surface finish.
- **Advantages or Significance for Improved Surface Finish:**
  - (a) Improves service life of components.
  - (b) Reduces initial wear of parts.
  - (c) Improves fatigue resistance.
  - (d) Improves quality of parts and components appearance.
  - (e) Decreases the corrosion rate by minimizing the depth of irregularities.

7.2 PRIMARY TEXTURE

QUESTIONS

1. Explain the following terms used in surface finish measurement:
   (i) Roughness, (ii) Lay, (iii) Waviness, (iv) Sampling length. **(W-10)**
2. What is primary and secondary texture on a surface ? **(S-09, 14; W-09, 12)**
3. What are the different methods of defining surface texture ? **(S-11; W-11)**
4. Draw neat sketch of primary texture (roughness) and secondary texture (waviness) and show on it, sampling length and lay'. **(S-12)**
5. Sketch primary and secondary texture. Show on it, 'sampling length and lay'. **(W-13)**
6. Define the following terminologies as per IS 3073-1967 for surface finish for a machine tool. (i) Primary texture, (ii) Secondary texture, (iii) Lay, (iv) Sample length. **(S.Q.P.)**
7. State the meaning of flaw, waviness, lay and roughness with respect to surface finish. **(W-15)**
8. Explain the terms. **(W-16)**
   (i) Primary texture (ii) Secondary texture
   (iii) Sampling length (iv) Lay
9. Explain: **(S-17)**
   (i) Primary texture, (ii) Secondary texture, (iii) Sampling length, (iv) RMS value in surface finish

- Surface irregularities of small wavelength are called ***primary texture*** or ***roughness***.
- They are called **micro-geometrical errors.**
- Primary texture includes:
  - (i) Irregularities of **third order** (irregularities due to feed marks of cutting tool) and (ii) **fourth order** (irregularities due to rupture of material caused due to separation of chip).
- **Primary texture** includes irregularities caused by direct action of cutting elements on materials.

- Reasons for the above irregularities leading to primary texture:
  (i) Cutting tool shape, (ii) Tool feed rate,
  (iii) Friction, (iv) Wear,
  (iv) Corrosion etc.
- **Evaluation** of surface finish is based on **height** and **character** of micro-geometrical irregularities.

7.3 SECONDARY TEXTURE (S-12; W-16)

QUESTIONS

1. Sketch primary and secondary texture. Show on it sampling length and lay. **(W-15)**
2. Design a general type plug gauge for checking a hole dimension $30^{+0.05}_{-0.03}$. Consider both wear allowance and gauge tolerance as 10% of work tolerance. **(S-16)**

- Surface irregularities of considerable wavelength of a periodic character are called ***secondary texture*** or ***waviness***.
- In other words, secondary texture or waviness includes irregularities of **larger wavelength**.
- They are called **macro-geometrical errors**.
- Secondary texture includes (i) **irregularities of first order**, (irregularities due to lack of straightness of guide-ways of tool, deformation of work under cutting forces, weight of material itself) and (ii) **second order** (irregularities due to vibrations and chatter marks).
- **Roughness** (primary texture) is **superimposed** upon the **waviness** (secondary texture).
- Thus, any finished surface could be considered as combination of two forms of wavelength i.e. small wavelength for roughness and long wavelength for waviness, superimposed upon each other.

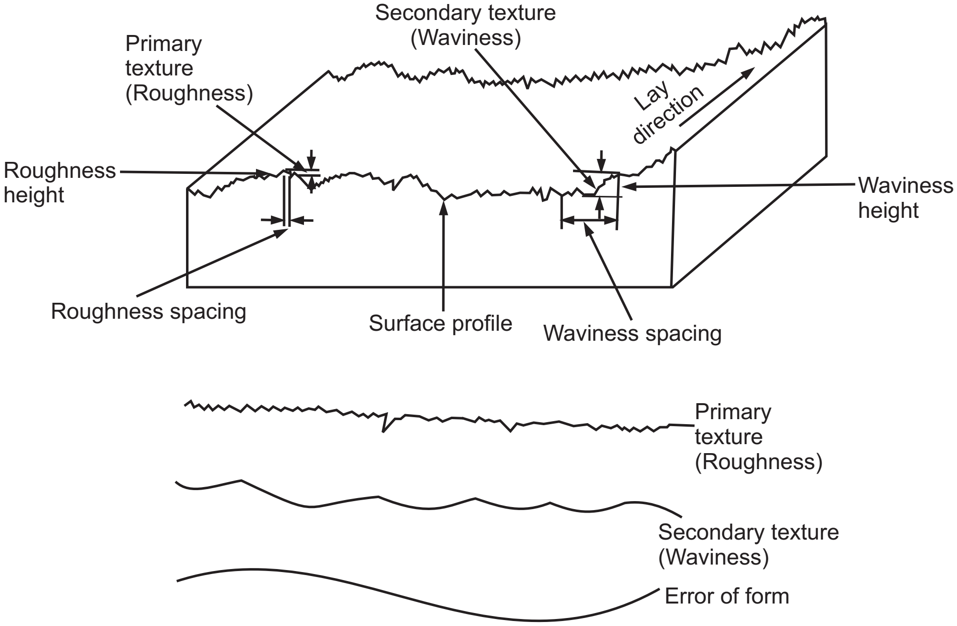


Fig. 7.1: Terminology of surface roughness

7.4 DIFFERENCE BETWEEN PRIMARY TEXTURE AND SECONDARY TEXTURE

QUESTIONS

1. Distinguish between 'Primary texture' and 'Secondary texture'. **(S-16)**

Primary Texture	Secondary Texture
1. They are surface irregularities of small wavelength.	1. They are surface irregularities of larger wavelength.
2. They are called as "Roughness" or "Micro-geometrical errors".	2. They are also called as "Waviness" or "Macro-geometrical errors".
3. They include irregularities of **third order** (for example, feed marks of cutting tool) and **fourth order** (for example, due to rupture of material caused due to separation of chip).	3. They include irregularities of **first order** (for example, due to lack of straightness of guideways of tool, deformation of work under cutting forces etc.) and **second order** (for example, due to vibrations and chatter marks).
4. They are caused due to direct action of cutting elements on material, such as, tool feed rate, friction, wear, corrosion etc.	4. They are caused due to misalignment of centres, wear of guideways, deformation of workpiece, vibration, lack of straightness, non-linear feed motion.

7.5 IMPORTANT TERMS OF SURFACE FINISH **(W-10)**

QUESTIONS

1. State the meaning of (i) Flaw, (ii) Waviness, (iii) Lay, (iv) Roughness w.r.t. surface finish. **(W-13)**
2. State the meaning of : (i) Sampling length, (ii) Lay, (iii) Waviness and (iv) Roughness w.r. to surface finish. **(S-15)**
3. State the meaning of flaw, waviness, lay and roughness with respect to surface finish. **(W-15)**
4. Sketch primary and secondary texture. Show on it sampling length and lay. **(W-15)**

(a) **Real surface:** It is surface limiting the body and separating it from the surrounding surface.

(b) **Geometrical surface:** It is the surface prescribed by the design or by the process of manufacture, neglecting the errors of form and surface roughness.

(c) **Effective profile:** It is a close representation of real surface obtained by instrumental means. **(W-15)**

(d) **Mean line of profile:** It is the line having form of geometrical profile and dividing the effective profile, such that, within the sampling length, the sum of squares of distances ($y_1, y_2, ... y_n$) between the effective point and mean line is minimum.

(e) **Centre line of profile:** Centre line is the line parallel to general direction of profile, for which, the areas acquired or accommodated by the profile above and below centre line are equal. When **wavelength is repetitive** in nature, both, **mean line** and **centre line** are same. **(W-13)**

(f) Sampling length (W-16): It is the length of profile necessary for evaluation of irregularities to be taken into account. It is also called as *cut-off length*.

It is measured in a direction parallel to the general direction of profile.

(g) Flaws (S-12): Flaws are defined as, 'irregularities, which occur at one place or at relatively infrequent or widely changing intervals in a surface'.

Examples of flaws: Scratches, cracks, random blemishes etc.

(h) Lay (S-12; W-16):

- It shows the direction of predominant surface pattern by tool marks or scratches.
- On any commercially produced surface, dominant pattern of surface finish marks are observed.
- These are tiny scratches left behind by the movement of the finishing tool during the course of relative movement with respect to the work. This pattern is termed as "Lay" of the surface.

- Various types of lays are explained below.

Sr. No.	Symbol	Meaning
1.	||	Lay parallel to the line-representing surface, to which, symbol is applied. (e.g. parallel shaping, diameter turning etc.)
2.	⊥	Lay perpendicular to line representing surface, to which, symbol is applied. (e.g. side view of shaping, diameter grinding etc.)
3.	X	Lay angular in both directions to the line representing surface, to which, symbol is applied (e.g. knurling).
4.	**M**	Multidirectional lay (e.g. lapping, superfinishing).
5.	**C**	Lay approximately circular relative to the centre of surface, to which, symbol is applied (e.g. facing on lathe).
6.	**R**	Lay approximately radial relative to the centre of surface, to which, symbol is applied (e.g. grinding on a turntable).

7.6 R_a VALUE

QUESTIONS

1. How to calculate R_a value ? (W-12)
2. How surface finish is to be represented on drawing? (W-12)
3. What is R_a and R_z values? (S-10, 13; W-13)
4. Define the terms, R_a, CLA, RMS and R_z values with respect to surface finish. (W-15, 16)

- R_a value is the *quantitative measure* of surface roughness.
- R_a value is defined *as, "the arithmetic average of ordinates y_1, y_2,……. y_n from mean line without considering algebraic signs".*
- R_a value is calculated by the following formula

$$R_a \text{ value} = \frac{\Sigma\ |y|}{n}$$

where, n is the number of divisions marked over sampling length 'L'.

- In short, R_a value is arithmetical mean deviation of surface profile from mean line. It is usually expressed in microns.
- Fig. 7.2 shows graph of a machined surface, for which, R_a value is to be measured.
- First of all, sampling length is chosen. Then, a reference line (or mean line) is drawn, such that, it divides the profile approximately into two equal areas above and below. Then, the deviations from mean line are measured as $y_1, y_2, y_3 \dots y_n$.
- Now, R_a value is calculated by using the formula,

$$R_a = \frac{(y_1 + y_2 + \dots + y_7 + y_8 + \dots y_{n-1} + y_n)}{n}$$

$$\therefore \qquad R_a = \frac{\Sigma\ |y|}{n}$$

where, n is number of divisions marked on mean line.

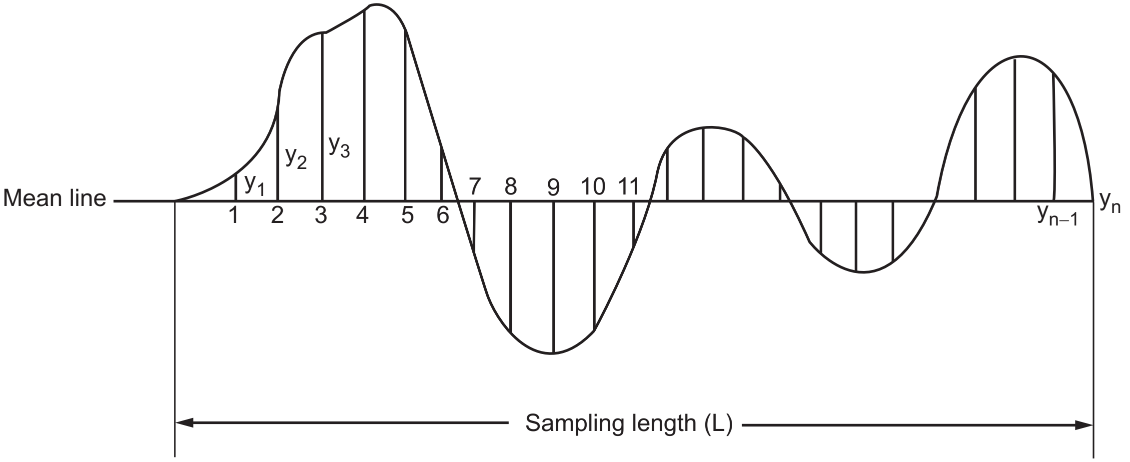


Fig. 7.2: Machined surface profile to calculate "R_a"

Note: Don't take deviations below mean line as negative. For example: y_7, y_8 … because we do not consider algebraic signs while calculating R_a.

7.7 TEN POINT HEIGHT IRREGULARITIES (R_z)

QUESTION

1. What is R_a and R_z values? **(S-13, W-13)**

- R_z value is "Ten point height irregularities'. To calculate 'R_z', a line parallel to mean line is drawn, such that, it will not cross the profile.
- R_z value is defined as, *"average difference between five highest peaks and five lowest valleys within sampling length measured from a reference line, which is not crossing the profile, but parallel to mean line".*
- R_z value $= \frac{1}{5}[(R_1 + R_3 + R_5 + R_7 + R_9) - (R_2 + R_4 + R_6 + R_8 + R_{10})]$

  where R_1, R_3, R_5, R_7, R_9 are highest peaks and R_2, R_4, R_6, R_8 and R_{10} are lowest valleys.

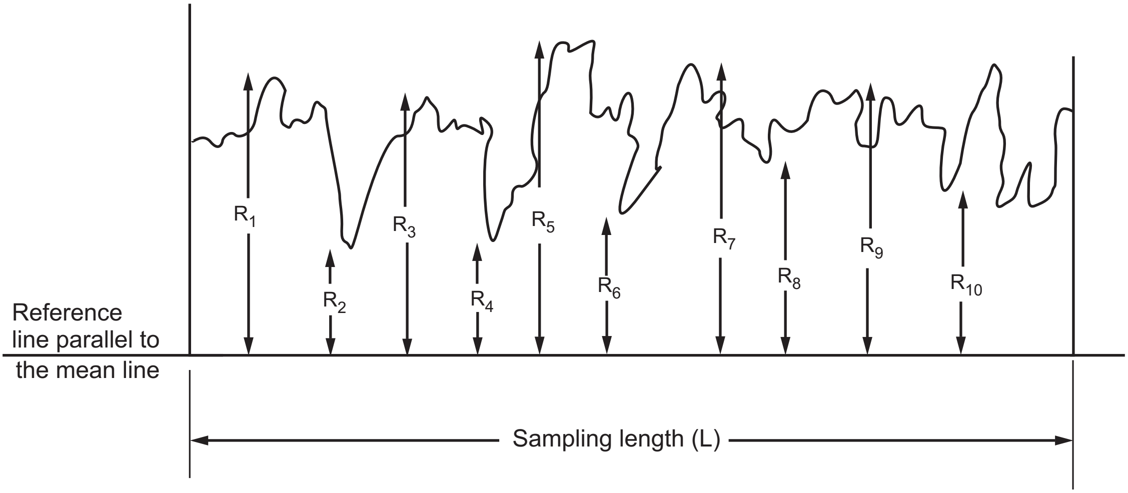


Fig. 7.3: Ten point height irregularities method to calculate R_z value

7.8 METHODS OF MEASURING PRIMARY TEXTURE

QUESTIONS

1. Define the terms, R_a, CLA, RMS and R_z values with respect to surface finish. **(W-15, 16)**
2. Distinguish between 'Primary texture' and 'Secondary texture'. **(S-16)**

- Three methods of measuring primary texture (roughness) of a surface are explained below. **(S-13; W-13)**

(a) Ten Point Height Method (R_z): **(W-15)**

- **R_z value** is defined as, *"the average difference between five highest peaks and five lowest valleys of surface texture within sampling length, measured from a reference line parallel to mean line and not crossing the profile"*. Refer Fig. 7.3.
- $R_z \text{ value} = \frac{1}{5}\{(R_1 + R_3 + R_5 + R_7 + R_9) - (R_2 + R_4 + R_6 + R_8 + R_{10})\}$

  where, R_1, R_3, R_5, R_7, R_9 are highest peaks and R_2, R_4, R_6, R_8 and R_{10} are lowest valleys.
- This method evaluates the total depth of surface irregularities within the sampling length. It denotes the amount of surface roughness.
- But, it doesn't give sufficient information about the surface, because shape of entire profile is neglected. It is used, when it is desired to control the cost of finishing for checking rough machining.

(b) R.M.S. Value:

QUESTIONS

1. Define CLA and RMS values as applied to surface roughness measurement. **(W-09, 13, 15; S-14, 15)**
2. Define the terms, R_a, CLA, RMS and R_z values with respect to surface finish. **(W-15)**
3. Distinguish between 'Primary texture' and 'Secondary texture'. **(S-16)**

- **Root mean square value** is defined as, *"square root of arithmetic mean values of squares of ordinates of surface measured from mean line"*.

- Let us assume that, sampling length 'L' is divided into 'n' equal parts. Ordinates are points 1,2,3,……,n, whose heights are $y_1, y_2, y_3, \ldots\ldots y_n$ from meanline.

  Then, RMS value = $\sqrt{\dfrac{y_1^2 + y_2^2 + y_3^2 + \ldots\ldots + y_n^2}{n}}$

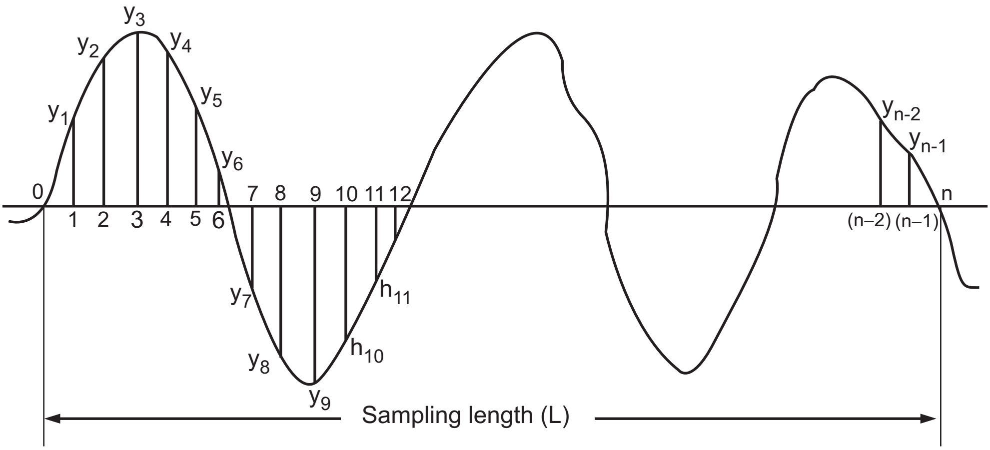


Fig. 7.4

(c) Centre Line Average Method or CLA Value: **(W-09, 13; S-14)**

- CLA value is defined as, "the average height of all ordinates of the surface from mean line, without considering algebraic signs". It means that, heights below the mean line, such as, h_7, h_8, h_9 … h_{12} and so on, should not be taken as negative.
- Let $h_1, h_2, h_3, \ldots\ldots h_n$ be the readings, then,

$$\text{CLA} = \frac{h_1 + h_2 + h_3 + \ldots \ldots + h_n}{n}$$

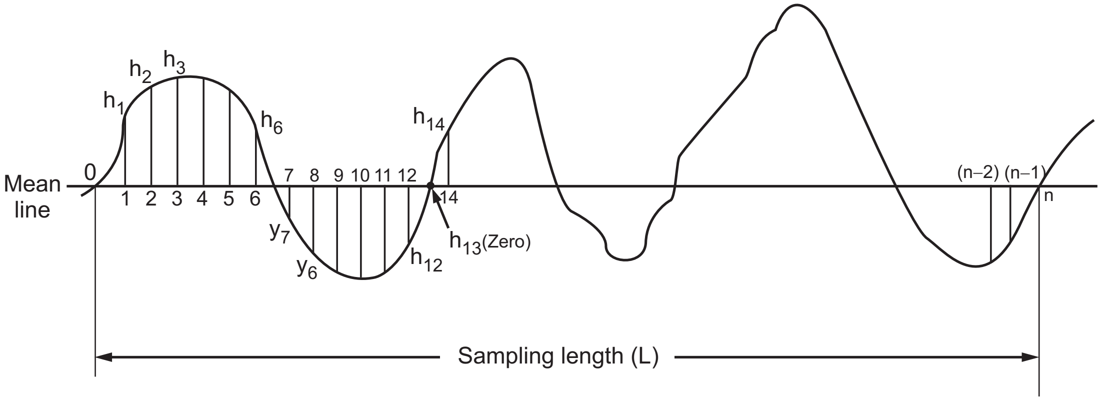


Fig. 7.5: CLA value by height

- But, to find CLA value above method is time consuming and causing fatigue to inspectors or engineer's. Also by this method, spacing chosen may be such that, important ordinates are likely to be missed.
- Things can be much simplified by using **a planimeter**, which can find out *the area of any curve*.

- For calculating CLA value by 'Area', we use the formula

$$\text{CLA value} = \frac{A_1 + A_2 + A_3 \dots \dots + A_n}{L} = \frac{\Sigma A}{L}$$

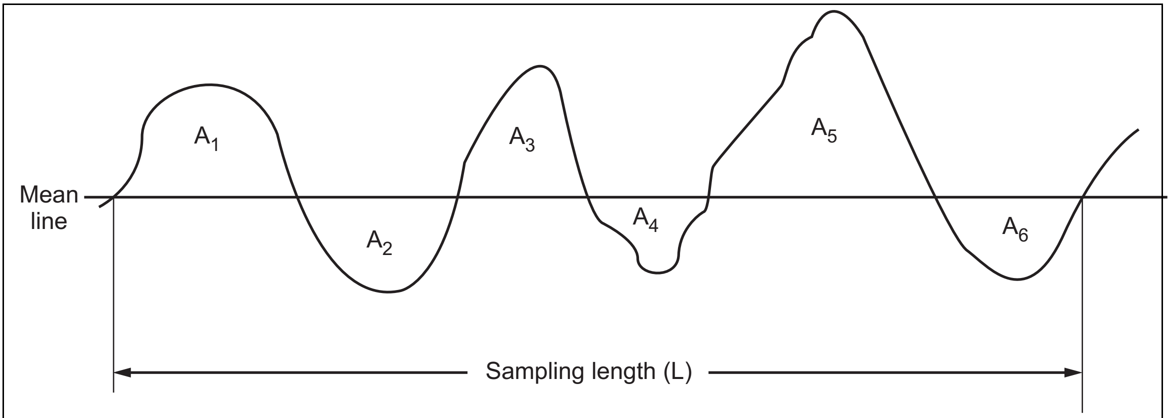


Fig. 7.6: CLA value by area

- CLA value measure is preferred over RMS value measure, because its value can be easily determined using planimeter or graph.

7.9 SURFACE FINISH SYMBOL

1. How surface finish is to be represented on drawing ? **(S-09, 14; W-11)**
2. List the main characteristics to be indicated on surface roughness symbol. Draw the sketch. **(W-13)**

- The symbol for surface finish as per IS standard is shown in figure 7.7.
  - Surface roughness value i.e. R_a in 'μm'.
  - Machining allowance in 'mm'.
  - Sampling length in 'mm'.
  - Method of machining such as milling, shaping etc.
  - Direction of lay in the symbol.

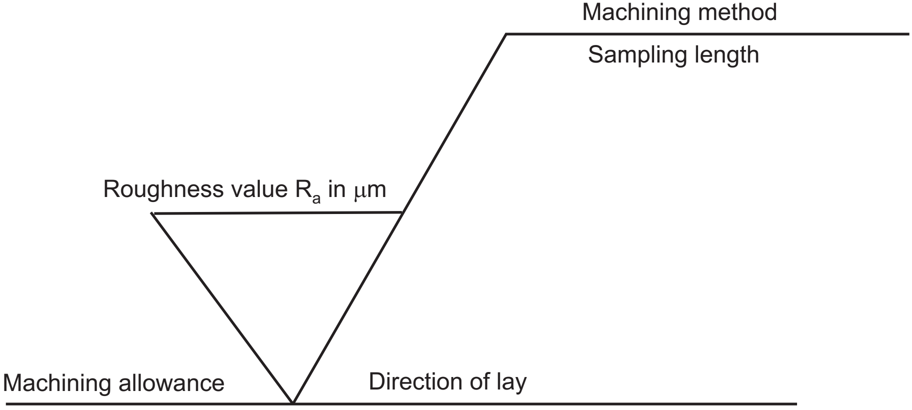


Fig. 7.7: Surface finish symbol

For example,

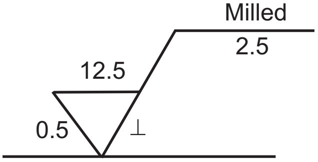


Fig. 7.8: Example of surface finish symbol

- In common practice a short form i.e. Inverted Triangles are used to include roughness, at various surfaces to avoid complexity in drawing.

Table 7.1: Roughness Symbols and Corresponding Values

Symbol	R_a value in μm
–	50
∇	12.5 to 25
∇ ∇	1.6 to 6.3
∇ ∇ ∇	0.2 to 0.8
∇ ∇ ∇ ∇	0.025 to 0.1

7.10 VARIOUS METHODS OF SURFACE FINISH MEASUREMENT

QUESTIONS

1. Describe any two qualitative methods of measurement. **(W-11)**
2. Describe how scratch inspection and microscopic inspection is carried out? **(S-13)**
3. What are the various techniques of qualitative analysis? Explain. **(S-14)**

Following two methods are used for measuring surface finish.

(1) Inspection by Comparison Methods or Qualitative Methods:

- In this method, surface texture is assessed by observation of surface.
- Texture of a surface to be tested is compared with surface of standard specimen of known roughness value, subjected to a condition that, both surface to be tested and surface of standard specimen should be finished by similar machining procedures.
- The various qualitative methods are as follows.
  - **(a) Visual inspection:** It is done simply by eye judgment, one can guess the surface texture. Sometimes, lenses with illumination can also be used.
  - **(b) Touch inspection:**
    - Even though roughness height of two surfaces is same, but if, frequency of irregularities in one surface is more, then that surface is said to be rougher than surface with less frequencies of irregularities.

- In this method, finger tip is moved along the surface at speed of 25 mm/sec and irregularities are detected.
- **Limitation of this method:** Minute flaws can not be detected and degree of surface cannot be calculated.

(c) Scratch inspection: Any rough surface has scratches and marks on it. Soft plastic is rubbed over the surface under test, which will be scratched due to surface irregularities. These scratches are observed by visual test.

(d) Surface photographs:

- In this method, photographs of surface are taken using illumination method. In case of vertical illumination method, surface irregularities or scratches appear as dark spots and flat portions of surface appear as bright areas.
- Photographs are taken using different illuminations and their results are evaluated, in terms of quality.

(e) Micro interferometer: Optical flat is placed on the surface. It is illuminated with monochromatic source of light; the fringe pattern of interference is observed and studied to know surface finish.

(f) Microscopic inspection: Various sets of master surfaces of known surface roughness values are available. A master surface is observed through one eyepiece of microscope and surface under test is observed through another eyepiece. Now, pattern of surface to be tested is adjusted to match with any one pattern of the master surface. Thus, we can know the roughness value of the given specimen.

(g) Use of photocells: Light of known intensity is projected on the surface. Some part of the light is absorbed and other is reflected. The reflected intensity is measured by photocell. Change in intensity is the measure of surface roughness.

Though these methods are rapid, their results are not reliable, because they can be misleading, if comparison of surface under test is not done with surface of standard specimen produced by similar techniques.

(2) Direct Instrument Measurements or Quantitative Methods:

- These are the methods of quantitative analysis of surface texture.
- They enable **to measure numerical value of surface finish** of any surface by using instruments such as profilometer, Tomilson surface meter etc.

7.11 STYLUS PROBE INSTRUMENTS / STYLUS TYPE SURFACE TEXTURE MEASURING INSTRUMENTS

QUESTION

1. Explain the principle of stylus probe type direct instrument measurement of surface finish. **(S-11, 13; W-11)**

Principle:

If a finely pointed probe or stylus is moved over the surface of a work-piece, the vertical movement of stylus caused due to irregularities in the surface can be used for measurement.

Construction:

- The instrument is drawn over the surface to be tested.
- Output is then amplified by suitable means and is used to operate a recording or indicating instrument.
- Stylus type instruments generally consist of following units:
  (a) Skid or shoe.
  (b) Finely pointed stylus or probe.
  (c) An amplifying device for magnifying the stylus movement and indicator.
  (d) Recording device to produce a trace.
  (e) Device for analysis of trace to give numerical value of surface finish.

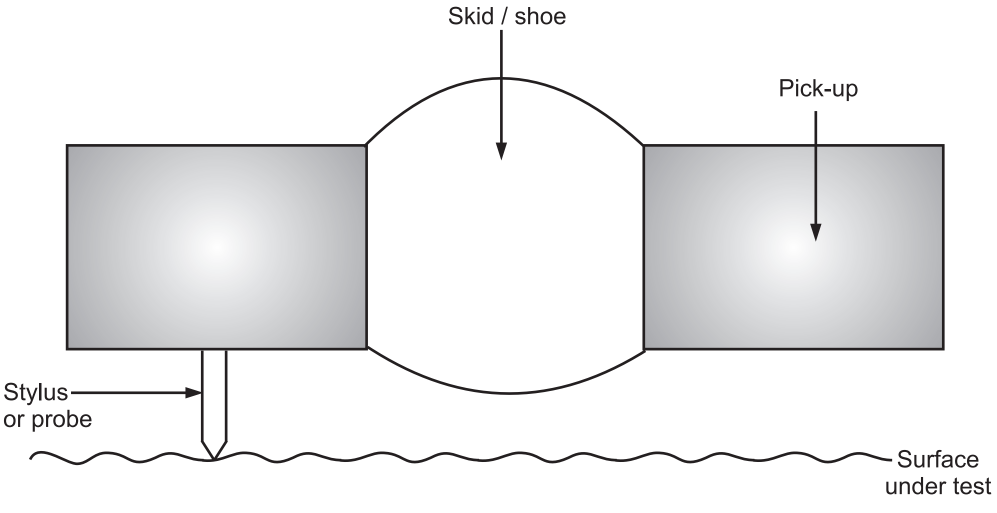


Fig. 7.9

Working:

- Skid or shoe is drawn slowly over the surface either by hand or by motor drive.
- The stylus moves over the surface along with the skid.
- Stylus is a fine point madeup of diamond or any such hard material.
- Stylus moves vertically up and down due to irregularities present on surface.
- The movements of stylus are used to modulate a high frequency current or to generate a voltage signal.
- The stylus movements are magnified by an amplifying device and recorded by a recording or indicating instrument to produce a trace.
- The trace is then analyzed, to have a numerical value.

7.12 DR. TOMILSON'S SURFACE METER (W-11)

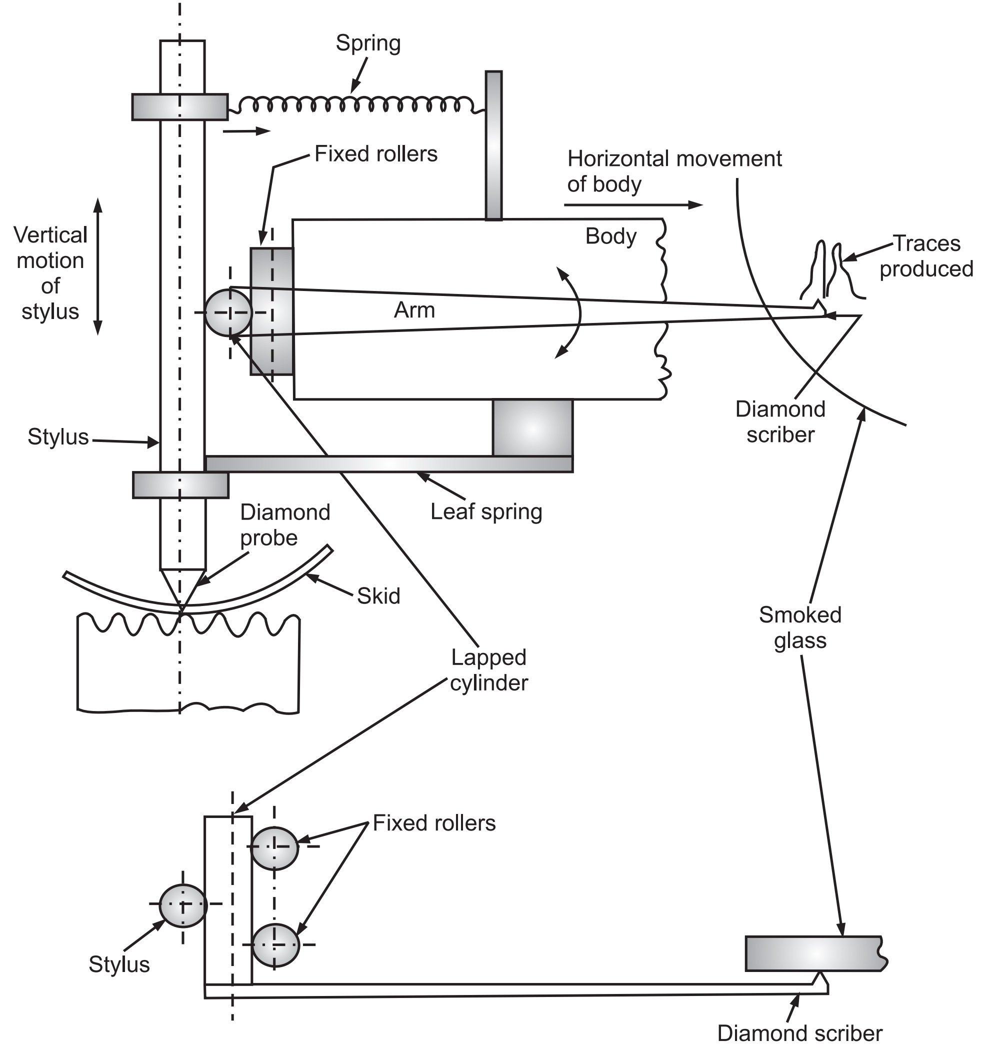


Fig. 7.10: Tomilson's surface meter

Construction:

- The instrument consists of a diamond probe or stylus held by spring pressure against the surface of a lapped cylinder of steel by a leaf spring.
- The lapped cylinder is supported on one side by the probe and on other side by fixed rollers.
- A light spring steel arm is attached to the lapped cylinder.
- The arm carries a diamond scriber at its tip, which rests against a smoked glass.
- Forces exerted by spring and leaf spring prevent the motions of stylus except in vertical direction up or down.

Working:

- While measuring the surface finish, the instrument is traversed across the surface by a synchronous motor.
- Any vertical movements of stylus due to irregularities cause the lapped cylinder to roll.
- By its rolling, the tight arm attached to its end will produce magnified movements on a smoked glass.
- The traces produced on the smoked glass are then further projected at X50 or X100 magnification to examine them by an optical projector.

7.13 PROFILOMETER

- **Profilometer** is an indicating and recording instrument used to measure roughness in microns.
- Profilometer consists of two units: (i) **A tracer** and (ii) **An amplifier**.

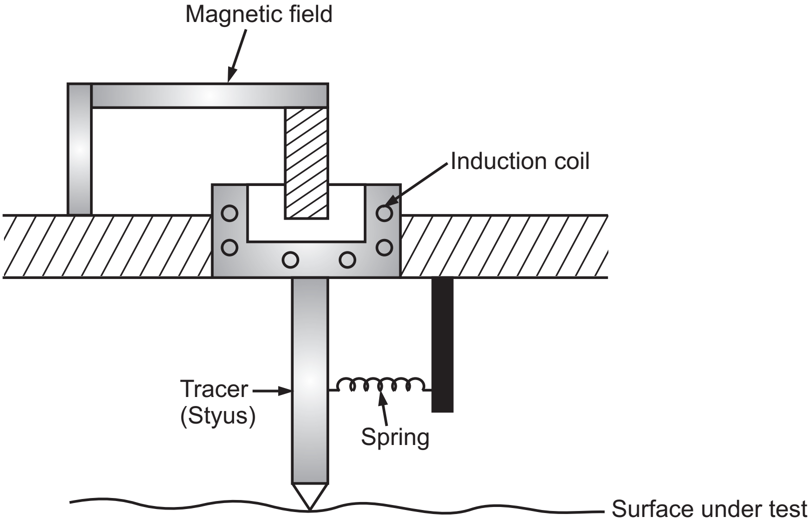


Fig. 7.11: Profilometer

- **Tracer** is a finely pointed stylus. It is mounted in pick up unit, which consists of an induction coil located in field of permanent magnet.
- When the tracer is moved across the surface to be tested, it gets displaced vertically up and down due to surface irregularities.
- This causes induction coil to move in the field of permanent magnet and induces a voltage.
- **Amplifier:** The induced voltage is amplified and recorded, and then registered on a reading meter calibrated in micrometers.

7.13.1 Advantages of Profilometer

(i) Portable.
(ii) Quick in use.
(iii) Pick-up unit can be traversed/moved over the surface by hand at any inclination to the horizontal axis.

7.13.2 Limitation of Profilometer

(i) Speed of pick-up unit may vary during its traverse movement. It produces error in reading.

7.13.3 Application of Profilometer

Profilometer is best suited for *"measuring surface finish of deep bores"*.

7.14 TAYLOR HOBSON TALYSURF

QUESTION

1. Explain the principle and working of Taylor Hobson Talysurf with block diagram. **(W-14)**

- Talysurf surface roughness tester is an electronic instrument working on carrier modulating principle.
- The measuring head consists of a diamond stylus of about 0.002 mm tip radius and skid or shoe, which is drawn across the surface by means of a motorised driving unit.
- Here, the arm carrying the stylus forms an armature, which pivots about the centre piece or centre leg of E-shaped stamping as shown in Fig. 7.12.
- On two legs of E-shaped stamping, there are two coils carrying an a.c. current. These two coils form an oscillator with other two resistances from an **'oscillator'**.
- As armature is pivoted about the central leg, any movement of stylus causes the air gap to vary (change). Due to this, amplitude of original a.c. current flowing in the coils is modulated (varied).
- Output of bridge consists of modulated signal, given by the oscillator.
- This signal is amplified by amplifier, which gives a modulated carrier.
- Further, this signal is demodulated and smoothened to get **a current**. This current is directly proportional to the vertical displacement of stylus.
- Now, the current is sent to pen recorder, which is used to produce permanent record of displacement of stylus in vertical direction. Also, a meter having calibrated circular scale is used to give numerical value directly.

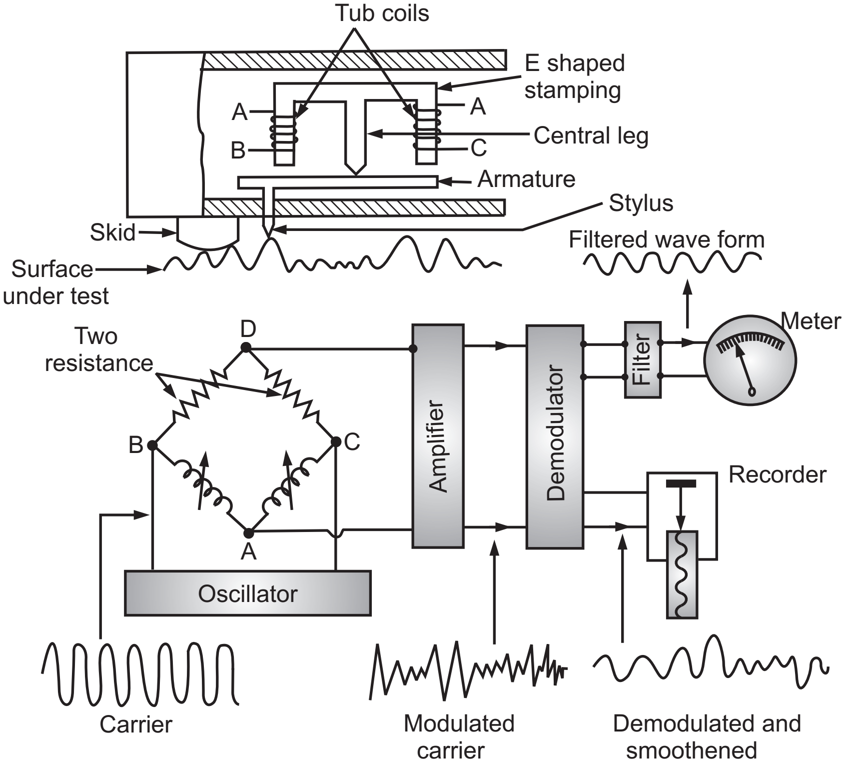


Fig. 7.12: Schematic Layout of Talysurf roughness tester

7.15 ADVANTAGES AND DISADVANTAGES OF DIRECT INSTRUMENT MEASUREMENT/QUANTATIVE METHODS

Advantages of Direct Instrument Measurement (Quantative methods):

(a) Output of instrument is in electrical form, which can be processed to obtain any desired roughness parameter.

(b) Results can be recorded or preserved for subsequent analysis purpose.

Disadvantages of Direct Instrument Measurement (Quantative methods):

(a) Instruments are bulky and complex.

(b) High initial cost.

(c) Needs skilled operators to perform measurements.

(d) Measurements are limited to a particular section of surface.

SOLVED PROBLEMS

Problem 7.1: *In the measurement of surface roughness height of successive 10 peaks and troughs were measured from a datum and were 33, 25, 30, 19, 22, 27, 29, 20, 18, 32 microns. If these measurements were obtained on 10 mm length, determine CLA and RMS values of surface roughness.* **(W-10, 11)**

Solution: Given data:

L = 10 mm (sampling length)

n = 10

Procedure:

(1) CLA (Centre Line Average method) value of surface roughness is given by,

$$\text{CLA value} = \frac{33 + 25 + 30 + 19 + 22 + 27 + 29 + 20 + 18 + 32}{10}$$

$$\therefore \quad \text{CLA value} = \mathbf{25.5\ microns}$$

(2)
$$\text{RMS value} = \sqrt{\frac{33^2 + 25^2 + 30^2 + 19^2 + 22^2 + 27^2 + 29^2 + 20^2 + 18^2 + 32^2}{10}}$$

$$\therefore \quad \text{RMS value} = \mathbf{26.03\ microns}$$

Problem 7.2: *In the measurement of surface roughness, heights of 20 successive peaks and valleys measured from datum are as follows: 45, 25, 35, 40, 25, 16, 40, 22, 25, 34, 25, 40, 20, 36, 28, 18, 20, 25, 30, 38 microns. If these measurements were made over a length of 20 mm, determine CLA value and RMS value of the surface.* **(W-14)**

Solution: Given data:

L = 20 mm (Sampling length)

n = 20

Procedure:

$$\text{CLA value} = \frac{\begin{pmatrix} 45 + 25 + 35 + 40 + 25 + 16 + 40 + 22 + 25 + \\ 34 + 25 + 40 + 20 + 36 + 28 + 18 + 20 + 25 + 30 + 38 \end{pmatrix}}{20}$$

$$= \mathbf{29.35\ microns}$$

$$\text{RMS value} = \sqrt{\frac{\begin{pmatrix} (45)^2 + (25)^2 + (35)^2 + (40)^2 + (25)^2 + (16)^2 + \\ (40)^2 + (22)^2 + (25)^2 + (34)^2 + (25)^2 + (40)^2 + (20)^2 + \\ (36)^2 + (28)^2 + (18)^2 + (20)^2 + (25)^2 + (30)^2 + (38)^2 \end{pmatrix}}{20}}$$

$$= \mathbf{30.51\ microns}$$

Important Points

- On any finished surface, imperfections or irregularities always occur in the form of successive hills and valleys.
- Surface irregularities of small wavelength are called as *primary texture* or *roughness*.
- Surface irregularities of larger wavelength of a periodic character are called as *secondary texture* or *waviness*.
- R_a *value* is defined as 'the arithmetic average of ordinates Y_1, Y_2, … Y_n from mean line without considering algebraic signs'.
- Three methods of measuring primary texture:
  - **(i) Ten point height method (R_z):** R_z is defined as 'the average difference between 5 highest peaks and 5 lowest valleys of surface texture within sampling length, measured from a line parallel to mean line and not crossing the profile'.
  - **(ii) R.M.S. value:** *Root mean square value* is defined as 'square root of arithmetic mean values of squares of ordinates of the surface measured from mean line'.
  - **(iii) Centre Line Average Method (CLA):** CLA is defined as 'the average height of all ordinates of surface from mean line without considering algebraic signs.

$$\text{CLA} = \frac{h_1 + h_2 + h_3 + \dots \dots + h_n}{n}$$

- Various qualitative methods are used for surface finish measurement, such as, visual inspection, touch inspection, scratch inspection, surface photograph, microscopic inspection, use of photo cells etc.
- Direct instruments such as Stylus probe, Dr. Tomilson's surface meter, Profilometer and Taylor Habson Talysurf are used for quantitative analysis.

Theory Questions for Practice

1. What is the importance of surface finish? Define primary texture and secondary texture.
2. Define R_a value and R_z value.
3. How will you represent surface finish symbol?
4. Define CLA and RMS values.
5. Enlist the various qualitative methods of surface finish measurement. Explain any one.
6. Explain the working of Dr. Tomilson's surface meter with suitable sketch.

Numerical Problems for Practice

1. In the measurement of surface finish, following readings are taken: 32, 25, 40, 20, 35, 18, 40, 25, 35, 20, 36, 18, 42, 22, 32, 21, 36, 18, 36, 20 microns. If these measurements were obtained over a length of 20 mm, determine CLA value and RMS value of the surface.

Ans. (i) CLA value = 28.55 microns

(ii) RMS value = 29.74 microns

2. In the measurement of surface roughness, heights of 20 successive peaks and valleys measured from datum are 35, 25, 40, 22, 35, 18, 42, 25, 35, 22, 36, 18, 42, 22, 32, 21, 37, 18, 35 and 20 microns. If these values are obtained over length of 20 mm, find CLA and RMS values.

Ans. (i) CLA value = 20 microns

(ii) RMS value = 30.51 microns

MSBTE Questions and Answers (As per G-Scheme)

Winter 2014

1. In the measurement of surface roughness, heights of 20 successive peaks and valleys measured from a datum line are as follows : **(4M)**

45, 25, 35, 40, 25, 16, 40, 22, 25, 34, 25, 40, 20, 36, 28, 18, 20, 25, 30, 38. If the measurements were made over a length of 20 mm, determine CLA and RMS values of the surface.

Ans. Refer Problem 7.2.

2. Explain the principle and working of Taylor Hobsan Talysurf with block diagram. **(6M)**

Ans. Refer Section 7.14.

Summer 2015

1. State the meaning of : **(4M)**
   - (i) Sampling length
   - (ii) Lay
   - (iii) Waviness
   - (iv) Roughness w.r. to surface finish.

Ans. Refer Article 7.5.

2. Define CLA and RMS values as applied to surface roughness. **(4M)**

Ans. Refer Article 7.8 (b) and (c).

Winter 2015

1. State the meaning of flaw, waviness, lay and roughness with respect to surface finish. **(4M)**

Ans. Refer Articles 7.5 (e), 7.3, 7.5 (b) and 7.2.

2. Define the terms, R_a, CLA, RMS and R_z values with respect to surface finish. **(4M)**

Ans. Refer Articles 7.6, 7.8 (c), 7.8 (b) and 7.8 (a).

3. Sketch primary and secondary texture. Show on it sampling length and lay. **(4M)**

Ans. Refer Articles 7.3 and 7.5.

Summer 2016

1. Distinguish between 'Primary texture' and 'Secondary texture'. **(4M)**

Ans. Refer Article 7.4.

2. Define CLA and RMS values as applied to surface roughness measurement. **(4M)**

Ans. Refer Article 7.8.

Winter 2015

1. State the meaning of flaw, waviness, lay and roughness with respect to surface finish. **(4M)**

Ans. Refer Articles 7.5 (e), 7.3, 7.5 (b) and 7.2.

2. Define the terms, R_a, CLA, RMS and R_z values with respect to surface finish. **(4M)**

Ans. Refer Articles 7.6, 7.8 (c), 7.8 (b) and 7.8 (a).

3. Sketch primary and secondary texture. Show on it sampling length and lay. **(4M)**

Ans. Refer Articles 7.3 and 7.5.

Summer 2016

1. Distinguish between 'Primary texture' and 'Secondary texture'. **(4M)**

Ans. Refer Article 7.4.

2. Define CLA and RMS values as applied to surface roughness measurement. **(4M)**

Ans. Refer Article 7.8.

Winter 2016

1. Define the terms. **(4M)**
   (i) CLA (ii) R_a (iii) RMS (iv) R_z

Ans. (i) CLA: Refer Article 7.8 (c). (ii) R_a: Refer Article 7.6.
(iii) RMS: Refer Article 7.8 (b). (iv) R_z: Refer Article 7.8 (a).

2. Explain the terms. **(8M)**
   (i) Primary texture (ii) Secondary texture
   (iii) Sampling length (iv) Lay

Ans. (i) Primary texture: Refer Article 7.2.
(ii) Secondary texture: Refer Article 7.3.
(iii) Sampling length: Refer Article 7.5 (f).
(iv) Lay: Refer Article 7.5 (h).

Summer 2017

1. Explain: **(4M)**
   (i) Primary texture, (ii) Secondary texture, (iii) Sampling length, (iv) RMS value in surface finish

Ans. (i) Primary texture: Refer Article 7.2.
(ii) Secondary texture: Refer Article 7.3.
(iii) Sampling length: Refer Article 7.5 (d).
(iv) RMS value in surface finish: Refer Article 7.8 (b).

2. Explain Taylor-Hobson-Talysurf with neat sketch. **(4M)**

Ans. Refer Article 7.14.

3. State methods of evaluation of surface roughness. Explain any one in detail. **(4M)**

Ans. Refer Articles 7.8 and 7.10.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

***

Chapter 8

MACHINE TOOL TESTING

About This Chapter ...

This chapter has a weightage of 4 marks and assigned duration is 04 hours. Here, we learn Different Alignment Tests like Parallelism, Straightness, Squareness testing, Roundness, Circularity etc. carried out on Lathe, Milling and Drilling machines.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	08 Marks	S-09	08 Marks
W-09	08 Marks	S-10	08 Marks
W-10	08 Marks	S-11	08 Marks
W-11	04 Marks	S-12	12 Marks
W-12	12 Marks	S-13	12 Marks
W-13	12 Marks	S-14	12 Marks
W-14	08 Marks	S-15	08 Marks
W-15	04 Marks	S-16	08 Marks
W-16	04 Marks	S-17	04 Marks

8.1 ALIGNMENT TEST OR GEOMETRICAL TEST

QUESTION

1. What is alignment test of a machine tool? State the instruments/equipments needed for it. **(S.T.P.-II)**

- When the machine tool is idle and unloaded, tests performed are called as **alignment tests**.
- **Alignment test** is carried out **'to check grade of manufacturing accuracy of the machine tool'**. It consists of checking the relation between various machine parts or elements (such as bed, table, spindle etc.).
- Alignment tests include checking of

(i) Parallelism (ii) Squareness (iii) Flatness (iv) roundness

Instruments required for alignment tests:

(i) Dial gauge, (ii) Dial gauge stand, (iii) Spirit level,
(iv) Mandrels, (v) Straight edges.

8.2 PERFORMANCE TEST OR PRACTICAL TEST

- **Performance test** consists of checking the accuracy of finished components and is known as **'Practical Test'**.

- It is carried out to know whether the machine tool is capable of producing the parts within the specified limits or not.
- Therefore, performance test consists of making the arrangements to conduct actual test on the machine, so that, accuracy of finished products can be checked.

8.3 DIFFERENCE BETWEEN ALIGNMENT TEST AND PERFORMANCE TEST

QUESTIONS

1. Differentiate between ‘Alignment Test’ and ‘Performance Test’ on any four parameters. **(W-08, 10, 12; S-13)**
2. Distinguish between 'Alignment test' and 'Performance test' of machine tool. **(S-15)**
3. Compare alignment test with performance test on any four parameters. **(W-15)**
4. Distinguish between 'Alignment test' and 'Performance test' of a machine tool. **(S-16)**

Alignment Test	Performance Test
1. Alignment tests are carried out for checking various parts of machine like spindle, slides, holding tables etc.	1. Performance tests are carried out to check the performance of machine tool in working condition.
2. Alignment test is also called *Geometrical Test.*	2. Performance test is called *Practical Test.*
3. These tests are carried out, when the machine tool is idle and not loaded (unloaded condition).	3. These tests are carried out in loaded condition (working).
4. These tests are carried out to check the grade of manufacturing accuracy of machine tool.	4. These tests are carried to check the accuracy of finished products.

8.4 PARALLELISM

QUESTION

1. Define parallelism. Explain how will you check parallelism of two axes and parallelism of an axis to a plane? **(W-09, S-14)**

Two vertical faces of any machine part are said to be parallel, when both of them are accurately at right angle to their common horizontal base.

(i) Parallelism of Two Axes:

- The parallelism of axes of two cylinders is to be tested.
- The instrument used for the test is **'dial gauge'**. It is supported on a base of such shape that, the base slides along one of the cylinders. The dial gauge is so adjusted that, its Feeler (Plunger) slides along the another cylinder.

- Maximum deviation between the axes of the cylinder at any point may be determined by gently rocking the dial gauge in a direction perpendicular to axis (1).

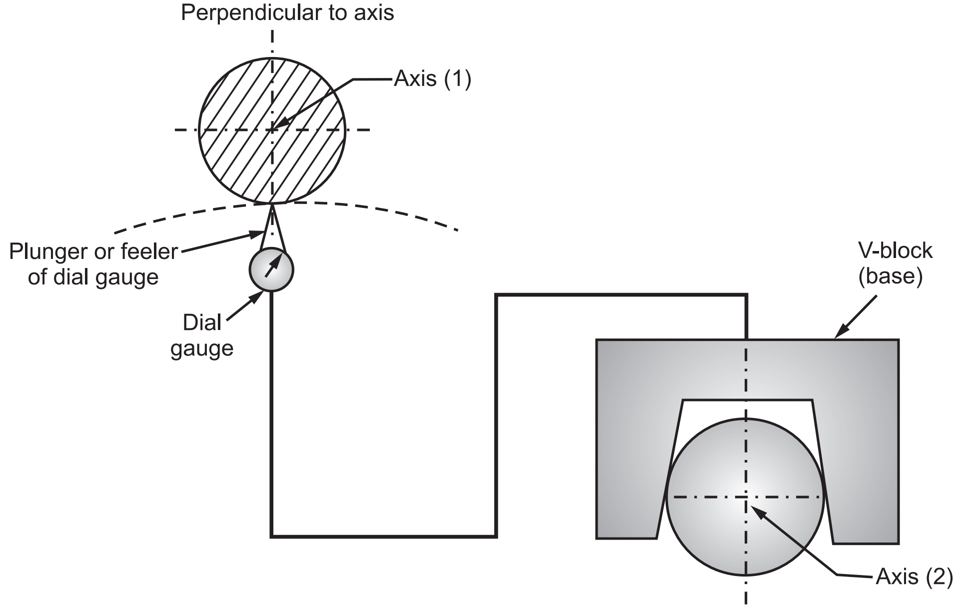


Fig. 8.1: Parallelism of two axes

(ii) Parallelism of Two Planes:

QUESTIONS

1. What is parallelism testing? What is the procedure for testing parallelism of two planes, in which, one plane is moving? **(S-10, 13)**
2. Explain how the parallelism between two planes and parallelism between two axes is checked with neat sketch. **(S-17)**

- The test for parallelism of two planes is carried out in two directions. Dial gauge is held on a support with a flat base and placed over one plane, [say plane (1)].
- Dial gauge is made to move over plane (1) for considerable length or distance in such a way that, its feeler or plunger is continuously resting over the surface of another plane [say plane (2)].

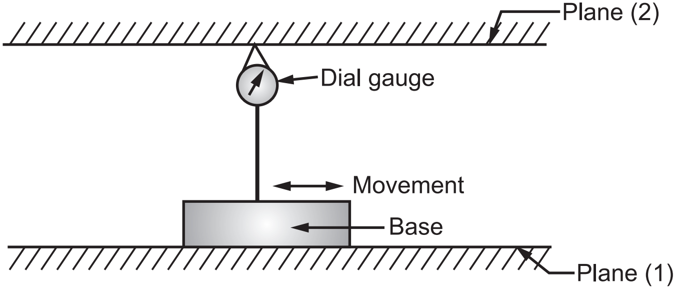


Fig. 8.2: Parallelism of two planes

(iii) Parallelism of an Axis to a Plane:

QUESTION

1. Explain, how will you check parallelism of two axes and parallelism of an axis to a plane? **(W-09)**

- In this test, a dial gauge is held on a support with a flat base and placed over the plane under test. The plunger of dial gauge is made to touch the surface of cylinder representing the axis. Dial gauge is moved along the plane over a given length, for which, parallelism test is to be performed, and corresponding reading of dial gauge is recorded.

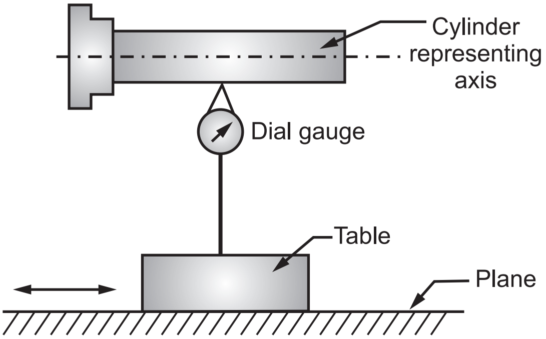


Fig. 8.3: Parallelism of an axis to a plane

(iv) Parallelism of an Axis to the Intersection of Two Planes:

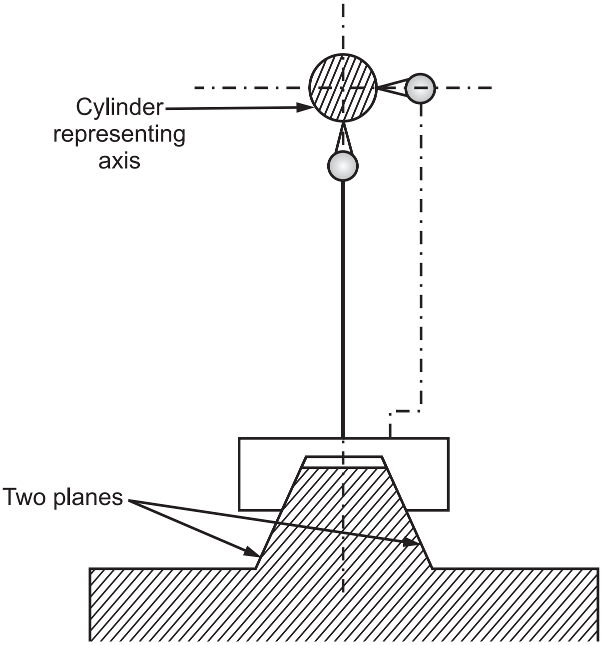


Fig. 8.4: Parallelism of an axis to the intersection of two planes

8.5 STRAIGHTNESS

- Concept of straightness can be easily understood from the following definition of line. **"A line is said to be straight over a given length, if variation in distance of all points lying on line** from two planes perpendicular to each other and parallel to general direction of line, **remains within the specified tolerance limits"**.

- In the above definition, the reference planes are so chosen that, their intersection is parallel to the straight line joining two points, which are located on the line to be tested and close to ends of the length under measurement.
- **Tolerance on straightness of a line** is defined as, *"the maximum deviation in relation to the reference straight line going to the two extremities or ends of line under examination".*

8.5.1 Test for Straightness by Using Spirit Level and Auto-collimator

- Tests for straightness can be carried out by using **spirit level** or **auto-collimator**.
- The above instruments determine the straightness of any surface by measuring the relative angular position of various adjacent sections of surface to be tested.
- For this purpose, initially a straight line is drawn on the surface under test. Then this drawn line is divided into number of equidistant sections.
- If spirit level is used, then length of each section should be equal to length of base of spirit level.
- If auto-collimator is used, then length of each section should be equal to length of base of plane reflector.
- Generally, the bases of spirit level block or reflector are fitted with two legs (or feets), such that,

  (i) Feets or legs have line contact with the surface under test, and

  (ii) Entire surface of base does not touch the surface under test.

  This ensures that, angular deviation obtained is between the two specified points.

(i) Spirit Level:

QUESTIONS

1. Explain procedure of 'straightness checking' using spirit level. **(S-09, 14; W-11)**
2. Describe with neat sketch, 'straightness checking' using spirit level. **(W-14)**

- The block of spirit level is moved linearly on the surface to be tested, in number of steps. Every step chosen is equal to the pitch distance between centre lines of two feets.
- When block of spirit level is kept on a perfectly flat surface, we observe that, vapour bubble is resting at the middle and topmost position of glass tube indicating zero reading on the scale engraved on glass tube.
- But, when the block of spirit level is moved over surface test, then this vapour bubble moves away from the middle position due to irregularities in straightness of surface. This variation in the spirit level is measured, which gives the angular variation in the direction of block.
- Angular variation can be correlated in terms of the difference of height between two points by knowing the least count of level and length of the base.
- Limitation of spirit level: It can be used to find out variation in straightness of horizontal surface only.

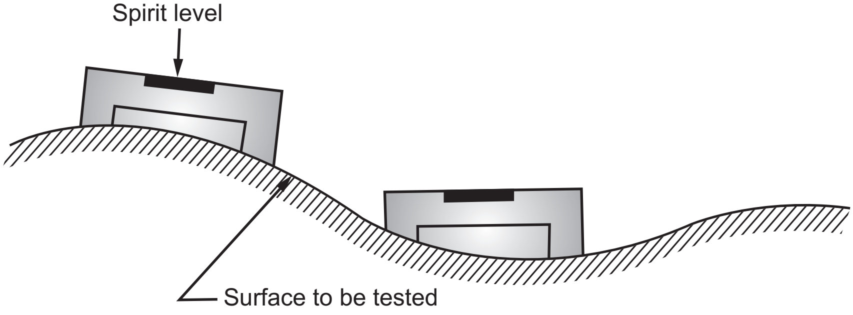


Fig. 8.5

(ii) Auto-collimator:

- Auto-collimator can be used to measure the straightness of surface in any plane.
- Auto-collimator is placed at a distance of 0.5 to 0.75 metre from the surface to be tested. It is held in desired position on any rigid support, which is independent of the surface to be tested.
- A parallel beam from auto-collimator is projected along the length of surface to be tested.
- A block resting on two legs or feets is placed on the surface under test.
- Block carries a plane vertical reflector mounted on its extreme left side in such a way that, face of reflector is facing auto-collimator.
- Plane reflector and auto-collimator are arranged in such a way that,
  (i) image of cross wires of the collimator appears very near to the centre of eyepiece, and
  (ii) linear movement of reflector over the entire length of surface under test is completed.
- Now, the reflector is moved towards the other end of surface in steps equal to the centre distance between the two legs or feets. During this movement, the tilting of reflector is noted down in seconds from the eyepiece.
  1 second of arc = 0.000006 mm/mm
- Now, the reflector is set at first position a-b (perfectly flat and straight) and first micrometer reading is noted down. This line is labelled as 'a-b' is treated as datum line or reference line. Successive readings at positions b-c, c-d, d-e …… and so on, are taken, till the plane reflector completes its linear movement over the entire length of surface under test.

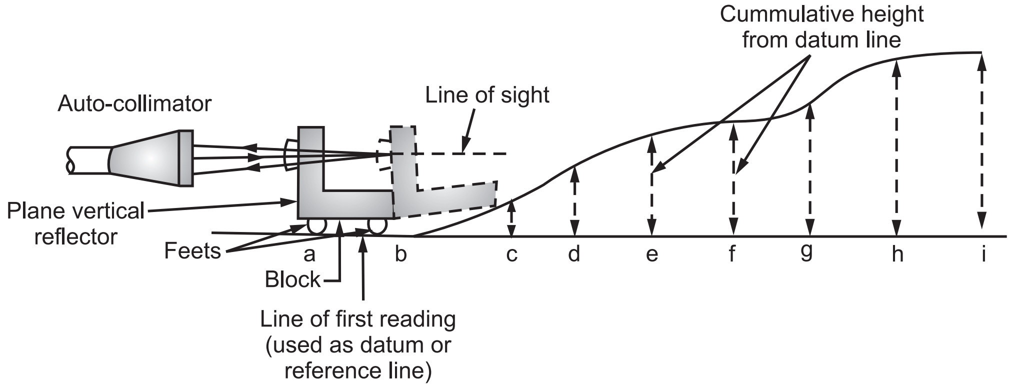


Fig. 8.6: Auto-collimator checking straightness

8.6 SQUARENESS

QUESTIONS

1. Explain how squareness of an axis of rotation with a given plane can be tested? **(S-10)**
2. Explain the terms – Squareness and Flatness. **(S-11)**
3. Draw sketch and write procedure for squareness test of drilling machine spindle. **(S-12)**

Two planes or two straight lines and a plane are said to be perpendicular, when the error of parallelism in relation to a standard square does not exceed more than specified permissible value.

(a) Squareness of an Axis of Rotation with a Given Plane:

- For this test, dial gauge is mounted on an arm, which is attached to a spindle representing the axis of rotation. Plunger of dial gauge should be (i) parallel to axis of rotation and, (ii) touching the plane.
- As the spindle revolves, the dial gauge describes a path having its plane perpendicular to the axis of rotation.

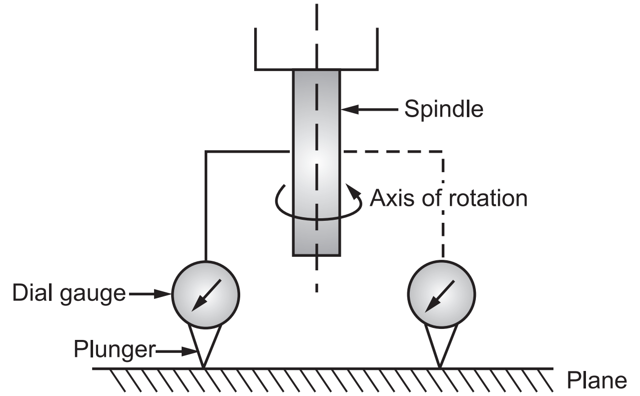


Fig. 8.7

- When no testing plane is specified, the dial gauge is revolved or rotated through 360°. Variation observed in the readings of instrument represents the deviation in parallelism between the plane of path traversed by dial gauge and the plane to be tested.

(b)To Check Squareness between Two Perpendicular Planes:

QUESTION

1. Explain squareness checking between two planes. **(S-09, 14; W-09)**

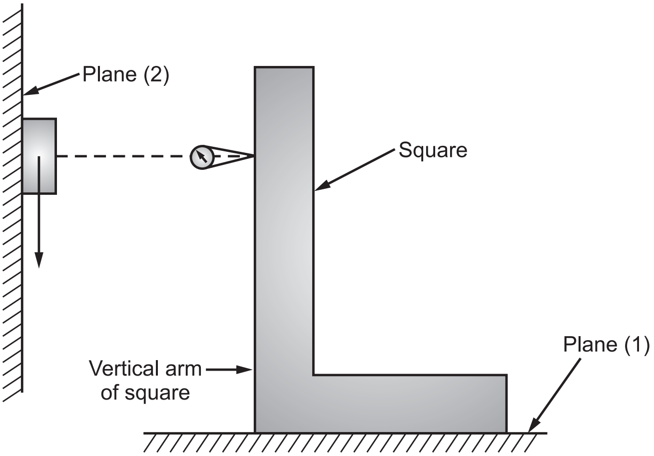


Fig. 8.8

- Squareness of two planes (1) and (2) is checked by placing a square on one plane (i.e. plane 1).

- Parallelism of 2nd plane with the free vertical arm of square can be determined by moving or sliding the dial indicator along 2nd plane.
- Plunger (feeler) of dial gauge is free to move against vertical arm of square.

(c) To Check the Squareness between Two Perpendicular and Fixed Axes:

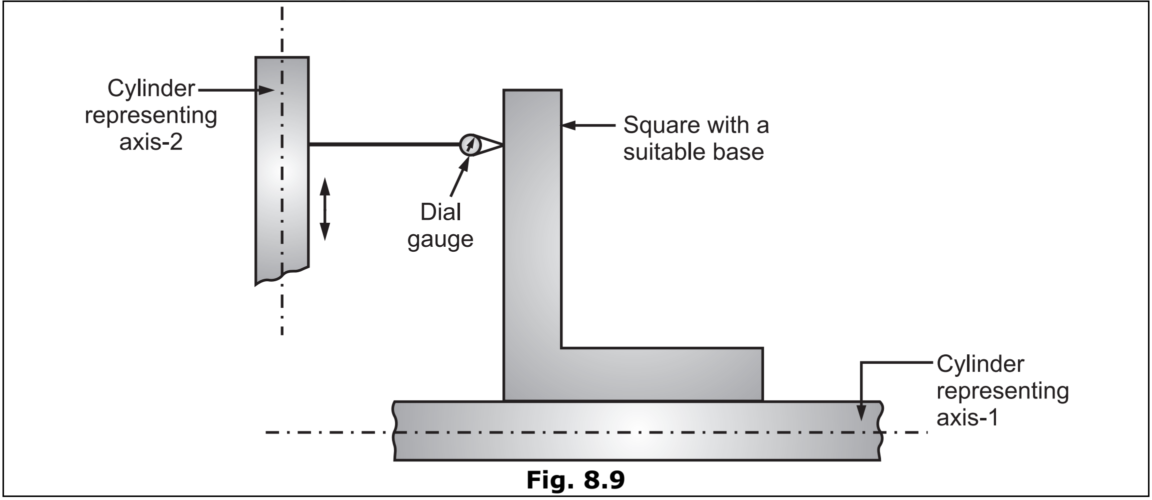


Fig. 8.9

- A square is fixed by keeping its base on the fixed horizontal cylinder representing axis-1.
- Dial gauge is mounted on vertical cylinder representing axis-2 with the help of dial gauge stand.
- Plunger of dial gauge is set in such a way that, it will be always touching or resting against the vertical arm of square.
- Now, move the dial gauge in vertical direction either upward or downward, against the vertical arm and note down variations in the readings of dial gauge indicator.
- No variation in the readings of dial gauge display indicate perfect squareness of two perpendicular axes.

8.7 SQUARENESS TESTING

(a) An axis at 90° to a Plane and Axis is Fixed:

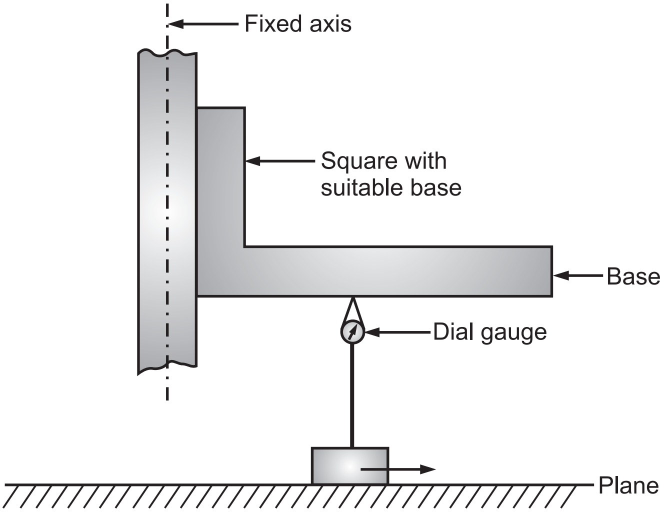


Fig. 8.10

- In this test, a dial gauge indicator is mounted on horizontal plane with the help of dial gauge stand having suitable base. Base of dial gauge indicator is allowed to move over the horizontal plane.
- To check the squareness, the dial indicator is moved along the plane and its plunger (filler) is moving against the surface of square.

(b) Optical Test for Squareness:

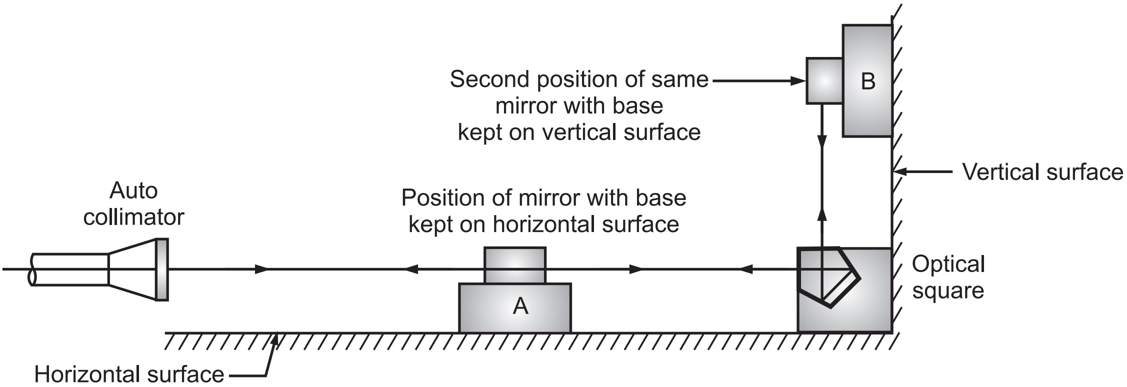


Fig. 8.11

- Squareness of any two machined surfaces can be easily checked by using **auto-collimator**.
- The axis of the incident beam from the auto-collimator forms the measuring datum or reference line.
- An optical square is utilized for turning the incident beam through exactly 90°.
- In order to perform this squareness test, it is assumed that, faces of both surfaces (horizontal as well as vertical) are perfectly straight.
- In addition to auto-collimator and optical square, a mirror block, made up of stainless steel and having flat base is required.
- Initially, flat base of mirror block is kept over the horizontal surface, in such a way that, collimator is exactly aligned with horizontal surface under test.
- A reading is taken in collimator at position 'A'. Refer figure 8.11.
- Now, the mirror block with base is kept over the vertical surface at position B as shown in the Fig. 8.11 and optical square reading is noted down in position 'B'.
- These two readings obtained corresponding to mirror positions 'A' and 'B' are compared, to find out whether both machined surfaces are accurately perpendicular (90°) to each other or not?
- If not, the readings will show magnitude and direction of error.

8.8 ROUNDNESS

- **Roundness** is defined as, *"a condition of a surface of revolution (like cylinder or cone) where all points of the surface intersected by any plane perpendicular to a common axis have same distance from centre.*

8.9 CIRCULARITY

- **Circularity** is defined as, *"a two-dimensional geometric tolerance, which controls how much a feature can deviate from a perfect circle?".*

8.10 DIFFERENCE BETWEEN ROUNDNESS AND CIRCULARITY

QUESTION

1. Distinguish clearly between roundness and circularity. **(W-13)**

Roundness	Circularity
1. Roundness is defined as 'a condition of a surface of revolution (like cylinder or cone), where all points of the surface intersected by any plane perpendicular to a common axis have same distance from centre.	1. Circularity is defined as "a two-dimensional geometric tolerance, which controls, how much a feature can deviate from a perfect circle?"
2. Roundness represents a particular geometric form of a body of revolution in all three dimensions.	2. Circularity represents a characteristic form of entire periphery of a plane figure, in two dimensions.

8.11 MEASUREMENT OF ROUNDNESS

Most commonly used methods or devices for measurement of roundness are:

(a) Diametral,
(b) Circumferential confining gauge,
(c) Rotating on centres,
(d) V-block piece rotating against a set probe having,
  (i) Fixed angle
  (ii) Adjustable angle.
(e) Three point probe (spaced equally at 120°)
(f) Accurate spindle:
  (i) Part fixed, Exterior spindle with Probe rotating.
  (ii) Probe fixed, Part rotates with spindle.

8.11.1 Rotating on Centres

- Roundness of some parts can be inspected by mounting them on centres. Refer figure 8.12.
- Reliability of results obtained depends on various factors like,
  (i) Inspected angles of centres
  (ii) Alignment of centres
  (iii) Surface conditions of centres and centre holes, and
  (iv) Run out of job
- Error in any one factor or combined error due to errors in all above factors will affect the result of this roundness test. Result obtained may be different from the actual (real) values.
- Therefore, while performing roundness test by this method, the above factors must be considered, examined and fulfilled.
- For workshop purpose, **'V'-block method** is quite accurate. This method is capable of indicating normal requirement of accuracy. For example: Precise job, where more accurate and more reliable results are desired.

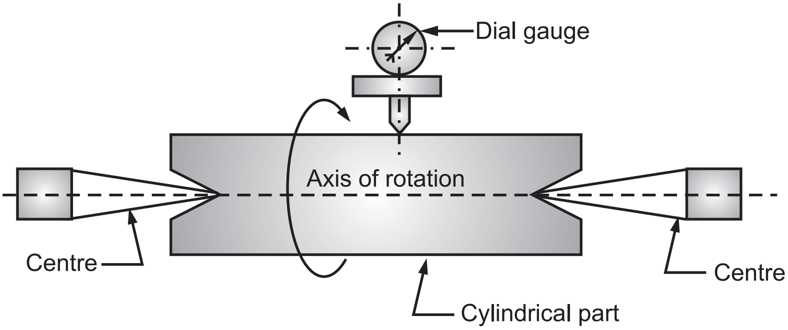


Fig. 8.12

8.12 CO-AXIALITY

- Co-axiality describes all relations of concentricity applied to a specified condition.
- **Coaxiality** is defined as, "a specific condition in which, two figures of same form and orientation are having a common axis. **For example:** Two cylinders.

8.13 RUN-OUT

- Run out describes about running of a job. Refer figure 8.13, where job is rotating with some another centre than its geometrical centre.
- **Run out** is defined as, "distance between the centre corresponding to job running and geometrical centre of job".

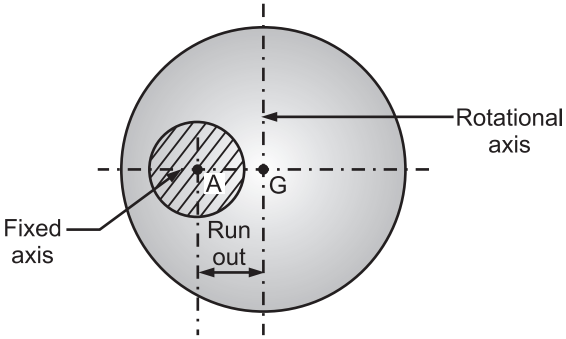


Fig. 8.13: Figure illustrating roundness

8.14 FLATNESS USING OPTICAL FLAT

QUESTIONS

1. By using optical flat and monochromatic light source, explain how you will determine, *"whether the given surface is concave or convex"*? **(W-08, 12; S-12, 16)**
2. Explain the terms – Squareness and flatness. **(S-11)**
3. Explain, how will you check flatness of work table on a horizontal milling machine? **(S-11)**
4. Explain how will you determine, whether the given surface is concave or convex by using optical flat and monochromatic light? **(S-15)**
5. Describe the flatness testing done by using optical flats. **(S.T.P.-II)**

- **Flatness** is defined as 'a three dimensional geometric tolerance, which controls, how much a feature can deviate from a flat plane?'.
- **Optical flats** are cylindrical pieces made up of a transparent material like glass or quartz. Contact surfaces of optical flat are polished to high accuracy.
- Optical flats are used to test the flatness of highly finished and lapped surfaces, such as, gauges, gauge blocks, micrometer anvils etc.
- When an optical flat is placed on the surface of workpiece, it will not form an intimate contact, but will be at slight inclination to the surface, forming an air gap between the two surfaces.

Working:

- Fig. 8.14 shows the optical ray diagram of optical flat. Initially, optical flat is kept on the surface to be tested and monochromatic light is made to incident on optical flat.

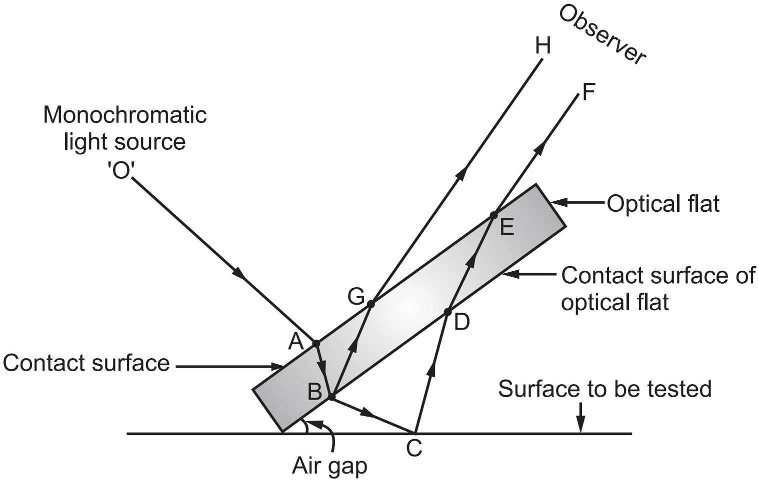


Fig. 8.14: Ray diagram of optical flat

- From light source 'O', the light ray 'OA' will be incident to top surface of optical flat. From 'A', it goes to 'B' due to refraction. At point 'B', the ray is divided into two parts i.e. reflected rays. And, they are B-C-D-E-F and B-G-H.
- From 'B', the refracted ray BC will come out till, it reaches point 'C'. From 'C', reflection will take place till 'D'. At 'D', again refraction takes place till point 'E'. And, again reflection will take place from E to F.
- Two parameters, (i) Air gap between optical flat surface under test, and (ii) Phase difference between the reflected rays, will generate the dark and bright band, which gives the idea about flatness of surface.
- Basic interference phenomena takes place between light rays, optical flat and surface under test.
- Ray B-C-D-E-F is longer than B–G–H by an **optical distance of 'BCD'.**

- If BCD = n · λ (n = 1, 2, 3, ...), two rays are said to be in phase and join together as a bright band.
- If BCD = $\frac{n}{2} \cdot \lambda$ (n = 1, 2, 3..), then rays are said to be out of phase and they cancel effect of each other and generate dark band.

Method to Decide whether the given Surface is Concave or Convex?

- When the surface under test is perfectly flat, there will be patterns of straight, parallel and equally spaced alternate light and dark bands on the surface.
- Now, even if light pressure is applied, there will not be change in the fringe pattern. [Refer Fig. 8.15 (a)]. It indicates and confirms the flatness of surface.
- But, if the surface is not flat, the bands obtained will be curved.

  If the bands curve around the line of contact, the **surface is convex**. [Refer Fig. 8.15 (b)].
- If the bands curve in opposite direction from the line of contact, the **surface is concave**. [Refer Fig. 8.15 (c)].

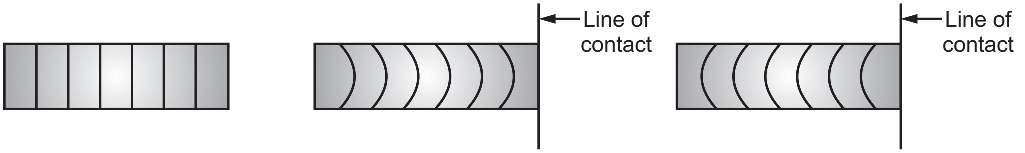


Fig. 8.15 (a): Flat surface **Fig. 8.15 (b): Convex surface** **Fig. 8.15 (c): Concave surface**

Important Note:

- If the surface under test is curved, and hence curvature of bands is more, circular bands with a central bright spot at the point of contact are observed. [Refer Fig. 8.16 (a)].
- To determine, *whether the surface is convex or concave*, it is pressed lightly with finger-tip at one edge. We may find two observations, which are given below.
  - (i) If centre of bands is displaced and the fringes come closer, then surface under test is concluded as convex surface. [Refer Fig. 8.16 (b)]. Here, **pressure is applied at one of edges**.
  - (ii) But, if no change is observed after applying light pressure about an edge, then **light pressure is applied at the centre**. Now, if the bands move apart and quantity of bands is reduced in numbers, then surface under test is concluded as concave surface. [Refer Fig. 8.16 (c)].

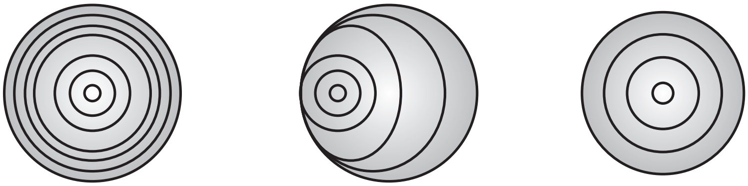


Fig. 8.16 (a): Curved surface **Fig. 8.16 (b): Convex surface** **Fig. 8.16 (c): Concave surface**

8.15 NPL FLATNESS INTERFEROMETER

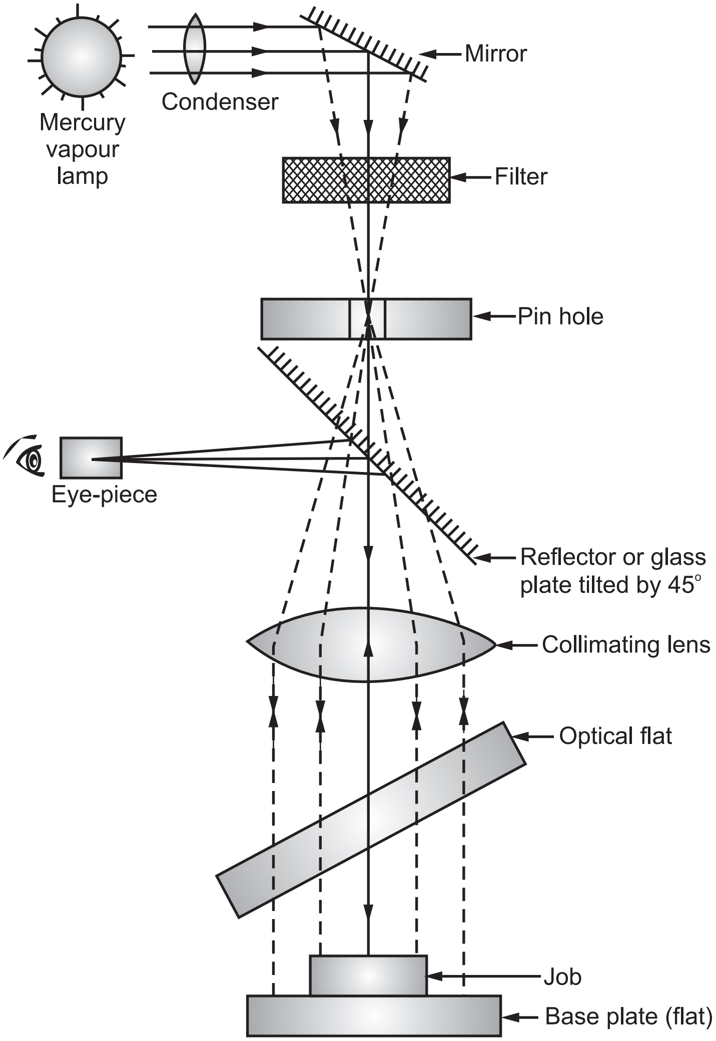


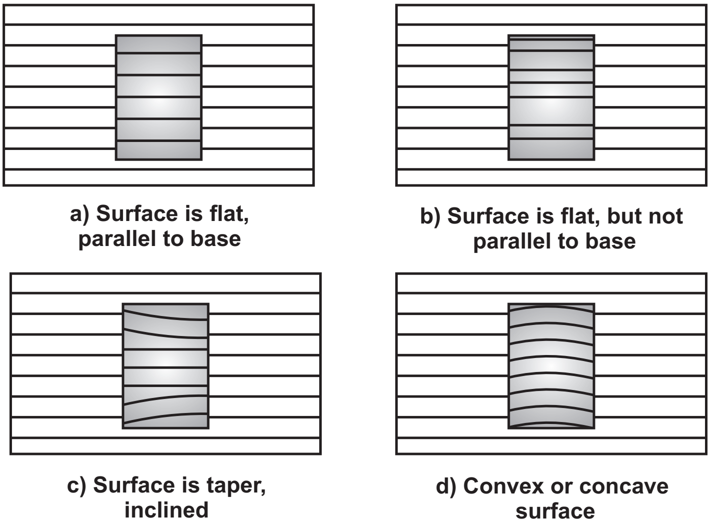
Fig. 8.17: Ray diagram of NPL flatness interferometer

Working:

- An instrument known as 'NPL flatness interferometer' is designed by National Physical Laboratory (NPL) for evaluation of surface.
- Here, flatness of the surface is compared with optically flat surface, which acts as a base.
- A light source (mercury vapour lamp) generates light, which passes through the green filter.
- These rays are brought to focus on pin hole, so that, its intensity can be increased.
- Pin hole is at the focal plane of a collimating lens. Due to this, radiations coming out of lens are parallel beam of light.

- The fringes formed are seen through a glass plate, which is tilted at 45° to optical axis. This glass plate is also known as reflector.
- The job to be tested is kept on the base plate (flat).
- Then optical flat, which is tilted to optical axis is placed above the job keeping a small gap (distance) between them. Due to this, interference fringes are generated.
- Some of the rays will reach to the flat base, which generate different fringes.
- Whereas remaining rays will reflect from surface of job under test, which shows property of that surface.

Observations:


a) Surface is flat, parallel to base

b) Surface is flat, but not parallel to base

c) Surface is taper, inclined

d) Convex or concave surface

Fig. 8.18: Observations through interferometer

Conclusion:

(a) If the **surface** to be tested is **flat and parallel** to the base plate (flat), then fringe patterns on both, base plate and job are straight, parallel and equally spaced. [Fig. 8.18 (a)].

(b) If **job is flat**, but **not parallel to base**, then **straight and parallel fringes of different pitch** are observed. [Fig. 8.18 (b)].

(c) If **job has taper**, then it is concluded that, surface is **inclined with some different angle**. [Fig. 8.18 (c)].

(d) If **job is convex or concave**, then fringe patterns are observed [Fig. 8.18 (d)].

8.16 VARIOUS TESTS TO BE CARRIED OUT ON LATHE, MILLING AND DRILLING MACHINES

- Geometric tests are carried out to ensure geometric accuracy, which influences the quality of the product and precision to be maintained during the service life of a machine tool.
- Geometric tests of tool under static and dynamic conditions is called as **"Machine tool geometry"**.

(a) Alignment Tests on Lathe Machine: (W-10)

1. **Levelling** of machine.
2. True running of **main cylinder**.
3. Axial slip of **main spindle.**
4. True running of **headstock centre**.
5. Parallelism of **main spindle** and **saddle**.
6. Parallelism of **tailstock guidways** with **carriage movement**.
7. Alignment of both **centres** in **vertical plane**.
8. Pitch accuracy of **lead screw**.
9. Axial slip of **lead screw**.

(b) Alignment Tests on Milling Machine:

1. Axial slip of **cutter spindle**.
2. True running of **internal taper**.
3. Parallelism of **table** with **arbor rising**.
4. Surface parallelism with **longitudinal movement.**
5. **Traverse movement** parallel with **spindle axis**.
6. Central T-slot parallel with longitudinal movement.
7. Central T-slot square with **arbor**.
8. Testing of column ways for **knee square** with **table**.
9. Test of **side inclination**.
10. Over **arm parallel** with **spindle**.

(c) Alignment Tests on Drilling Machine:

1. Flatness of **clamping** surface of **base**.
2. Flatness of **clamping** surface of **table**.
3. Perpendicularity of **drill head** guide to **base**.
4. Perpendicularity of **drill head** guide with **table**.
5. Perpendicularity of **spindle sleeve** with **base**.
6. **True** running of **spindle** taper.
7. Parallelism of **spindle** axis with its **vertical** movement.
8. Squareness of **clamping** surface of table to its **axis**.
9. Squareness of **spindle** axis with **table**.
10. Test for **deflection**.

8.17 ALIGNMENT TESTS ON LATHE MACHINE

QUESTIONS

1. Sketch the experimental set-ups for following alignment tests: (i) Parallelism of main spindle to saddle movement, (ii) True running of head stock centre. **(W-10)**
2. Describe with neat sketch, alignment testing of a lathe machine as per IS standard procedure. **(S.T.P.-II)**

1. True Running of Lathe Main Spindle: (W-08)

- Fig. 8.19 shows the arrangement of required set-up for conducting test.

- This test can be carried out by using a dial gauge and stand only.
- Fix the dial gauge to stand and to a carriage of lathe machine.
- Confirm that, the plunger/pointer/feeler of dial gauge touches the lathe spindle.
- Headstock is then rotated about its own axis. If the indicator does not show any variation in readings taken during the test, then it confirms *'true running of lathe spindle'*.

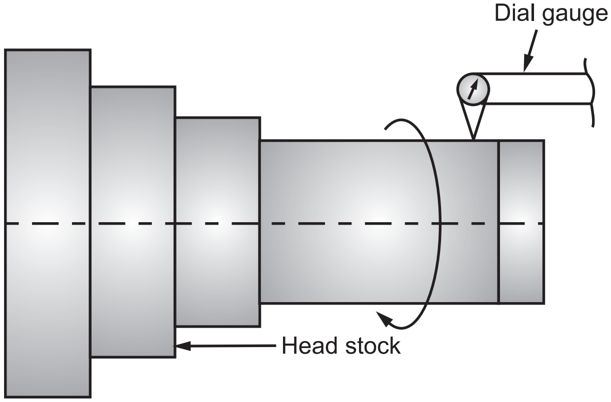


Fig. 8.19: Alignment of lathe machine

2. Levelling the Lathe Machine:

- Levelling of lathe machine is to be checked by using a sensitive spirit level.
- For accuracy, machine should be installed such a way that, lathe bed will be truly horizontal.
- Spirit level is then placed at a – a as shown in Fig. 8.20.

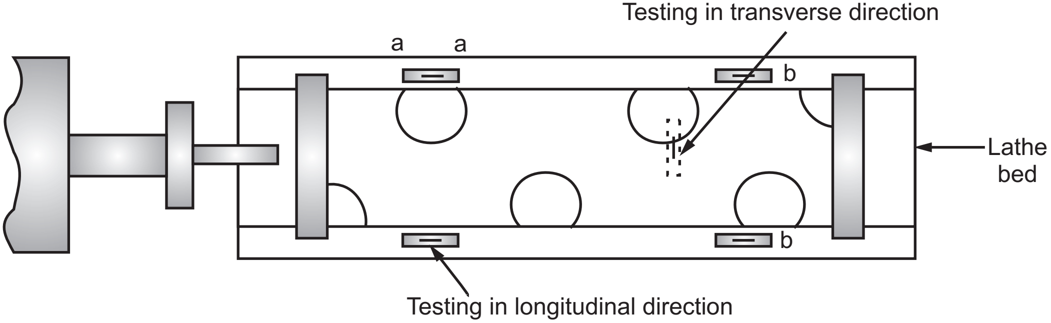


Fig. 8.20: Levelling of lathe machine

- **For tests in horizontal direction**, spirit level is moved along the length of bed and readings at various places are noted down.
- **For tests in the transverse direction**, spirit level is placed on a bridge piece to cover the gap between front and rear guide ways. Now, note down the reading (b – b).
- If the readings obtained are found to be uniform and constant throughout, it can be concluded that, the bed surface is perfectly levelled.

3. Parallelism of Main Spindle to Saddle: **(W-10)**

- A dial gauge along with its stand is mounted on the saddle, such that, its plunger always touches the mandrel. Now, the saddle is moved to perform "To and Fro motion".

- It checks the parallelism in vertical as well as horizontal plane.

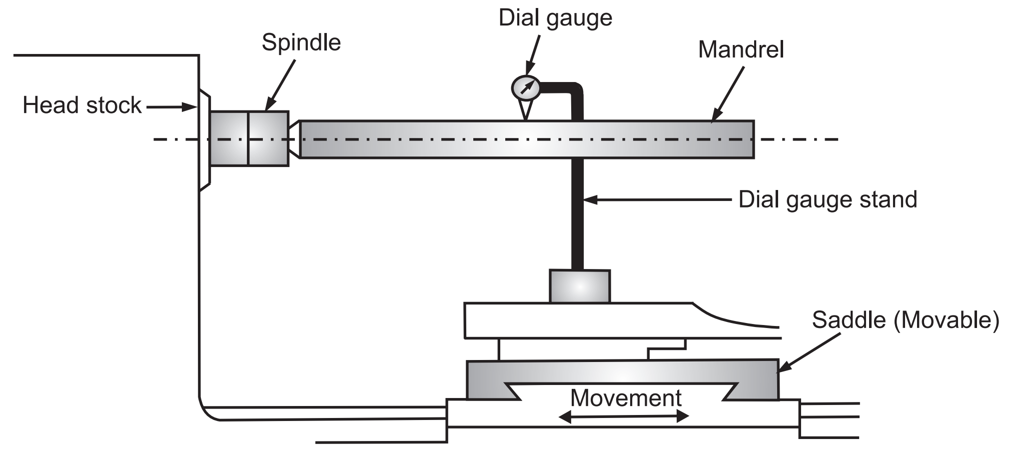


Fig. 8.21

4. Parallelism of Tail Stock Sleeve with Saddle Movement:

- Dial gauge indicator is used for measurement of parallelism.
- Dead centre of tailstock is mounted on the end of the sleeve, which is capable of moving in horizontal (axial) direction.
- Sleeve surface should be perfectly parallel to the movement of carriage.
- Dial gauge indicator with its stand is mounted on the saddle, and the saddle is moved to and fro (horizontally towards left and right).
- Dial gauge indicator will check the parallelism in horizontal plane as well as vertical plane .

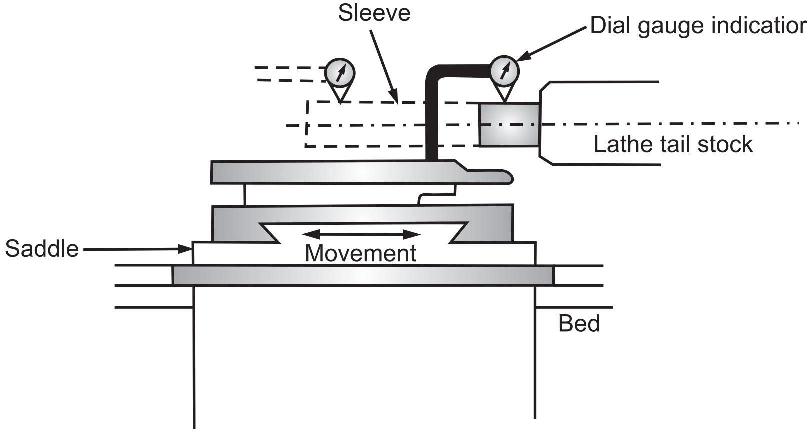


Fig. 8.22

5. Parallelism of Tailstock Guideways with the Movement of Carriage:

- This test is carried out for testing **alignment of spindle axis** with the **tailstock centre**, when job is fixed and held between headstock and tailstock.
- A test block, specially designed for this test is placed on tailstock guide ways.

- Dial gauge indicator with the help of its mounting stand, is mounted on the carriage as shown in Fig. 8.23, and plunger (or feeler) set in such a way that, it will be always in contact with the workpiece.
- For this purpose, plunger of dial gauge is pressed against both the surfaces, horizontal and vertical.
- Now, carriage is moved for a specified distance.
- During this movement of carriage, variations (if present) are noted down.
- This test is carried out on both, horizontal and vertical surfaces.

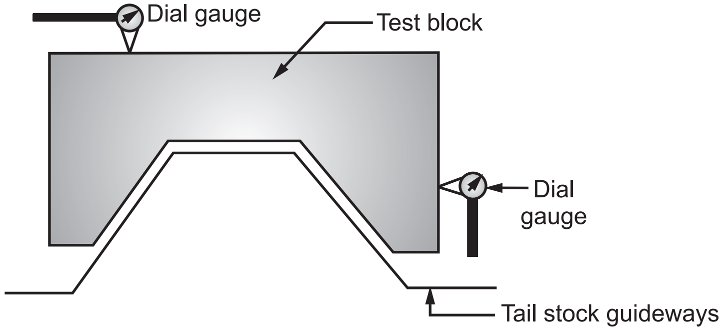


Fig. 8.23

6. Alignment of Both Centres in Vertical Plane:

QUESTION

1. Describe with neat sketch, alignment testing of lathe centres in vertical plane. **(W-14)**

- Fix a mandrel between two centres of lathe machine.
- Mount dial gauge indicator with magnetic stand on carriage of machine.
- Press the plunger of dial gauge indicator against the surface of mandrel in vertical plane only.
- Maximum variation in the readings should not exceed the permissible specified limit. Then move the carriage, to note initial and final readings.

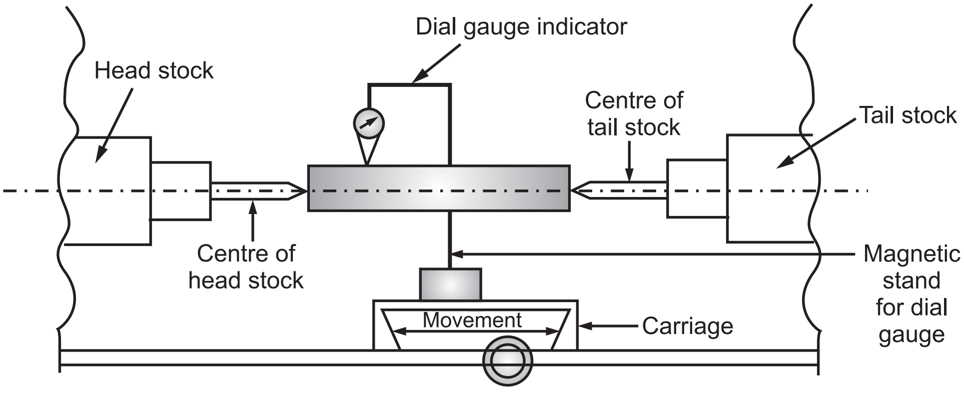


Fig. 8.24

7. Parallelism of Lathe Axis with Lathe Bed: **(W-08, 12; S.Q.P.)**

- A test mandrel and a dial gauge indicator are used for this test.
- Test mandrel is held and fixed between the centres of head stock and tail stock of lathe machine.

- Dial gauge is held in the compound rest in such a way that its plunger will be always in contact with the surface of mandrel.
- Variations in the dial gauge indicator (if found) in vertical as well as horizontal plane is indicated on the dial gauge.
- Carriage is moved in traverse direction (horizontally towards left and right side). Since dial gauge is mounted on carriage, it will also move alongwith carriage movement.

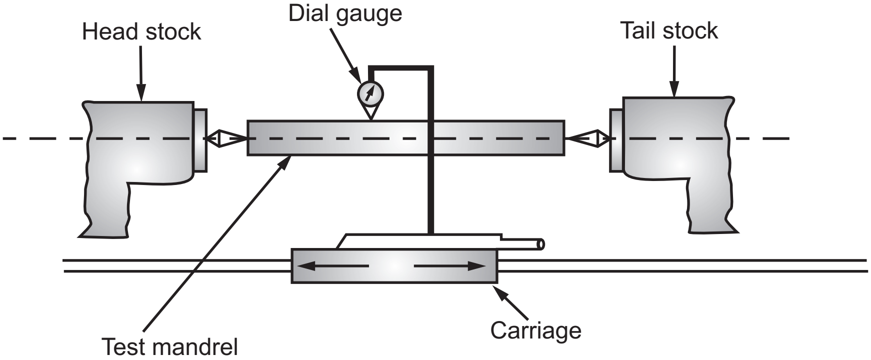


Fig. 8.25

8.18 ALIGNMENT TESTS ON MILLING MACHINE

1. **Cutter Spindle Axial Slip or Float:**
   - **Axial slip** is defined as, *"an axial movement of spindle, which may repeat positively with each revolution".*
   - Clamp the dial gauge stand to table, such that, the plunger or feeler of dial gauge indicator is touching the face of locating spindle shoulder. [Refer Fig. 8.26].
   - Now rotate the spindle about its centre and note down the variations observed in the readings shown on dial gauge indicator.
   - This is to be tested at two points 180° apart from each other. It is expected that, the value of maximum variation in dial gauge readings should not be more than specified permissible range.

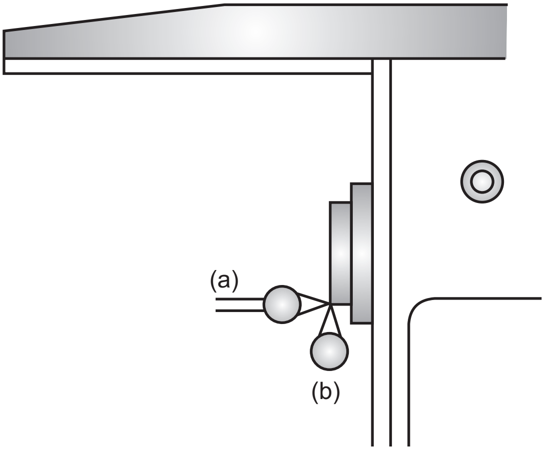


Fig. 8.26

2. Transverse Movement Parallelism with Spindle Axis:

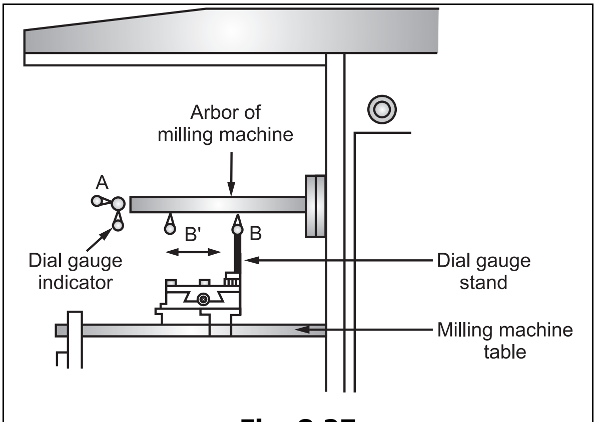


Fig. 8.27

- Fig. 8.27 shows the arrangement required to carry out test, using a dial gauge indicator along with its mounting stand arrangement.
- Mount and fix the dial gauge indicator with the help of its stand, on the table of milling machine.
- Use arbor of milling machine as shown in Fig. 8.27. A stationery mandrel can also be used instead of arbor.
- Initially, place the plunger (or feeler) of dial gauge indicator touching the arbor at point 'B' to check along vertical plane. Note down the reading of dial gauge indicator (1st reading).
- Now move the dial gauge indicator along with its stand in transverse direction upto point B' and note down the second reading of dial gauge indicator (2nd reading).
- If no variation is found in first (1st) and second (2nd) reading, then transverse movement is parallel with spindle axis.

3. True Running of Internal Taper:

- Fix a mandrel as shown in Fig. 8.28.
- Dial gauge indicator is mounted with the help of dial gauge stand, in such a way that, plunger will touch the surface of mandrel.
- It is ensured that, plunger remains in contact with mandrel, while carrying the test.
- This test is carried out at two places, given below:
  - (i) Near to spindle nose, refer position (1).
  - (ii) At a distance of 300 mm from spindle nose, refer position (2).

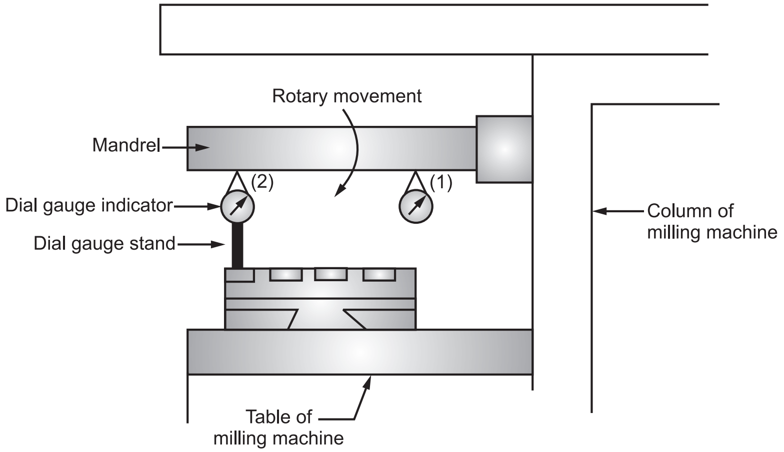


Fig. 8.28

- Consider that plunger of dial gauge indicator is at position (1). Now, rotate the mandrel and observe the readings shown on dial indicator, to find out the value of maximum variation (if present) is noted down as 1st reading.
- Now, dial gauge indicator is mounted with the help of its stand at position (2), which is 300 mm away from position (1). Repeat the same procedure and note down 2nd reading.
- Difference between 1st and 2nd readings indicates an error in true running of internal taper.
- This error should not exceed the specified permissible value.

4. **Surface Parallelism with Longitudinal Movement:**
   - Fix a mandrel and a dial gauge indicator in such a way that, the plunger of dial gauge indicator will touch the table surface. Also, plunger is slightly pressed against the table surface, so that, it will be always in contact with table surface throughout the test. Refer Fig. 8.29.
   - Test the table surface for maximum travel.
   - Readings shown by dial gauge indicator are observed to find out maximum variation (if present), i.e. error in parallelism of surface during horizontal movement. This error should not exceed more than the specified permissible value.

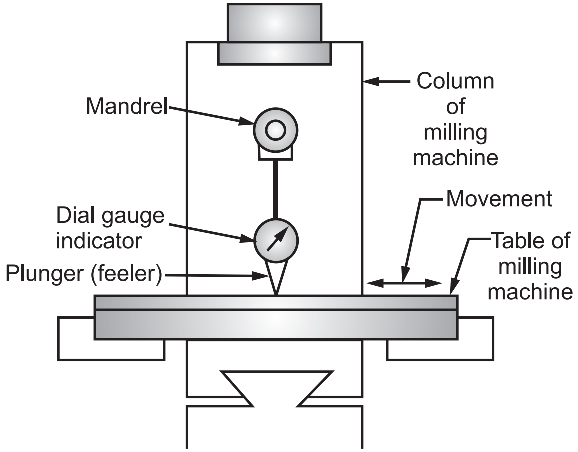


Fig. 8.29

8.19 ALIGNMENT TESTS ON DRILLING MACHINE

1. **Flatness of Clamping Surface of the Base:**
   - Fig 8.30 shows the arrangement to carry out this test on drilling machine.
   - To perform this test, Gauge block and Straight edge are used.
   - Keep the gauge blocks on the base, on which, the straight edge is to be kept.
   - A filler gauge is used to find out gap between straight edge and base (if present).
   - This gap (if present) is called as an error in flatness of claming surface. Its value should not be more than 0.1 mm per 100 mm length of clamping surface.

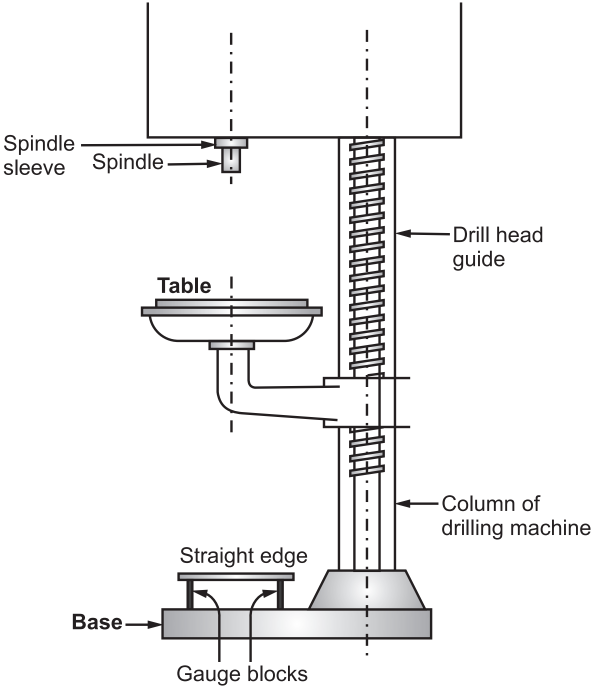


Fig. 8.30: Flatness of drilling machine table

2. Perpendicularity of Drill Head Guide to the Base Plate:

- Fig. 8.31 shows the arrangement, where frame level is used for testing.

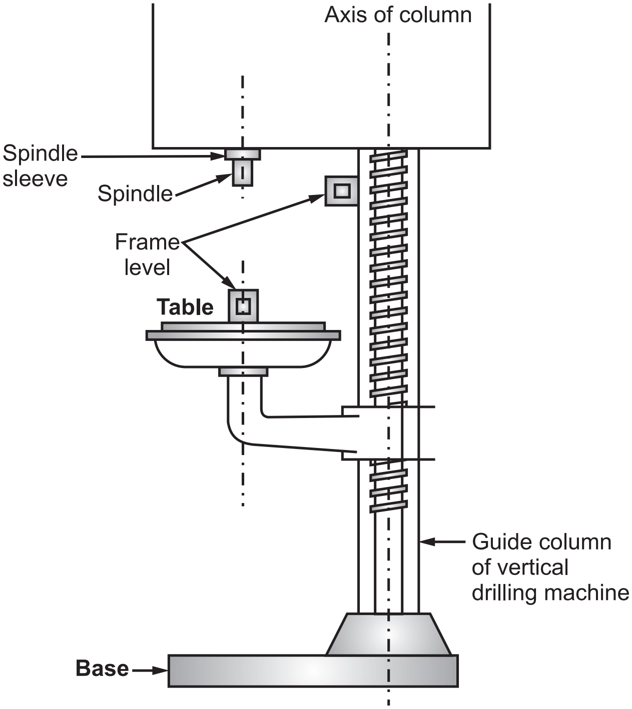


Fig. 8.31: Squareness of drill head and base

- Testing is carried out for two positions:
  (a) In vertical plane passing through the axes of both, 'spindle' and 'column'.
  (b) In a plane, which is exactly perpendicular to the vertical plane, described in position (a).
- Press the frame levels on guide column and base plate. Note down the difference between readings of the two levels, which is called as an error.
- Amount of error indicates that, drill head guide and base plate are not exactly perpendicular to each other. If value of error is very very small as negligible, perfectness in perpendicularity can be proved.
- But, if observed readings of both frame level are same, then we conclude that, drill head guide and base plate are exactly perpendicular to each other.

3. True Running of Spindle Taper:

- Place a 'Test mandrel' properly with drill head as shown in Fig. 8.32.
- Mount the dial gauge indicator on table surface.
- Now, rotate the mandrel slowly and note down the variations observed in readings of dial gauge indicator.
- Maximum variation found in the readings is called as error.
- The error should not exceed 0.03 mm per 100 mm length, over which, readings are observed.

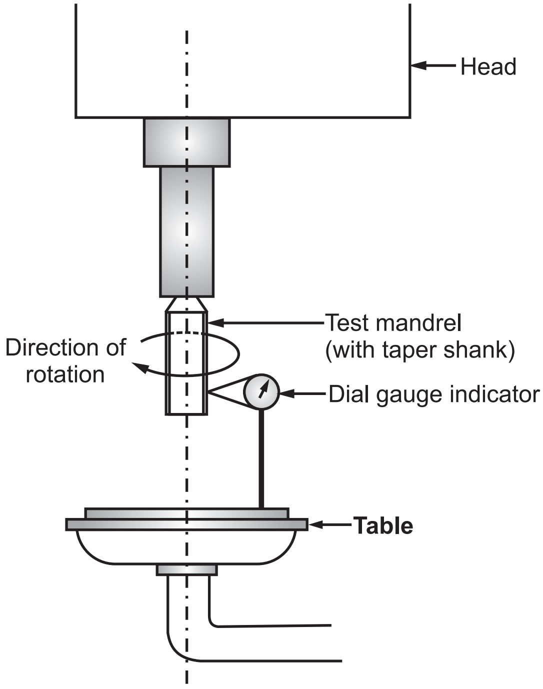


Fig. 8.32: True running of spindle taper

4. Squareness of Clamping Surface of Table to its Axis:

- Mount test mandrel in the tapered hole of spindle.
- Mount dial gauge indicator, in such a way that, its plunger is appropriately pressed against the table surface. [Refer Fig. 8.33].
- Now, rotate the table slowly and note down the variations in the readings observed, from dial gauge.
- Maximum difference in the readings observed is called as error. Value of error should not be more than 0.05 per 300 mm of diameter.

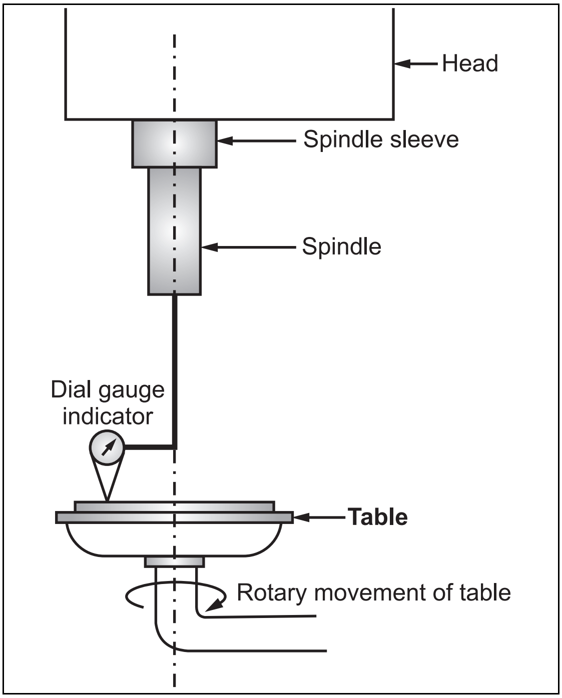


Fig. 8.33: Squareness of clamping surface

5. Parallelism of Spindle Axis with Vertical Movement in Case of *'Bench Drilling Machine'*:

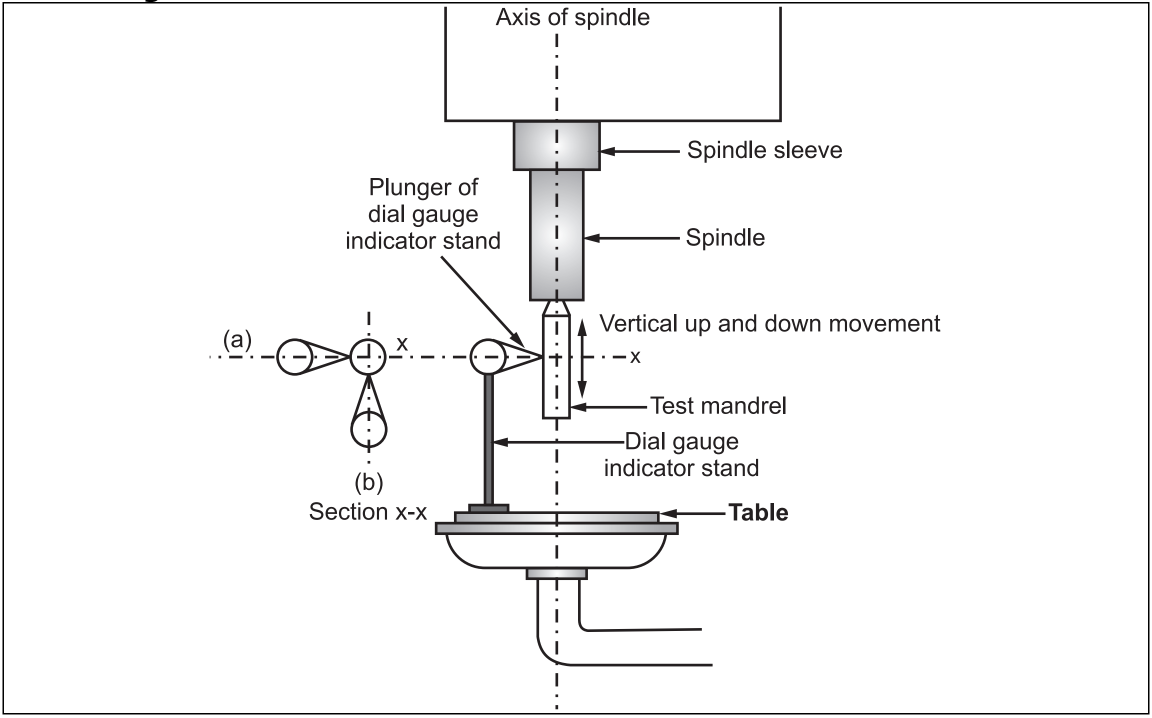


Fig. 8.34: Bench drilling machine

- This test is performed in two planes, which are at right angle (perpendicular) to each other.
- A 'Test mandrel' is fitted in the spindle of machine.
- A dial gauge indicator is mounted on the table surface in such a way that, its plunger always remains in contact with the surface of mandrel.
- Spindle is made to move slowly in upward and downward direction. Readings at different points are noted down from dial gauge indicator. Maximum variation in the readings observed is called as error in the parallelism.

SOLVED PROBLEMS

Problem 8.1: *Calculate the Alignment error for Headstock and Tailstock for the following data:* **(S-12, 13)**

Initial Reading of Dial Indicator = 0.1 mm
Final Reading of Dial Indicator = 0.2 mm
Movement of Carriage along longitudinal direction = 100 mm

Solution: Given Data:

Initial Reading of Dial Indicator = 0.1 mm
Final Reading of Dial Indicator = 0.2 mm
Total transverse movement = 100 mm

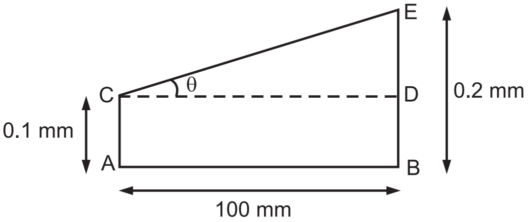


Fig. 8.35

From the figure,

We have, $$\tan\theta = \frac{ED}{CD} = \frac{ED}{AB} = \frac{EB - DB}{AB} \qquad [\because\ l\,(CD) = l\,(AB)]$$

$$\therefore \qquad \tan\theta = \frac{0.2 - 0.1}{100} \qquad [\because\ DB = CA = 0.1\text{ mm}]$$

$$\therefore \qquad \tan\theta = \frac{0.1}{100} = 1 \times 10^{-3}$$

$$\therefore \qquad \theta = \tan^{-1}(1 \times 10^{-3}) = \mathbf{0.05729°}$$

Also, $$\sin\theta = \frac{ED}{CE}$$

$$\therefore \qquad CE = \frac{ED}{\sin\theta} = \frac{EB - DB}{AB} = \frac{0.2 - 0.1}{\sin(0.05729)} = \mathbf{100.01\ mm}$$

Important Points

- **Alignment or Geometrical test:** Alignment test is carried out 'to check the grade of manufacturing accuracy of the machine tool'. It consists of checking the relation between various machine parts or elements (such as bed, table, spindle etc.).
- **Performance or Practical test:** Performance test (also called as practical test) consists of checking the accuracy of finished components.

- **Straightness:** "A line is said to be straight over a given length, if the variation of the distance of its points from two planes perpendicular to each other and parallel to the general direction of the line, remains within the specified tolerance limits".
- Tests for straightness can be carried out by using spirit level or auto-collimator.
- **Roundness:** It is defined as 'a condition of a surface of revolution (like cylinder or cone), where all points of the surface intersected by any plane perpendicular to a common axis in case of cylinder and cone are equidistant from the axis or centre'.
- **Circularity:** It can be defined as, "a two-dimensional geometric tolerance, which controls how much a feature can deviate from a perfect circle".
- **Flatness:** It is defined as 'a three dimensional geometric tolerance, which controls how much a feature can deviate from a flat plane'.
- **Squareness:** Two planes, two straight lines and a plane are said to be perpendicular, when the error of parallelism to a standard square does not exceed more than a specified permissible value.

Theory Questions for Practice

1. Differentiate between alignment test and performance test.
2. Define parallelism and straightness.
3. Explain the procedure of straightness testing by using spirit level.
4. Define squareness, circularity and roundness.
5. Define co-axiality and run-out.
6. Describe the procedure of checking flatness using optical flat.
7. Enlist the various tests carried out on lathe machine.
8. Enlist the various tests carried out on milling machine.
9. Enlist the various tests carried out on drilling machine.
10.

MSBTE Questions and Answers (As Per G - Scheme)

Winter 2014

1. Describe with neat sketch : **(8M)**
   (i) Straightness checking using spirit level.
   (ii) Alignment testing of lathe centres in vertical plane.

Ans. Refer Article 8.5.1 (ii), Article 8.17 (6).

Summer 2015

1. Explain how will you determine, whether the given surface is concave or convex by using optical flat and monochromatic light? **(4M)**

Ans. Refer Article 8.14.

2. Distinguish between 'Alignment test' and 'Performance test' of machine tool. **(4M)**

Ans. Refer Article 8.3.

Winter 2015

1. Compare alignment test with performance test on any four parameters. **(4M)**

Ans. Refer Article 8.3.

Summer 2016

1. Distinguish between 'Alignment test' and 'Performance test' of a machine tool. **(4M)**

Ans. Refer Article 8.3.

2. By using optical flat and monochromatic light source, explain how will you determine, *'whether the given surface is convex or concave or flat'*? **(4M)**

Ans. Refer Article 8.14.

Winter 2016

1. Draw the sketch and write the procedure for squareness testing of drilling machine spindle with table. **(4M)**

Ans. Refer Article 8.19 (4).

Summer 2017

1. Explain how the parallelism between two planes and parallelism between two axes is checked with neat sketch.

Ans. Refer Articles 8.4 (ii) and 8.4 (i). **(4M)**

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 9

QUALITY CONTROL

About This Chapter ...

This chapter has a weightage of 6 marks and assigned duration is 3 hours. Here, we learn Quality, Its definition and Characteristics. We also learn Quality of design, Quality of conformance, Quality of performance, Reliability, Cost, Quality assurance, Inspection and its stages.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	08 Marks	S-09	04 Marks
W-09	08 Marks	S-10	08 Marks
W-10	04 Marks	S-11	04 Marks
W-11	04 Marks	S-12	04 Marks
W-12	04 Marks	S-13	04 Marks
W-13	08 Marks	S-14	09 Marks
W-14	12 Marks	S-15	10 Marks
W-15	12 Marks	S-16	08 Marks
W-16	12 Marks	S-17	12 Marks

9.1 QUALITY

QUESTION

1. Define the term 'quality'. State meaning of terms, 'quality of products' and 'quality of services'. **(S.T.P.-II)**

Quality is a relative term, commonly used with reference to the end use of the product.

- Any equipment or machine is manufactured for doing a specific work.
- To construct an equipment or machine, many parts or components (either manufactured within the company or manufactured and supplied from vendors/suppliers or readymade items bought out from market) are assembled. Thus, performance of machine depends upon individual performance of each component or part.

Quality may be **defined** in several ways as,

(a) The component is said to possess good quality, if it works well in the equipment, for which, it is meant. Thus, quality is defined as "*fitness for purpose*".

(b) *Quality* is a *distinguishing feature* or *grade of product* in appearance, performance, life, reliability, taste, odour, maintainability etc.

(c) *Quality* is a degree, to which, a specified product manufactured by a company is preferred by consumers over competing products of equivalent grade, but manufactured by other companies.

(d) *Quality* is a *measure of degree of general excellence* of the product.

Fig. 9.1: Spiral of progress in quality

9.2 FACTORS AFFECTING THE QUALITY OF PRODUCT (W-16)

- Machines.
- Raw Material used.
- Men (skilled or semiskilled or unskilled labour).
- Manufacturing processes.
- Dimensional variations in the product.
- Various stages of inspection.
- Types of material handling systems.

9.3 QUALITY CHARACTERISTICS

- **Quality characteristic** can be defined as, *"any physical or chemical property such as dimension, temperature, pressure, taste, odour or other such requirement used to define the nature of product or service".*
- For example: In case of a hollow metallic pipe, its quality can be defined by stating the quality characteristics, such as, external and internal diameters, length, type of metal used etc.

Classification of Quality Characteristics:

- Quality characteristics can be classified on the basis of various parameters, such as type, method of measurement etc.

(i) According to type:

- Table 9.1 given below shows the classification of quality into 5 types.
- Each type is illustrated with the help of suitable examples.

(ii) According to analysis:

- Quality characteristics may be:
  - **(a) Directly measurable** like Weight, shear stress, specific gravity, length etc.
  - **(b) Non-measurable** like rejections due to flaws, cracks, breakages etc.

Table 9.1: Classification of Quality Characteristics

Type	For Example
1. Technological	Diameter, Length, Viscosity, Temperature etc.
2. Psychological	Beauty, Taste, Odour etc.
3. Contractual	Safety, Guarantee, Warranty etc.
4. Time oriented	Reliability, Maintainability, Life etc.
5. Ethical	Honesty, integrity etc.

9.3.1 Sequence of Activities for any Quality Characteristic

- Fig. 9.2 shows the sequence of activities performed for each quality characteristic.

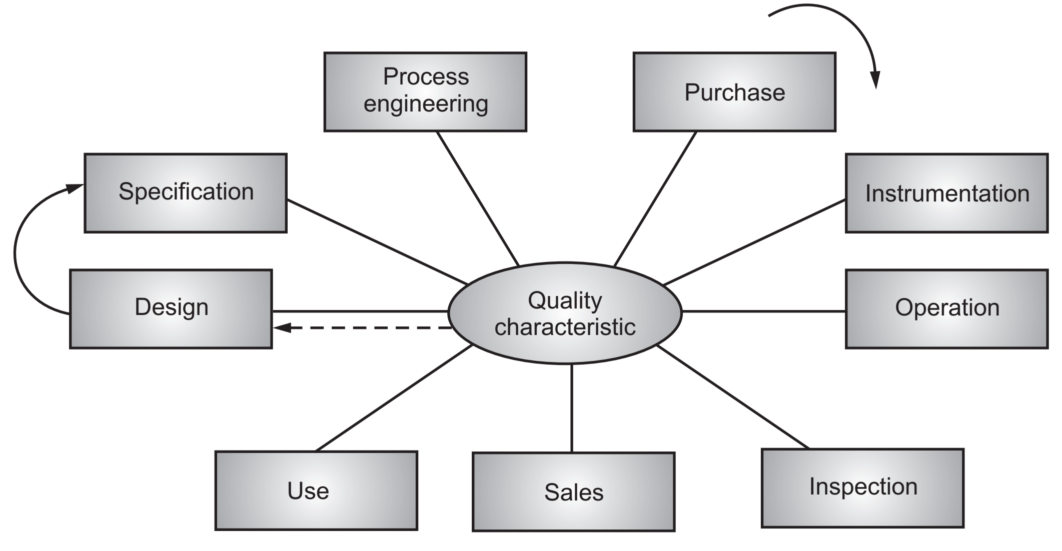

Fig. 9.2: Sequence of activities for any quality characteristic

9.4 QUALITY SPECIFICATION

QUESTION

1. Write a short note on 'Quality specification'. **(W-08)**

- Specification is a definition of design. Design remains a concept in the mind of design engineer, until he defines it through verbal description, sample drawing etc.

- Demands of consumer are analyzed and then translated into requirements desired in the product to be designed, developed and produced for sales in market. These requirements are called as *specifications*. Thus, each specification contains list of essential characteristics and their tolerances.
- One specification may be sufficient or separate specifications may be necessary to describe the quality characteristics of any material or product etc.
- Once a specification is available, anybody in the industry can communicate very easily with anybody else. Also, design engineers can use short hand specifications to define a complex product in simple way, so that, it can be understood by everybody working in various departments of company, especially production, inspection, marketing, sales etc.

9.5 TYPES OF SPECIFICATIONS

9.5.1 Standard Specifications

- The work of specification has been greatly simplified by growth of standard, for materials, components, processes, tests and products etc.
- Most of the countries have their own standard bodies. These standard bodies formulate the specifications for various types of products.
- In India, it is Bureau of Indian Standard (BIS). There are a number of technical committees working in BIS for standardizing the specifications for the benefit of consumer as well as producer. The members of committee are selected from manufactures, consumers, research organizations, government departments and other relevant fields.

9.5.2 Consumer Specifications

- When BIS specifications are not available or not suitable for a particular customer need, the customer provides specifications to suit his particular needs and if the producer agrees, he produces the product. These are called as *consumer specifications.*

9.5.3 Company Specifications

- When a company manufactures the products based on its own specifications due to varied constraints and the consumer accepts them, the specifications may be called as *company specifications*.

9.5.4 Contract Specifications

- They are the specifications decided by mutual contract agreed between manufacturer (producer) and customer. They are formulated and developed specifications, which indicates the compromise between consumer specifications and company specifications.

9.5.5 Process Specifications

- It is necessary to specify the process to produce a particular product with specified quality.

- They may include,
  - Specification identification.
  - Material to be used is identified by shorthand designation.
  - Sequence of operations to be performed.
  - Description of each operation.
  - Process conditions (such as time cycle, temperature, pressure, humidity (etc.) required to be maintained in order to produce the product, with minimum deviations.

9.5.6 Test Specifications

- They include,
  - Need and scope of test.
  - Purpose of test.
  - Apparatus to be used i.e. testing instruments etc.
  - Method of selection and preparation of a sample, for inspection.
  - Test procedure.

9.6 QUALITY CONTROL

- **Quality control** is defined as, "an effective system for integrating the quality development, quality maintenance and quality improvement efforts of various departments in an organization, so as, to enable production and services at the most economical levels, which allows full customer satisfaction".
- It can also be defined as, "the tools, devices or skills, through which, quality activities are carried out".
- By means of quality control, we can measure and compare actual quality performance with specified standards, so that, necessary actions can be taken in case of deviations.

9.7 OBJECTIVES OF QUALITY CONTROL

QUESTION

1. State the various objectives of the quality control. **(S-17)**

- **Improved Income:** To improve company’s income by making the product more acceptable to customers.
- **Cost Reduction:** To reduce company’s production cost by improving quality of products being manufactured, which obviously reduces number of non-defective products, scrap and hence economical loss.
- **Interchangeability:** To achieve interchangeability in mass production.
- **Customer’s Satisfaction:** To ensure satisfaction of customer by manufacturing products of high quality level, thereby minimizing number of consumer complaints regarding replacement of defective product received and poor performance of product causing trouble to operate.
- **Optimum Quality:** To produce optimum quality at minimum price.
- **Integration of Quality Effects:** To integrate quality development, quality maintenance and quality improvement efforts of various departments.
- **Quality Mindness:** To create quality mindness among the workers.

9.8 QUALITY OF DESIGN

QUESTION

1. Write a short note on 'Quality of design'. **(W-08)**
2. State and explain the meaning of (i) Quality of design, (ii) Quality of conformance and (iii) Quality of performance with suitable examples. **(S.Q.P.)**
3. State the meaning of 'Quality of Design' and 'Quality of Conformance'. **(S-16)**
4. State the various factors controlling the quality of design. **(S-17)**

- Quality of design is concerned with the *tightness of specification* for manufacturing product.
- Quality of design is defined as, "the quality specified by design engineer, on behalf of customer".
- A design specified by very tight and closed tolerances to basic size of component to be manufactured is said to have higher quality of design than a design specified by wide or loose tolerances.
- For example: A part to be manufactured with drawing tolerance of ± 0.001 is considered to have better quality of design than a smaller part with drawing tolerance of ± 0.01.
- Generally, greater the requirement for strength, fatigue resistance, life, function and interchangeability of a manufactured item, better is the quality of design.
- Needless to say that, design should be simplest and least costly without any compromise in customer requirements.

Factors Governing Quality of Design:

- Types of customers in the market.
- Intended life, environmental condition, reliability, improvement in continuity of service.
- Specific requirements such as strength, fatigue resistance, life, interchangeability of manufactured items.
- Economical considerations with Profit to company.

9.9 QUALITY OF CONFORMANCE

QUESTIONS

1. What is quality of conformance? List factors controlling the quality of conformance? **(S-10, 15, W-12)**
2. Explain the economics of quality of conformance. **(S-11, 13)**
3. Explain quality of conformance and quality of performance. **(W-13)**
4. State the meaning of 'Quality of Design' and 'Quality of Conformance'. **(S-16)**
5. Explain quality of conformance and quality of performance and state factors affecting quality of product. **(W-16)**

- **Quality of conformance** is concerned with, how well; the *manufactured product conforms* to the *'quality of design'*.
- Quality of conformance is an important area of quality control, where most of the sampling methods and statistical techniques have been experimented and used to analyse the quality of manufactured components or parts.
- When a consumer purchases a product from market, and starts to operate it, then performance (in actual depends upon, (i) Quality of design, and (ii) Quality of conformance.

Factors Governing Quality of Conformance:

- Raw materials, machines, tools, measuring instruments should be capable of producing finished parts having adequate standards. In addition, they should be maintained properly.
- Appropriate process selection and adequate process control.
- Trained and experienced operators.
- Effective inspection programme.
- Feedbacks of internal inspection as well as customers should be analysed for taking corrective action.
- Proper care should be taken in transportation, shipment and storage of finished products or goods.

9.10 QUALITY OF PERFORMANCE

QUESTIONS

1. Explain quality of performance. **(W-13)**
2. Explain quality of conformance and quality of performance and state factors affecting quality of product. **(W-16)**

- **Quality of performance** is concerned with, *'how well the manufactured product gives its performance'*.
- It deals with the total performance of product.
- **Factors Governing Quality of Performance:**
  (i) Quality of design, and
  (ii) Quality of conformance.
- Even if, the quality of design is best, the product may give poor performance due to lack of conformance control. Similarly, if quality of conformance is best, the finished product may not perform well, because quality of design specified before actual manufacturing is not correct.
- Therefore, we conclude that, best possible quality of design and good quality of conformance, together will ensure excellent quality of performance.
- If quality of performance of product is not good, then it leads to
  (i) Increase in consumer complaints,
  (ii) Increase in consumers' claims for replacement within specified warranty period, against damaged product.
  (iii) Increase in number of calls from consumers for repairing and servicing of product.

  It badly affects the reputation of firm and sales volume of product.
- Thus, a continuing feedback system is necessary for providing quality information to act as a basis for decision-making regarding the optimization of a quality product.

9.11 RELIABILITY

QUESTION

1. Define reliability. State the factors to be considered for achieving a reliable design. **(W-14)**

- **Reliability** is defined as, *'the probability of a product that will give satisfactory performance over sufficient time period'*.
- It is the capability of a 'product not to break down' when it is being used.
- **Quality Control** maintains consistency of product and thus affects reliability.
- **Quality Control** is entirely a separate function, which is concerned with small period required for manufacturing the product. Whereas, **Reliability** is concerned with long period of time (life of product), during its use.
- **Reliability** is also defined as, "*the probability of a product functioning in the intended manner over its intended life*".
- Mathematically, reliability is given by,

$$R_T = e^{-\lambda T}$$

Where, R_T = Reliability over life 'T'.

λ = Failure rate i.e. number of failures per unit time.

- Reciprocal of λ is called as 'Mean life' or 'Mean Time Between Failures (MTBF)'.
- Various number of components are suitably assembled to create a product. Therefore, reliability of product depends upon functioning of each component in well manner.

For Example:

- If we purchase a electric lamp, which may light properly at the time of purchase, but may burn off after 200 hours of use, then it is not said to be reliable.
- Whenever a consumer purchases a product, he expects that, it should give satisfactory performance over a reasonable long period of time; hence what is important is that, a product should function and continue to function for reasonable time.
- In majority of cases, it is not possible to check every product. Each individual product varies from other products. Then also, it is desired to function in intended manner for intended time.

9.11.1 Factors to be Considered for Achieving Excellent Reliability

(a) Protection against external parameters: Parts should be protected from extreme temperature, pressure, vibrations etc.

(b) Maintainability: Product should be easily maintainable. In case of consumer's call regarding improper functioning of product, service engineer can visit customer's place and repair it in minimum period.

(c) Simple designing: Simplicity of **product design**.

(d) Serviceability: Product should be easily serviceable.

(e) Safety: Extremely safe while operation.

9.12 MAINTAINABILITY

- **Maintainability** is defined *as, 'the probability that, a product will be restored to its operational effectiveness within the given period, when maintenance action is performed in accordance with the prescribed procedure'*.

- Maintenance action is, nothing but, the prescribed operative process to correct an equipment failure, when the equipment fails to operate.
- Maintenance is carried out at or near the place of use, where repair or replacement of failed part or product can be easily done.

9.13 COST OF QUALITY

QUESTION

1. Explain "Cost of Quality" and "Value of Quality". **(W-08, 09, 13, 16; S-12, 14)**

- Cost of quality is defined as, *"cost or expenditure incurred in carrying out the quality activities, to fulfill quality needs of consumers".*
- It includes,
  - Market research costs of discovering (to find) needs of customers.
  - Product research and development cost for creating newer product concepts.
  - Design cost of translating product concepts into specifications.
  - Cost of manufacturing planning in order to meet quality specifications.
  - Cost of inspection.
  - Cost of quality assurance.
  - Cost for processing consumer complaints, Field service and such other functions to improve quality.

9.14 VALUE OF QUALITY

QUESTION

1. Explain "Cost of Quality" and "Value of Quality". **(W-08, 09, 13, 16; S-12, 14)**

- The company is rewarded by capturing higher share of market, very less complaints from customers and firmer prices (No bargaining). If the quality of products is extremely good, then the product is said to have certain value.
- Value of quality can be defined as, "*direct or indirect returns gained by the company due to implemented missions of quality control*".
- Value of quality comprises of,

  (i) Value inherent in design.

  (ii) Value inherent in conformance to that design.
- Value inherent in design is usually called as *grade*.
- **Grade** is the **variation in specifications** amongst the competitive products of other companies doing same functional use.
- **Examples of Grade:** Appearance, Reliability, Interchangeability, Performance, Maintainability etc.

- **Benefits of value of quality:**
  - (i) Direct factors such as,
    - (a) Increase in sales volume (quantity).
    - (b) Saving due to increased production.
    - (c) Reduction in scrap and rework cost.
  - (ii) Indirect factors such as,
    - (a) Reputation of manufacturer,
    - (b) Goodwill of customer,
    - (c) Psychological stability due to increased sale,
    - (d) Security of job among workers.

9.15 OPTIMUM QUALITY OF DESIGN

QUESTION

1. Explain the meaning of optimum quality of design with the help of graph. **(S-10, 15)**
2. Explain 'cost of quality' and 'value of quality' with the help of graph. **(W-14)**
3. Explain the concept of cost of quality and value of quality by using suitable graph. **(W-15)**
4. Explain 'Cost of Quality' and 'Value of Quality' with the help of graph. **(S-16)**

- Optimum quality of design is called as the balance between cost of quality and value of quality.
- Data collected during market survey, such as, expected sale of product, profit, competition in the market etc. is used to design the component or product, which will meet the needs of consumers.
- But, it is not necessary that company should produce 100% quality product because, more the quality expected, more will be the production cost.
- Therefore, aim of company is to produce products, which will meet requirements of consumer at lower cost.
- Consider the following two cases.

  Case (I): Quality of design is improved from (1) to (2), we observe that,

  (a) Increase in cost of quality = 'C_1' (in ₹)

  Increase in value of quality = V_1 (in ₹)

  (b) $V_1 > C_1$ which shows that, gains or returns are more than the expenditure incurred for improving quality of design.

  Therefore, improvement in quality of design from (1) to (2) is profitable.

  Case (II): Quality of design is further improved from (2) to (3), we observe that,

  (a) Increase in cost of quality = 'C_2' (in ₹)

  Increase in value of quality = 'V_2' (in ₹)

  (b) $V_2 < C_2$, which indicates that, gains or returns are less than the expenditure incurred for improving quality of design. Therefore, improvement in quality of design beyond point (2) is uneconomical.
- Thus, point (2) shows optimum quality of design, and gives maximum profit.

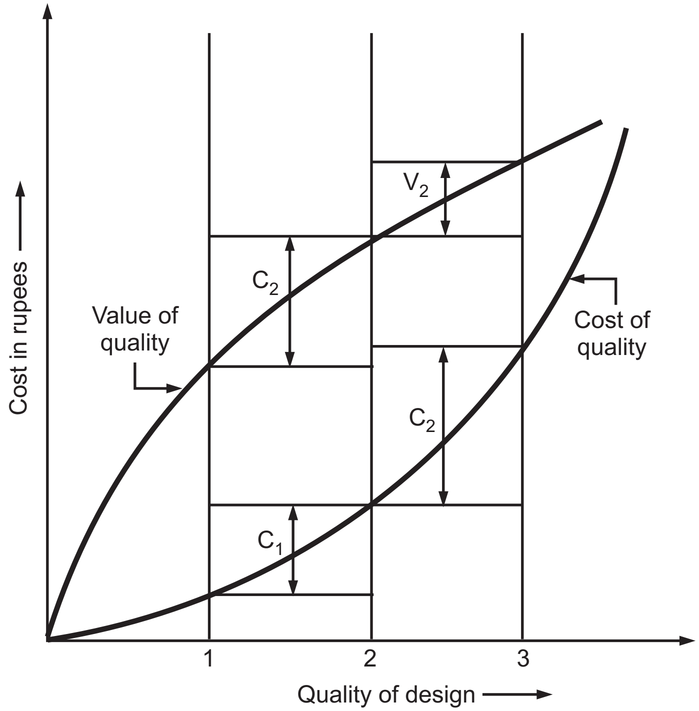

Fig. 9.3

- Therefore, improvement in quality of design upto point 2, will give maximum profit. Improvement in quality of design from point 2 to 3 is uneconomical.

9.16 ELEMENTS OF COST OF QUALITY

- Cost of quality is defined as, *"the cost of carrying out the quality functions, so as, to meet the quality needs of consumers".*
- It may be categorized into:
  (a) Cost of Prevention
  (b) Cost of appraisal
  (c) Cost of failure.

9.16.1 Cost of Prevention

- Cost of prevention is defined, as "the expenditure in carrying out the quality activities in order to prevent production of defective parts".
- This is what; we spend to ensure that, no faulty work is produced in the first place. It is the cost of quality control in its widest sense.
- It includes,
  - Cost of quality planning i.e. cost of market research and product development.
  - Cost of quality control i.e. cost associated with implementing quality plans.
  - Cost of quality engineering, technical and supervisory costs of preventing the recurring defects.
  - Cost of investigation, analysis and correction of causes of defect by quality control department.

9.16.2 Cost of Appraisal

- Cost of appraisal consists of costs associated with measuring, evaluating or auditing products, components and purchased materials.
- In other words, it is the cost of evaluating quality and identifying and separating non-conforming parts.
- It includes,
  - Receiving parts inspection.
  - In-process parts inspection.
  - Finished parts inspection.
  - Cost of maintaining accuracy of setup for inspection.
  - Maintenance and calibration of inspection equipment.
  - Review of test and processing of inspection data.
  - Quality audit.

9.16.3 Cost of Failure

- Cost of failure is the cost of all products and services, which 'fail' to comply with their specifications and drawings. It is also called as **cost of rework and repair.**
- It can be classified as,

  a) Cost of Internal failure

  b) Cost of External failure

9.16.3.1 Cost of Internal Failure

- It is the cost associated with defective products, components and materials, which failed to meet quality requirements and results in manufacturing losses.
- It includes,
  - Cost associated with scrap i.e. cost of material and labour charges.
  - Cost of rework and repair i.e. cost of converting defective items into non-defective items.
  - Cost of re-inspecting and re-testing the repaired items.

9.16.3.2 Cost of External Failure

- It consists of costs incurred, because of transportation (i.e. delivery) of defectives to the consumers.
- It includes,
  - Cost of processing complaints from the consumers.
  - Cost of inspecting and repairing defective items returned by consumers.
  - Cost of replacing the defective materials.

9.17 INSPECTION

- Inspection is *'the act of checking of material, products or components of products at various stages of manufacturing'.*
- It includes following 3 activities:
  1. Interpretation of specifications.
  2. Measurement of product.
  3. Comparison of (1) and (2) to check whether the products confirm to prescribed standards or not.
- Inspection involves checking of material, product or components of products at various stages with reference to certain pre-determined factors, detecting and sorting out defectives.

9.18 OBJECTIVES OF INSPECTION

QUESTION

1. State the various needs of the inspection. **(S-17)**

(a) **Receiving inspection:** Inspection of incoming raw material or bought out items to ensure that, they are according to specifications.

(b) **In-process inspection:** To prevent further operation on material, which is spoiled in prior operation. i.e. Inspection of raw materials or semifinished products when they undergo processing from one operation to another. This will help to isolate the faulty semi-finished goods, before they enter for next operation.

(c) **Finished good inspection:** To inspect the finished products to find out the defects and its sources. It may be necessary to perform the functional test (finished product is run to see whether, it performs according to its specifications or not?) to evaluate the fitness of product.

(d) **Consumer satisfaction and company goodwill:** Good Consumer relation by preventing the delivery of defective products to the customer.

(e) Due to development of precision measuring instruments and methods of inspection, the old crude machines have changed to better designed precision machines.

(f) Gauge and Equipment maintenance.

(g) **Decision on scrap:** It is necessary to take decision on the defective parts. Some of them may be acceptable after minor repairs.

(h) To facilitate the manufacture of interchangeable parts.

9.19 INSPECTION STAGES/TYPES

9.19.1 Incoming Inspection (Receiving Inspection)

- **Receiving inspection** is the inspection of incoming raw materials, components, sub-assemblies, and purchased parts to ensure that, they are according to required specifications.

- Aim of incoming inspection is to prevent goods, which do not fulfill the quality requirements, from entering the production process and thereby causing production problems and reducing the quality of finished products. Incoming inspection therefore takes place before the goods lead to any operation.

9.19.2 In-process Inspection

- **In-process inspection** is the inspection of raw materials, as it undergoes processing from one operation to another. It can be carried out as follows:

(1)First piece inspection:

- First piece inspection is carried out on the first item made after the machine set-up.
- If the work conforms to the prescribed standard, the operator is allowed to carry out the further production. If the work is unsatisfactory, then rectification is done at first stage only.

Advantages:

(a) Wastage is minimized at early stage of production.
(b) By testing the first piece, the faults in setting up of the machine or process can be traced out and corrected.

Disadvantages:

(a) Production of similar product is kept on hold, till first piece is inspected.
(b) During inspection of 1st piece, men and machine may remain idle. In addition to this, 1st piece is found to acceptable, then production can be resumed. But, if 1st piece produced does not conform with specifications, then machine settings are changed, several times till the conformation of 1st piece. Therefore, machine hours and men hours both are wasted and found to be accepted for want of 1st piece inspection.

(2) Floor inspection:

- Under floor inspection system, inspection is carried near the machines or at the machine shop floor.
- The inspector walks around the shop floor, from machine to machine and checks samples of the work performed by various workers.

Advantages:

(a) It is suitable, when the products manufactured are heavy in weight.
(b) After each operation, the product being manufactured is inspected to check its conformance, before going to next operation. Handling and conveying of semifinished products from shop floor to inspection department and again back to shop floor to undergo next operation, is highly reduced, if floor inspection is implemented.
(c) It reduces waiting time of semifinished products to undergo inspection due to already accumulated work in inspection department.
(d) No need to change and disturb the existing line layout of machinery.
(e) Defects may be quickly discovered and corrected.

Disadvantages:

(a) Inspection of quality may be affected by vibration, dust, poor lighting etc.

(b) There may be possibility of pressure from workers over inspector to accept the faulty work.

(c) Inspection of semi-finished products using highly précised measuring instruments to obtain accurate measurements is very difficult to perform at shop floor.

(d) Cost of inspection is high, because of need of skilled inspectors and many sets of gauging devices.

(e) There may be accumulation (storage) of semi-finished near the machines on shop floor waiting for inspection.

(3) Operator Inspection:

- The operator himself carries out inspection during manufacture.

(4) Last Piece Inspection:

- It is carried out on the last item manufactured in a given lot.
- Inspection of last item manufactured in a lot helps to identify and rectify the faults in manufacturing machines or error in settings. If these faults are not detected, and if manufacturing of next lot is started, more number of defectives will produce, causing economical cost and delay in delivery of products.

(5) Centralized Inspection:

- Under this system, inspection is carried out in a separate room fully equipped with all measuring instruments and inspection devices.
- Raw material and semi-finished products to be inspected are conveyed from shop floor to centralized inspection room.
- It is used, where, accuracy is the highest requirement and precision measuring instruments are used.
- It is also used, when the required inspection devices can not be brought on shop floor.

Advantages:

- A large quantity of jobs can be economically checked with use of very few inspection devices.
- Sub-division of inspection into simple tasks makes it possible to employ less skilled inspectors.
- Ideal conditions required for accurate measurement can be artificially maintained in inspection room.
- As there is no need of conveying measuring instruments from inspection station to shop floor, chances of their damages, wear, tear etc. due to handling are very less, and accuracy of instruments is not affected.
- Proper care of costly and delicate instruments can be taken, so that, they can inspect the jobs very accurately.
- Supervision of inspection work is possible.

Disadvantages:

- A large amount of spoiled work may accumulate at the place, before the defect is corrected at the machine.
- Handling expenses and total production time of material and total processing time, both are increased.
- Defects due to machine set-up and other machining errors are not quickly traced out.
- This method is not suitable for inspecting heavy parts.
- Semi-finished products after every operation are conveyed to central inspection room for inspection and after inspection, acceptable semi-finished parts are again sent back to shop floor for next operation.

9.19.3 Final Inspection

- It is carried out after the final manufacturing stage. All or few finished products ready for dispatch in market are inspected to know, how well, they are performing.
- Aim of final inspection is to prevent defective products being sent to customers.

9.20 DIFFERENCE BETWEEN INSPECTION AND QUALITY CONTROL

QUESTION

1. Compare inspection and quality control. **(S-09, 14; W-09, 11, 14)**
2. "Inspection is a part of quality control." Justify. **(W-15)**

Inspection	Quality control
1. It is a part of quality control.	1. It involves inspection at various stages, but only inspection does not mean quality control.
2. It is an act of checking material, parts, components or products at various stages of manufacturing and sorting out the defectives from good items.	2. It is an effective system for integrating Quality Development, Quality Maintenance and Quality Improvement efforts of various departments in an organization to enable the production to be carried out at the most economical level and to achieve consumer satisfaction.
3. It uses precision measuring instruments and gauges. For example: Vernier, Tool maker's microscope profile projector.	3. It uses tools such as statistical quality control charts, acceptance sampling, process capability study, quality audits, field complaints etc.

Inspection	Quality control
4. It is concerned with quality of past production.	4. It is concerned with the quality of future production. For example, take a sample, inspect it, if it is defective, find out the reasons and take corrective actions to avoid such defectives in future. Data obtained after inspection is evaluated to find, whether quality of products is meeting specifications or not? If not, it suggests to change process parameters.
5. Inspectors are responsible for the inspection activity.	5. Everybody working in an organization is responsible for quality of products produced.

Note: From the above comparison, it can be easily understood that, inspection results are used as inputs for quality control missions of organisation.

9.21 'QUALITY ASSURANCE FUNCTION'

- **Quality Assurance** is defined as, "the act of creating confidence amongst the consumers about quality of product". This is achieved by producing products having best quality by manufacturers to fulfill maximum requirements of customers in the market.
- Quality assurance is also defined as, "the promise or assurance given by manufacturers to consumers, that quality of product is best and it will achieve consumer satisfaction".

9.21.1 Three Important Stages of Quality Assurance

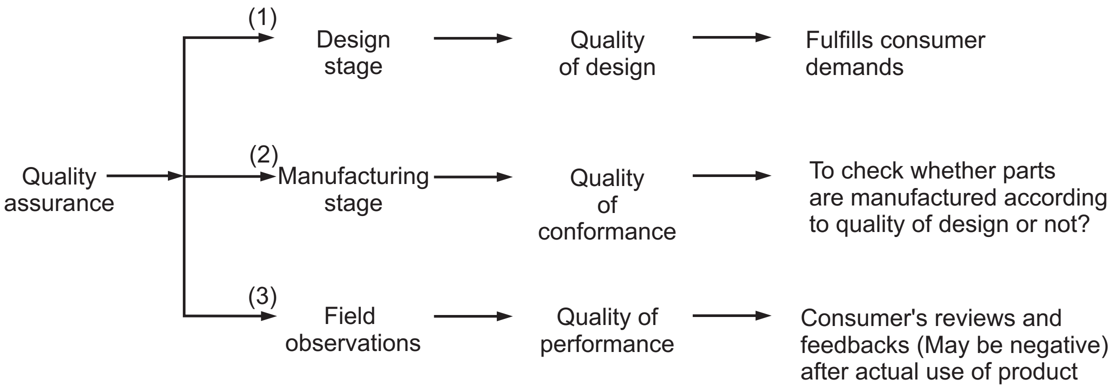

Fig. 9.4: Quality assurance function

(a) **Design stage:** It is preliminary stage, where consumer requirements are translated into design specifications. Quality of design specifications should fulfill maximum requirements of maximum consumers. It is never possible to fulfill each and every requirement of call consumers.

(b) **Manufacturing stage:** It is post production stage, where all the manufactured parts are inspected to find out their conformance with the design specifications. It is desired that, all parts manufactured have high quality of conformance, which are assembled to give the required product. This stage assures high quality of conformance.

(c) **Field observations:**

- Here, quality of performance is observed, when the product purchased by consumer is actually used by him/her.
- Performance of product is analysed with respect to its reliability, durability and maintenance to increase life of product.
- Quality assurance = Quality of design + Quality of conformance + quality of performance.

9.21.2 Main Goals of Quality Assurance

(a) Plan and implement all activities to satisfy quality standards for a product.
(b) Ensure continuous quality improvement.
(c) Set up benchmarks to generate ideas for quality improvement.
(d) Ensure that, all activities are carried out by following concerned statutory norms and safety requirements.
(e) Communication to all authorities and customers regarding traceability and suitability of products.

9.21.3 Activities of 'Quality Assurance Function'

(a) Setting up quality levels.
(b) Quality survey or Quality audit.
(c) Quality rating of outgoing production.
(d) Processing of field complaints.
(e) Preparation of executive report on quality of product and efforts taken for improving it.

9.21.4 Advantages of ‘Quality Assurance Function'

(a) Less rejections, hence less scrap.
(b) Improved productivity.
(c) Consumer satisfaction.
(d) Fewer defects.
(e) Fewer complaints from consumer.
(f) Good consumer relations.

9.21.5 Relationship between Various Quality Concepts

- Figure 9.5 illustrates the relationship between various quality concepts.
- At the core, we have **'inspection process'**, which collects basic data for all subsequent processes and decision-making.
- **'Quality Control (QC)'** consists of tools and techniques for collecting inspection data and subjecting it to further analysis. Quality control tools provide the basis of accepting or rejecting a part.
- **'Quality Assurance (QA)'** is a managerial function, which ensures that, all the quality related activities are performed in an optimum manner.
- All these activities such as inspection, QC and QA are the elements of a Corporate level management policy, commonly known as **'Total Quality Management (TQM)'**.
- Inspection, QC and QA are referred as activities at operational levels and middle management level. Whereas, TQM involves corporate policies with commitment of top management to ensure high quality level.

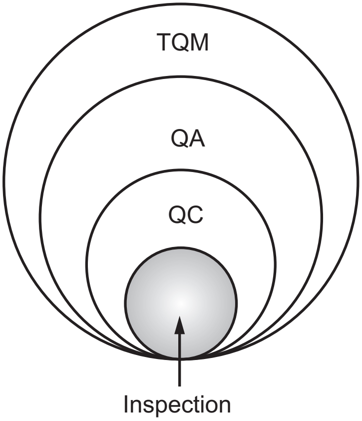

Fig. 9.5: Relationship between various quality concepts

9.21.6 Difference between Quality Control and Quality Assurance

QUESTION

1. Differentiate the term 'Quality Control' from 'Quality Assurance'. **(W-10)**

Quality Control	Quality Assurance
1. It is defined as 'an effective system for integrating the quality development, quality maintenance, and quality improvement efforts of various departments in an	1. It deals with the question of assuring the desired quality, reliability and services in the product through scientific techniques.

Quality Control	Quality Assurance
organization, so as to enable production and services at the most economical levels, which allows full customer satisfaction’.	
2. It is referred as ‘the tools, devices or skills, through which quality activities are carried out’.	2. Quality assurance function is nothing but, the evaluation of company's quality activities, which is reported to management. Thus, management is kept informed for taking corrective actions required, if needed.
3. It involves various inspection stages, use of quantity control charts and statistical techniques to control and improve quality.	3. It involves design stage, manufacturing stage and field observations.
4. It detects deviations from the set quality standards and fix them.	4. It improves the existing quality standards rather than fixing errors in manufacturing. Thus, it prevents deviations.
5. It can change product quality.	5. It cannot change product quality.
6. It is related to activities performed to fulfil quality requirements.	6. It creates confidence in the organization.
7. It puts major responsibility on quality control inspectors.	7. It shifts responsibility to middle and top level managers.
8. Major activities are testing, inspection, drawing control charts etc.	8. Major activities are defining quality standards, quality audit, selection of tools etc.

Important Points

- *Quality* is a relative term, commonly used with reference to the end use of the product. The demands of consumer are translated into requirements and analyzed requirements are called as *specifications.*
- *Quality control* is defined as ‘an effective system for integrating the quality development, quality maintenance, and quality improvement efforts of various departments in an organisation, so as to enable production and services at the most economical levels, which allows full customer satisfaction.
- *Quality of design* is concerned with the tightness of specification for the manufacture of product.

- *Quality of conformance* is concerned with, how well; the manufactured product conforms to the quality of design.
- *Quality of performance* is concerned with how well the manufactured product gives its performance.
- *Reliability* is the probability of a product that will give satisfactory performance over sufficient time period.
- *Maintainability* is defined as 'the probability that, a product will be restored to its operational effectiveness within the given period, when maintenance action is performed in accordance with the prescribed procedure'.
- *Cost of quality* is defined as 'the cost of carrying out the quality functions so as to meet the quality needs of consumers'.
- *Value of quality* can be defined as 'direct or indirect returns gained by the company due to missions of quality control'.
- *Inspection* is 'the act of checking of material, products or components of products at various stages of manufacturing'.

Theory Questions for Practice

1. Define quality and explain factors affecting the quality.
2. What is quality specification? State its types.
3. Define quality control. What are the objectives of quality control?
4. Define (i) quality of design (ii) quality of conformance, and (iii) quality of performance.
5. Define reliability. Explain in brief, elements of reliability.
6. What are the factors considered while designing reliability?
7. Define maintainability.
8. Define cost of quality and value of quality.
9. Explain the concept of optimum quality of design.
10. Define inspection. What are its objectives?
11. Explain in brief, various inspection stages.
12. Differentiate between inspection and quality control.
13. What is 'quality assurance function'? State its advantages.
14. State the difference between quality assurance and quality control.

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2014

1. Define reliability. State the factors to be considered for achieving a reliable design. **(4M)**

Ans. Refer Article 9.11.

2. Compare inspection and quality control. **(4M)**

Ans. Refer Article 9.20.

3. Explain 'cost of quality' and 'value of quality' with the help of graph. **(4M)**

Ans. Refer Articles 9.13, 9.14 and 9.15.

Summer 2015

1. What is quality of conformance? List the factors controlling quality of conformance. **(4M)**

Ans. Refer Article 9.9.

2. Explain the meaning of optimum quality of design with the help of graph. **(4M)**

Ans. Refer Article 9.15.

Winter 2015

1. Explain the concept of cost of quality and value of quality by using suitable graph. **(4M)**

Ans. Refer Article 9.15.

2. "Inspection is a part of quality control." Justify. **(4M)**

Ans. Refer Article 9.20.

Summer 2016

1. Explain 'Cost of Quality' and 'Value of Quality' with the help of graph. **(4M)**

Ans. Refer Article 9.15.

2. State the meaning of 'Quality of Design' and 'Quality of Conformance'. **(4M)**

Ans. Refer Article 9.8 and 9.9.

Winter 2016

1. Explain 'Cost of Quality' and 'Value of Quality' **(4M)**

Ans. Refer Articles 9.13 and 9.14.

2. Explain quality of conformance and quality of performance and state factors affecting quality of product. **(8M)**

Ans. Refer Articles 9.9, 9.10 and 9.2 respectively.

Summer 2017

1. State the various needs of the inspection. **(4M)**

Ans. Refer Article 9.18.

2. State the various objectives of the quality control. **(4M)**

Ans. Refer Article 9.7.

3. State the various factors controlling the quality of design. **(4M)**

Ans. Refer Article 9.8.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 10

TOTAL QUALITY MANAGEMENT

About This Chapter ...

This chapter has a weightage of 4 marks and assigned duration is 3 hours. In this chapter, we learn Concept of TQM, its principles, Quality Audit and Six-sigma concept.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	16 Marks	S-09	12 Marks
W-09	08 Marks	S-10	08 Marks
W-10	16 Marks	S-11	08 Marks
W-11	22 Marks	S-12	12 Marks
W-12	12 Marks	S-13	12 Marks
W-13	08 Marks	S-14	11 Marks
W-14	08 Marks	S-15	08 Marks
W-15	12 Marks	S-16	08 Marks
W-16	–	S-17	08 Marks

10.1 TOTAL QUALITY MANAGEMENT

QUESTIONS

1. What is TQM? **(W-08, 09, 13)**
1. Define TQM. Describe any 3 principal elements of TQM. **(W-14)**
2. State concept of Total Quality Management (TQM). List down its principles. **(S.T.P.-II)**
3. Define TQM. Describe any 3 principal elements of TQM. **(W-15)**

- **Total Quality Management** (TQM) can be defined as *'control of all the transformations of an organization to satisfy consumer needs in most economical manner'*.
- TQM is a **consumer focused management strategy,** where, suitable techniques are applied to *reduce the waste, improvement in product quality and better performance of organization*. It is a **continuous process**, where all activities are carried out for satisfying needs of consumer.

- TQM uses the fundamental idea of involvement of all staff members in an organization, where quality of work of all employees working at all the functional areas of organization is improved. TQM involves applications of statistical and other QC tools alongwith self-development and creativity.

10.2 PRINCIPLES OF TQM

1. List the principles of TQM and discuss any one of them. **(W-10)**
2. What are the principles of total quality management ? Explain any two of them. **(S-10, W-11, 14)**
3. State objective and tools of TQM. **(W-08)**
4. Define TQM. Describe any 3 principal elements of TQM. **(W-15)**
5. State the principles of TQM. **(S-16)**

- To start TQM in any organization, it is necessary to understand some key elements of TQM, because they change the attitude and culture within the organization to create a well-defined improvement of products and services.

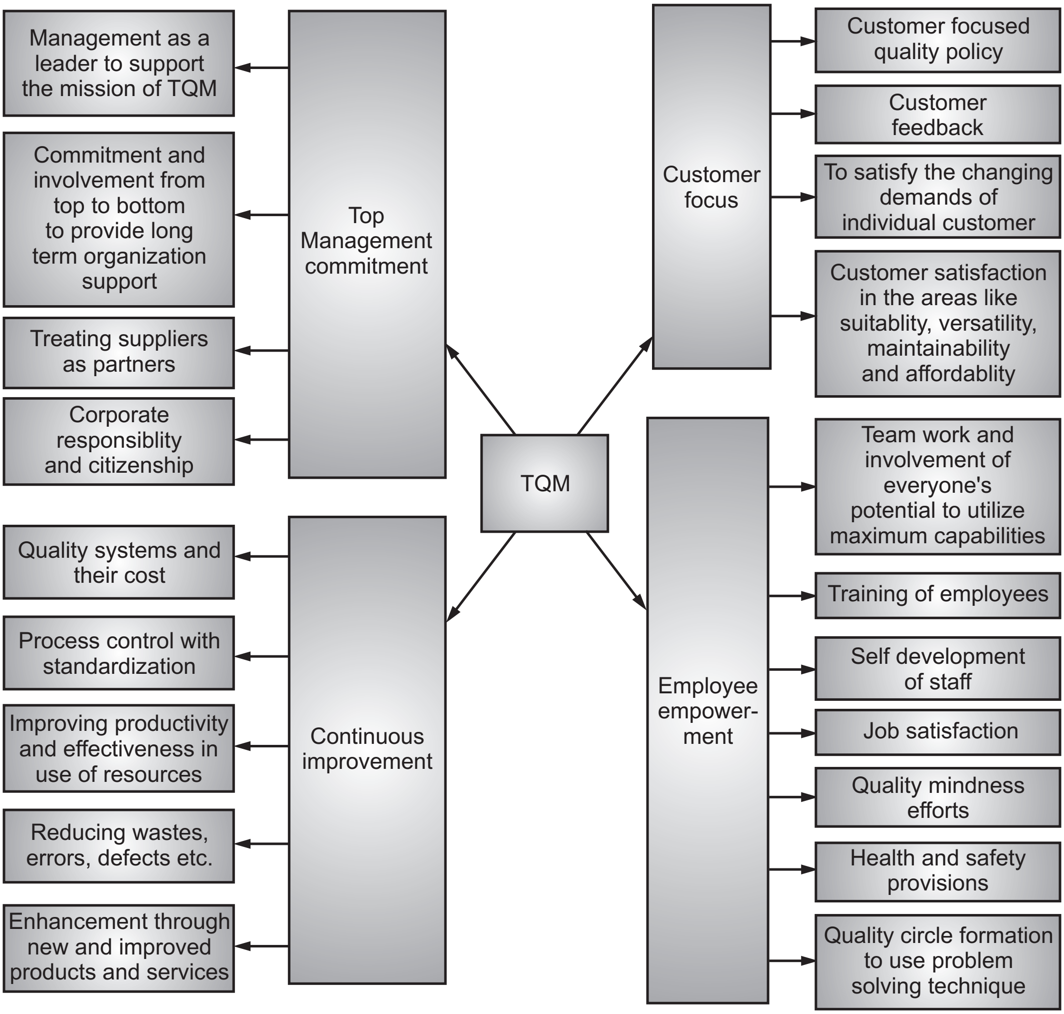

Fig. 10.1: TQM approach/wheel

Important key elements/Principles of TQM are given below:

(a) Customer Satisfaction:

(i) It is the ultimate goal in TQM. It means that, the company should fulfill needs or requirements of consumers which never remain constant and keep on changing according to time, environment, fashion, standard of living etc.

For example: Suitability, Reliability, Versatility, Maintainability, Affordability etc. of product.

(b) Do it right first: TQM adopts the policy of zero defect. There is no scope for rework and rejections. Zero defect is achieved, by use of statistical process control and by concentrating on prevention of defectives.

(c) Continuous Improvement: In order to fulfill its changing requirements of customers the organization must concentrate on various updates regarding new processes, equipments, innovations in a particular field, advancements in technology etc.

(d) Commitment of Top Management: For starting TQM, '**Complete change**' is needed in system and structure of the organization. Any change in existing practices is always resisted by workers and even the employees working at top level management.

Therefore, top level management should clarify concept, policies and benefits of TQM to employees and support their activities to fulfill the mission of TQM.

(e) Employee Involvement and Empowerment:

(i) All persons working in organization should be involved in TQM operation with an understanding that, TQM is everybody's responsibility.

(ii) All staff members should be trained in various areas like meeting skills, positive attitude towards customer, quality improvement, suggestion system, quality circles, etc.

(iii) Staff members should be sponsored to enhance/improve their knowledge, recently invented working skills, and various workshops conducted outside organization.

(iv) Staff members should be given power and authority to complete their tasks to obtain better results towards quality improvement.

(f) Process centered:

- Process is a series of steps, which take inputs from suppliers (either external or internal) and transform them into outputs, which are delivered to customers (either external or internal).
- Various steps required to carry out each process are well defined, and performance measures are continuously monitored in order to detect unexpected variations.

(g) Integrated system:

- An organization consists of different departments to perform different functions. Structure of organizations is drawn in vertical manner, starting from Chairman or President upto low level.
- Whereas, structure of TQM is drawn in horizontal manner, showing the processes arranged in sequence and inter-connecting each other. This is the path of TQM, to be followed to achieve desired quality.

In addition to the above basic principles, TQM is also based on the following principles.

(i) Production process and work methods must be designed consciously to achieve quality of conformance.

(ii) Quality must be monitored (checked) to identify problems quickly and correct them immediately.

(iii) Companies should convey procedure and result of TQM implementation to their suppliers to get good quality inputs from them.

10.3 BENEFITS/OBJECTIVES OF TQM

1. State objectives of TQM. **(W-09)**
2. State importance of TQM. **(W-13)**

(a) Advantages Unique to TQM:

(i) TQM makes company a leader in the market and not the follower.

(ii) TQM forms a closed a loop of customers, workers and management to achieve the objectives of quality.

(iii) It makes the company more sensitive and attentive towards consumer needs.

(iv) It makes the company ready to easily adopt the changing techniques and procedures.

(b) Benefits to customers:

(i) Only a small per cent of total number of consumers may face some problems with the product, which can be easily repaired by service engineer.

(ii) Goodwill of consumers towards company due to much better response and care by company in resolving their complaints within short time.

(iii) Greater satisfaction.

(c) Benefits to company:

(i) Productivity improvement.

(ii) Reduced quality costs.

(iii) Increased capacity in the areas of problem solving techniques.

(v) Improvement in human relations and work area morale.

(d) Benefit to staff:

(i) Employee empowerment (staff is given authority and power for best quality results).

(ii) Job satisfaction, interest in work and security of job.

(iii) More training and Improvement in skills.

(iv) Reduced employee grievances (complaints of employees) related to salary package, working conditions, bonus/incentives etc.

10.4 SALIENT FEATURES OF TQM APPROACH

(a) To identify the changing needs of consumer with time.

(b) To design a product or service, which will meet, *"what customers want"?.*

(c) To design a production process based on "doing the job right for the first time".

(d) To preserve the records of results after implementing any TQM activity, so that, it can be used as a tool for improvement in future.

10.5 NECESSITY FOR TQM

1. TQM adds value to the services offered to customers. It means giving the customer more than his expectations.
2. All persons should be involved and motivated to carry out TQM activities and commitments.
3. TQM provides assurance that, processes are well understood to everybody.
4. TQM is economical to both, producer and consumer for long time.

10.6 REASONS OF FAILURE OF TQM

1. Lack of commitment from top management.
2. Focusing on only few and specific techniques and not on entire system.
3. TQM program or activities get stopped after training of employees. But, no further implementation is seen due to negligience.
4. Expecting immediate results, not a long term investment.

10.7 DIFFERENCE BETWEEN QUALITY CONTROL AND TQM

Quality Control (QC)	Total Quality Management (TQM)
1. QC does inspection after the production.	1. TQM improves design quality of product and production system.
2. QC focuses on the adverse effects of **poor quality**.	2. TQM focuses on **identifying and eliminating causes** of **poor quality.**
3. Here, consumer is a **purchaser**.	3. Here, consumer is a **user**.
4. Goal of QC is to reduce the number of defectives.	4. Goal of TQM is to reduce number of defectives to zero.
5. QC is the responsibility of staff members working in quality control department.	5. TQM is the responsibility of everybody working in organization.
6. Improving quality **increases cost**.	6. Improving quality typically **pays for itself**.

10.8 METHODS AND ACTIVITIES OF TQM

- Method and procedure gives the guideline for achieving the objective and meeting the policies of the organization. Based on **strengths**, **weaknesses** and **opportunities** of organizations, different techniques are required to be identified, interlinked with each other and combined into a single process clearly indicating priority for the techniques to be applied or adopted (used).

Activities involved in TQM are:

- Team work.
- Integration and co-ordination of all activities of all departments such as Product design, R and D, Production planning, Production, Sales, Services to attain desired goals.
- Installing motivation system.
- Maintaining a sound quality system to perform the tasks.
- By maintaining good working conditions and by offering best possible facilities for the workers, because everbody's work contributes to quality, otherwise work done by workers will affect the quality adversely or badly.

Techniques of TQM:

- Techniques of TQM assist in applying the process or method, which can identify and measure the extent of wastages in manufacturing industries.
- Further, TQM techniques are implemented to reduce measured wastage upto zero.
- Effective and commonly used techniques of TQM are,

(i) Just in time (JIT),
(ii) Business process,
(iii) Re-engineering,
(iv) Zero defect,
(v) Training employees,
(vi) Motivation schemes,
(vii) Housekeeping, safety etc.

Tools of TQM:

- Tools of TQM collect the fact or data, analyze it and present the fact as **information** to the management.
- Tools of TQM **help in selecting the proper technique for reducing and eliminating the wastage.**
- Commonly used and effective tools of TQM are,

(i) Flow process chart
(ii) Scattered data
(iii) Frequency distribution
(iv) Histogram
(v) Graphs
(vi) Cause and effect method

10.9 PDCA (PLAN-DO-CHECK-ACT)

QUESTIONS

1. What is PDCA cycle ? Explain. **(S-09, 13; W-09, 11)**
2. Explain PDCA cycle. **(W-12)**

- PDCA is a continuous improvement tool.
- **PDCA** is a four-step problem solving process typically used for improvement of business process.

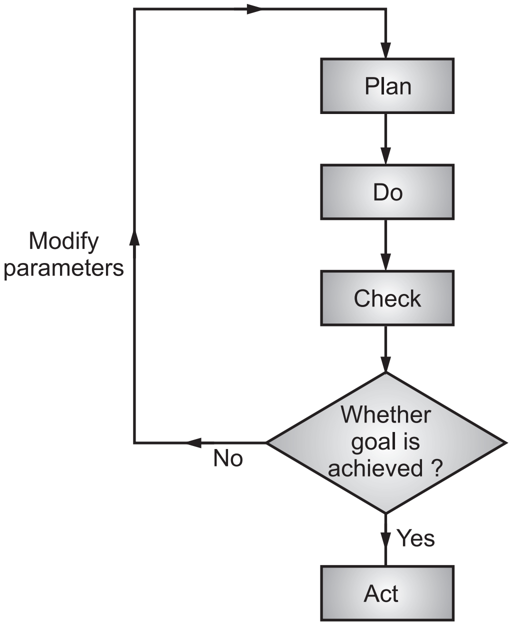

Fig. 10.2: Flowchart for PDCA

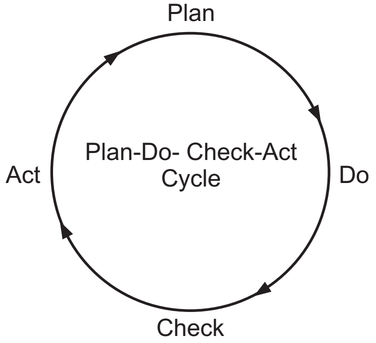

Fig. 10.3: PDCA cycle

Plan (What and Why ?):

- Identify the problem exactly by using various tools like cause and effect.
- Analyse the problem and define it clearly.
- Set measurable and attainable goals.
- Identify stakeholders and develop necessary communication channels to communicate and gain approval.
- Divide or break up overall system into individual processes.
- Find out the root causes of problem by meetings for detailed discussions, amongst the members.
- Collect and analyze data to validate root cause.
- Formulate a hypothesis.
- Verify or revise the original problem statement.

Do (Develop and Implement Solutions):

- List out the number of alternative solutions.
- Select the best solutions.
- Establish experimental success data.
- Design an experimental or practical set up to test the effect of solution. Establish the parameters of design experiment.

- Provide education and train the employees.
- Implement the experiment or solution on a trial or pilot basis.

Check (Evaluate the Results):

- Collect the data/results obtained after implementation of pilot solution. This is done to find out the extent to which, desired results have been achieved.
- If yes, go to next level i.e. "Act".
- If no, then find out the possible work areas or methods, where improvement is required.
- After making necessary changes in the problem statement, again Go back to 'Plan' for revising the problem statement. For this revised problem statement, again repeat, 'PDCA' cycle from step (1) Plan to last step (4) act in similar way.

Act (Implement the Full Scale Solution):

- If the results of measurement and analysis are found satisfactory during 'check' stage, the next step is to adopt the changed process by standardization and is incorporated into regular procedures or work instructions.
- Identify training need to employees for full implementation.
- Make some arrangement to monitor solution.
- Continuous improvement.

10.10 JIDOKA

- Jidoka is a Japanese term used at Toyota, which means **"Autonomation with a Human touch"**.
- Autonomation means "intelligent automation" or "humanized automation".
- In practice, automated process is sufficiently aware of itself, so that it will,
  (i) detect process malfunction or product defects.
  (ii) stop itself.
  (iii)alert operator (worker).
- Future goal of autonomation is self co-rotation. An example is the creation of "Type-G automated loom" in 1924. Before 1924, each loom was watched for thread breakage by a single operator. If a broken thread was not caught quickly, it was ruining an entire run of cloth. Operator time (for restart 90% waiting) and ruined cloth, both were leading to wastes.
- When Toyota started manufacturing cars, the philosophy of Jidoka was carried over to the manufacturing process, on Toyota factory's floor. A problem can potentially stop the entire production line until the problem is fixed. Once, the fix is identified, the existing process is improved to prevent a recurrence of problem in the future.

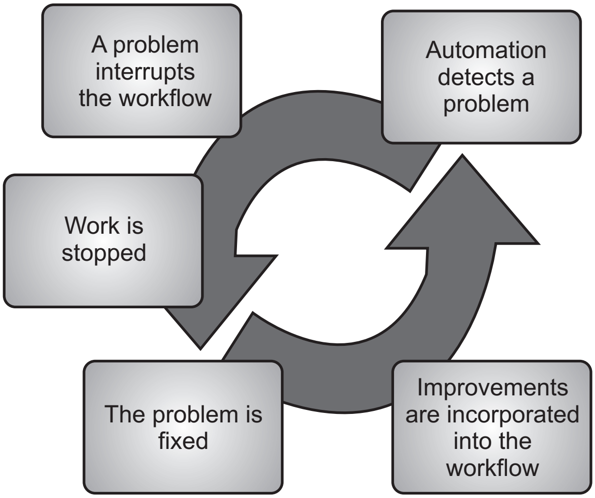

Fig. 10.4

- Jidoka also refers to the practice of stopping a manual production line or process, when something goes wrong.
- Jidoka involves the automatic detection of errors or defects during production. Therefore, when a defect is detected, the production stops and leads forcefully to give immediate attention to the problem. Productivity reduces due to slow production, but it is believed that, this helps to detect a problem earlier and avoids the spread of bad practices. Autonomation transfers a level of human intelligence to automated machinery.

10.10.1 Benefits of Jidoka

(a) Avoids spread of bad practices.
(b) No defective articles are produced.
(c) It adds human judgement to an automated equipment.
(d) It minimizes poor quality.
(e) It prevents possibility of equipment breakdown.
(f) Results in high quality products.
(g) Improvement in productivity.
(h) Lesser consumer complaints, so no or less compensation is to be given to the consumer due to high quality finished goods and products.
(i) Less or No 'repair and rework' costs.

10.11 QUALITY CIRCLE

QUESTION

1. Explain procedure of problem solving using quality circle. **(W-08, 11; S-09,14)**

- Concept of Quality Circle is to **solve work related problems** by using **basic problem solving techniques**.
- **Quality circle** is defined as, "a **small group of people** doing similar work, who meet regularly under the leadership of their supervisor, to identify and discuss their work related problems".
- **Quality circle** is a '**form of participative management**', which assumes that, a group of individuals working together will invariably come up with better solution than one individual working alone.
- **Quality circle** is a '**problem-solving technique**', which assumes that, suggestions for quality improvement should come from those, who have the greatest knowledge about the job.
- **Quality circle** is '**a human resource development technique**', which includes the development of skills, capabilities, confidence and creativity of the people through education, training, work experience and participation.

10.11.1 Characteristics of Quality Circle

- Quality circles are small primary groups of employees/workers. The group must be small (4 to 12 workers) lead by a supervisor, called as ***facilitator***.
- Members of quality circle should be the workers doing similar work. The workers/employees interested in same area of work for improvement may come together to form a circle.
- Membership of quality circle is most voluntary. It is not at all made compulsory.
- The members meet regularly say once a week or according to an agreed and specified schedule.
- Quality circle members are specially trained in techniques of analysis and problem solving methods, so that, they can work and contribute more effectively, in quality improvement activities.
- **Purpose of Quality Circle:** 'To identify and solve work related problems and to improve quality and productivity'.
- Quality circle enables every member to use his/her hidden talents and creative skills to perform against the challenging tasks. Quality circle members get the benefit of self development, updates and competence amongs them.
- Quality circle members work for quality improvement, without affecting regular work. It creates a feeling of job, satisfaction and job security.
- Their successful contribution in company's goal of quality improvement create a feeling of proudness amongst them.

10.11.2 Functioning of Quality Circle

QUESTION

1. Explain procedure of problem solving using quality circle. **(W-12, S-13)**

(a) **Problem identification:** To identify different problems to be solved related to work area.

(b) **Problem selection:** To decide the priority of problems on the basis of severity causing poor quality control and select the problem to be solved first.

(c) **Problem analysis:** Analyze the selected or chosen problem through basic problem solving technique.

(d) **Generate alternative solutions:** Identify and evaluate causes of problem. Discuss about the problem in the meeting and suggest possible solution to solve problem. Members may generate number of alternative solutions, due to difference in opinions.

(e) **Select the most appropriate solution:** Quality circle members discuss and evaluate all alternative solutions by comparison and select the best solution amongst all.

(f) **Prepare plan of action:** Quality circle members prepare plan of action to implement the best solution, agreed by all.

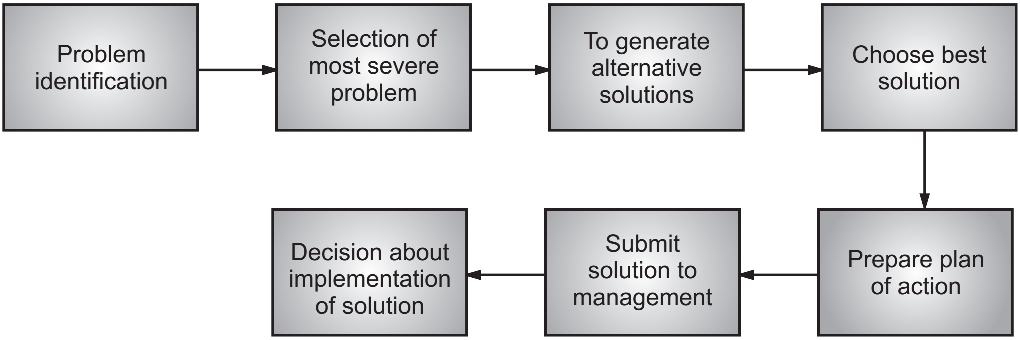

Chart: Quality Circle

(g) **Submit solution to management:** Quality circle members submit the best solution to management for approval.

(h) **Implementation of solution:** Management takes the decision on implementation of solution. Initially, the solution is implemented on small scale, called as **trial or pilot test**.

If pilot/trial test is successful in giving better results, then the solution can be implemented on full scale.

10.11.3 Objectives of Quality Circle

1. To improve the quality and productivity and to contribute in development of company.
2. To identify and solve work related problems.
3. To reduce cost of products and services by reduction of waste, effective utilization of resources, avoiding un-necessary errors and defects.
4. To develop and utilize the tremendous potential of workers.

5. To tap 'creative intelligence' of persons working in the organization and to make full use of available or existing human resources.
6. To authorize and allow the employees to develop and use greater amount of 'knowledge and skill'. Motivate them to face a wide range of challenging task.
7. To have 'Proper communication' in the organization.
8. To create 'Job satisfaction' among the workers.
9. To increase 'loyalty and commitment' of employees towards the organization and its desired achievements.
10. To satisfy the human needs of 'recognition', 'achievement' and 'self development'.

10.11.4 Limitations of Quality Circle

1. Employees working as Quality circle members may turn from their routine work to the task of organizing themselves, taking trainings, which sometimes may lead to undue wastage of man hours.
2. Time and money is required for implementation of new concept.
3. Sometimes, over expectations of employees may lead to disappointments.
4. Some employees may show non-willingness and may not co-operate the quality circle members.
5. Changes in existing system with appropriate control is required.
6. Resistance and non-operation of some employees.

10.11.5 Factors Leading to Failure of Quality Circle

1. Lack of interest and support from management.
2. Some members may not contribute to activities of quality circle and remain absent in many periodic meetings of Quality control.
3. Improper selection of team members.
4. The leader (facilitator) chosen may have lack of leadership qualities. It means, appointing him was the wrong decision.
5. Some members of Employee's Union create problems and feed others with negativity.
6. Lack of training to members.
7. Lack of sufficient awareness and knowledge among workers.
8. Bad practices of politics in organization.

10.12 QUALITY AUDIT (ADEQUACY)

QUESTIONS

1. Discuss the concept 'Quality Audit'. **(W-10)**
2. State the importance of Quality Audit. **(W-11)**
3. Define Quality audit. **(S-14)**
4. What is Quality Audit? And state the step by step procedure to implement it in manufacturing organization. **(S-15, S.Q.P.)**
5. Explain in brief, the concept of "quality audit". **(W-15)**

- Quality audit is an important tool for achieving the desired goals of an organization.

- **Quality audit** is defined as, 'a systematic and independent examination to determine,
  - (i) Whether quality activities carried out in the organization and their results fulfill the planned arrangement or not?
  - (ii) Whether the arrangements are suitable to achieve desired effectives or not?
  - (iii) Whether the arrangements are implemented effectively or not?
- Quality audit ensures adequacy of quality control system working for improvement in quality of product.
- **Quality audit** is also defined as, "an examination of records and quality activities to verify their accuracy, usually carried out by a third party (company certified for doing quality audit)".
- Quality audit is carried out at specified periodic schedule. Apart from schedule, quality audit is conducted to check the system if symptoms of bad quality are observed.
- Once a quality system is established, quality audit is done to,
  - (i) measure effectiveness of quality activities.
  - (iii) submit results of audit to top level management alongwith suggestions recommended.
- Quality audit is carried out at various departments. Active co-operation of all employees concerned with quality of product and working in various department of organization is essential to carry out 'effective quality audit'.
- Quality audit ensures the adequacy of control system for betterment of quality.
- In brief, quality audit is the examination of records or activities to verify their accuracy, usually carried out by a third party. (Any other organization certified for audit purpose) or expert auditors appointed within organziation.
- Once a system of quality is established, then quality audit is done to measure effectiveness regarding quality activities and results of audit are submitted to top level management.

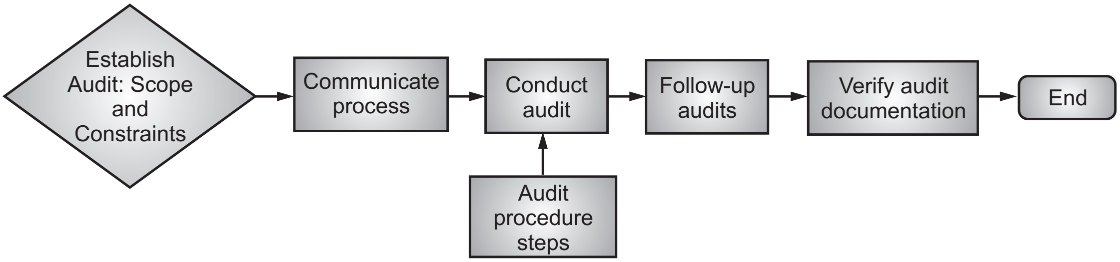

Fig. 10.5: Quality audit process

- Quality audit is carried out to examine,

(i) Design department:

(a) Whether design specifications can fulfill maximum demands of consumer.

(b) Whether design specifications are adequacy or not?

(c) Whether design specifications are simple and easy to understand for machine workers, production supervisors, inspectors etc. or not?

(ii) Production Department:

(a) To examine whether the *manufacturing specifications* conform to design specifications or not.

(b) Whether manufacturing specifications had been clearly understood (especially Production department) to machine operators or not?

(c) Whether manufacturing machines specified by the design department are suitable and adequate or not?

(d) Whether the specified manufacturing tools are properly used or not?

(iii) Inspection Department:

(a) Whether inspection methods are properly selected to give accurate results of measurements or not?

(b) Whether measuring instruments available in inspection department are adequate or not?

(c) Whether measuring instruments are periodically checked for any deviation from accurate measurements or not?

(d) Whether measuring instruments are re-calibrated regularly to retain accurate measurements to prevent deviations due to their continuous use or not?

(iv) Quality Control Department:

(a) Whether enough data of measurement results carried out by inspection department is collected for analysis or not?

(b) Whether suitable statistical quality control (SQC) techniques, such as process capability, frequency distribution methods, control charts etc. are applied correctly for the purpose of quality control or not?

(v) Field Work / Sales Departments:

(a) Whether necessary and immediate actions are taken on consumer complaints or not?

(b) Whether consumers are satisfied with the services of company or not?

- Results of audit are properly documented and forwarded to the quality manager as well as the concerned sections or departments of organization.
- Any discrepancies found in audit are rectified within a reasonable period.
- Thus, quality audit is said to be an helping tool for improvement in quality of product.

10.12.1 Purpose/Importance of Quality Audit

QUESTION

1. State the importance of 'Quality audit'. **(S-16)**

(1) To take corrective action in case of deviations from the specified goals.

(2) To check the adequacy of measuring instruments, gauges and test equipments, required for inspection.

(3) To check whether system is working properly or not?

(4) To know whether the identified problems have been corrected or not?

(5) It does preparations for attaining a good quality system.

(6) It offers opportunities for improvement.

(7) To resolve customer complaints regarding quality.

(8) It reduces rejection rate of products. In other words, quality audit increases production rate due to reduced number of defectives produced and hence lowers the rejection rate.

(9) It helps to evaluate own quality performance.

(10) To concentrate the focus on potential problems.

(11) It prescribes procedure for verification of vendor's capacity.

10.12.2 Scope of Quality Audit

Scope of Quality Audit covers various aspects:

(i) Policies and procedures regarding:

(a) Operators.
(b) Quality control.
(c) Administration.

(ii) Operating effectiveness:

(a) Records, interpretations, corrective action.
(b) Equipment control.
(c) Inter-departmental co-ordination.
(d) Assessment of product quality.

(iii) System effectiveness:

(a) Storage and handling practices.
(b) Field complaints and corrective action.
(c) Tool and gauge control.
(d) Changes in product design.

10.12.3 Types of Quality Audit

QUESTION

1. Explain the various types of quality audit. **(S-17)**

(a) Adequacy audit or Management audit: It determines, whether the documentation process and the procedures specified in quality audit manual are adequate (or enough), to satisfy consumers or not?

(b) Compliance audit: It is carried out to establish the extent to which, the documented system is implemented.

(c) External audit: It is carried out by an outside organization, having specialization in audit. A mutual contract is made by the company without outside organization to provide goods or services to do so. It may be an adequacy or compliance audit.

(d) Internal audit: It is carried out by company on its own quality systems. Its purpose is to give assurance to the management, that the specified quality systems are effectively achieved.

10.13 SIX-SIGMA AND TQM

QUESTION

1. Explain six-sigma system as applied in TQM. **(W-10)**

- Six sigma management is the technique of reducing variations in all critical processes to reduce number of defectives produced at the end.
- Six sigma technique is applied to reduce the variations existing within *plus or minus six standard deviations (± 6σ) of the process selected and followed to produce non-defective products.*

Similarities between Six Sigma and TQM:

1. Like TQM, the philosophy of six-sigma also is to reduce defective products.
2. Like TQM, six-sigma also has a direct link with profitability achieved by saving the cost of rejections, cost of rework and repair, cost of processing consumer complaints etc.
3. In fact, six-sigma techniques contribute in achieving the goals desired by TQM techniques more effectively and improves process control.

- Six sigma technique is applied to reduce the variations found amongst the products manufactured at same time, leading to defective products.
- Six sigma is rigid to implement and allows very small variations to lie within six standard deviations either plus or minus (± 6σ) and reduces quantity of defective products.

Differences between Six sigma and TQM:

- Both, six sigma and TQM are effective tools for quality management, but, a thin line of difference (slight variations) exists between them.
- Refer the comparison given below.

Six Sigma	TQM
1. No compromise or flexibility in carrying out quality activities is allowed in six sigma techniques. Due to this rigidness, tougher and harder targets of quality can be achieved.	1. Use of TQM tools cannot achieve tougher and harder targets of quality.
2. Six sigma is new and modified concept than TQM. Even though six sigma and TQM have certain similarities, six sigma cannot be used as exact replacement of TQM.	2. TQM tools were established before the evolution of six-sigma techniques.
3. Six sigma concentrates on making small changes in the processes and systems to ensure high quality.	3. TQM concentrates on maintaining existing quality standards.

Six Sigma	TQM
4. Six sigma is complicated process, which needs specifically trained individuals to work.	4. TQM is less complex to implement. So it does not require specifically trained employees.
5. Six sigma is result oriented approach, giving much better and effective results.	5. TQM gives less rejections and tries to reduce the cost of wastage, scrap etc. by maintaining the existing quality standards.

10.14 SIX-SIGMA AND ITS EXPLANATION WITH EXAMPLE

QUESTIONS

1. What do you mean by six-sigma ? Describe with suitable example. **(W-08)**
2. Explain the methodology for system improvement using six-sigma. State various certifications used in six-sigma. **(S-11)**
3. State statistical meaning of six-sigma. How it is used in quality improvement? State methodology of six-sigma for system improvement. **(S.T.P.-II)**
4. Explain the methodology of six sigma. **(S-17)**

- **Six-sigma** is defined as *'a disciplined and systematic data drive approach for eliminating defects in any process of manufacturing company or service industry'*.
- Objective of applying six sigma projects is to implement a measurement based strategy, which concentrates on process improvement and reduction in variations amongst the products.
- In other words, six-sigma is a management technique designed to create manufacturing, services etc., which reduces defectives and maintains cycle time.
- Six sigma refers to a goal of achieving zero defects, by using statistical quality control methods. Its approach is based upon normal distribution concept.
- Six sigma is mainly focused on output of process. It tries to achieve minimum level of defectives produced by maintaining the process within the range of 6σ.
- After applying six sigma techniques, we find that, maximum outputs of process will meet the specification (call it $\bar{X}$). But, some will deviate to a varying extent, measured by the standard deviation (σ). So, some units will have a specification of $\bar{X} \pm 1\ \sigma$ and few others will have $\bar{X} \pm 2\ \sigma$ and some $\bar{X} \pm 3\ \sigma$.
- For example: When number of observations are plotted in the form of frequency polygon for any variable characteristic, such as, diameter of shafts produced, then frequency polygon shows a smooth curve obtained by joining various points (observations) on the graph.
- This graph is called as **Normal distribution curve**.
- Graph drawn is symmetrical about the central line representing 'Mean' ($\bar{X}$) and extends $+3\sigma$ on right side and -3σ on left side.
- Therefore, process capability is specified as 6σ, which is represented in figure 10.6 in the form of normal distribution curve.

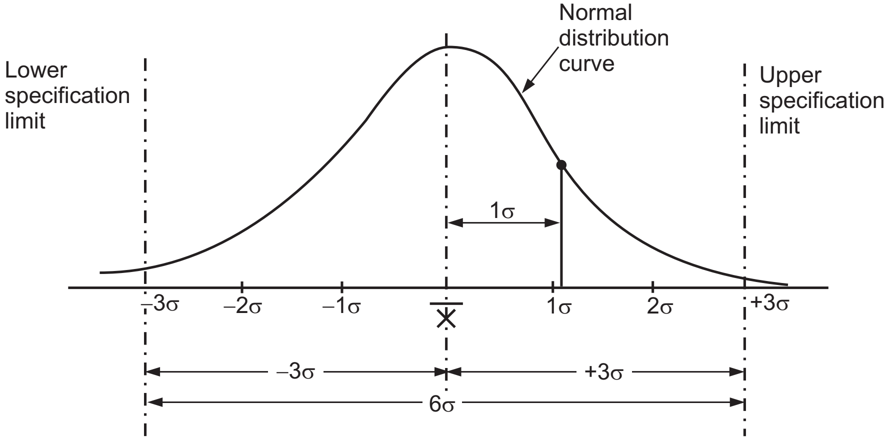

Fig. 10.6: Six sigma graph

10.4.1 Statistical Approach of Six Sigma

- Six sigma technique refers to a goal of achieving zero defectives, by using methods of statistical quality control.
- Approach of six sigma technique depends upon normal distribution.
- Following table shows sigma levels and corresponding percentage of total areas under the curve within specified levels.

Specified limits	**Percentage of total area within specified levels ($\bar{X} \pm 3\sigma$)**
$\bar{X} \pm \sigma$	68.26%
$\bar{X} \pm 2\sigma$	95.44%
$\bar{X} \pm 3\sigma$	99.73%
$\bar{X} \pm 6\sigma$	99.9999998

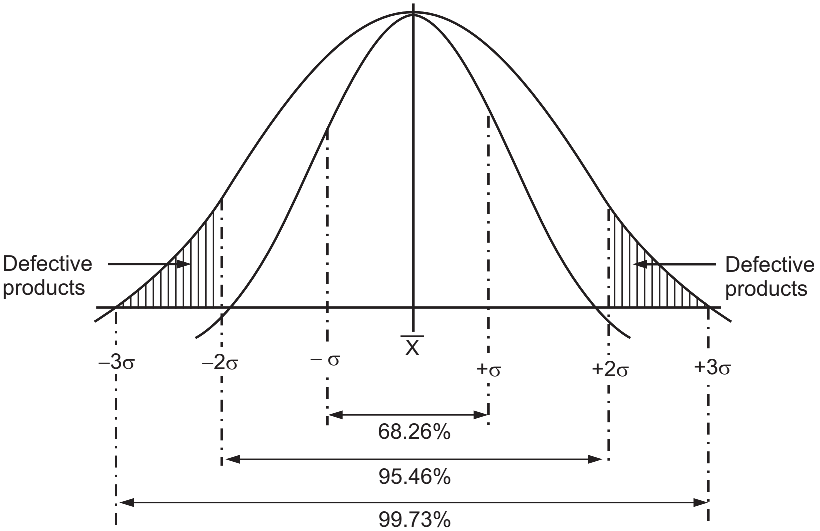

Fig. 10.7: Six sigma - Statistical approach

- Let us assume that, 1 million (10 lacs) as the total quantity of products produced. Refer the following three cases, where six sigma technique is applied.

(i) If $\bar{X} \pm 3\sigma$ are the limits, then from the specified table, we see that, 99.73% of total products are falling within the limits. They are said to be non-defective products.

$\therefore$ Percentage of defective products = 100% − 99.73% = 0.27%.

$\therefore$ Number of defective products out of 1 million (10 lacs) products manufactured = $\left(\frac{0.27}{100}\right) \times 10{,}00{,}000 =$ **2700**.

(ii) If $\bar{X} \pm 2\sigma$ are the limits, then from the specified table, we see that, 95.44% of total product produced are falling within the limits. These products are called as non-defective products.

$\therefore$ Percentage of defective products = 100% − 95.44% = 4.56%.

$\therefore$ **Number of defective products = $\left(\frac{4.56}{100}\right) \times$ 10,00,000 = 45600**.

(iii) Now, if we take $\bar{X} \pm 6\sigma$ as limits, then from the specified table, we observe that, 99.9999998% of total products produced are falling within the limits. These products are called as non-defectives.

$\therefore$ Percentage of defective products = 100% − 99.9999998%

= **2×10^{-7}%**

$\therefore$ Number of defectives = 2×10^{-7}% of 10,00,000

$$= \left(\frac{2 \times 10^{-7}}{100}\right) \times 10{,}00{,}000$$

= **0.002**

- It means that, number of defectives in 1 million products (10 Lacs) produced in just 0.002, very close to zero.
- Suppose, the quantity of products produced is increased upto 1 billion, keeping the limits $\bar{X} \pm 6\sigma$ (same as above).

$\because$ 1 billion = One thousand millions

$\therefore$ 1 billion = 1000 millions = 1000 × 10 Lacs

[$\because$ 1 million = 10 Lacs]

= 1000 × (10,00,000) = **1×10^9**

Percentage of defective products = 2×10^{-7}% [Refer Case (iii)]

$\therefore$ $\begin{bmatrix}\text{Number of defective products} \\ \text{found in 1 billion products} \\ \text{produced}\end{bmatrix} = 2 \times 10^{-7}\% \times 1 \times 10^9$

$$= \frac{2 \times 10^{-7}}{100} \times 1 \times 10^9$$

= **2**

- Therefore, we can conclude that, only 2 defectives will be found in 1 billion products produced. In other words, only two points will fall outside the curve (Normal distribution curve) created by $\bar{X} + 6\sigma$ and $\bar{X} - 6\sigma$. This is called as six sigma technique achieving very less defectives, very very close to zero defectives.

Practical Example of Six Sigma Technique:

- Let us take an example of time taken by a bus of transport company to travel from Pune to Mumbai on everyday of a month. Due to various factors, time taken by bus will be different on each day of month.
- Note down the time taken by bus to travel on each day of a month.
- Suppose following data is obtained.

Time taken by bus	160 minutes	170 minutes	180 minutes	190 minutes	200 minutes
Number of days, on which bus took same time (frequency)	4 days	5 days	12 days	06 days	03 days

- With the help of data obtained, plot the points on a graph having time taken on X-axis and frequency on Y-axis. Draw a smooth curve passing through all points plotted.
- Obtained curve will be bell shaped, like normal distribution curve. Thus, using rigid 6σ method, the transport company can assure their travellers, than bus will reach within 180 minutes.
- This achieves customer/traveller satisfaction and goodwill for company.

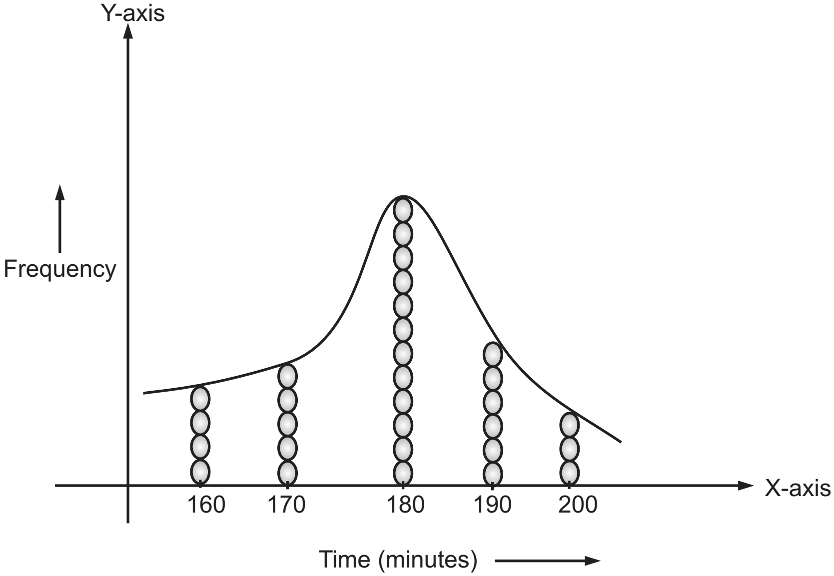

Fig. 10.8

Note: Similar type of bell shaped smooth curve can be obtained for all types of manufacturing processes.

10.15 SIX SIGMA CERTIFICATION

QUESTION

1. State the meaning of six-sigma and state its significance. **(W-13)**

- Six sigma certification is the confirmation of an individual's capability with respect to specific competency.
- Six sigma competence provides you,
  (a) Ability to deliver business benefits effectively.
  (b) Knowledge and skill to increase and improve efficiency of all processes and workflows.
  (c) Ideal preparation for a leadership role.
  (d) Analytical, statistical, facilitation and project management skills etc.
- Six sigma as a management methodology has helped thousands of professionals and industries world wide to reduce cycle times.
- Increased productivity, improved quality and delivery of process etc. can be achieved easily.
- Six sigma professionals exists at every level – each with a different role to play.

(a) An employee certified by Master black belt:
  (i) Trains black belts and green belts.
  (ii) Acts as an six-sigma technologist.

(b) An employee certified by Black belt:
  (i) Leads problem solving projects.
  (ii) Trains and give coaching to project teams.

(c) An employee certified by Green belt:
  (i) Assists with data collection and analysis for black belt projects.

(d) An employee certified by Yellow belt:
  (i) Participates as a project team member.
  (ii) Reviews improvement of process, which support the project.

(e) An employee certified by White belt:
  (i) Understands six sigma concepts from an awareness point of view.
  (ii) Such employee may or may not be member of six sigma project team, but works with local problem solving teams and hence supports the overall project.

10.15.1 Importance/Advantages of Six–Sigma Programme

QUESTIONS

1. State the importance of six-sigma quality program. **(W-12)**
2. Explain the importance of six-sigma programme. **(W-11; S-12)**

1. **Customer driven:**
   - Six-sigma technique is able to determine 'how and what improvements can be made, even before the start of manufacturing processes, so that, no defects or shortcomings will be seen in the products manufactured.
   - Therefore, six sigma method is called as proactive rather than reactive.
   - Every customer will receive non-defective product. Therefore, all customers will be satisfied.
2. **Continuous Improvement Environment:**
   - Six-sigma is valuable, because it creates an environment for improving productivity and efficiency in the company.
   - It gives everyone an opportunity to make improvements to traditional and existing processes. Employees, who are trained in Six Sigma processes, are able to identify problem areas which can be resolved before actual manufacturing.
   - Employees are able 'to visualize how processes are currently being completed' and 'to identify improvement ideas continuously'.
   - If six sigma technique is applied, it will improve the productivity and capability to perform the difficult tasks.
   - Continuous improvement helps to improve existing products and processes, develop new products and processes, which ultimately provide financial savings through improved efficiency and effectiveness.
3. **Customer satisfaction:**
   - The increasing market competition in today's business world, have compelled the producers to offer better quality products or services to their customers, at very low and competitive prices with good quality to satisfy consumers.
4. **Dominance over other quality control programmes:**
   - Six Sigma is dominant over all other existing quality improvement techniques, due to its rigidness and no compromise in quality activities.
   - Six sigma is customer driven approach, which aims of reducing number of defectives upto zero.

10.16 PRINCIPLES INVOLVED IN APPLICATION OF SIX-SIGMA

QUESTION

1. State the principles of six-sigma techniques. **(S-09)**

Methodology of six-sigma consists of five steps namely:

1. **Define:**
   (i) Identify the critical processes in manufacturing procedure to produce non-defective products only.
   (ii) Define the product, which will fulfill all needs or demands of consumer.

2. **Resources:**
   - (i) Define performance standards.
   - (ii) Validate measurement system.
3. **Analyse:**
   - (i) Establish product capability.
   - (ii) Define performance objectives.
   - (iii) Identify sources of variation.
4. **Improve:**
   - (i) Find out potential causes.
   - (ii) Discover relationship among the variations.
   - (iii) Establish operating tolerances.
   - (iv) Improve continuously.
5. **Control:**
   - (i) Determine process capability.
   - (ii) Implement process control.

10.17 DMAIC

QUESTION

1. Write a short note on DMAIC cycle. **(W-08)**

- It is a methodology used by six-sigma technique.
- This methodology is used, when the product is in existence at your company, but is not meeting customer satisfaction or is not performing adequately.

(D) Define:

- The first step is 'to identify, within each sub-process, the possibilities for quality problems, through the use of different statistical tools'.

(M) Measure:

- The second most important step is 'to establish a base of measurement, i.e. Reference value.
- Then extent of every problem is evaluated and compared with reference value.
- It is also necessary to identify and arrange the possible problems sequentially in the decreasing order of severity. Quality indicators are used to measure number of defects, number of missed commitments, cost of waste or rework.

(A) Analysis:

- In third step, new goals or targets are set. Then route maps are created for increasing the existing performance level upto newly set target levels.

- It begins with benchmarking key product performance. It means to set a standard or reference, against which, the sigma levels attained by comparable process can be evaluated as the basis of new target.
- Conventional quality problem solving techniques like 'Brainstorming', 'Cause and Effect Analysis' and other statistical methods are used for carrying out the activity of analysis. Thus, reasons causing defects in each subprocess are identified. Then, they are rectified either by re-designing the product or re-engineering the process.

(I) Improvement:

- The objective of this step is to confirm the key process variables and improve.
- In short, it is the improvement in the process by eliminating defects. This is achieved through a well defined and implemented quality control program measures for preventing the problem.
- Steps involved are:
  (a) Elaborate the problem statement and its root causes.
  (b) For each root cause, identify the possible counter measures or solutions (what to do?).
  (c) Rank the effectiveness of each counter measure or solution as low, medium and high.
  (d) Identify the specific action (how to do it?) for implementing each counter measure.
  (e) Rank each specific action in accordance with its feasibility. Feasibility means, whether that specific action can be implemented without increased cost or expenses, within less time etc.
  (f) Decide and choose the best specific action to implement.
  (g) Check the results after implementation to find or evaluate, whether the root causes for the particular problem have been reduced.
  (h) Prevent the problem and its root cause by taking care with men, material, machines, manufacturing process, environment etc.

(C) Control:

- The final step of six-sigma implementation is to hold or retain the gains, which have been obtained from the improved stage. Any negligence towards control may lead to original state, from where, we have started.
- The gains can be hold or retained by introducing new process conditions, documentations and transforming them into systems. Thus, gains become permanent.
- Control can be established through validation of measurement system, process capability determination and implementation of process control.

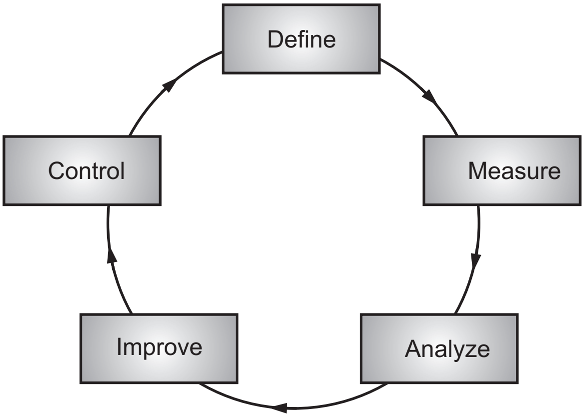

Fig. 10.9: DMAIC cycle

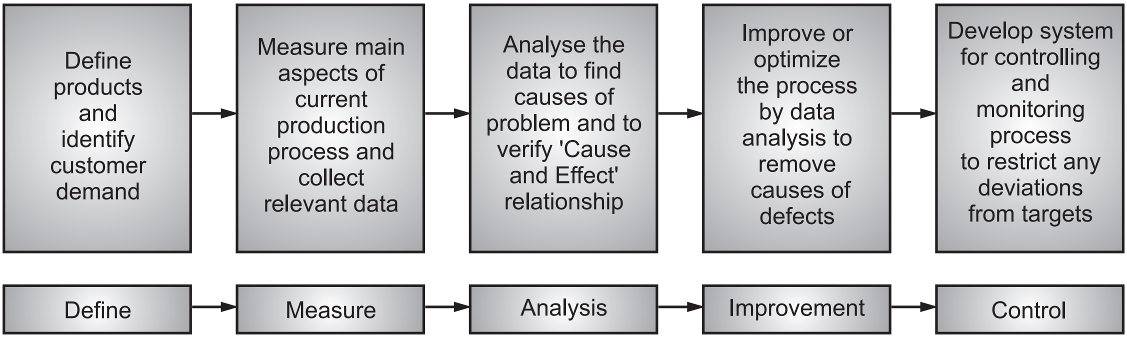

Fig. 10.10: Flowchart of DMAIC

10.18 DMADV

- DMADV is an another methodology used by six sigma technique.
- This should be used, when a product or process is not in existence at our company and it needs to be developed.
- Thus, using DMADV technique, it is possible for six-sigma programme to create a brand new business process from ground level using DFSS (Design for six-sigma).

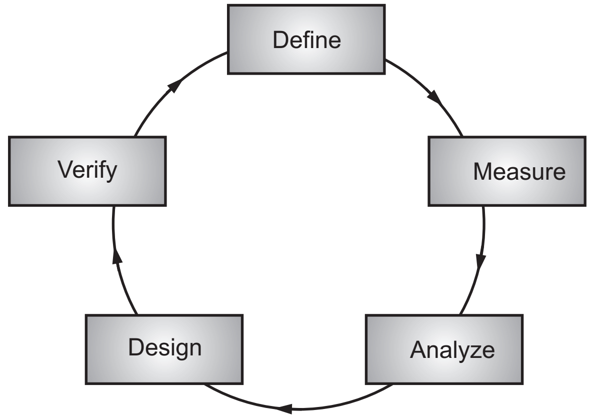

Fig. 10.11: DMADV cycle

DMADV methodology is briefly explained as below:

(a) **Define:** The company will identify the demands and needs of customers through historical information, customer feedback and other information sources. This will define the goals of the project.

(b) **Measure:** It is the step to use the specified/procedure to collect data, record and information about the processes needed to successfully manufacture the product or service.

(c) **Analyze:** The result of manufacturing process (i.e. finished product or service) is tested to create a baseline for improvement. The data obtained after testing is used to identify the possible areas within the process for further improvement.

(d) **Design:** The results of tests are compared with consumer demands. Any additional adjustments are made, if needed. This involves design modifications and verification. The improved manufacturing process is tested and feedback is collected from a test group of customers, before the final product is widely released.

(e) **Verify:** This is an ongoing process. As soon as, the product or service is released, customer reviews are consistently monitored to make instant changes in the manufacturing process for better sales. System is further developed for keeping the track records of consumer feedbacks on the improved products or services.

- DMADV is also known as DFSS i.e. "Design for six-sigma".

10.19 DIFFERENCE BETWEEN DMAIC AND DMADV CYCLE

DMAIC Cycle	DMADV Cycle
1. It works on an existing process. It is used for measuring and assessing the current performance of existing system.	1. It is used, when a new system has to be implemented. It takes the customer needs into consideration, in relation to the product or service. It measures the requirement of customer alongwith specifications in detail.
2. Here, problem in the existing process is analyzed to find the root cause. This helps in rectifying the process to eliminate errors.	2. Here, different processes are identified, needed to successfully manufacture the products or services. These processes are tested for checking their capability and stability.
3. It helps in eliminating errors.	3. It helps in fulfilling needs of customers.
4. In general, DMAIC concentrates on making improvements to a business process to reduce or eliminate defects.	4. In general, DMADV develops an appropriate business model designed to meet customer requirements.

10.20 VENDOR QUALITY RATING (V.Q.R.)

QUESTION

1. What do you understand by vendor quality rating ? **(S-12)**

- Raw materials are processed to manufacture finished products using tools, machines, equipments etc.
- Therefore, quality of finished products depends upon the quality of raw materials and tools purchased from vendors. So, it is essential to evaluate the quality of sample product received from various vendors.
- Results of evaluation help the purchase department to make decision of purchase.
- Vendor quality rating uses various formulae, to obtain a quantitative measure of vendor quality.
- In broad sense, **vendor quality rating** is defined as, *'the procedure to evaluate the ability of vendor to meet quality requirements'*.

- These ratings are used to select the best vendor amongst all the vendors (ready to supply their products to our company) on the basis of comparison and reviews.

Necessity of Vendor Quality Rating:

(a) To measure, how well each vendor is doing, qualitywise.

(b) To compare various vendors.

(c) To judge performance of each vendor for some period, which can be extended, if required.

(d) To eliminate the vendors, who repeatedly fail to meet quality requirements.

10.21 VENDOR RATING (V.R.)

- Only vendor quality rating is not enough to make decisions regarding purchase.
- In addition to vendor quality rating, following factors are also considered to take correct decision: (i) Prices, (ii) Discount, (iii) Delivery on time, (iv) Services offered, (v) Capability to supply required quantity in specified duration.
- Therefore, *vendor rating plans* are developed by officers working in purchase department.
- These officers are responsible for taking purchase decision considering all above factors. Thus, company is benefited on purchase of items having desired quality at low rates.
- Different vendor ratings are briefly discussed as below.

(a) Categorial plan: This is a non-quantitative system, in which, the purchase officers conduct meetings with different vendors to discuss on various points, to rate vendors as plus, minus or neutral.

(b) Weighted plan: Each vendor is scored on the basis of quality, price, service etc. A composite rating is calculated for each vendor, to rate them by numbers such as 0, 1, 2, …… 49, 50 and so on.

(c) Cost ratio plan: This plan compares the vendors on the total cost in terms of money for a specific purpose. Total cost includes price quotations, quality cost, delivery cost and service cost.

Important Points

- TQM is a customer focused management strategy, which applies suitable technique to eliminate waste.

- Key elements of TQM are, (a) Customer satisfaction, (b) Continuous improvement, (c) Commitment of top management, and (d) Employee empowerment.
- Quality circle is defined as 'a small group of people doing similar work' who meet regularly, to identify and discuss their work problems'.
- "Six-sigma" refers to the variations that exists within plus or minus six standard deviations of the process outputs. Six-sigma actually measures the output of your process.

Theory Questions for Practice

1. Define 'Total Quality Management'. Explain Principles involved in TQM.
2. What are the benefits of TQM?
3. What is quality circle? Explain its functioning.
4. What are the characteristics of quality circle?
5. What is quality audit? Explain its significance.
6. What is Six-sigma? Give its importance with suitable example.
7. What are the various principles involved in application of six sigma?
8. Explain step by step procedure of quality audit carried out for a manufacturing company.

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2014

1. Define TQM. Describe any 3 principal elements of TQM. **(8M)**

Ans. Refer Articles 10.1 and 10.2.

Summer 2015

1. What is Quality Audit? And state the step by step procedure to implement it in manufacturing organization. **(8M)**

Ans. Refer Article 10.12.

Winter 2015

1. Explain in brief, the concept of "quality audit". **(4M)**

Ans. Refer Article 10.12.

2. Define TQM. Describe any 3 principal elements of TQM. **(4M)**

Ans. Refer Articles 10.1 and 10.2.

Summer 2016

1. State the principles of TQM. **(4M)**

Ans. Refer Article 10.2.

2. State the importance of 'Quality audit'. **(4M)**

Ans. Refer Article 10.12.1.

Summer 2017

1. Explain the various types of quality audit. **(4M)**

Ans. Refer Article 10.12.3.

2. Explain the methodology of six sigma. **(4M)**

Ans. Refer Article 10.14.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 11

ISO STANDARDS

About This Chapter ...

This chapter has a weightage of 4 marks and assigned duration is 3 hours.

In this chapter, we learn ISO 9001:2008 series, IS 14000 evaluation and implications, Necessity of ISO certification and other quality systems, and TS-16949.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	04 Marks	S-09	08 Marks
W-09	08 Marks	S-10	04 Marks
W-10	08 Marks	S-11	04 Marks
W-11	–	S-12	08 Marks
W-12	08 Marks	S-13	12 Marks
W-13	08 Marks	S-14	08 Marks
W-14	–	S-15	–
W-15	–	S-16	–
W-16	06 Marks	S-17	–

11.1 ISO 9000 SERIES

QUESTION

1. What is ISO 9000 ? Explain various features of it. **(S-10)**

- ISO 9000 is a series of standards developed and published by the ISO that define, establish and maintain an effective quality assurance system for manufacturing and service industries.
- ISO 9000 is the only available internationally accepted standard for quality management system in the world.
- It stands for system standardization and certification rather than product standardization and certification.
- ISO promotes standardization to facilitate international exchange of goods and services and to develop international economic, technical and intellectual co-operation.

- ISO 9000 facilitates mutual recognition of any product legally produced or marketed in one country to be accepted in principle in another country.
- As a buyer, a company would prefer to deal with ISO certified supplier, who has demonstrated his capability to a third party (may be consumer), in the areas of design, development, production, installation, service, quality product, meeting the requirements.
- ISO 9000 is a series of six internationally agreed upon standards to guide and audit company's quality management practices, documents and records. The various models are ISO 9000, ISO 9001, ISO 9002, ISO 9003, ISO 9004 and ISO 8402.

11.1.1 Benefits/Advantages of ISO 9000

QUESTIONS

1. What are the benefits by becoming an ISO 9000 company. (W-08, S-12))
2. State the advantages and limitations of ISO 9000 company. (W-12, 13; S-13
3. Explain the advantages and limitations of ISO 9000 company. (W-16)

- ISO 9000 series of standards enable to meet the requirements of an internationally uniform quality system.
- It enables the company to build customer confidence that, it is capable of delivering the products or services of desired quality.
- It could enhance foreign exchange. So it is important for the industries to adopt ISO: 9000 to compete in the international market.
- It reduces the need for assessment by multiple buyers. It thus avoids time and money spent on multiple inspection of the products for conformance.
- It motivates the employees and develops pride in them for achieving excellence.
- It ensures sound quality assurance system. This results in improvement in efficiency, and reduction in inspection, scrap and rework.
- Adoption of ISO 9000 helps to enhance quality image of the company.
- **ISO 9000 helps the company to :**
  - (a) Define clearly the need of the company.
  - (b) Specify the right components, processes, tools and equipments for the job.
  - (c) Achieve a system of management and control.
  - (d) Distribute information to right people and at the right times.
  - (e) It provides a framework for continuous improvement in quality.

11.1.2 Disadvantages of ISO 9000

(W-08, 13)

- The implementation of ISO 9000 series of standards is very much depending on resources. The formulating and documenting of the system is time consuming and may involve considerable clerical expenses.
- Assessment and registration are also expensive.
- Unless carefully interpreted and planned, the system can become burdensome and expensive, quite often impending normal operations.
- The need to change attitudes and accept new working practice may strain the management capability of the company beyond its ability to cope.

11.2 ISO 9001 : 2008

- **'ISO 9001:2008'** is the modern version of 'ISO' based on designing and implementing a process based management system. Its aim is to improve the performance of organisation continuously.
- During the development of ISO 9001:2008 (an International Standard), the quality management principles stated in ISO 9000 and ISO 9004 have been taken into consideration.
- All requirements of ISO 9001:2008 are generic. They are intended to be applicable to all organizations, regardless of type, size and product.
- ISO 9001:2008 is least concerned about quality management systems, and quality assurance. But, it is focused on business management systems and business assurance. i.e. how a business operates to deliver value, products and services to customers and other interested parties or stakeholders.
- As per ISO 9001:2008 specifications, the organization,
  - (a) needs to demonstrate its ability to consistently provide the products to fulfill both, customer demands as well as applicable statutory and regulatory norms, and
  - (b) aims to enhance customer satisfaction through the effective application of system, including processes for continuous improvement of system and assurance of conformity to customer and applicable statutory and regulatory norms.
- Design and implementation of an organization's quality management system is influenced by,
  - (a) its organizational environment, changes in that environment, and the risks associated with that environment,
  - (b) its varying (changing) needs,
  - (c) its particular objectives,
  - (d) the products it provides,
  - (e) the processes it employs,
  - (f) its size and organizational structure.
- This International Standard promotes the adoption of a process approach, when developing, implementing and improving the effectiveness of a quality management system, to enhance customer satisfaction by meeting customer requirements.

- Application of a system of processes within an organization, together with the identification and interaction of these processes, and their management to produce the desired outcome, is referred as the *"process approach"*.
- Process approach is continuous control to interlink the individual processes within the system of processes, as well as, over their combination and interaction.
- ISO 9001:2008 describes a simple business cycle that should apply to any organization.

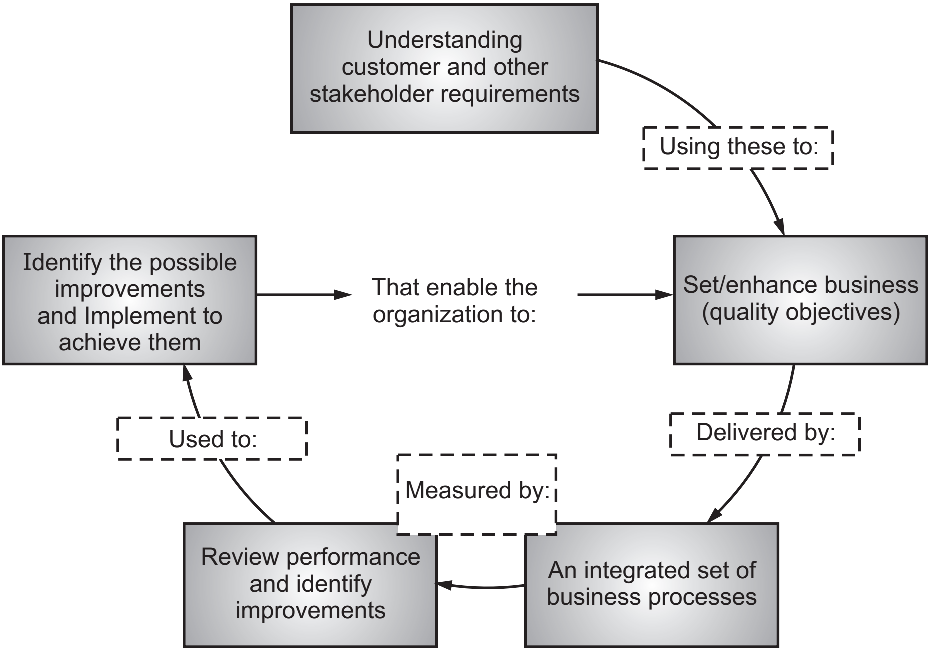

Fig. 11.1: Living the business performance cycle

- Features of ISO 9001: 2008 are,

1. **Consumer demands, The first step:**
   - Figure 11.1 shows that, customers play a significant role in defining requirements as inputs. ISO 9001:2008 defines to understand 'what customers actually want from the organization' and 'what products and services will truly satisfy them' by market research. This is market research, part of the marketing world. No organization should ever try and develop/launch a product or service without knowing, there is a market for it and that, it will be used by potential customers.
2. **To develop business objectives:**
   - Organizations concentrate on the following parameters,
     (a) Corrective actions,
     (b) Purchasing new equipments,
     (c) Sales or market share,
     (d) Skilled labour.

- This is nothing but, a business plan to show, "**Which** will do **What** And **When**"? Business processes are then designed to describe, how products and services will be created and delivered to customers'.

3. **Evaluation:**
   - Good organizations go further by identifying and using different methods to measure their performance against the desired goals.
   - These are used to identify improvement opportunities, which are then carried out to change the operative procedure to complete the business cycle.
   - This enables better delivery of the existing objectives and allows for enhanced objectives to be set for next time.

11.2.1 Benefits/Advantages of ISO 9001:2008 Certification

- Purpose of ISO 9001:2008 is to set out some key principles for a business cycle, but it does not try to cover everything.
- ISO 9001:2008 and its requirements have brought quality into the world of senior management and the boardroom, where business decisions are made, objectives set and direction given.
- **ISO 9001 certification** is not just suitable for large organizations, but also small businesses will be benefited by adopting efficient quality management systems to save time and cost of production, improved efficiency and ultimately improved customer relationships.
- An **ISO 9001 certificate** will provide maximum benefit to organization, if it approaches **ISO 9001 implementation** in a practical way.
- This will ensure that, the adopted quality management systems will improve the business. By adopting an approach, which implements more **efficient working practices** and focuses on business objectives of organization, we can achieve a system supporting our staff and improved satisfaction.

Benefits to Organization:

- To meet customer requirements.
- To increase customer satisfaction with your products.
- To get more revenue and business from new customers.
- To improve product quality and productivity.
- For proper documentation, understanding, and communication in the company processes.
- To develop a professional culture and better employee morale.
- To keep management and employees focused on quality.
- To improve efficiency, reduce waste and save money.
- To achieve international quality recognition.
- To allot areas of responsibility across all staff members of organization.
- Provides senior management with an efficient management process.
- Communicates a positive message to staff and customers.
- Identifies and encourages more efficient and time saving processes.
- Highlights the process deficiencies.

- Provides continuous assessment and improvement.
- Marketing opportunities.

Benefits to Customers:

- Improved quality and service.
- Delivery on time.
- Fewer returned defective products and complaints.

11.3 PROCEDURE OF AUDIT IN GETTING ISO CERTIFICATION

QUESTION

1. Explain the quality audit procedure of ISO 9000. **S-11**

The various steps involved are,

1. Gap Analysis with respect to requirements of management system:

- This means you compare, where you are now, to where you have to be, in order to find your baseline and get the scope of work.
- You will have some kind of a quality system existing already, but it is not meeting all requirements of the standard.
- Result of gap analysis is to identify the gaps, and what is needed to fill them.

2. Write documentation:

- This includes,
  (i) Framing Quality policy and Quality objectives.
  (ii) Preparation of Quality manual, Process manual, Mandatory procedures and required process procedures.
  (iii) Designing various Quality records.
- Your documentation will have to meet the requirements of ISO quality standard. It will also have to fit your company's quality goals. Your quality documentation says, 'what you do', 'how you do it', and provides proof that, 'you do it'. You must be able to demonstrate that, you are continuously improving your quality system as well as product or service, and customers' satisfaction.

3. Training:

- All employees will require some training. The amount of training is dependent on each individual's responsibilities.

4. Implementation of Quality Management System:

- Work through the plan you created, and bring your system up to the required standard.
- Results of Gap analysis will identify gaps, which be filled by revising, adding or improving.
- It means identifying your main processes to check whether, they meet the requirements or not.
- If not, then necessary improvements are made to meet the requirements of standard. And it means documenting your system.
- After a few months, your quality system and your people should be ready for the registration audit.

5. Co-ordination with certification body and Preliminary Audit by Certification Body:

- The number of auditors needed, and the time involved to conduct a registration audit will vary according to the size and complexity of your company.

- During an ISO audit, the auditor(s) will examine your records and will talk with your people. It is very important that, your staff is properly trained and your records are maintained in correct order.
- Auditors write up problems as “non-conformances” or "observations". Non-conformances can be “major” or “minor”.
- A major non-conformance will not allow for certification by ISO standard. Minor non-conformances may or may not prevent your certification; it depends upon number and severity of your non-conformances. Auditors have a fair amount of discretion in their write up, indicating you will get ISO certification or not at first attempt.
- Observations will not withdraw your certification; they are usually suggestions by the auditor regarding improvement scope alongwith procedure to be followed to achieve.

6. Corrective actions:

- Fix problems you find, using your formal correction procedure to do it.
- Initiate for Corrective Actions by conducting Management Review Meeting to discuss, decide and clarify on review points raised in meeting and Observations given in Preliminary Audit.

7. Certification Audit

8. Getting ISO Certification

11.4 ISO 14000

QUESTION

1. State the importance of QS 14000 standard. **(S-13, 14; W-13))**

1. ISO 14000 environmental management standards help organizations to,
   (a) Minimize their operations, which adversely affect the environment (water, air and land).
   (b) Mandatory to follow applicable laws, regulations and other environment oriented requirements.
   (c) Continuous improvement in (a) and (b).
2. **Objectives of ISO 14000 series of norms:**
   (i) To promote more effective and efficient environmental management in organizations.
   (ii) To provide useful and usable tools, which are cost effective, and enough flexible.
   (iii) To reflect best organizational practices available for collecting, interpreting and communicating environmentally relevant information.
3. ISO 14000 includes representation of core set of standards used by organizations for designing and implementing an effective environmental management system.
4. As per ISO 14000 norms, it is mandatory for organizations to identify all environmental impacts and then to implement required actions to improve the processes as per priority with significant aspects.
5. Prior to development of ISO 14000 series, the companies were used to set their own systems. Due to this, comparison of environmental effects amongst the companies was difficult. Therefore, universal ISO 14000 series was developed.

6. ISO 14000 is a series of standards, guidelines and reference documents, which covers the eco-labelling, environmental aspects, life cycle assessment, environmental auditing and evaluation of environmental performance.
7. **Principal elements of standards** are:
   (a) Environmental policy.
   (b) Planning.
   (c) Implementation.
   (d) Operation.
   (e) Inspection for taking corrective action.
   (f) Management review.

11.5 ISO/TS 16949

- ISO/TS 16949 is 'International Quality Management Standard' specified for the community of manufacturers, or suppliers of automotive parts.
- ISO/TS 16949:2009 includes technical specifications for automotive quality management systems, which are mandatory for thousands of suppliers producing and delivering parts, sub-assemblies, process materials, and services offered to major automobile manufacturers.
- Aim or goal of ISO/TS 16949 is 'Development of a quality management system', which provides for continual improvement, concentrating on defect prevention and reduction of variation and waste in the supply chain.
- ISO/TS 16949 actually consists of all ISO 9001 (2000) specifications along with a large number of specific requirements needed in automotive industries. There are approximately 1,039 separate and specific requirements in the basic ISO/TS 16949 Standard.
- ISO/TS 16949 is a "quality system" or a "quality management system" consisting of rules known as "**requirements**".

Important requirements specified in ISO/TS 16949:

(i) Requirements to assure that, the organization's output (whether product, service, or both) meets customer specifications.
(ii) Requirements to assure that, activities of quality management system are consistently implemented, which can be verified by conducting an independent audit.
(iii) Requirements for practices, which can measure the effectiveness of various aspects of the system.
(iv) Requirements that, support continual improvement of the company's ability to meet customer needs.

11.5.1 External Benefits of an ISO/TS 16949 Quality Management System

1. Satisfies demands of current or prospective customers for registration.
2. Improves customer focus.
3. Boost international acceptance and credibility.
4. Places the organization in top category of business.

5. Keeps the organization prepared for external audits and inspections i.e. regulators, customers etc.
6. Continual improvement.
7. Provides competitive advantage.

11.5.2 Internal Benefits of an ISO/TS 16949 Quality Management System

1. **Transforms the operation of organization from detection mode to prevention mode**, i.e. Minimization of producing non-conformities, prevention of pollution by stating the cause and its remedial measures, eliminating hazards and risks to protect the health and safety of employees and others.
2. **Creates consistency throughout the organization** built around "**best practices**".
3. **Improves business performance.**
4. **Very less dependency on key individuals** by distributing responsibility and accountability across many more people. The ultimate aim is that, tasks or processes do not collapse, just because of one person leaving or changing job. And it is seen that, each person is contributing small share of food.
5. **Provides blueprint for controlled and disciplined growth** i.e. during expansion of organisation, it can be seen as a way to organize the business, systematic practices, and ensure management accountability.
6. **Ensures consistent training** i.e. People very new to process are trained using road map. They refer to the specified/designed road map, while they are learning. After this, their performance is tested against the set road map.

Important Points

- **'ISO 9001:2008'** is the modern version of ISO based on designing and implementing a process based management system, which aims at continuously improving organization's performance.
- ISO 14000 is a series of standards, guidelines and reference documents, which covers the eco-labelling, environmental aspects, life cycle assessment, environmental auditing and environmental performance evaluation etc.
- ISO/TS 16949 is the international quality management standard specifically intended for organizations in the automotive industry supply community.

Theory Questions for Practice

1. What is ISO 9001:2008? Give its outstanding features.
2. What are the benefits of ISO certification?
3. What is the procedure for getting ISO certification?
4. What is QS 14000? Explain in brief.

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2016

1. Explain the advantages and limitations of ISO 9000. **(6M)**

Ans. Refer Articles 11.1.1 and 11.1.2.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 12

STATISTICAL QUALITY CONTROL

About This Chapter ...

This chapter has a weightage of 20 Marks and assigned duration is 7 hrs.

Here, we learn Statistical Quality Control Techniques, Advantages of SQC, Variable and Attribute Measurement, Central Tendency, Dispersion, Normal Distribution Curve, Variability, Control Charts, Process Capability etc.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	20 Marks	S-09	22 Marks
W-09	07 Marks	S-10	12 Marks
W-10	10 Marks	S-11	11 Marks
W-11	10 Marks	S-12	20 Marks
W-12	24 Marks	S-13	28 Marks
W-13	24 Marks	S-14	07 Marks
W-14	32 Marks	S-15	24 Marks
W-15	24 Marks	S-16	18 Marks
W-16	26 Marks	S-17	28 Marks

12.1 STATISTICAL QUALITY CONTROL

QUESTIONS

1. What is Statistical Quality Control ? State the benefits of S.Q.C. **(W-08, 09, 10, 16; S-15)**
2. What is Statistical Quality Control ? State its objectives. **(W-11,12; S-14)**

- A quality Control system is called as SQC, when statistical techniques are employed to control the quality or to solve quality problems.
- It consists of three general activities.
  (a) Systematic collection and recording of data accurately.
  (b) Analysing the data.
  (c) Practical implementation or Management action.
- In brief, Statistical Quality Control is the process of involving collection, analysis and interpretation of data to solve a particular problem.

- It is based on law of large numbers and Mathematical theory of probabilities. Modern techniques of SQC and acceptance sampling have an important role in improvement of quality, enhancement of productivity, creation of consumer confidence and development of industrial economy of country.

12.2 ADVANTAGES OF SQC

QUESTION

1. State the four benefits of SQC. **(W-13, 16)**

(a) Efficiency and Cost reduction.
(b) More effective pressure or control on quality efforts.
(c) Reduction of scrap and Better utilization of raw material.
(d) Improvement in inspection standards.
(e) Easy detection of faults.
(f) Reduction in consumer complaints and Improvement in producer-consumer relations.
(g) Creating quality awareness amongst employees and Improvement in their morale.
(h) Improves productivity.
(i) Reduces wastage of men and machine hours.
(j) Easy to apply.

12.3 VARIABLE AND ATTRIBUTE MEASUREMENT

QUESTION

1. State and explain meaning of terms, "Quality by variables" and "Quality by attributes". **(S.T.P.-II, S.Q.P.)**

Statistical data can be categorized into variable data or attribute data. The statistical methods for analyzing variable data are different from attribute data. In general, more information can be obtained, when data is in variable form.

12.3.1 Variables

- 'When measurements are carried out to find quality characteristic of a component, the quality is said to be expressed by '*variables*'. For example, length of bar in mm.
- It is done with the help of precision measuring instruments.
- The data obtained is called as '*continuous data*'.
- The value can be in fraction.
- Examples for Variables are,
  (a) Dimensions of a part measured. (b) Hardness in Rockwell units.
  (c) Temperature in Kelvin. (d) Compressive strength in N/mm^2.

12.3.2 Attributes

- 'When a record shows only the numbers of work pieces/items or products conforming and non-conforming to any specified requirement, it is said to be *attribute*'.

- It is recorded with the help of laid down standards. For example, GO and NO GO gauge.
- Data obtained is called as '*discrete data*'.
- The value cannot be in fraction i.e. number of defectives will be 0, 1, 2 or more.
- Examples,
  - (a) Number of defectives found in a sample.
  - (b) Blow holes in casting.

12.3.3 Difference between Variable Inspection and Attribute Inspection

QUESTION

1. Differentiate between variable and attribute inspection on any four parameters.

(S-10, 13; W-13)

Variable Inspection	Attribute Inspection
1. It is the method of measuring the quality characteristic to be inspected with the help of precision measuring instrument.	1. It is the method of judging the conformance or non-conformance of quality characteristic with the laid down standard such as gauges.
2. Actual dimensions are measured with the help of micrometer, vernier caliper etc. and data is recorded, e.g. length of bar.	2. The conformance or non-conformance is usually inspected with the help of NO-GO and GO gauges and parts are classified as defective or non-defective.
3. It gives detailed information about the quality characteristic.	3. It just gives information about whether the parts are acceptable or not.
4. It is time consuming.	4. It requires minimum time.
5. Higher inspection cost.	5. Lesser inspection cost.
6. It may cause fatigue to the inspectors.	6. It dose not cause fatigue to the inspectors.
7. The data obtained is called continuous data and can have any value.	7. The data obtained is called discrete data. It has integer value. e.g. number of defectives cannot be in fraction.
8. Control charts used are $\overline{X}$ and R.	8. Control charts used are P and C.

12.4 DIFFERENT SQC TOOLS **(S-09)**

QUESTION

1. State different SQC tools and explain any one. **(W-14, 16)**

The various tools of SQC are enlisted below.

(a) Histogram
(b) Bar chart
(c) Frequency polygon
(d) Process capability study
(e) Various control charts.

12.5 UNIT

- Unit is one i.e. consisting of a number of similar items, objects etc.

12.6 UNIVERSE OR POPULATION

- The universe may be thought of as a common source, from which, the total collection of unit is obtained.
- Statistical methods are based on the concept of distribution of exceeding larger number of observations, termed as 'Infinite Universe' or 'Population'.

12.7 CELL

- While grouping the data into a frequency distribution, the cell boundaries should be chosen half way between two possible observations and cell intervals should be equal.
- The interval along the scale of measurement of each ordered class is termed as 'cell'.

12.8 GROUPED FREQUENCY

- It is an arrangement showing the frequency of occurrence of values in ordered classes.
- The interval along the scale of measurement of each ordered class is termed as a cell and the frequency for any cell is the number of observations in that cell.

12.9 RELATIVE FREQUENCY

- The relative frequency of any cell is the frequency for that cell divided by total numbers of observations.

12.10 FREQUENCY DISTRIBUTION

QUESTION

1. Define : **(W-14)**
   - (i) Frequency distribution
   - (ii) Central tendency
   - (iii) Dispersion
   - (iv) Variance

- When the measured sizes of all the parts are plotted against the frequency of occurrences of each size in the form of graph, it is known as *frequency distribution*.
- The height of curve at any point is proportional to the frequency of occurrence of that particular size.
- While grouping the data into a frequency distribution, the cell boundaries should be chosen half way between two possible observations and cell intervals should be equal.
- Frequency distribution can be represented graphically by following ways.

(a) Frequency Histogram

(b) Frequency Polygon

(c) Bar Chart

12.10.1 Frequency Histogram

- In the graph, the sides of column represent the upper and lower cell boundaries and their heights are proportional to the frequencies of occurrences within the cells.

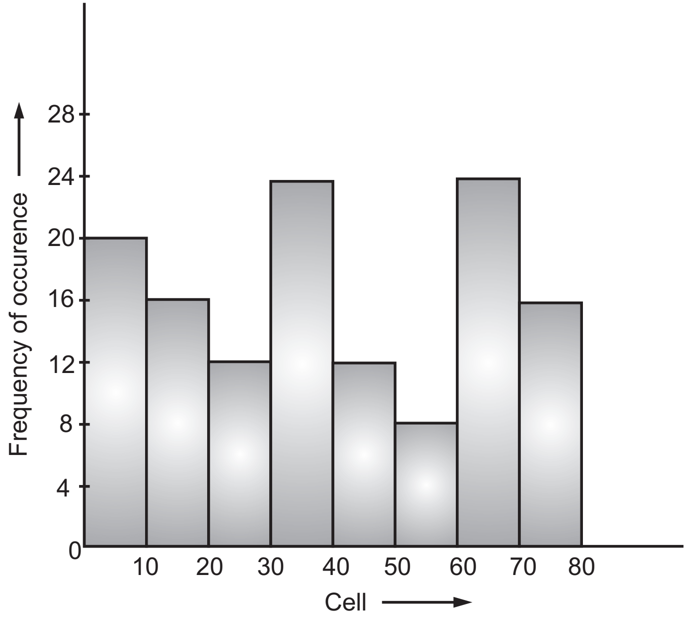


Fig. 12.1

- In drawing a histogram, it is assumed that, the frequency is centered at the mid-value of cell or class.
- Simple construction and inspection of histogram makes it an effective tool.
- A random sample is taken from the lot and measurements are performed for the selected quality characteristic.
- When there is a large variation in the obtained data, then the data may be grouped into cell.

12.10.2 Frequency Polygon

- Frequency polygon consists of series of straight lines joining points, which are plotted at cell mid-points with a height proportional to cell frequency.
- Frequency polygon has the advantage of plotting several distributions on the same axis, thereby making certain comparisons possible, which is not possible in case of histogram.

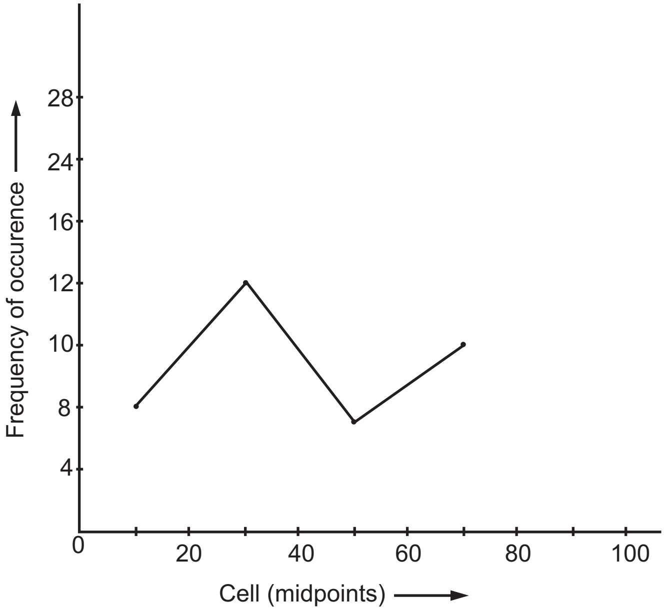


Fig. 12.2

12.10.3 Bar Chart

- Bar chart is a graphical representation of the frequency distribution, in which, the bars are centered at the mid-point of the cells and the heights of bars are proportional to the frequencies in the respective cells.

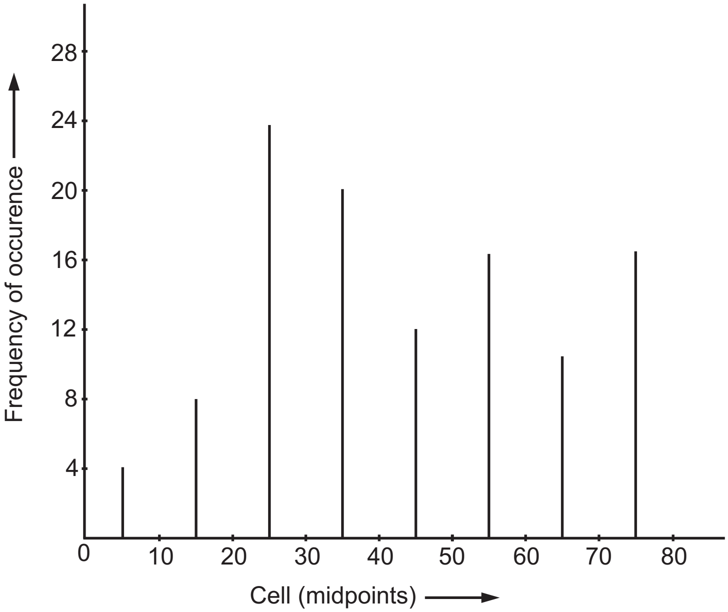


Fig. 12.3

12.11 CENTRAL TENDENCY

- "When accurately measured, the dimensions of most of the components tend to concentrate close to middle of the two extremes." This is said to be '*Central Tendency*'. Two extremes means the highest and lowest measured values.
- Alternatively, the maximum number of components will have sizes equal to or approximately close to the middle size and the sizes bigger or smaller than the middle size will be less frequent and lies near the two extremes.
- Central tendency is usually expressed in three ways:
  (a) The average value (Arithmetic Mean).
  (b) The middle value (Median).
  (c) The most frequently occurring value (Mode).

12.11.1 Arithmetic Mean - $\bar{X}$

(S.Q.P.)

- Arithmetic mean is defined as, "the average of all the values of variables in the sample".
- If $X_1, X_2, X_3, \ldots\ldots, X_n$ are the n values of the variable X in the sample, then their arithmetic mean is given by,

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \ldots\ldots + X_n}{n}$$

i.e. $$\bar{X} = \frac{\Sigma X}{n}$$

- If X_1 occurs f_1 times, X_2 occurs f_2 times etc. and lastly X_n occurs f_n times and n is the number of observations, i.e. $n = f_1 + f_2 + f_3 + f_4 + \ldots\ldots\ldots\ldots\ldots\ldots + f_n$,

  Then, arithmetic mean is given by,

$$\bar{X} = \frac{f_1X_1 + f_2X_2 + f_3X_3 + \ldots\ldots + f_nX_n}{f_1 + f_2 + f_3 + \ldots\ldots + f_n}$$

$$\therefore \quad \bar{X} = \frac{\Sigma fx}{\Sigma f} \quad \text{or} \quad \bar{X} = \frac{\Sigma\, fx}{n}$$

12.11.2 Median

(S.Q.P.; S-15)

"When all the observations are arranged in ascending or descending order, then median is the magnitude of middle case".

Case 1:

If number of observations (n) is odd and their values are arranged in ascending order, then median is given by, $\left(\frac{n+1}{2}\right)^{th}$ value.

Case 2:

If number of observations (n) is even and their values are arranged in ascending order then the median is taken as, Average of $\left(\frac{n}{2}\right)^{th}$ value and $\left(\frac{n}{2} + 1\right)^{th}$ value.

12.11.3 Mode

(S.Q.P.; S-15)

- "Mode is the value that occurs most frequently in a frequency histogram or frequency polygon".
- It is the observed value corresponding to the high point of the graph.

For Example,
If the recorded observations are,
4,5,4,2,3,4,6,4,9,6,9,7,4.
The value '4' occurs most frequently (5 times), therefore, mode = 4

12.12 DISPERSION

(W-14)

Dispersion is defined as, *"the extent to which, data is scattered about the zone of central tendency"*.

The various measures of dispersion are 'Range', 'Standard deviation' and 'Variance'.

12.12.1 Range (R)

(S.Q.P.; S-15)

- *Range* is defined as, *"the difference between largest observed value and smallest observed value".*
- Range = Largest observed value – Smallest observed value.
- It is the simplest measure of dispersion in a sample. It is particularly used in plotting control charts.

12.12.2 Standard Deviation (RMS value)

(S.Q.P.; S-15)

- Standard Deviation is defined as, *"the root mean square of the deviations from the arithmetic mean"*. It is also called as RMS value and is denoted by σ.
- If X_1, X_2, X_3… X_n are 'n' number of observations, and $\overline{X}$ = arithmetic mean, then,

$$\sigma = \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \ldots (X_n - \overline{X})^2}{n}}$$

12.12.3 Variance

(W-14)

- It is the sum of squares of deviations from the arithmetic mean divided by number of observations.
- In other words, *Variance is the square of standard deviation i.e. σ^2.*

$$\therefore \qquad \text{Variance} = \sigma^2 = \frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \ldots + (X_n - \overline{X})^2}{n}$$

12.13 NORMAL DISTRIBUTION CURVE

- In the frequency distribution, if the number of observations are increased and if only the chance causes of variation are present in the quality characteristic measured, the frequency polygon appears as a bell-shape and approximates to normal distribution curve.

12.13.1 Characteristics

QUESTION

1. Draw normal distribution curve and state its characteristics. **(S-09)**
2. State the characteristics and applications of normal distribution curve. **(S-16)**

1. Normal distribution curve is bell shaped and symmetrical about the mean.
2. The curve is fully defined by $\bar{X}$ and σ.
3. Theoretically N.D. curve extends from −3σ to +3σ. However, for all practical purposes, we can consider normal curve extending only 3σ values to the left and 3σ values to right of mean. i.e. $\bar{X} \pm 3\sigma$.
4. The most coated limits in connection with the curve are,

Specific Limits	Per cent of Total Area
$\bar{X} \pm \sigma$	68.26%
$\bar{X} \pm 2\sigma$	95.46%
$\bar{X} \pm 3\sigma$	99.73%

5. When we select 3σ limits, we are 99.73% sure that, the observations will lie within these limits.

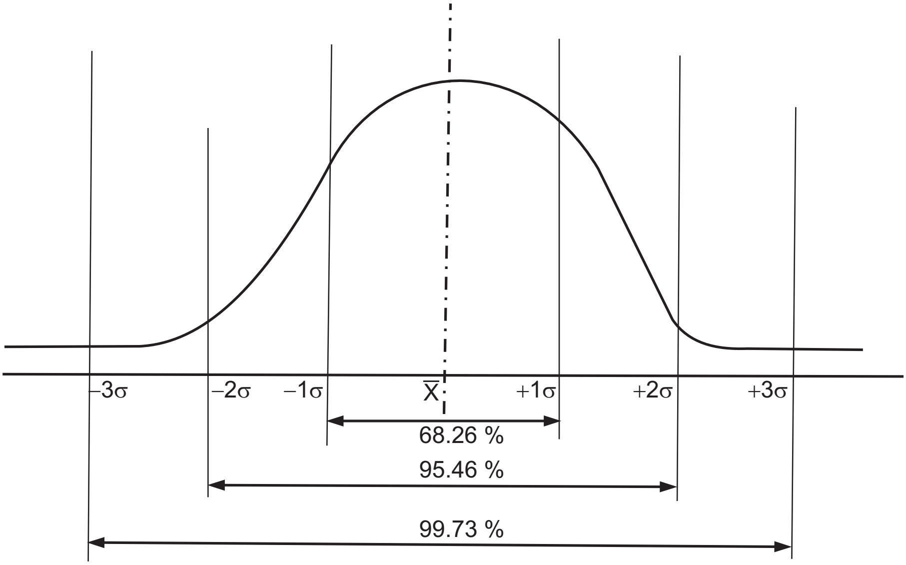


Fig. 12.4: Normal distribution curve

12.13.2 Applications / Significance of N.D. Curve

1. The frequencies of occurrence of the parts are plotted against their respective classes of sizes. If the curve approximates to N.D. Curve, it means, no assignable causes of variation are present and only chance causes are present.

2. In process capability study, N.D. curve is used to find, whether the process is capable of meeting the specified tolerance or not.
3. The area under the curve between two limits represents the total percentage of production, which will lie between these limits.
4. When we select 3σ limits, we are 95.73% sure that, the observations will lie within permissible limits.
5. It helps to calculate the expected proportion of observations, which will be less than or equal to specified value $\overline{X}$.
6. It also helps to calculate the expected proportion of observation, which will be beyond the specified value of $\overline{X}$.

12.14 VARIABILITY

- No production process can produce all items exactly alike.
- Production process consists of combination of men, materials and machine. Each of these elements of combination has some natural variability. This variability cannot be eliminated because it is impossible to identify.
- **For example:**
  - **(i) Raw material:** Suppose a drilling operation is to be performed on casting. The raw material used for producing the casting products may have some variability from unit to unit. Some units will be harder than others.
  - **(ii) Machines:** If the operation is being done on mass production by number of workers on different machines, the conditions of these machines may differ; some machines may be in poor condition, or improperly maintained. Hence, second source of variation is the machine.
  - **(iii) Man:** The third source of variation, man is the most variable among all. His decisions and actions directly affect the extent of variability more than the other sources like materials and machines. There may be differences among the skill of workers doing the same job.
- There are two types of variations:
  - (a) Variations due to assignable causes.
  - (b) Variations due to chance causes.

12.14.1 Variation Due to Assignable Causes (S-17)

QUESTION

1. Explain inherent and assignable source of variations. (W-13)

- They possess greater magnitude as compared to variations due to chance causes and they can be easily traced or detected.
- They may occur due to,
  1. Differences among machines.
  2. Differences among materials.
  3. Differences among workers.

4. Differences in each of these factors over time.
5. Differences in their relationship with each another.

- These variations may cause due to change in working condition, lack of quality mindness and human error.

  For example: Due to continuous use of drill to make holes in various components, its cutting edge performance may be dull, after sometime, which will tend to make slightly smaller diameter holes than the specified drill size.

12.14.2 Variation Due to Chance Causes or Inherent Causes

- These variations are inherent in any process or part.
- They are difficult to trace and control even under best conditions of production, since these variations may be due to some inherent (unavoidable) characteristics of a process or machine, which occur randomly.
- For example: (i) A little play between nut and screw arised during life of mchine may lead to backlash error and may cause a change (or variation) in dimension of a machined part. (ii) Power fluctuations.
- If the variations are due to chance causes, the observations will follow a normal distribution curve, i.e. the nature of graph plotted by analysis of obtained readings will approximate to N.P. curve.

12.14.3 Differentiation between Variations due to Assignable Causes and Variations due to Chance Causes

Variations due to assignable causes	Variations due to chance causes
1. They are due to unnatural variation in the elements of production, i.e. M^3 (Material, machine and man).	1. They are due to inherent or natural variation in the elements of production i.e. M^3.
2. They can be easily detected or traced, as their causes can be identified and analysed.	2. They are difficult to trace, because their causes cannot be identified. These variations occur randomly and they are accidental in nature.
3. They possess greater magnitude.	3. The chance causes affect each component in separate manner. They may cancel each other's effect.
4. Examples: Differences among M^3, change in working condition, lack of quality mindness.	4. Examples: A little play between nut and screw leads to backlash error, which may cause variations in dimension of part.

12.15 CONTROL CHARTS (W-16)

- Control chart is a graphical representation of the collected information.
- The information may pertain to measure quality characteristics like length, diameter, thickness etc.
- **Control chart** is a
  - (i) device to specify the state of statistical control.
  - (ii) procedure to attain or achieve statistical control.
  - (iii) tool to judge whether a state of statistical control is attained/achieved or not?

12.15.1 Various Control Charts

QUESTIONS

1. Name the control charts for variables and attributes. Give suitable examples of each. **(W-09; S-14)**
2. Classify the "Quality Control Charts". **(S-13; W-16)**
3. State different types of control charts used in SQC. State the types of charts suitably used for Quality by Attributes and Quality by Variables. **(S.Q.P.)**
4. Classify the quality control charts and differentiate between variable and attribute charts (any four points). **(S-16)**

Chart

The commonly used control charts are,

(a) The average of the measurements in the sample is known as $\overline{X}$ **chart**. It shows centering of process.

(b) The range of measurements in the sample is known as **R chart**. R chart show uniformity or consistency of process. Even, if the average value of variations observed in the reading obtained on a component is same or near to target value, the process is said to be out of control, if the variation in readings is found to be large. This is detected by 'Range' chart (R chart).

(c) The percentage of defectives in the sample is known as **P chart**.

(d) The number of defects in the sample is known as **C chart**.

Both $\overline{X}$ and R charts are control charts for variables, whereas P and C charts are control charts for attributes.

12.15.2 Purpose/Merits of Control Charts

- The main purpose of the control chart is to find out the deviations in the quality of the product, so that, improvements can be quickly made to correct the process before large quantities of defectives being produced resulting in wastage, i.e. the chart gives advance warning of the change in trend of the production towards the increasing number of defective articles.
- Other important purposes are:
  - (a) To determine, whether the given process can meet the existing specification without a fundamental change in production process.
  - (b) To secure information to be used in establishing or changing production process.
  - (c) To provide a basis for current decision on acceptance or rejection of manufactured or purchased products.
  - (d) Quality characteristics can be measured as well as expressed in numbers.
  - (e) To give a feedback, which can be used for planning and control purposes in future.
  - (f) To ensure optimum product quality level.
  - (g) To find out lots, which needs 100% inspection instead of sampling inspection to save cost of wastage and goodwill of consumers towards company.

12.15.3 Demerits of Control Charts

(a) Results of analysis may be affected due to errors in measurement and calculation.

(b) Highly skilled and trained labour is required to conclude exact results due to their complexity.

12.15.4 Plotting of $\overline{X}$ and R Chart

(W-16)

QUESTION

1. Write the various steps in constructing $\overline{X}$ and R charts. Consider suitable example. **(S-15)**

Step – I: Calculate Average ($\overline{X}$) and Range (R) for each sample.

- A good number of samples of items manufactured are collected randomly at different intervals of time and their quality characteristics (e.g. diameter, thickness, length, weight etc.) are measured.

For Example: If a sample contains five items (i.e. n = 5), whose dimensions are X_1, X_2, X_3, X_4 and X_5, then,

$$\bar{X} = \frac{X_1 + X_2 + X_3 + X_4 + X_5}{5}$$

and R = (Largest value – Smallest value)

Step – II: Calculate grand average $\bar{\bar{X}}$ and average range $\bar{R}$.

- It is obtained by dividing the sum of all '$\bar{X}$' values and 'R' values by number of samples i.e. subgroups, i.e.

$$\bar{\bar{X}} = \frac{\Sigma \bar{X}}{N},$$

and

$$\bar{R} = \frac{\Sigma R}{N}$$

where N = Number of samples

Step – III: Calculate 3σ limits for $\bar{X}$ chart

- The control limits are given by,

$$\text{Upper control limit } \bar{X} = \text{UCL}\bar{X} = \bar{\bar{X}} + 3\,\sigma \cdot \bar{X}$$

$$\text{Lower control limit } \bar{X} = \text{LCL}\bar{X} = \bar{\bar{X}} - 3\,\sigma \cdot \bar{X}$$

Here, $\sigma.\bar{X}$ = Standard deviation of averages = $\frac{\sigma'}{\sqrt{n}}$

where, n = sample size and σ′ = Standard deviation of universe = $\frac{\bar{R}}{d_2}$

where, d_2 is a factor depending upon sample size.

- The control limits for $\bar{X}$ can also be calculated using following formulae.

(i) $\text{UCL}\,\bar{X} = \bar{\bar{X}} + A_2\bar{R}$ and $\text{LCL}\,\bar{X} = \bar{\bar{X}} - A_2\bar{R}$

(ii) $\text{UCL}\,\bar{X} = \bar{\bar{X}} + A_1\sigma'$ and $\text{LCL}\,\bar{X} = \bar{\bar{X}} - A_1\sigma'$

(iii) $\text{UCL}\,\bar{X} = \bar{\bar{X}} + A\,\sigma'$ and $\text{LCL}\,\bar{X} = \bar{\bar{X}} - A\,\sigma'$

Step – IV: Calculate 3σ limits for R chart.

(i) $\text{UCL}\,R = D_4\,\bar{R}$ and $\text{LCL}\,R = D_3\,\bar{R}$

(ii) $\text{UCL}\,R = D_2\,\sigma'$ and $\text{LCL}\,R = D_1\,\sigma'$

Notes: Values of various factors such as d_2, D_4, D_3, D_2, D_1, A, A_1, A_2 are based on normal distribution and can be obtained from standard tables for a particular sample size. Refer **'Appendix'** attached at the end of book.

Step – V: Plot $\bar{X}$ and R chart.

(i) For $\bar{X}$ chart, the central line on $\bar{X}$ chart should be drawn as solid horizontal line as $\bar{\bar{X}}$. The upper and lower control limits should be drawn as dotted horizontal lines at the calculated values.

(ii) For R chart, central line on R chart should be drawn as solid horizontal line as $\bar{R}$ and control limits should be drawn as dotted horizontal lines.

Step – VI:

The values of $\bar{X}_1$, $\bar{X}_2$, $\bar{X}_3$ … $\bar{X}_n$ are plotted on $\bar{X}$ chart, whereas, values of R_1, R_2, R_3, … R_n are plotted on R chart. Points falling outside the control limits are indicated by cross, whereas, points falling inside the control limits are encircled.

Step – VII:

Draw conclusions from control chart.

- The lack of control is indicated by points falling outside control limits on either $\bar{X}$ or R chart.
- When all the points fall inside the limit (UCL and LCL), it means the process is in control.
- 1 out of 40 or 2 out of 100 points can be tolerated and process is said to be in control.
- The process is said to be out of control when,
  (i) A point falls outside the control limits.
  (ii) A run of more than eight points on the same side, either above or below the central line.

Note: If calculated lower control limit value (LCL) is negative, then assume or appropriate its value as "zero".

12.15.5 Objectives of $\bar{X}$ and R-chart

(i) They show the centering of the process.
(ii) They show any changes in the process average.
(iii) They give the information about the appropriate action to be taken for changing the specification and manufacturing process.
(iv) They provide the necessary information to carry out capability study.

12.15.6 Limitations of $\bar{X}$ and R-chart

(i) They are impossible to understand without training.
(ii) They can cause confusion among tolerance limits and control limits.
(iii) They can be used only for one individual characteristic at (dimension such as length or width or taste or any quality parameters) a time.
(iv) They are costly and time consuming activities such as, measuring, computing and plotting charts.

12.15.7 Trends of $\bar{X}$ Control Chart

(1) Extreme Variation:

- Extreme variation is recognized by the points falling outside the upper and lower control limits.

- The width of control limits on the control chart represents the variation due to the inherent characteristics of the process, which means the normal permissible variation in machines, materials and men.

Causes of Extreme Variation:

(i) Error in measurement and calculations.
(ii) Samples chosen at a peak position of temperature, pressure and such other factors, i.e. improper random sampling.
(ii) Wrong setting of machine, tools etc.
(iii) Samples being chosen at wrong times, either on commencement or end of an operation.

During production of the entire quantity over long time, the intermediate products could not have any chance to be selected for sample. Thus, the sampling does not represent true picture of entire quantity.

(2)Shift:

- When a series of consecutive points fall above or below the centre line on either $\bar{X}$ or R chart, it can be assumed that, shift in the process has taken place indicating presence of some assignable cause.
- It is generally assumed that, when 8 consecutive points lie above or below the centre line, the shift has occurred.

Causes of Shift:

(i) Change in material.
(ii) Change in operator, inspector, inspection equipment.
(iii)Change in machine setting.
(iv)New operator, carelessness of the operator.
(v) Loose fixture etc.

(3)Erratic Fluctuations:

- This may be due to single cause or a group of causes affecting the process level and its spread.
- The cause of erratic fluctuations is rather difficult to identify. It may be due to different causes acting at different times on the process.

Causes of Erratic Fluctuations:

(i) Frequent adjustments of machine.
(ii) Different types of material being processed.
(iii)Change in operator, machine, test equipment etc.

(4)Indication of Trend:

- If the consecutive points on $\bar{X}$ or R chart tend to move steadily either towards LCL or UCL, it can be assumed that, process is indicating a "Trend".
- It means that, change is taking place slowly and even though all the points are falling within control limits, but, after some time, there is a possibility that process may go out of control, if proper care or corrective action is not taken.

Causes of Trend:

(i) Tool wear.
(ii) Wear in threads of clamping device.
(iii) Effects of temperature and humidity.
(iv) Accumulation of dirt, choke up and jamming of fixtures and holes.

12.16 PROCESS CAPABILITY

QUESTIONS

1. State the importance of capability study in solving quality problem. **(S-10, W-12)**
2. Define the process capability and state how it is achieved. **(S-13; W-13)**
3. State meaning of process capability. How it is determined? **(S.T.P.-II)**
4. Define process capability. State how it is achieved? **(W-15, 16)**
5. Explain the process capability. **(S-17)**

- Process capability is defined as, ***"the minimum 'spread'** of specific measurement variation, which will include 99.73% measurements from the given process"*.
- It is the probability or rate, at which, product will be manufactured within the tolerance limits.
- In $\overline{X}$ and R chart, we have seen that, variability in the process can be controlled, within control limits of $\pm 3\sigma \cdot \overline{X}$.
- Here, 6σ' is known as process capability restricting the spread of process within limits.
- Process capability = 6σ'.
- 6σ' (natural tolerance) is taken as a measure of spread of process.
- By this study, it becomes possible to know the % of products, which will be produced within ±3σ limits on either side of mean $\overline{\overline{X}}$.

12.16.1 Applications of Process Capability

(a) To find whether, the process is capable of meeting the specified tolerance limits, or not.
(b) To determine centering of process.
(c) To find out, why the process is failing to meet the specifications.
(d) To find out, actual variability of process.
(e) To improve equipment maintenance, operator training and reduce costs.
(f) It helps to predict the extent, to which, the process will be able to hold tolerances.

(g) It helps to choose the appropriate process amongst the best competitive processes available. The chosen process should manufactured the products, which lie within the permissible limits.

(h) To decide the specification limits.

(i) To test theories of causes of defects during quality improvement programmes.

(j) To find variation from piece to piece.

(k) To reduce wastage during production.

(*l*) To save money as well as time.

12.16.2 Procedure for Doing Process Capability Study

Step 1: Calculate $\bar{X}$ and R for each sample.

Step 2: Calculate Grand average $\bar{\bar{X}}$ and average range $\bar{R}$. It measures centering of process.

Step 3: Calculate process capability = $6\ \sigma' = 6\ \frac{\bar{R}}{d_2}$; where d_2 is a factor for particular sample size. This measures the itemwise variability of process.

Step 4: Calculate specified tolerance, i.e. $(X_{max} - X_{min})$.

When a controlled process is required to meet two specification limits i.e. upper and lower specification limits, the possible situations may be grouped into 3 general classes as described below.

1. $(X_{max} - X_{min}) > 6\sigma'$

i.e. Specified tolerance > Natural tolerance.

where, X_{max} = Upper specification limit and X_{min} = Lower specification limit

Conclusions:

(a) Practically, all the products manufactured will meet the specifications.

(b) If $(X_{max} - X_{min}/6\sigma')$ ratio is considerably large. [It means $(X_{max} - X_{min})$ is very large as compared to $6\sigma'$], frequency of control charts may be reduced.

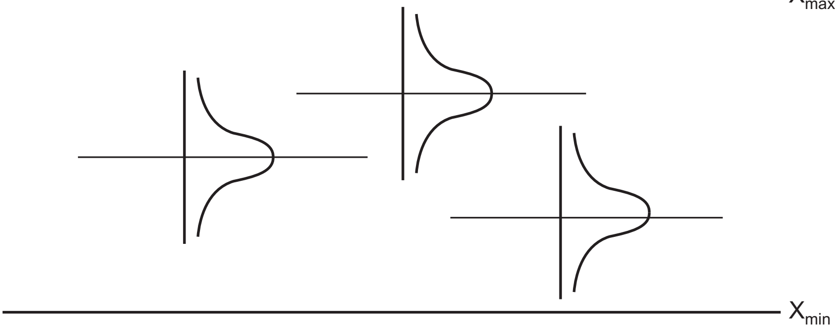


Fig. 12.5

2. (X_{max} – X_{min}) < 6σ′

i.e. Specified tolerance < Natural tolerance

Conclusion:

Here, defectives will always be there.

Suggestions:

(a) Increase the limits of tolerance, i.e. user wider tolerances.

(b) Reduce the dispersion, i.e. find out the causes of scattered measurement values and correct the process to restrict variations.

(c) Suffer and sort out the defectives, if it is not economical to make any change in process.

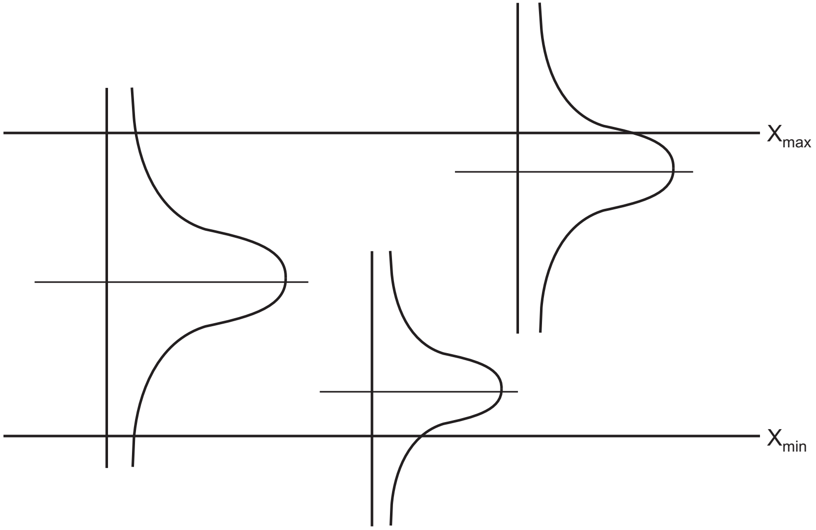


Fig. 12.6

3. (X_{max} – X_{min}) = 6σ′

i.e. specified tolerance = Natural tolerance.

Conclusion:

Spread of process is approximately equal to difference between upper and lower specification limits.

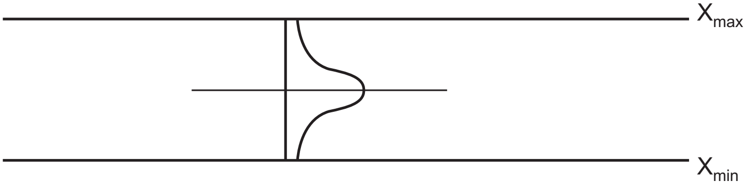


Fig. 12.7

Suggestions:

(a) It is necessary to maintain the centering of process.

(b) Reduce dispersion, if it is economical to do so.

(c) Advisable to increase tolerance, to take care against minor shift of centering of process.

12.17 DEFECT AND DEFECTIVE

- An item is said to be ***defective***, if it fails to conform to the specifications in any of the quality characteristics.
- Each characteristic that does not meet with the specifications is called as ***defect***.
- An item is said to be **defective**, if it contains at least **one defect**.
- For example: If a casting contains undesirable hard spots, blowholes, cracks etc., the casting is defective and hard spots, blowholes, cracks are called as defects.

12.18 FRACTION DEFECTIVE

- Fraction defective is defined as, *"the ratio of number of defective articles to the total number of articles actually inspected"*.
- It is always expressed as decimal fraction.

12.19 P-CHART

- P-chart is an attribute control chart i.e. for quality characteristics that can be classified as either conforming or non-conforming to the specifications.
- For example, dimensions of male and female components such as shaft and its mating hole checked by GO and NO GO gauges.

12.19.1 Steps to Draw P-Chart

(S-17)

1. Record the data for each subgroup on number of articles inspected and number of defectives.
2. Compute P (fraction defective) for each subgroup as,

$$P = \frac{\text{Number of defectives in subgroup}}{\text{Number of articles inspected in subgroup}}$$

3. Compute $\bar{P}$ (Average fraction defective) as,

$$\bar{P} = \frac{\text{Total number of defectives in a period or in all subgroups}}{\text{Total number of articles inspected in that period or in all subgroups}}$$

4. Compute control limits,

$$\text{UCL P} = \bar{P} + 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$$

$$\text{LCL P} = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$$

5. Plot each point as obtained and control limits as calculated.

   The points falling outside control limits are identified, (If any).
6. If the points fall outside the control limits, there may be two reasons:

   (a) Assignable causes of variation may be present.

   (b) Standard of Quality level is different for assumed standard P.

12.19.2 Objectives of P-Chart

Because of lower inspection and maintenance costs of P-chart, they usually have a greater area of economical applications than control charts used for variable.

(a) To find out average proportion of defective articles submitted for inspection, over a period of time.

(b) In a sampling inspection of large lots.

(c) To bring attention to management, any changes in average quality level.

(d) To identify and correct the causes of bad quality.

(e) Provides useful record of quality history management.

(f) To suggest, whether it is necessary to use $\bar{X}$ and R chart to diagnose quality problems.

12.20 "C" CHART

- Like 'P' chart, an another control chart named as 'C' chart is used for attribute.
- It shows number of defects or non-conformities in an inspected unit, such as automobile casting, a cloth etc.
- This is based on Poisson's distribution.
- It applies to number of defects in a subgroup of constant size.
- For 'C' chart:

We have, $$\text{Central line} = \bar{C} = \frac{\text{Number of defects in all subgroups}}{\text{Total number of subgroups}}$$

$$\text{Upper control limit, UCL C} = \bar{C} + 3\sqrt{\bar{C}}$$

$$\text{Lower control limit, LCL C} = \bar{C} - 3\sqrt{\bar{C}}$$

- Plot each point as obtained and plot control limits as calculated.
- The points falling outside control limits are identified (if any).

12.20.1 Applications of C Chart

(a) Number of surface defects in an aircraft wing.

(b) Number of defects such as blowholes, cracks in a casting.

(c) Number of imperfections observed in a cloth of unit area.

(d) Number of surface defects in galvanized sheet.

(e) Number of small holes in glass bottles.

12.21 DIFFERENCE BETWEEN VARIABLE AND ATTRIBUTE CHARTS

QUESTION

1. Differentiate between variable and attribute charts (any four). **(S-12, 15)**
2. Classify the quality control charts and differentiate between variable and attribute charts (any four points). **(W-15)**
3. Differentiate between 'Variable chart' and 'Attribute chart' (four points). **(S-16)**

Variable Charts ($\bar{X}$ and R)	**Attribute Charts (P, nP, C, U charts)**
1. Examples: $\bar{X}$ and R	1. Examples: P, nP, C, U charts.
2. Data required is variable data (i.e. measured quality characteristic of a product, to find whether it meets the specifications or not).	2. Data required is attribute data (i.e. conformance or non-conformance of using laid down standards GO and NO GO gauges).
3. Control of individual quality characteristic.	3. Control of proportion of defectives or defect in a sample of constant size or number of defects per unit.
4. Provides detailed information on process average and variation for control of individual dimension.	4. They do not provide detailed information for control of individual dimension.
5. They are not easily understood, unless training is provided.	5. They are simpler to understand as compared to $\bar{X}$, R charts.
6. They are time consuming due to involvement of processes like measuring, calculation and plotting.	6. They involve less cost and time.
7. Sample size is small.	7. Sample size is generally larger.
8. Cost of maintenance is high as data is collected by measuring instruments, which are subjected to early wear and tear. Also they need to periodically recalibrated.	8. Comparatively less as data is collected by Go and No Go gauges.
9. Sample size is smaller.	9. Sample size is larger.

12.22 DIFFERENCE BETWEEN $\bar{X}$, P AND C CHARTS

Sr. No.	**Comparative point**	**$\bar{X}$ and R charts**	**P and nP charts**	**C and U Charts**
1.	Data used	Variable	Attribute	Attribute
2.	Form of input data	Measured values of a quality characteristics	Number of defectives produced in each subgroup	Number of defects found in a product or part.

Sr. No.	Comparative point	$\bar{X}$ and R charts	P and nP charts	C and U Charts
3.	Purpose	To control individual quality characteristics	To control overall fraction defectives in all subgroups or in the entire process.	To control overall number of defects in every component or part or product.
4.	Sample size (n)	4 or 5	Sample having components between 20 to 100	Sample may be any convenient unit such as Area of 1 m^2 in case of cloth, one assembly etc.
5.	Advantages	(1) Provides detailed information about process average and variation. (2) Data available is fully utilized to give accurate results.	(1) Easy to understand. (2) Less time consuming due use of limit gauges. (3) Not able to give exact picture, but provides an overall trend and picture of quality status.	(1) Advantages of C and U charts are similar P and nP charts. (2) In addition to advantages mentioned for P and nP charts, 'C' chart and 'U' chart provides the extent of defectiveness, by which, the necessary and correct action can be taken to prevent reoccurrence of defects.

12.23 C_p AND C_{pk} Calculations

- When we speak about the capability of process, we often refer to a couple of indices which are called as C_p and C_{pk}.
- These two indices together, can tell us, how capable our process is?

12.23.1 C_p

- Process capability ratio or index is given by,

$$C_p = \frac{\text{Specification range}}{\text{Process capability}}$$

i.e.

$$C_p = \frac{\text{Upper specification limit} - \text{Lower specification limit}}{6\sigma}$$

$$= \frac{U_{SL} - L_{SL}}{6\sigma}$$

- Assuming that, the process is normally distributed, then denominator i.e. 6σ represents 99.73% limits of process distribution.
- If $C_p = 1$, it means that, specification range (or width) is same as the process capability (distribution width) and when the process average is centered at $\left(\frac{U_{SL} + L_{SL}}{2}\right)$ without any shift, then the probability of actual dimension to lie within specification limits is 0.9978.
- If $C_p \leq 1$, then it means that, process variability is outside the specification range. Thus, the process is not capable of producing parts within specification limits and the process must be improved, before producing parts.
- If $C_p \geq 1$, it means that, the process variability is lower than specification limits and process has minimal capability.
- Thus, C_p is a measure of ability of process to meet the desired specifications.
- It shows the closeness of parts of a group with the target value.

12.23.2 C_{pk}

- C_{pk} index is the position of total process variation (distribution width i.e. 6σ) in relation to the mean specification.
- C_{pk} reflects the current process average's proximity to either U_{SL} or L_{SL}.
- It is determined by,

$$C_{pk} = \min\left[\frac{\overline{X} - LSL}{3\sigma}, \frac{USL - \overline{X}}{3\sigma}\right]$$

- For example, if $USL = 20$, $\overline{X} = 16$, $LSL = 8$, $\sigma = 2$, then

(i) Standard capability ratio, $C_p = \frac{U_{SL} - L_{SL}}{6\sigma} = \frac{20 - 8}{6 \times 2} = 1$,

(ii) Average specifications limits, $\frac{U_{SL} + L_{SL}}{2}$ i.e. $\frac{20 + 8}{2} = 14$,

It means that, if process is centered within the assumed specification limits (USL and LSL), then only a small proportion about 0.27% (i.e. 100% − 99.73%) = 1 − 0.9973 = 0.0027) of product would be defective.

- However, we can calculate C_{pk} as,

$$C_{pk} = \min\left[\frac{16 - 8}{3 \times 2}, \frac{20 - 8}{3 \times 2}\right] = \min\,[0.67, 2] = 0.67$$

It states that, process average is currently near the USL.

Note: If the process were centred at $\overline{X}$ = 14, the value would have been 1.0. It means that, if the actual average is equal to midpoint of specification range, then $C_{pk} = C_p$.

- An acceptable process will require either reducing the standard deviation or increasing tendency of centering or both.

12.24 U-CHART

- U-chart is the count of non-conformities or defectives in a unit. This is based on Poisson's distribution.
- When the subgroup size varies from sample to sample, it is necessary to use U-charts.
- In other words, if C is the total number of defects found in only one sample and n is the number of inspection units in a sample, then we have,

$$\text{Central line, } u' = \frac{C}{n} = \frac{\text{Number of defects in a sample}}{\text{Number of units in a sample}}$$

Control limits of U-chart are,

$$\text{UCL `U'} = u' + 3\sqrt{\frac{u'}{n}}$$

$$\text{LCL `U'} = u' - 3\sqrt{\frac{u'}{n}}$$

12.25 nP-CHART

- nP chart is almost same as 'P' chart. This is used to express results in whole numbers instead of fractions. This is based on binomial distribution. The difference is,
  - (i) If subgroup size is variable, control chart for fraction defective, i.e. P-chart is used.
  - (ii) If subgroup size is constant, control chart for actual number of defectives, known as nP-chart is preferred, due to the following reasons:
  - (a) nP-chart saves one calculation for each subgroup, the division of number of defectives by sub-group size to get fraction defective P.
  - (b) More easy to understand.
- In nP-chart, we plot number of defectives found in each sample instead of calculating the fraction defective as in case of P-chart.

- The average fraction defective $\bar{P}$ is used as the best available estimate of 'P'.

and Central line, $\bar{P} = \frac{\text{Total No. of defectives}}{\text{Total No. of inspected items}} = \frac{\Sigma nP}{\Sigma n}$

- Multiply this calculated $\bar{P}$ by n. We get the value of $n\bar{P}$.

The Control limits for nP - chart are

$$\text{UCL (nP)} = n\bar{P} + 3\sqrt{n\bar{P}\,(1 - \bar{P})}$$

$$\text{LCL (nP)} = n\bar{P} - 3\sqrt{n\bar{P}\,(1 - \bar{P})}$$

SOLVED PROBLEMS

Problem 12.1: *Find mean, mode and median of following data 2, 3, 4, 5, 2, 3, 4, 5, 4, 5.*

Solution: Procedure:

(1) Mean $\bar{X}$: We have,

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \ldots\ldots + X_n}{n}$$

Therefore, $\bar{X} = \frac{2 + 3 + 4 + 5 + 2 + 3 + 4 + 5 + 4 + 5}{10} = \mathbf{3.7}$

(2) Mode:

Value	**Frequency (Number of times occurred)**
2	2
3	2
4	3
5	3

As, 4 and 5 are occurring most number of times, both are mode. Hence, data is bi-modal data.

(3)Median:

Arranging data (10 values) in ascending order - 2, 2, 3, 3, 4, 4, 4, 5, 5, 5.

As n is even,

Median is average of $\left(\frac{n}{2}\right)^{th}$ and $\left(\frac{n}{2} + 1\right)^{th}$ terms./

$\therefore\ \frac{n}{2} = \frac{10}{2} = 5^{th}$ term, that is 4.

And $\left(\frac{n}{2} + 1\right)^{th} = \frac{10}{2} + 1 = 6^{th}$ term, that is 4.

Average of 4 and 4 is again 4.

$\therefore$ Median is **4**.

Problem 12.2: *Find mean, mode, median and standard deviation for the following data:* **(S.Q.P.)**

105.4	*105.2*	*104.9*	*106*	*105.7*	*105.2*	*105.4*	*105.2*	*106*	*105.9*
105.3	*105.4*	*104.8*	*105.7*	*105.3*	*105.3*	*105*	*106*	*104.8*	*105.6*

Solution: Given data: Number of readings, n = 20.

Procedure:

1. Mean:

$$\text{Mean, } \bar{X} = \frac{X_1 + X_2 + X_3 + \ldots\ldots + X_n}{n}$$

$$= \frac{\begin{bmatrix} 105.4 + 105.2 + 105.4 + 105.2 + 104.9 + 106 + 105.7 \\ + 105.2 + 106 + 105.9 + 105.3 + 105.4 + 104.8 + 105.7 \\ + 105.3 + 105.3 + 105 + 106 + 104.8 + 105.6 \end{bmatrix}}{20}$$

$$= \mathbf{110.675}$$

2. Mode:

- Mode is the quantity, which has occurred maximum number of times, in data given.

In simple words, mode is the most frequently occurred value amongst all the values.

From the given data, we can see,

Value	104.8	104.9	105	105.2	105.3	105.4	105.6	105.7	105.9	106
Frequency of occurrence	2	1	1	4	3	3	1	2	2	3

Therefore, mode is 105.2, the value which occurred 4 times in the data

3. Median:

- Arranging the data in ascending order, we have,

  104.8, 104.8, 104.9, 105, 105.2, 105.2, 105.2, 105.2, 105.3, 105.3, **105.3**, **105.4**, 105.4, 105.4, 105.6, 105.7, 105.7, 105.9, 105.9, 106, 106, 106.

  ∴ Total number of readings (values) are 22.

- As the number of reading (n) is even, therefore, median should be the average of $\left(\frac{n}{2}\right)^{th}$ value and $\left(\frac{n}{2} + 1\right)^{th}$ value.

- As n = 22, therefore $\left(\frac{n}{2}\right)^{th}$ value = $\left(\frac{22}{2}\right)^{th}$ value = 11^{th} value,

  and $\left(\frac{n}{2} + 1\right)^{th}$ value = $\left(\frac{22}{2} + 1\right)^{th}$ value = 12^{th} value.

- From the data arranged in ascending order, 10^{th} value is 105.3 and 11^{th} value is 105.4. Therefore, median = $\frac{105.3 + 105.4}{2}$ = **105.35**.

Problem 12.3: *Eight samples of size 5 have been collected with following observations:*

Sr. No.	$\bar{X}$	*R*
1.	*2.008*	*0.027*
2.	*1.998*	*0.011*
3.	*1.995*	*0.017*
4.	*2.001*	*0.009*
5.	*2.003*	*0.014*
6.	*1.997*	*0.017*
7.	*2.002*	*0.023*
8.	*1.997*	*0.021*
9.	*2.003*	*0.015*
10.	*2.011*	*0.026*

Given: $A_2 = 0.577, D_3 = 0, D_4 = 2.114.$

Draw appropriate control charts and put your conclusions. **(W-08; S.Q.P.)**

Solution: Given data: $A_2 = 0.577$, $D_3 = 0$ and $D_4 = 2.114$

Procedure:

1. As per the data given is in variable form, the appropriate control charts, $\bar{X}$ and R Charts are to be drawn. Therefore, lets calculate the values of grand average ($\bar{\bar{X}}$) and average Range ($\bar{R}$) in steps 2 and 3 respectively.

2. $$\bar{\bar{X}} = \frac{\Sigma\bar{X}}{N} = \frac{2.008 + 1.998 + 1.995 + 2.001 + 2.003 + 1.997 + 2.002 + 1.997 + 2.003 + 2.011}{10}$$

$$\therefore \quad \bar{\bar{X}} = \mathbf{2.00195}$$

3. $$\bar{R} = \frac{\Sigma R}{N} = \frac{0.027 + 0.011 + 0.017 + 0.009 + 0.014 + 0.017 + 0.023 + 0.021 + 0.015 + 0.026}{10}$$

$$\therefore \quad \bar{R} = \mathbf{0.018}$$

4. Control limits for $\bar{X}$ chart:

$$\textbf{UCL } \bar{\mathbf{X}} = \bar{\bar{X}} + A_2.\,\bar{R} = 2.00195 + (0.577 \times 0.018) = \mathbf{2.012}$$

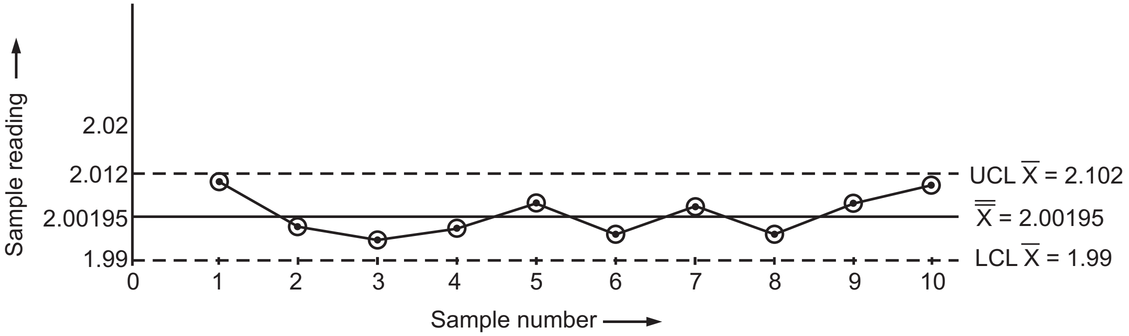
$$\textbf{LCL } \bar{\mathbf{X}} = \bar{\bar{X}} - A_2.\,\bar{R} = 2.00195 - (0.577 \times 0.018) = \mathbf{1.99}$$

5. Control limits for R chart:

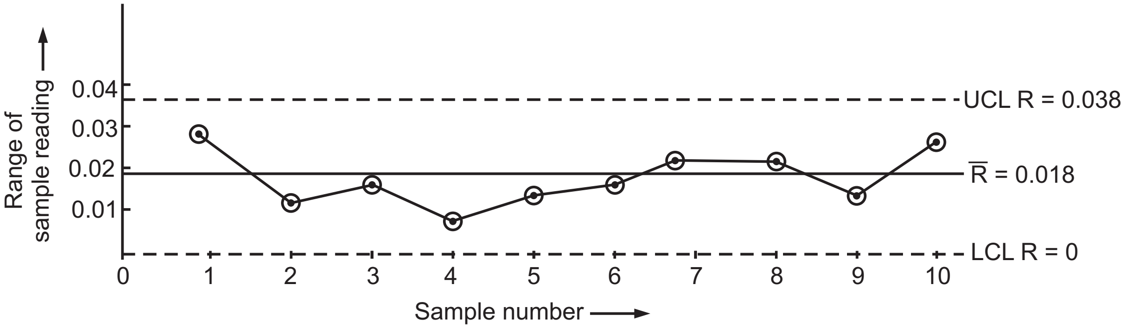
$$\textbf{UCL R} = D_4 \times \bar{R} = 2.114 \times 0.018 = \mathbf{0.038}$$

$$\textbf{LCL R} = D_3 \times \bar{R} = 0 \times 0.018 = \mathbf{0}$$

6. **Conclusion:** Process is under control, as all readings (point) fall within the control limits as represented by dotted lines in the plotted graphs.



(a) $\bar{X}$ chart



(b) R-chart

Fig. 12.8

Problem 12.4: *10 samples of size 5 have been collected with following observations.*

Sr. No.	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
$\bar{X}$	*2.011*	*2.008*	*2.001*	*2.003*	*1.998*	*1.995*	*1.997*	*1.997*	*2.002*	*2.003*
R	*0.011*	*0.017*	*0.009*	*0.026*	*0.27*	*0.21*	*0.014*	*0.017*	*0.023*	*0.015*

Given $A_2 = 0.577$, $D_3 = 0$, $D_4 = 2.114$.

Draw the appropriate control chart and explain, whether the process is in statistical control or not?

Solution: Given data: Sample size (n) = 5, Number of samples, N = 10, $A_2 = 0.577$, $D_3 = 0$, $D_4 = 2.114$.

Procedure:

(1) Type of data given is variable data measured by measuring instruments.

Therefore, we will plot variable type of control charts, $\bar{X}$ and R charts.

(2) Grand average:

$$\bar{\bar{X}} = \frac{\Sigma\bar{X}}{N} = \frac{\begin{array}{c}2.011 + 2.008 + 2.001 + 2.003 + 1.998 + 1.995\\ 1.997 + 1.997 + 2.002 + 2.003\end{array}}{10}$$

$$= 2.0015 \cong 2$$

(3) Average range:

$$\bar{R} = \frac{\Sigma R}{N} = \frac{\begin{array}{c}0.011 + 0.017 + 0.009 + 0.026 + 0.27 + 0.21\\ +0.014 + 0.017 + 0.023 + 0.015\end{array}}{10}$$

$$= 0.0612$$

(4) Control limits for $\bar{X}$ chart:

$$\textbf{UCL } \bar{\mathbf{X}} = \bar{\bar{X}} + A_2 \cdot \bar{R} = (2.0015 + 0.577 \times 0.0612) = 2.0368 \cong \mathbf{2.04}$$

$$\textbf{LCL } \bar{\mathbf{X}} = \bar{\bar{X}} - A_2 \cdot \bar{R} = (2.0015 - 0.577 \times 0.0612) = 1.9661 \cong \mathbf{1.97}$$

(5) Control limits for R chart:

$$\textbf{UCL R} = D_4 \times \bar{R} = 2.114 \times 0.0612 = 0.1293 \cong 0.13$$

$$\textbf{LCL R} = D_3 \times \bar{R} = 0 \times 0.0612 = 0$$

(6) Plotting $\bar{X}$ and R chart:

Fig. 12.9

(7) Conclusion: All the readings are within control limits. Therefore, process is under control.

Problem 12.5: *The following are $\overline{X}$ and R values of 10 samples of items 5 each:*

Sample Number	$\overline{X}$	R
1	57.80	1.50
2	58.80	1.75
3	58.80	2.00
4	59.80	2.25
5	59.90	2.25
6	60.00	2.00
7	60.30	1.00
8	60.40	1.50
9	60.90	2.00
10	61.80	1.75

The specification limits for the components are 59 ± 3.5. Establish the control limits for $\overline{X}$ and R chart. Will the process be able to meet its specifications? [Given: $A_2 = 0.577$, $D_3 = 0$, $D_4 = 2.11$]. **(W-12)**

Solution: Given data: Sample size (n) = 5, Number of sample (N) = 10,

$X_{max} = 59 + 3.5 = 62.5$ and $X_{min} = 59 - 3.5 = 55.5$.

Procedure: We have,

$$\textbf{Grand average, } \overline{\overline{X}} = \frac{\Sigma \overline{X}}{N} = \frac{\overline{X}_1 + \overline{X}_2 + \overline{X}_3 + \ldots + \overline{X}_{10}}{10}$$

$$\therefore \quad \overline{\overline{X}} = \frac{\begin{pmatrix} 57.8 + 58.8 + 58.8 + 59.8 + 59.8 + 60.0 \\ + 60.3 + 60.4 + 60.9 + 61.8 \end{pmatrix}}{10}$$

$$= \mathbf{59.84}$$

$$\textbf{Average Range, } \overline{R} = \frac{\Sigma R}{N} = \frac{R_1 + R_2 + R_3 + \ldots + R_{10}}{10}$$

$$\overline{R} = \frac{\begin{pmatrix} 1.50 + 1.75 + 2.00 + 2.25 + 2.25 + 2.00 \\ + 1.00 + 1.50 + 2.00 + 1.75 \end{pmatrix}}{10}$$

$$= \mathbf{1.8}$$

(1)Control limits for $\overline{X}$ chart:

$$\textbf{UCL } \overline{X} = \overline{\overline{X}} + A_2\overline{R} = 59.84 + (0.577 \times 1.8) = \mathbf{60.8786}$$

$$\textbf{LCL } \overline{X} = \overline{\overline{X}} - A_2\overline{R} = 59.84 - (0.577 \times 1.8) = \mathbf{58.8014}$$

(2)Control limits for R chart:

$$\textbf{UCL R} = D_4 \cdot \bar{R} = 2.11 \times 1.8 = \mathbf{3.798}$$

$$\textbf{LCL R} = D_3\ \bar{R} = 0 \times 1.8 = \mathbf{0}$$

(3)Process capability study:

$$X_{max} = 59 + 3.5 = 62.5$$

$$X_{min} = 59 - 3.5 = 55.5$$

$$\therefore \quad \textbf{Specified tolerance} = X_{max} - X_{min} = 62.5 - 55.5 = \mathbf{0.7} \qquad \text{... (i)}$$

$$\textbf{Natural tolerance,} \quad 6\sigma' = 6 \times \frac{\bar{R}}{d_2} \qquad \left[\because\ \sigma' = \frac{\bar{R}}{d_2}\right]$$

$$\therefore \quad \sigma' = 6 \times \frac{1.8}{2.326} \quad \left(\begin{array}{c}\text{Assuming } d_2 = 2.326 \text{ for sample size}\\ \text{of 5. Refer Appendix attached.}\end{array}\right)$$

$$\therefore \quad \sigma' = \mathbf{4.643} \qquad \text{... (ii)}$$

As $(X_{max} - X_{min})$ is more than $6\sigma'$, process is capable of meeting the tolerances.

Problem 12.6: *The following are $\bar{X}$, R values of 20 subgroups of 5 readings.*

$\bar{X}$	*34.0,*	*31.6,*	*30.8,*	*33.0,*	*35.0,*	*33.2,*	*33.0*	*32.6,*	*33.8,*	*37.8*
	35.8,	*35.4,*	*34.0,*	*35.0,*	*33.8,*	*31.6,*	*33.0,*	*28.2,*	*31.8,*	*35.6*
R	*4, 4, 2, 3, 5, 2, 5, 13, 19, 6, 4, 4, 14, 4, 7, 5, 5, 3, 9, 6*									

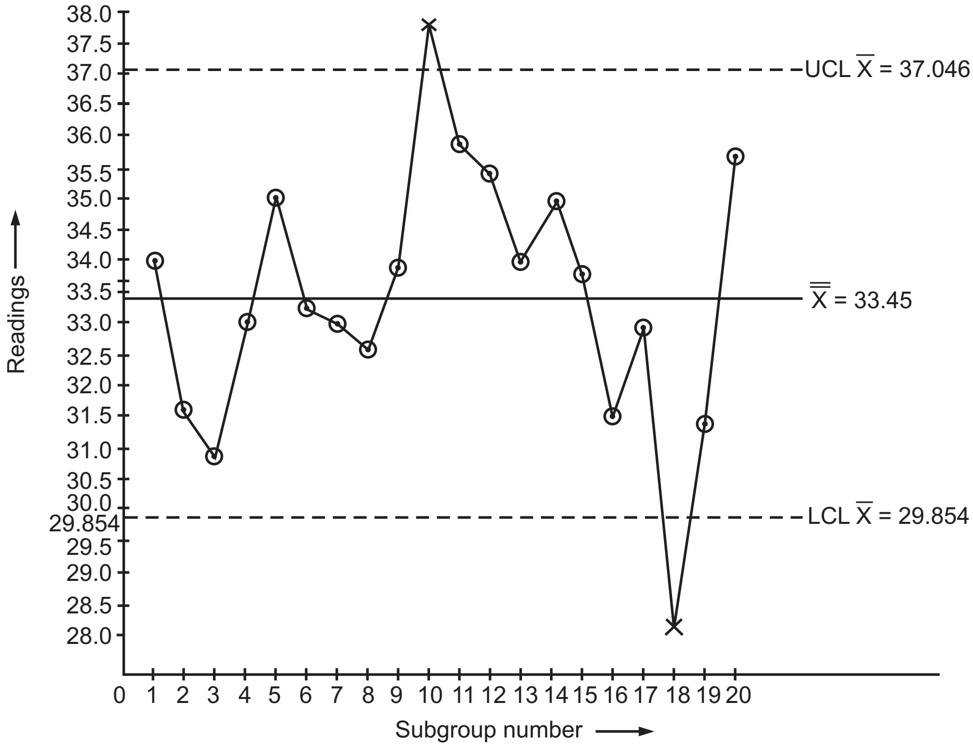
The specification limits for the components are 40.37 ± 0.10. **(W-13)**

Determine: (a) Control limits for $\bar{X}$ and R charts. (b) Draw $\bar{X}$ and R charts.

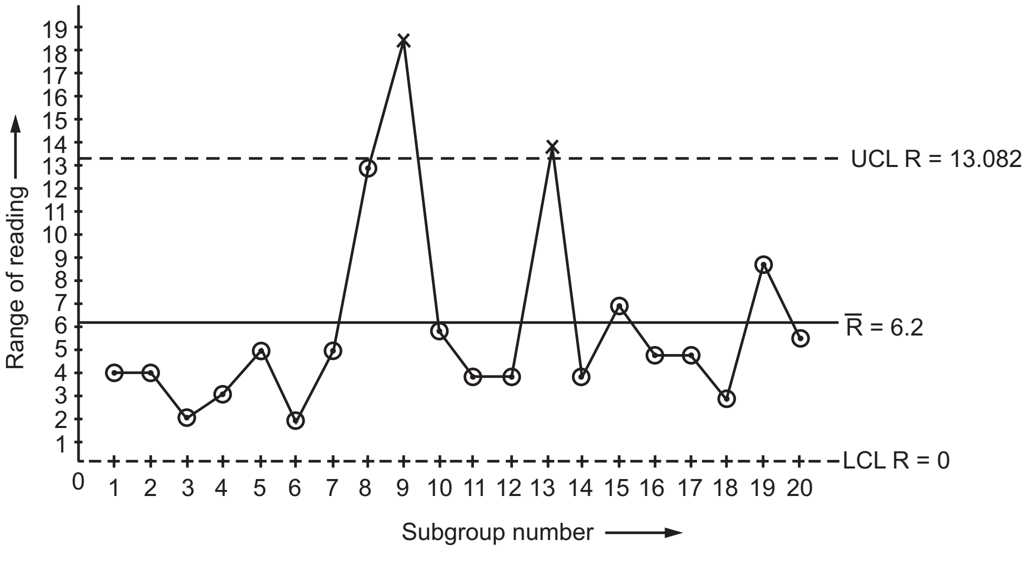
Solution: Given data: Sample size (n) = 5, Number of samples (N) = 20, $X_{max} = 40.37 + 0.10 = 40.47$ and $X_{min} = 40.37 - 0.10 = 40.27$.

Procedure:

1. $\bar{X}$ - R charts are to be drawn.
2. $$\bar{\bar{X}} = \frac{\Sigma \bar{X}}{N} = \frac{\left[\begin{array}{c}34 + 31.6 + 30.8 + 33 + 35 + 33.2 + 33 + 32.6 + 33.8 + 37.8\\ + 35.8 + 35.4 + 34 + 35 + 33.8 + 31.6 + 33 + 28.2 + 31.8 + 35.6\end{array}\right]}{20}$$
   $$= \mathbf{33.45}$$
3. $$\bar{R} = \frac{\Sigma R}{N} = \frac{\left[\begin{array}{c}4 + 4 + 2 + 3 + 5 + 2 + 5 + 13 + 19 + 6 + 4 + 4\\ + 14 + 4 + 7 + 5 + 5 + 3 + 9 + 6\end{array}\right]}{20} = \mathbf{6.2}$$
4. For a sample size of 5 readings, let us assume, $A_2 = 0.58$, $D_3 = 0$ and $D_4 = 2.11$. (Refer Appendix)
5. **Control limits for $\bar{X}$ chart**,
   $$\textbf{UCL } \bar{\mathbf{X}} = \bar{\bar{X}} + A_2\bar{R} = 33.45 + (0.58 \times 6.2) = \mathbf{37.046}$$
   $$\textbf{LCL } \bar{\mathbf{X}} = \bar{\bar{X}} - A_2\bar{R} = 33.45 - (0.58 \times 6.2) = \mathbf{29.854}$$
6. **Control limits for R chart**,
   $$\textbf{UCL R} = D_4\bar{R} = 2.11 \times 6.2 = \mathbf{13.082}$$
   $$\textbf{LCL R} = D_3\bar{R} = 0 \times 6.2 = \mathbf{0}$$
7. Plotting $\bar{X}$ and R chart:



(a) $\overline{X}$ chart



(b) R-chart

Fig. 12.10

Problem 12.7: *A subgroup of 5 items each is taken from a manufacturing process at a regular interval. A certain quality characteristics is measured, and $\bar{X}$ and R values are computed. After 25 groups, it is found that $\Sigma\bar{X} = 357.50$ and $\Sigma R = 8.80$. If the specification limits are 14.40 ± 0.40 and if the process is in statistical control, what conclusion can you draw about the ability of the process to produce items within specification?* **(W-08)**

Solution: Given data: Sample size (n) = 5, Number of samples or subgroups (N) = 25, $X_{max} = 14.4 + 0.4 = 14.8$, $X_{min} = 14.4 - 0.4 = 14$, $\therefore X_{max} - X_{min} = 14.8 - 14 = 0.8$, $\Sigma\bar{X} = 357.50$ mm, $\Sigma R = 8.80$ mm

Procedure: Take $d_2 = 2.326$ (Assumed for a sample size of 5)

Grand Average: $\bar{\bar{X}} = \frac{\Sigma\bar{X}}{N} = \frac{357.50}{25} = \mathbf{14.3}$

Average Range: $\bar{R} = \frac{\Sigma R}{N} = \frac{8.80}{25} = \mathbf{0.352}$

$\therefore$ $\sigma' = \frac{\bar{R}}{d_2} = \frac{0.352}{2.326} = \mathbf{0.15133}$ $[\because d_2 = 2.326]$

$\therefore$ $\sigma\bar{X} = \frac{\sigma'}{\sqrt{n}} = \frac{0.15133}{\sqrt{5}} = \mathbf{0.067678}$

(1) Control limits for $\bar{X}$ chart:

$$\text{UCL }\bar{X} = \bar{\bar{X}} + 3\sigma\cdot\bar{X} = 14.3 + (3 \times 0.067678) = \mathbf{14.503}$$

$$\text{LCL }\bar{X} = \bar{\bar{X}} - 3\sigma\cdot\bar{X} = 14.3 - (3 \times 0.067678) = \mathbf{14.097}$$

(2) Process capability:

Now, $X_{max} = 14.40 + 0.40 = 14.80$

$X_{min} = 14.40 - 0.40 = 14.00$

$\therefore$ $X_{max} - X_{min} = 14.80 - 14.00 = \mathbf{0.80}$

And Process capability, $6\sigma' = 6 \times 0.15133 = \mathbf{0.90798}$

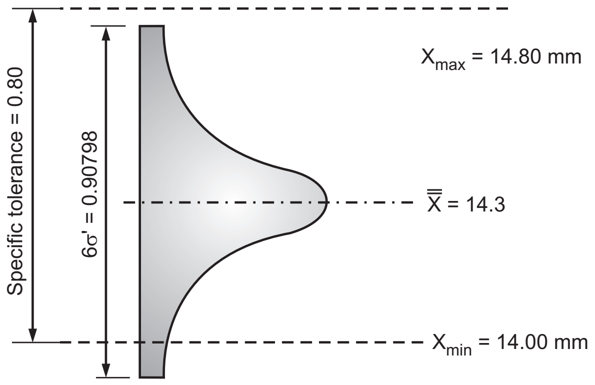


Fig. 12.11

(3) Conclusion: Here, 6σ' value exceeds $(X_{max} - X_{min})$ value, so we conclude that, $(X_{max} - X_{min}) < 6\sigma'$. Therefore defective parts will always be there.

Problem 12.8: *Determine the control limits for $\bar{X}$ and R charts, if $\Sigma \bar{X} = 357.50$ and $\Sigma R = 9.90$. Number of subgroups = 20. It is given that $A_2 = 0.18$, $D_3 = 0.41$, $D_4 = 1.59$ and $d_2 = 3.735$. Also, find the process capability.*

Solution: Given data:

$$\Sigma \bar{X} = 357.50$$

$$\Sigma R = 9.90$$

Number of subgroups (N) = 20.

$A_2 = 0.18$, $D_3 = 0.41$, $D_4 = 1.59$, $d_2 = 3.735$.

Procedure: We have,

Grand Average: $\bar{\bar{X}} = \frac{\Sigma \bar{X}}{N} = \frac{357.5}{20} = \mathbf{17.875}$

Average Range: $\bar{R} = \frac{\Sigma R}{N} = \frac{9.90}{20} = \mathbf{0.495}$

$\therefore$ $\sigma' = \frac{\bar{R}}{d_2} = \frac{0.495}{3.735} = \mathbf{0.1325}$

(1)Control limits for $\bar{X}$ chart:

$$\text{UCL } \bar{X} = \bar{\bar{X}} + A_2 \cdot \bar{R} = 17.875 + (0.18 \times 0.495) = \mathbf{17.964}$$

$$\text{LCL } \bar{X} = \bar{\bar{X}} - A_2 \cdot \bar{R} = 17.875 - (0.18 \times 0.495) = \mathbf{17.786}$$

(2)Control limits for R chart:

$$\text{UCL R} = D_4 \cdot \bar{R} = 1.59 \times 0.495 = \mathbf{0.787}$$

$$\text{LCL R} = D_3 \cdot \bar{R} = 0.41 \times 0.495 = \mathbf{0.203}$$

(3)Process capability:

To find the process capability, we take $6\sigma'$.

Therefore, process capability = $6\sigma' = 6 \times 0.1325 = \mathbf{0.795}$

Problem 12.9: *Control chart for $\bar{X}$ is to be prepared for a certain dimension of component. The subgroup size is 4, after 20 subgroups, it is found that $\Sigma \bar{X} = 825.6$ mm and $\Sigma R = 5.60$ mm. Compute the central line and the control limit for $\bar{X}$ chart. Take $D_2 = 2.059$.*

If the specifications are 41.0 ± 0.40 mm and are normally distributed, can the process meets the specification requirement ?

Solution: Given data: Sample or subgroup size (n) = 4, Number of subgroups (N) = 20, $\Sigma \bar{X} = 825.6$ mm, $\Sigma R = 5.6$ mm

$\therefore$ $X_{max} - X_{min} = 41.4 - 40.6 = 0.8$ mm.

Procedure:

(1) Central line:

We have, Central line, $\bar{\bar{X}} = \frac{\Sigma \bar{X}}{N} = \frac{825.6}{20} = \mathbf{41.28}$

And, $\bar{R} = \frac{\Sigma R}{N} = \frac{5.6}{20} = \mathbf{0.28}$

$\therefore \quad \sigma' = \frac{\bar{R}}{d_2} = \frac{0.28}{2.059} = \mathbf{0.1359}$

$\therefore \quad 3\sigma\cdot \bar{X} = \frac{3\sigma'}{\sqrt{n}} = \frac{3 \times 0.1359}{\sqrt{4}} = \mathbf{0.2038}$

(2) Control limits:

$$\textbf{UCL } \bar{X} = \bar{\bar{X}} + 3\sigma\bar{X} = 41.28 + 0.2038 = \mathbf{41.4838}$$

$$\textbf{LCL } \bar{X} = \bar{\bar{X}} - 3\sigma\bar{X} = 41.28 - 0.2038 = \mathbf{41.0762}$$

(3) Specified tolerance:

$X_{max} = 41 + 0.40 = 41.40$ mm

$X_{min} = 41 - 0.40 = 40.60$ mm

$\therefore \quad X_{max} - X_{min} = 41.40 - 40.60 = \mathbf{0.8}$

(4) Natural tolerance: The process capability = 6σ′ = 6 × 0.1359 = **0.8154**.

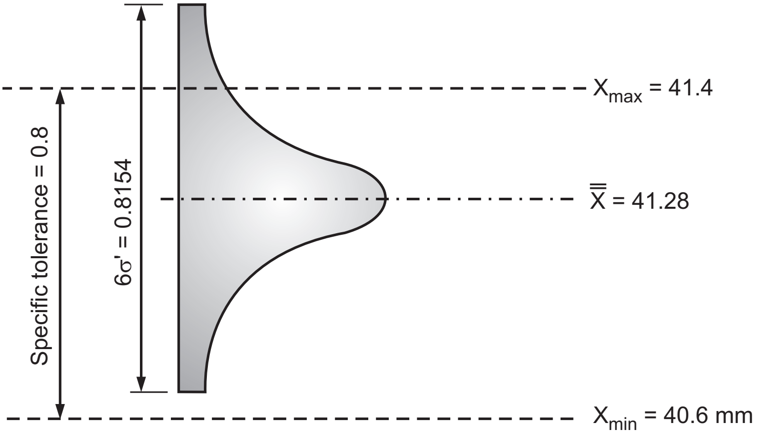


Fig. 12.12

(5) Conclusion: In this case, $(X_{max} - X_{min}) < 6\sigma'$. Therefore, defective parts will always be there. Moreover centering is not done properly. If the centering of process is improved, the number of defective parts can be considerably reduced.

Problem 12.10: *The following are the results of 20 lots. Each lot contains 750 objects. Number of defective objects in each lot are as follows:*

48, 83, 70, 85, 90, 56, 51, 71, 36, 50, 29, 51, 29, 31, 37, 80, 70, 48, 67, 57. Analyze the data on the base of appropriate control chart. Calculate control limit and state whether the process is in control. **(S-09; W-10, 12)**

Solution: Given data: Lot size, (n) = 750, Number of lots, (N) = 20

Procedure: (1) For the first lot having number of defectives as 48, we calculate,

$$\textbf{Fraction defective} = \frac{\text{Number of defectives}}{\text{Lot size or Number of articles inspected}} = \frac{48}{750} = \mathbf{0.064}$$

Doing so, for remaining 19 lots, we get,

Lot No.	Number of Defectives	Fraction Defectives	Lot Number	Number of Defectives	Fraction Defectives
1.	48	0.064	11.	29	0.04
2.	83	0.11	12.	51	0.068
3.	70	0.09	13.	29	0.038
4.	85	0.11	14.	31	0.041
5.	90	0.12	15.	37	0.05
6.	56	0.074	16.	80	0.11
7.	51	0.068	17.	70	0.09
8.	71	0.094	18.	48	0.064
9.	36	0.048	19.	67	0.09
10.	50	0.066	20.	57	0.07
			Total number of defectives	1139	

From the above table, we have, total number of detectives = 1139

(2)Central line of P chart: It is average fractional defective denoted as $\bar{P}$.

$$\bar{P} = \frac{\text{Total no. of defectives}}{\text{Total no. of workpieces inspected}} = \frac{1139}{20 \times 750} = 0.07593 \cong \mathbf{0.076}$$

(3)Control limits for P chart:

$$\textbf{UCL P} = \bar{P} + 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}} = 0.07593 + 3\sqrt{\frac{0.07593\ (1 - 0.07593)}{750}}$$

$$= 0.1049 \cong \mathbf{0.105}$$

$$\textbf{LCL P} = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}} = 0.07593 - 3\sqrt{\frac{0.07593\ (1 - 0.07593)}{750}}$$

$$= 0.0469 \cong \mathbf{0.05}$$

(4)Construction of P-chart:

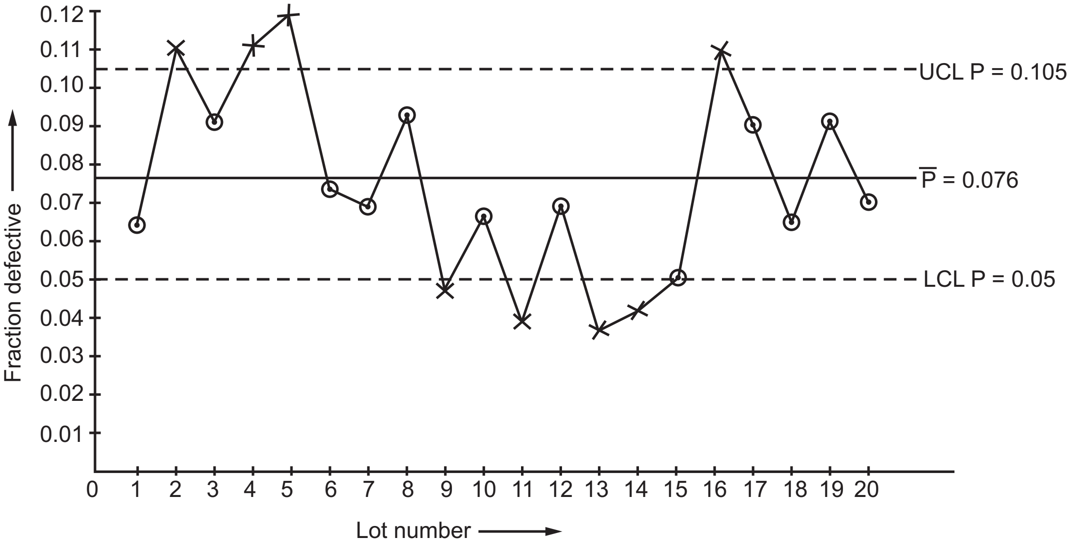


Fig. 12.13

Problem 12.11: *The following are the inspection results of 20 lots of magnets. Each lot having 750 magnets. Number of defective magnets in each lot are 48, 83, 70, 85, 45, 56, 48, 67, 37, 52, 47, 50, 47, 57, 53, 34, 29 and 30. Calculate the average fraction defective and the control limits for P chart.* **(W-11)**

Solution: Given data: Lot size (n) = 750

Number of lots (N) = 20

Procedure:

We have, total number of magnets in all lots = 750 × 20

$$\textbf{(1) Average fraction defective} = \frac{\text{Number of defective magnets in a lot}}{\text{Total number of magnets inspected in the lot}}$$

$$\therefore \quad \overline{P} = \frac{\begin{pmatrix} 48 + 83 + 70 + 85 + 45 + 56 + 48 + 67 + 37 \\ + 52 + 47 + 50 + 47 + 57 + 53 + 34 + 29 + 30 \end{pmatrix}}{750 \times 20} = \mathbf{0.0625}$$

(2) Control limits of P-chart:

$$\text{UCL P} = \overline{P} + 3\sqrt{\frac{\overline{P}\,(1 - \overline{P})}{n}}$$

$$= 0.0625 + 3 \times \sqrt{\frac{0.0625 \times (1 - 0.0625)}{750}} = \mathbf{0.089}$$

$$\text{LCL P} = \overline{P} - 3\sqrt{\frac{\overline{P}\,(1 - \overline{P})}{n}}$$

$$= 0.0625 - 3\sqrt{\frac{0.0625 \times (1 - 0.0625)}{750}} = \mathbf{0.036}$$

Problem 12.12: *Table given below shows number of defectives found in inspection of a lot for 100 plugs each. Draw control chart and check whether process is in control or not?*

Lot Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Number of Defectives	*6*	*3*	*1*	*4*	*3*	*0*	*11*	*5*	*2*	*3*

Solution: Given data: Lot size (n) = 100 and Number of lots (N) = 10.

Procedure:

(1) For first lot, Fraction defective $= \frac{\text{Number of defectives}}{\text{Lot size (n)}} = \frac{6}{100} = \mathbf{0.06}$.

If same procedure is carried out for remaining 9 lots, we will get,

Lot Number	1	2	3	4	5	6	7	8	9	10
Fraction Defective of particular lot	0.06	0.03	0.01	0.04	0.03	0.00	0.11	0.05	0.02	0.03

(2) Average fraction defective: It is calculated as the average or arithmetic mean value of all the fraction defectives.

$$\therefore \quad \text{Average fraction defective, } (\bar{P}) = \frac{\text{Algebraic sum of all fraction defectives}}{\text{Total number of fraction defectives (lots)}}$$

$$= \frac{\begin{bmatrix} 0.06 + 0.03 + 0.01 + 0.04 + 0.03 + 0.00 \\ + 0.11 + 0.05 + 0.02 + 0.03 \end{bmatrix}}{10}$$

$$\therefore \quad \bar{P} = \mathbf{0.038}$$

(3) Control Limits:

$$\textbf{UCL P} = \bar{P} + 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$$

$$= 0.038 + 3\sqrt{\frac{0.038\ (1 - 0.038)}{100}} = \mathbf{0.0954}$$

$$\textbf{LCL P} = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$$

$$= 0.038 - 3\sqrt{\frac{0.038\ (1 - 0.038)}{100}} = -\ 0.0193 \equiv \mathbf{0}$$

Since, negative number of defectives not possible, hence, LCL is taken as 0.

(4) Construction of P-chart:

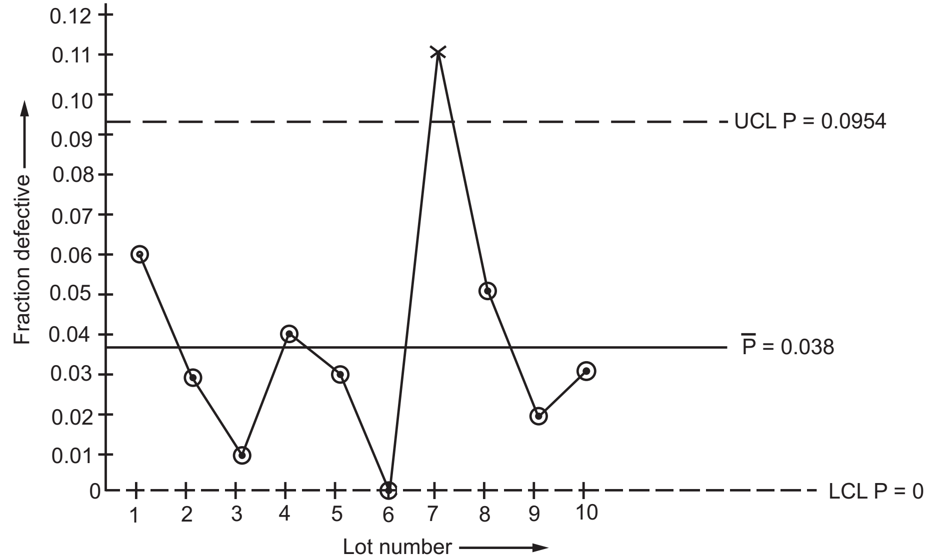


Fig. 12.14

(5) Conclusion: As point no. 7 falls outside upper limit, hence, process is out of control.

Problem 12.13: *Following are inspection results of magnets for five observations. Draw appropriate control chart and conclude,* **(S-13, S-16)**

Week number	*1*	*2*	*3*	*4*	*5*
Number of magnet inspected	*728*	*724*	*720*	*730*	*724*
Defectives found	*48*	*83*	*80*	*58*	*60*

Solution:

Procedure: (1) As number of defectives are given, P-chart is to be drawn.

(2) Calculate fraction defective for each week as, $\left(\frac{\text{Number of defectives}}{\text{n}}\right)$.

$$\text{For first week, P} = \frac{\text{Number of defectives}}{\text{n}} = \frac{48}{724} = 0.06$$

Accordingly, we get,

Week Number	Job Inspected	Defectives	% Defectives
1	724	48	0.06
2	728	83	0.114
3	724	70	0.096
4	720	80	0.111
5	730	58	0.07
Total	Total no. of jobs inspected = 3626	Total no. of defectives = 339	

(3) **Central line**, $\bar{\text{P}} = \frac{\text{Total no. of defectives}}{\text{Total jobs inspected}} = \frac{339}{3626} = \mathbf{0.093}$

(4) In this numerical, lot size varies for every week. Therefore, average number of jobs inspected per week should be calculated.

$$\therefore \qquad \text{n} = \frac{3626}{5} = \mathbf{725.2}$$

(5) **Control limits for $\bar{\text{P}}$ chart:**

$$\text{UCL P} = \bar{\text{P}} + 3\sqrt{\frac{\bar{\text{P}}(1-\bar{\text{P}})}{\text{n}}}$$

$$= 0.093 + 3 \times \sqrt{\frac{0.093\ (1-0.093)}{725.2}} = \mathbf{0.125}$$

$$\text{LCL P} = \bar{\text{P}} - 3 \times \sqrt{\frac{\bar{\text{P}}(1-\bar{\text{P}})}{\text{n}}}$$

$$= 0.093 - 3 \times \sqrt{\frac{0.093\ (1-0.093)}{725.2}} = \mathbf{0.06}$$

(5) **Construction of P-chart:**

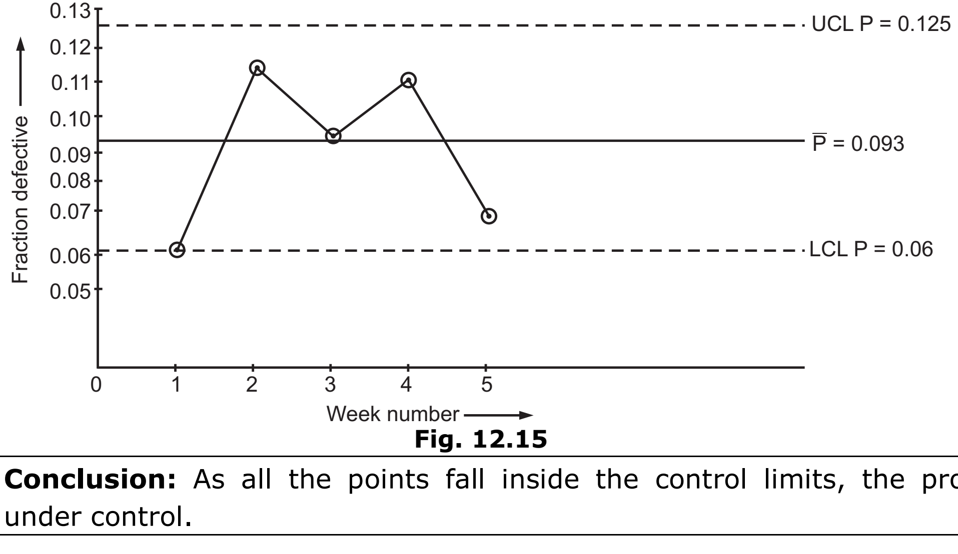


Fig. 12.15

(7) **Conclusion:** As all the points fall inside the control limits, the process is under control.

Problem 12.14: *Following are the inspection results of magnets for 10 observations. Draw appropriate control chart and write your conclusion.* **(W-15)**

Given $A_2 = 0.58$, $D_3 = 0$, $D_4 = 2.11$

Day	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Number of defective magnets	*58*	*83*	*70*	*80*	*72*	*58*	*64*	*78*	*80*	*84*
Magnets inspected	*721*	*728*	*720*	*730*	*720*	*700*	*710*	*700*	*710*	*740*

Solution:

Procedure:

(1) As number of defectives or defective magnets are given, P-chart must be used.

(2) Fraction defective of each day: For the first day having lots of 721 magnets, the number of defective magnets given are 58.

$$\therefore \quad \text{For first day, fraction defective, P} = \frac{\text{Total number of defective magnets on } 1^{st} \text{ day}}{\text{Total number of magnets inspected on } 1^{st} \text{ day}}$$

$$\therefore \qquad P = \frac{58}{721} = 0.08044$$

Using the same procedure to calculate fraction defectives of remaining lots, we get,

Day	1	2	3	4	5	6	7	8	9	10
Number of defective magnets	58	83	70	80	72	58	64	78	80	84
Magnets inspected in that particular day	721	728	720	730	720	700	710	700	710	740
Fraction defective of that particular day (P)	0.08044	0.114	0.0972	0.1096	0.1	0.083	0.901	0.1114	0.1126	0.1135

$$\therefore \quad \text{Average fraction defective, } \bar{P} = \frac{\text{Total number of defectives in 90 days}}{\text{Total number of magnets inspected in 10 days}}$$

$$= \frac{58 + 83 + 70 + 80 + 72 + 58 + 64 + 78 + 80 + 84}{721 + 728 + 720 + 730 + 720 + 700 + 710 + 700 + 710 + 740}$$

$$\bar{P} = \frac{727}{7179} = \mathbf{0.1013} \cong 0.10$$

And average number of magnets inspected per day = n = $\frac{7179}{\text{Total number of days}}$

$$= \frac{7179}{10}$$

$$= \mathbf{717.9}$$

(3) **Control limits for P-chart:**

$$\textbf{UCL P} = \bar{P} + 3\sqrt{\frac{\bar{P}\ (1 - \bar{P})}{n}}$$

$$= 0.10 + 3\sqrt{\frac{0.10 \times (1 - 0.10)}{717.9}} = \mathbf{0.134}$$

$$\textbf{LCL P} = \bar{P} - 3\sqrt{\frac{\bar{P}\ (1 - \bar{P})}{n}}$$

$$= 0.10 - 3\sqrt{\frac{0.10 \times (1 - 0.10)}{717.9}} = 0.0664$$

(4) Construction of P-chart:

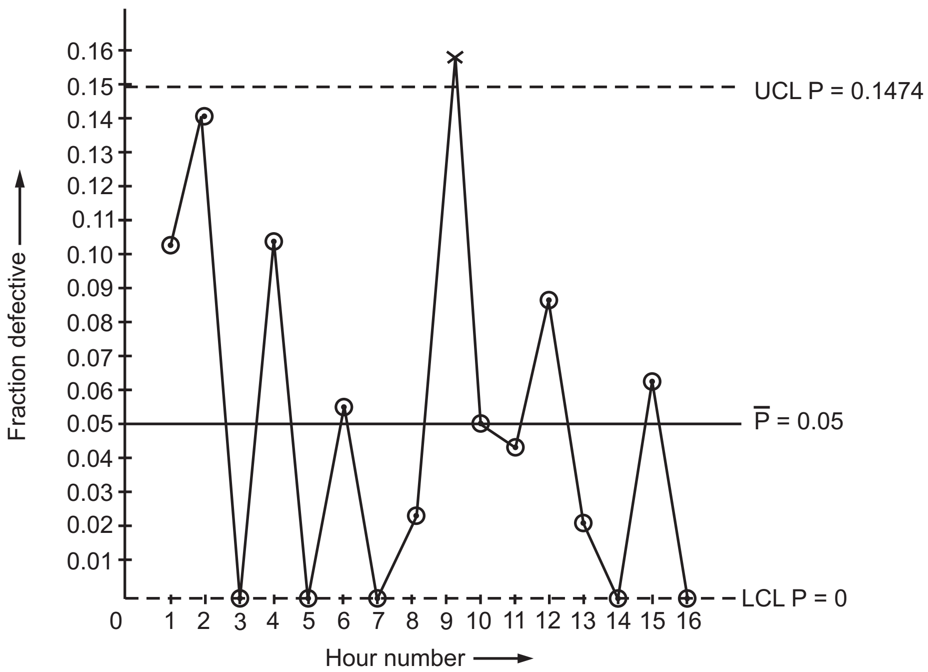


Fig. 12.16

Conclusion: All readings fall within the permissible limits, therefore, the process is in control.

Problem 12.15: *In a manufacturing process, the number of defectives found in the inspection of 10 lots of 400 items each are given below :*

Lot number	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Number of defectives	*2*	*0*	*14*	*3*	*1*	*18*	*6*	*0*	*3*	*6*

Determine the trial control limits for np chart and state whether the process is in control. **(W-14)**

Solution: Given data: Number of lots, N = 10, Lot size, n = 400

Procedure: From the data given, we can calculate total number of defectives.

$$\therefore \quad \Sigma\, nP = 2 + 0 + 14 + 3 + 1 + 18 + 6 + 0 + 3 + 6 = \mathbf{53}$$

Total number of items inspected,

$$\Sigma\, n = \text{Number of lots} \times \text{Lot size} = 10 \times 400 = \mathbf{4000}$$

(1) $$\text{Average fraction defective } \bar{P} = \frac{\Sigma\, nP}{\Sigma\, n} = \frac{53}{4000} = \mathbf{0.01325}$$

(2) **Central line of nP chart:**

$$n\bar{P} = 400 \times 0.01325 = \mathbf{5.3}$$

(3) **Control limits for nP chart:**

$$\text{UCL (nP)} = n\bar{P} + 3\sqrt{n\bar{P}\,(1 - \bar{P})}$$

$$= 5.3 + 3 \times \sqrt{5.3 \times (1 - 0.01325)} = \mathbf{12.16}$$

$$\text{LCL (nP)} = n\bar{P} - 3\sqrt{n\bar{P}\,(1 - \bar{P})}$$

$$= 5.3 - 3 \times \sqrt{5.3 \times (1 - 0.01325)} = -1.56 \cong \mathbf{0}$$

(4) **Conclusion:** As UCL (nP) = 12.16, we find that, the lot numbers (3) and (6) containing number of defectives as 14 and 18 respectively will fall out of control limits. Therefore, the process is not in statistical control.

Problem 12.16: *Number of defects found in a inspection of 10 assemblies are 2, 3, 2, 5, 2, 3, 5, 3, 0, 1 respectively. Draw appropriate control chart and conclude.* **(S-14)**

Solution:

Procedure:

(1) Since number of **defects** are given, we will use **C-chart**, it is called as defect chart.

(2) **For 'C' chart:**

$$\textbf{Central line: } \bar{C} = \frac{\text{Number of defects}}{\text{Total Number of inspected items}}$$

$$= \frac{2 + 3 + 2 + 5 + 2 + 3 + 5 + 3 + 0 + 1}{10} = \mathbf{2.6}$$

(3) **Control limits:** $$\textbf{UCL C} = \bar{C} + 3\sqrt{\bar{C}}$$

$$= 2.6 + 3\sqrt{2.6} = \mathbf{7.43}$$

$$\textbf{LCL C} = \bar{C} - 3\sqrt{\bar{C}}$$

$$= 2.6 - 3\sqrt{2.6} = -2.23 \cong \mathbf{0}$$

(4) **Construction of C-chart:**

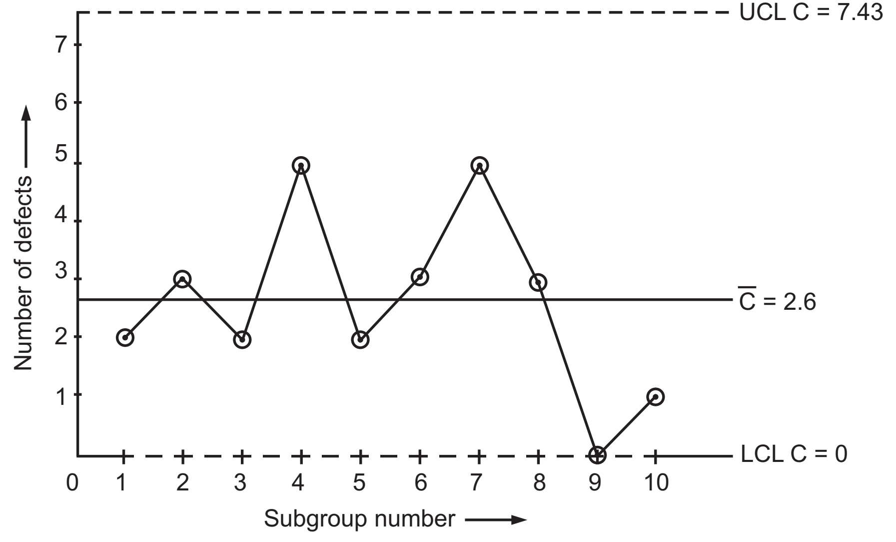


Fig. 12.17

(5) **Conclusion:** All points lie between control limits. Hence, process is in control.

Problem 12.17: *Following table shows the number of defects observed on 25 similar big castings:*

Casting Number	*Number of Defects*	*Casting Number*	*Number of Defects*
1	*7*	*14*	*24*
2	*14*	*15*	*14*
3	*14*	*16*	*9*
4	*18*	*17*	*9*
5	*8*	*18*	*11*
6	*14*	*19*	*10*
7	*8*	*20*	*8*
8	*11*	*21*	*9*
9	*20*	*22*	*11*
10	*12*	*23*	*7*
11	*22*	*24*	*26*
12	*15*	*25*	*8*
13	*8*	-	-

(i) Calculate control limits.

(ii) Draw a suitable control chart for the given data and comment on it.

Solution:

Procedure:

(1) As number of **defects** are given, we will use **C-chart**.

(2) **For C chart:**

$$\textbf{Central line: } \bar{C} = \frac{\text{Number of defects}}{\text{Total number of subgroups}}$$

$$= \frac{\begin{bmatrix} 7 + 14 + 14 + 18 + 8 + 14 + 8 + 11 + 20 + 12 \\ + 22 + 15 + 8 + 24 + 14 + 9 + 9 + 11 + 10 \\ + 8 + 9 + 11 + 7 + 26 + 8 \end{bmatrix}}{25}$$

$$= \mathbf{12.68}$$

(3) **Control limits for C chart:**

$$\text{UCL C} = \bar{C} + 3\sqrt{\bar{C}} = 12.68 + 3\sqrt{12.68}$$

$$= \mathbf{23.36}$$

$$\text{LCL C} = \bar{C} - 3\sqrt{\bar{C}} = 12.68 - 3\sqrt{12.68}$$

$$= \mathbf{1.99}$$

(4) **Construction of C-chart:**

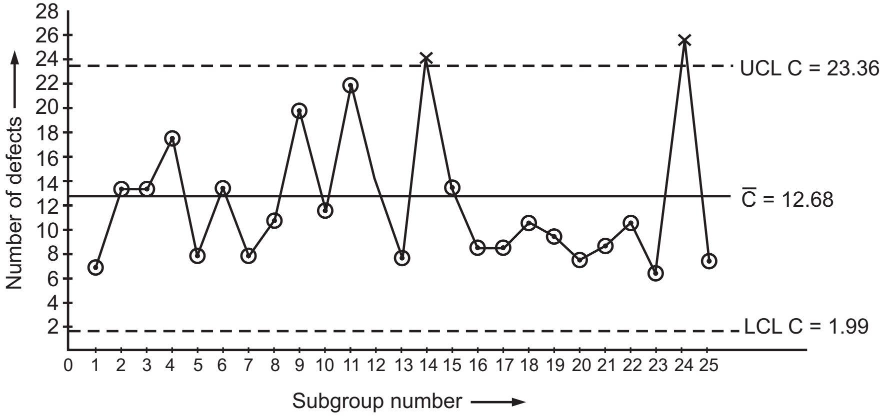


Fig. 12.18

(5) Comment: As readings (14) and (24) are falling outside the control limits, process is out of control.

Problem 12.18: *The following table gives the number of errors in alignment observed at the final inspection of a certain model of an aeroplane. Prepare a C-chart and comment on it.* **(S-15)**

Aeroplane number	01	2	3	4	5	6	7	8	9	10	11	12	13
Number of alignment defect	07	6	6	7	4	7	8	12	9	9	8	5	5

Aeroplane number	14	15	16	17	18	19	20	21	22	23	24	25
Number of alignment defect	9	8	15	6	4	13	7	8	15	6	6	10

Solution: Procedure:

(1)For 'C' chart:

$$\text{Central line, } \bar{C} = \frac{\text{Number of defects}}{\text{Total number of subgroups}}$$

$$= \frac{\begin{bmatrix} 7 + 6 + 6 + 7 + 4 + 7 + 8 + 12 + 9 + 9 + 8 + 5 + 5 + 9 \\ + 8 + 15 + 6 + 4 + 13 + 7 + 8 + 15 + 6 + 6 + 10 \end{bmatrix}}{25}$$

$$= \mathbf{8}$$

(2) Control limits for C chart:

$$\textbf{UCL C} = \bar{C} + 3\sqrt{\bar{C}} = 8 + 3\sqrt{8} = \mathbf{16.48}$$

$$\textbf{LCL C} = \bar{C} - 3\sqrt{\bar{C}} = 8 - 3\sqrt{8} = -0.48 \cong \mathbf{0}$$

(3) Construction of C chart:

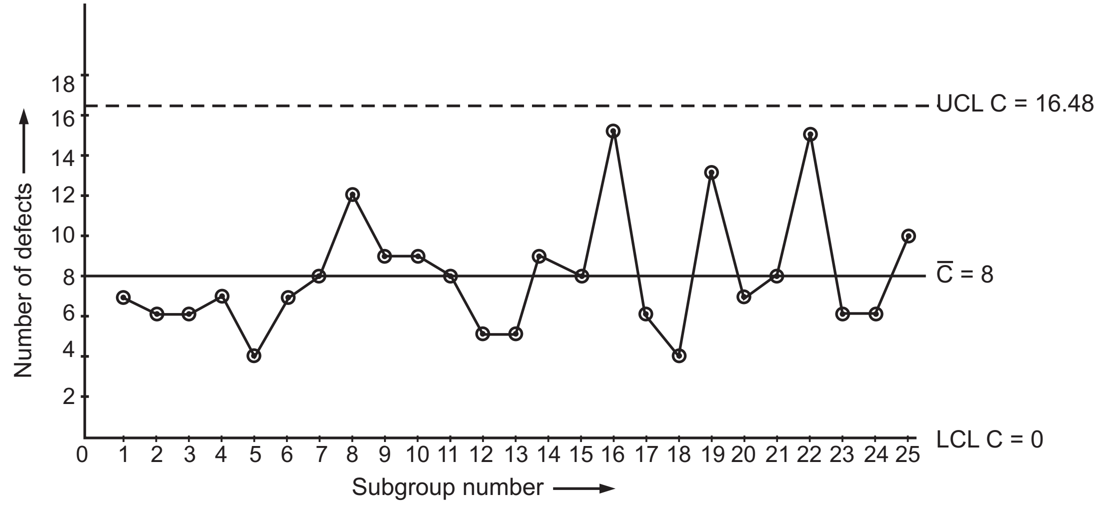


Fig. 12.19

(4) Conclusion:

As no reading falls outside the control limit, the **process is in statistical control**. In other words, we can say all points lie between the limits.

Important Points

- A quality Control system is called as *SQC*, when statistical techniques are applied to control the quality or to solve quality problems.
- When measurements are carried out to find quality characteristic of a component, the quality is said to be expressed by *variables*.
- When a record shows only the numbers of workpieces/items conforming and non-conforming to specified requirement, it is said to be *attribute*.
- *Control chart* is a graphical representation of the collected information.
- *Process capability* may be defined as 'the minimum 'spread' of specific measurement variation, which will include 99.73% of the measurement from the given process'.
- Process capability = 6σ', since 6σ' is taken as a measure of spread of process, which is also called as natural tolerance.

Theory Questions for practice

1. What is Statistical Quality Control? Enlist the advantages of SQC.
2. Define variable and attribute measurement.
3. Differentiate between Variable inspection and Attribute inspection.
4. Define (i) Central tendency, (ii) Arithmetic mean, (iii) Median and (iv) Mode.

5. Define (i) Dispersion, (ii) Range (iii) Standard deviation and (iv) Variance.
6. What is Normal distribution curve? State its characteristics and applications.
7. Differentiate between variations due to assignable causes and variations due to chance causes.
8. What is control chart? State its purpose and types.
9. What is process capability? Explain its significance.
10. Write down the procedure for doing process capability study.
11. Define defect, defective and fraction defective.
12. Enlist all the steps with formulae used to draw P-Chart?
13. State the applications of C Chart.
14. Differentiate between Variable and Attribute charts.
15. Write a short note on C_p and C_{pk}.

Numerical Problems for Practice

1. The following are $\overline{X}$ and R values for 20 subgroups of 5 readings.

   $\overline{X}$ = 34.0, 31.6, 30.8, 33.0, 35.0, 33.2, 33.0, 32.6, 33.8, 37.8, 35.8, 38.4, 34.0, 35.0, 33.8, 31.6, 33.0, 28.2, 31.8, 35.6

   R = 4, 4, 2, 3, 5, 2, 5, 13, 19, 6, 4, 4, 14, 4, 7, 5, 5, 3, 9, 6.

   The specified limits for components are 40.37 ± 0.1. Establish control limits for $\overline{X}$ and R chart and state whether the process will the meet specification?

2. The components were taken in subgroups of 5 items, 10 such subgroups were checked. The $\overline{X}$ and R values noted are:

Subgroup Number	1	2	3	4	5	6	7	8	9	10
$\overline{X}$	34	30.8	35	33	33.8	35.8	34	33.8	31.8	33
R	4	2	5	5	19	4	14	7	9	5

   Establish the control limits for $\overline{X}$ and R charts. Draw the charts and tell whether, the product will meet the specifications or not? How much is process capability for subgroup size 5? Take $A_2 = 0.577$, $D_3 = 0$, $D_4 = 2.115$.

3. The number of defects found in each sample of cloth of 1 sq.m area are noted down as follows. Draw appropriate control chart and state, whether the process is in control or not?

Sample Number	1	2	3	4	5	6	7	8	9	10	11	12
Number of defects found	8	9	5	8	5	9	9	11	8	7	6	4

MSBTE Questions and Answers (As Per G-Scheme)

Winter 2014

1. State different SQC tools and explain any one. **(4M)**

Ans. Refer Article 12.4 and any one from Articles 12.10, 12.15 and 12.16.

2. Explain following trends of $\overline{X}$ control chart. **(8M)**

(i) Extreme variations, (ii) Shift, (iii) Erratic fluctuations and (iv) Indication of trend

Ans. Refer Section 12.5.7.

3. Determine the control limits for $\overline{X}$ and R charts if $\Sigma \overline{X} = 357.50$ and $\Sigma R = 9.90$. Number of subgroups = 20. It is given that $A_2 = 0.18$, $D_3 = 0.41$, $D_4 = 1.59$ and $d_2 = 3.735$. Draw control charts and write your conclusions. Also find the process capability. **(8M)**

Ans. Refer Problem 12.8.

4. In a manufacturing process, the number of defectives found in the inspection of 10 lots of 400 items each are given below : **(8M)**

Lot number	1	2	3	4	5	6	7	8	9	10
Number of defectives	2	0	14	3	1	18	6	0	3	6

Determine the trial control limits for np chart and state whether the process is in control.

Ans. Refer Problem 12.15.

5. Define : **(4M)**

(i) Frequency distribution

(ii) Central tendency

(iii) Dispersion

(iv) Variance

Ans. Refer Articles 12.10, 12.11 and 12.12.

Summer 2015

1. Define median, mode, range and standard deviation. **(4M)**

Ans. Refer Articles (1) 12.11.2, (2) 12.11.3, (3) 12.12.1, (4) 12.12.2.

2. Write the various steps in constructing $\overline{X}$ and R charts. Consider suitable example. **(4M)**

Ans. Refer Article 12.15.4 and Problem 12.2.

3. Differentiate between variable charts and attributable charts (any four). **(4M)**

Ans. Refer Article 12.21.

4. What is S.Q.C.? State the benefits of S.Q.C. **(4M)**

Ans. Refer Articles 12.1 and 12.2.

5. The following table gives the number of errors in alignment observed at the final inspection of a certain model of an aeroplane. Prepare a C-chart and comment on it. **(8M)**

Aeroplane number	1	2	3	4	5	6	7	8	9	10	11	12	13
Number of alignment defect	7	6	6	7	4	7	8	12	9	9	8	5	5
Aeroplane number	14	15	16	17	18	19	20	21	22	23	24	25	
Number of alignment defect	9	8	15	6	4	13	7	8	15	6	6	10	

Ans. Refer Problem 12.18.

Winter 2015

1. 10 samples of size 5 have been collected with following observations. **(8M)**

Sr. No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
$\bar{X}$	2.011	2.008	2.001	2.003	1.998	1.995	1.997	1.997	2.002	2.003
R	0.011	0.017	0.009	0.026	0.27	0.21	0.014	0.017	0.023	0.015

Given $A_2 = 0.577$, $D_3 = 0$, $D_4 = 2.114$.

Draw the appropriate control chart and explain, whether the process is in statistical control or not?

Ans. Refer similar Problem 12.3.

2. Following are the inspection results of magnets for 10 observations. Draw appropriate control chart and write your conclusion. **(8M)**

Given $A_2 = 0.58$, $D_3 = 0$, $D_4 = 2.11$

Day	1	2	3	4	5	6	7	8	9	10
Number of defective magnets	58	83	70	80	72	58	64	78	80	84
Magnets inspected	721	728	720	730	720	700	710	700	710	740

Ans. Refer similar Problem 12.13.

3. Define process capability. State how it is achieved? **(4M)**

Ans. Refer Article 12.16.

4. Classify the quality control charts and differentiate between variable and attribute charts (any four points). **(4M)**

Ans. Refer Articles 12.15, 12.15.1 and 12.21.

Summer 2016

1. Differentiate between 'Variable chart' and 'Attribute chart' (four points). **(4M)**

Ans. Refer Article 12.21.

2. State the characteristics and applications of normal distribution curve. **(6M)**

Ans. Refer Articles 12.13.1 and 12.13.2.

3. Following are the inspection results of magnets for five observations. Draw appropriate control chart and conclude. **(8M)**

Week Number	1	2	3	4	5
Number of magnets inspected	728	724	720	730	724
Defectives found	48	83	80	58	60

Ans. Refer similar Problem 12.13.

Winter 2016

1. Define process capability and state how it is achieved. **(4M)**

Ans. Refer Article 12.16.

2. What is statistical quality control? State the benefits of SQC. **(4M)**

Ans. Refer Articles 12.1 and 12.2.

3. State different SQC tools and explain any one. **(4M)**

Ans. Refer Article 12.4 and refer any one sub-article (Either 12.10.1, 12.10.2, 12.10.3, 12.15 with 12.15.1 or 12.16)

4. Define 'control charts' and give its classification. Explain stepwise procedure of plotting $\overline{X}$ chart. **(6M)**

Ans. Refer Article 12.15, 12.15.1 and 12.15.4.

7. Following are the inspection results of soldered PCB boards for 6 days. Draw proper control chart and conclude. [08 M]

Day	**1**	**2**	**3**	**4**	**5**	**6**
Number of PCB checked	20	25	22	20	25	24
Defects found	4	3	2	3	4	2

Ans.

- As number of defects are given, we can use 'C' chart. But, here the sample size (subgroup size) per day is not constant.
- Sample size, i.e. number of PCB inspected (n) is different for different day. Therefore, the appropriate chart for the given data is **U chart.**

Stepwise procedure to draw U chart:

(1) Calculate Central line ($\overline{U}$) :

We know, $$\overline{U} = \frac{\text{Total number of defects found}}{\text{Total numberof PCB inspected}}$$

$$\therefore \quad \bar{U} = \frac{4 + 3 + 2 + 3 + 4 + 2}{20 + 25 + 22 + 20 + 25 + 24}$$

$$= \frac{18}{136} = \mathbf{0.13}$$

(2) Calculate control limits by using the following formulae:

$$\text{UCL U} = \bar{U} + 3\sqrt{\frac{\bar{U}}{n}} \quad \ldots \text{(i)}$$

$$\text{LCL U} = \bar{U} - 3\sqrt{\frac{\bar{U}}{n}} \quad \ldots \text{(ii)}$$

- But, we see that, value of n is changing every day, i.e. 20, 25, 22, 20, 25 and 24. Therefore, we can obtain 6 upper control limits and 6 lower control limits from equations (i) and (ii). In this case, we have to draw six control charts for six subgroups or samples, which makes the construction of U chart to be very complex, lengthier and time consuming procedure.
- To reduce time and fatigue to persons, an alternative method based on statistical quality control is used.
- in this method, let n = Average number of PCB inspected per day

$$\therefore \quad n = \frac{20 + 25 + 22 + 20 + 25 + 24}{6} = \mathbf{22.67}$$

- Now, we can calculate the control limits using equations (i) and (ii).

$$\text{UCL U} = 0.13 + 3 \times \sqrt{\frac{0.13}{22.67}} = \mathbf{0.3571 \cong 0.36}$$

$$\text{LCL U} = 0.13 - 3 \times \sqrt{\frac{0.13}{22.67}} = \mathbf{0.0971 \cong 0.1}$$

(3) Construction of U chart:

Let us calculate the value of U for each sample.

Consider sample of day 1.

$$U_1 = \frac{\text{Total number of defects found on day 1}}{\text{Total numberof PCBs inspected on day 1}}$$

$$= \frac{4}{20} = 0.2$$

In the similar way, we can conclude U for remaining days.

$$\therefore \quad U_2 = \frac{3}{25} = 0.12$$

$$U_3 = \frac{2}{22} = 0.09$$

$$U_4 = \frac{3}{20} = 0.15$$

$$U_5 = \frac{4}{25} = 0.16$$

and $$U_6 = \frac{2}{24} = 0.083$$

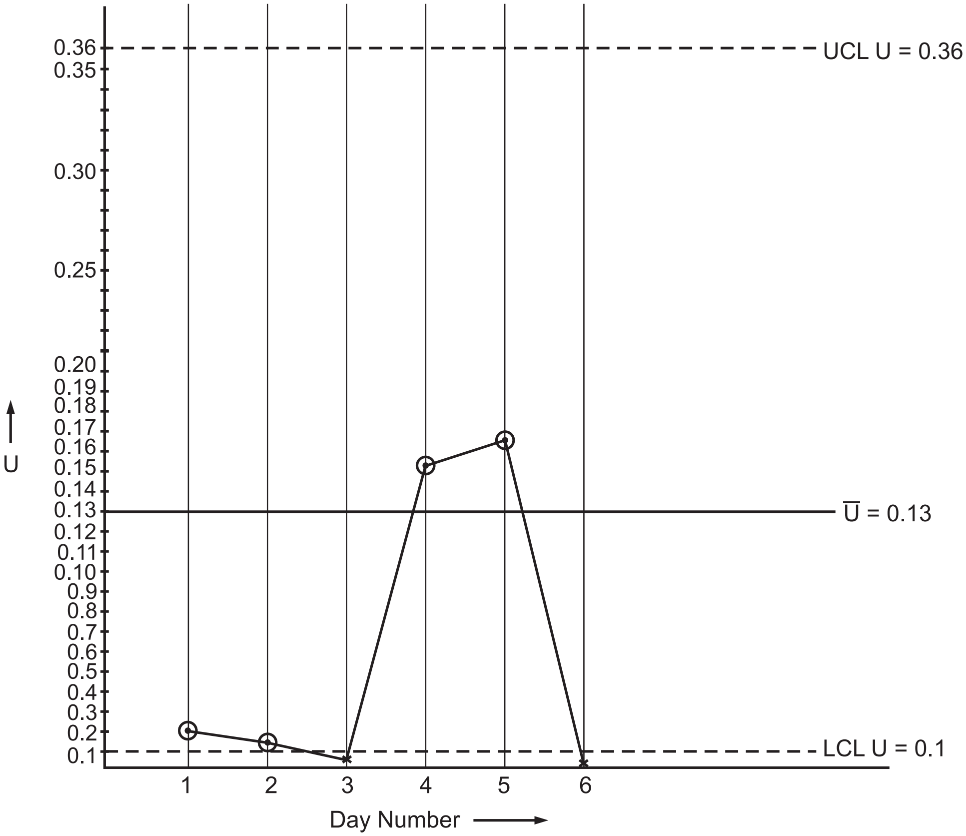


Fig. 2.20: U chart

(4) Conclusion: Number of defects in two samples drawn on 3rd day and 6th day are falling outside the lower control limit, but the variation is very low in both cases. Therefore, slight improvement in manufacturing process of PCB is recommended.

Summer 2017

1. Explain the procedure for P-chart. **(4M)**

Ans. Refer Article 12.19.1.

2. State the various factors responsible for the variation due to assignable causes. **(4M)**

Ans. Refer Article 12.14.1.

3. Explain the process capability. **(4M)**

Ans. Refer Article 12.16.

4. In a capability study of a lathe use in turning a shaft to a diameter of 23.75 ± 0.1 mm a sample of 6 consecutive pieces was taken each day for 8 days. The diameter of these shafts are given below. **(8M)**

1st day	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day
23.77	23.80	23.77	23.79	23.75	23.78	23.76	23.76
23.80	23.78	23.78	23.76	23.78	23.76	23.78	23.79
23.78	23.76	23.77	23.79	23.78	23.73	23.75	23.77
23.73	23.70	23.77	23.74	23.77	23.76	23.76	23.72
23.76	23.81	23.80	23.82	23.76	23.74	23.81	23.78
23.75	23.77	23.74	23.76	23.79	23.78	23.80	23.78

Construct $\overline{X}$ and R chart and find out the process capability for the machine. Take A_2 = 0.48, D_3 = 0, D_4 = 2 and d_2 = 2.534.

Ans. **Given data:** A_2 = 0.48, D_3 = 0, D_4 = 2 and d_2 = 2.534.

It is given that, a sample having 6 shafts manufactured consecutively was drawn each day. Their actual diameters were measured and noted down. This procedure was repeated for 8 days.

∴ Number of samples drawn, N = 8

and Number of shafts in each sample = Sample size, n = 6.

Procedure:

To draw $\overline{X}$ chart and R chart, following procedure can be adopted.

(1) Calculate $\overline{X}$ and R values for each sample:

Sample calculation for first day to calculate $\overline{X}_1$ and R_1.

$$\text{Average, } \overline{X}_1 = \frac{X_1 + X_2 + \ldots + X_6}{n}$$

$$\therefore \quad \overline{X}_1 = \frac{23.77 + 23.80 + 23.78 + 23.73 + 23.76 + 23.75}{6}$$

$$\therefore \quad \overline{X}_1 = \mathbf{23.765}$$

$$\text{Range, } R_1 = \text{(Largest value – Smallest value) of sample}$$

$$= 23.80 - 23.73 = \mathbf{0.07}$$

Similarly, we can obtain value of $\overline{X}$ and R for all samples as shown below.

	1st day	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day
$\overline{X}$	23.765	23.77	23.772	23.776	23.772	23.76	23.776	23.776
R	0.07	0.11	0.06	0.08	0.04	0.05	0.06	0.07

(2) Calculate grand average $\bar{\bar{X}}$ and Average range $\bar{R}$:

We have, $\bar{\bar{X}} = \frac{\Sigma \bar{X}}{N}$

$$\therefore \quad \bar{\bar{X}} = \frac{\bar{X}_1 + \bar{X}_2 + \ldots + \bar{X}_N}{N}$$

$$\therefore \quad \bar{\bar{X}} = \frac{\begin{bmatrix} 23.765 + 23.77 + 23.772 + 23.776 + 23.772 \\ + 23.76 + 23.776 + 23.766 \end{bmatrix}}{8}$$

$$\therefore \quad \bar{\bar{X}} = 23.7696 \cong \mathbf{23.77}$$

$$\text{Average Range, } \bar{R} = \frac{\Sigma R}{N}$$

$$= \frac{R_1 + R_2 + \ldots + R_N}{N}$$

$$= \frac{\begin{bmatrix} 0.07 + 0.11 + 0.06 + 0.08 + 0.04 + 0.05 \\ + 0.06 + 0.07 \end{bmatrix}}{8}$$

$$\therefore \quad \bar{R} = \mathbf{0.0675}$$

(3) To calculate control limits for $\bar{X}$ chart:

As the value of factor (A_2) is given as 0.48 for sample size ($n = 6$), therefore, control limits for $\bar{X}$ chart are calculated as mentioned below.

$$\text{UCL } \bar{X} = \bar{\bar{X}} + A_2 \cdot \bar{R}$$

$$= 23.77 + (0.48 \times 0.0675) = \mathbf{23.8}$$

$$\text{LCL } \bar{X} = \bar{\bar{X}} - A_2 \cdot \bar{R}$$

$$= 23.77 - (0.48 \times 0.0675) = 23.7376$$

$$\cong \mathbf{23.74}$$

(4) To calculate control limits for R chart:

As the values of factors, $D_3 = 0$ and $D_4 = 2$ are given, then control limits for R chart are calculated as given below.

$$\text{UCL } R = D_4 \times \bar{R} = 2 \times 0.0675 = \mathbf{0.135}$$

$$\text{LCL } R = D_3 \times \bar{R} = 0 \times 0.0675 = \mathbf{0}$$

(5) To draw $\overline{X}$ and R charts:

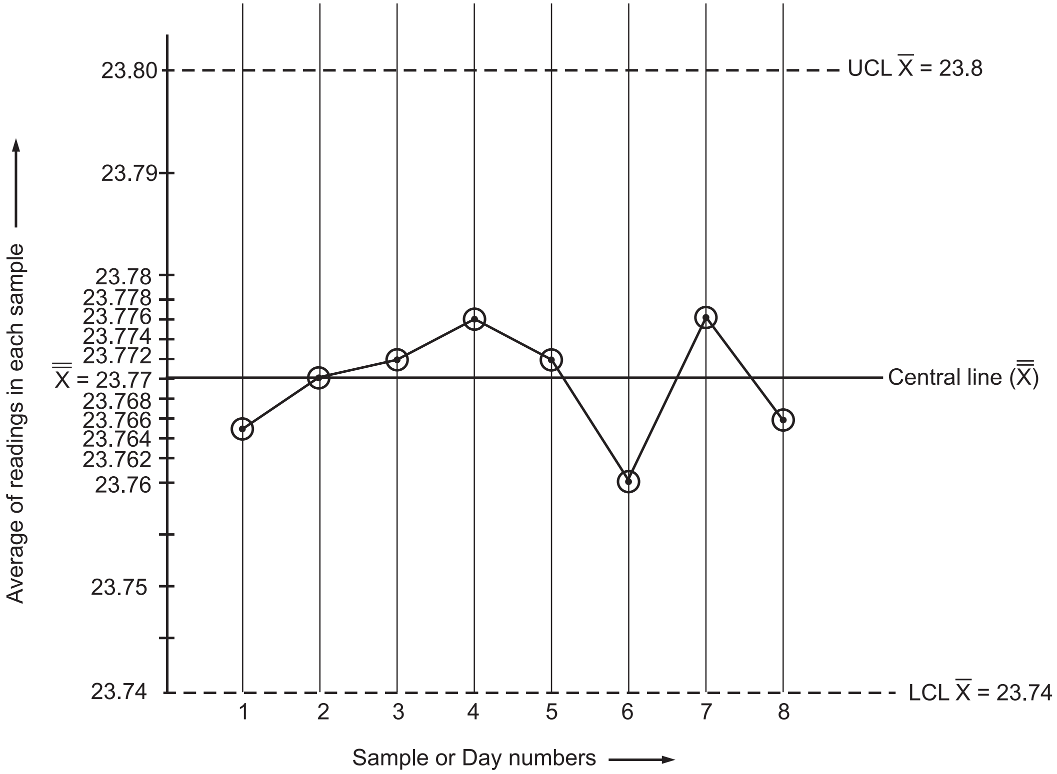


Fig. 12.21: $\overline{X}$ chart

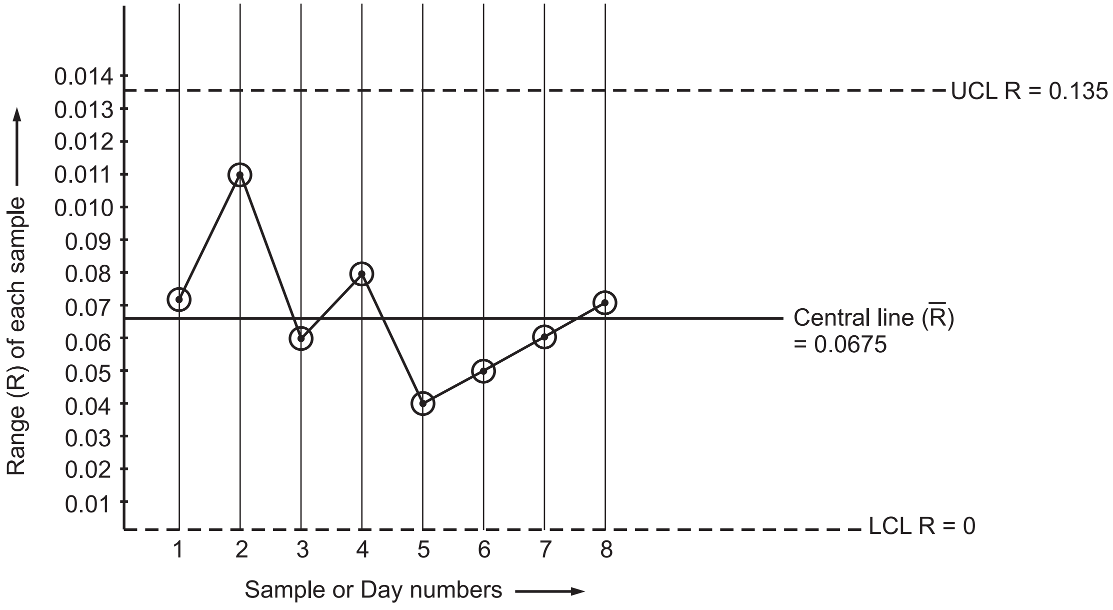


Fig. 12.22: R chart

(6) Conclusion: Since, all the points plotted on $\overline{X}$ and R chart lie within the control limits, it can be concluded that, process is in control.

(7) Calculate process capability of the machine:

Shaft diameter is specified as, 23.75 ± 0.1 in mm.

$$\therefore \quad X_{max} = 23.75 + 0.1 = 23.85, \text{ and}$$

$$X_{min} = 23.75 - 0.1 = 23.65$$

Therefore, specified tolerance = $X_{max} - X_{min}$

$$= 23.85 - 23.65 = \mathbf{0.20}$$

We know that, Natural tolerance = $6\sigma' = 6 \times \frac{R}{d_2}$

$$\therefore \quad \text{Natural tolerance} = 6\sigma' = \frac{6 \times 0.0675}{2.534}$$

$$\therefore \quad \text{Natural tolerance, } 6\sigma' = 0.1598 \cong \mathbf{0.16}$$

On comparing specified tolerance and natural tolerance, we find that, $(X_{max} - X_{min})$ is more than 6σ's and we conclude that, the process of manufacturing shafts is capable of meeting the specified tolerances.

5. The following table gives the numbers of missing rivets noted at aircraft final inspection.

Air Plane No.	**Number of missing reverts**	**Air Plane No.**	**No. of missing reverts**	**Air Plane No.**	**No. of missing reverts**
1	8	10	12	19	11
2	16	11	23	20	9
3	14	12	16	21	10
4	19	13	9	22	22
5	11	14	25	23	7
6	15	15	15	24	28
7	8	16	9	25	9
8	11	17	9		
9	21	18	14		

Find $\overline{C}$. Compute trial control limits and plot control chart for C. What values of C would you suggest for the subsequent period? **(8M)**

Ans. Given data: Number of air planes inspected, N = 25.

Number of missing rivets are given after inspecting each air plane.

Procedure:

Steps to draw C chart are given below.

(1) For C chart,

$$\text{Central line, } \bar{C} = \frac{\begin{bmatrix} 8 + 16 + 14 + 19 + 11 + 15 + 8 + 11 + 21 \\ +12 + 23 + 16 + 9 + 25 + 15 + 9 \\ 9 + 14 + 11 + 9 + 10 + 22 + 7 + 28 + 9 \end{bmatrix}}{25}$$

$$\therefore \quad \bar{C} = \mathbf{14.04}$$

(2) Control limits:

$$\text{UCL C} = \bar{C} + 3\sqrt{\bar{C}}$$

$$= 14.04 + 3 \times \sqrt{14.04} = \mathbf{25.28 \cong 25.3}$$

$$\text{LCL C} = \bar{C} - 3\sqrt{\bar{C}}$$

$$= 14.04 - 3 \times \sqrt{14.04} = \mathbf{2.799 \cong 2.8}$$

(3) Construction of C chart:

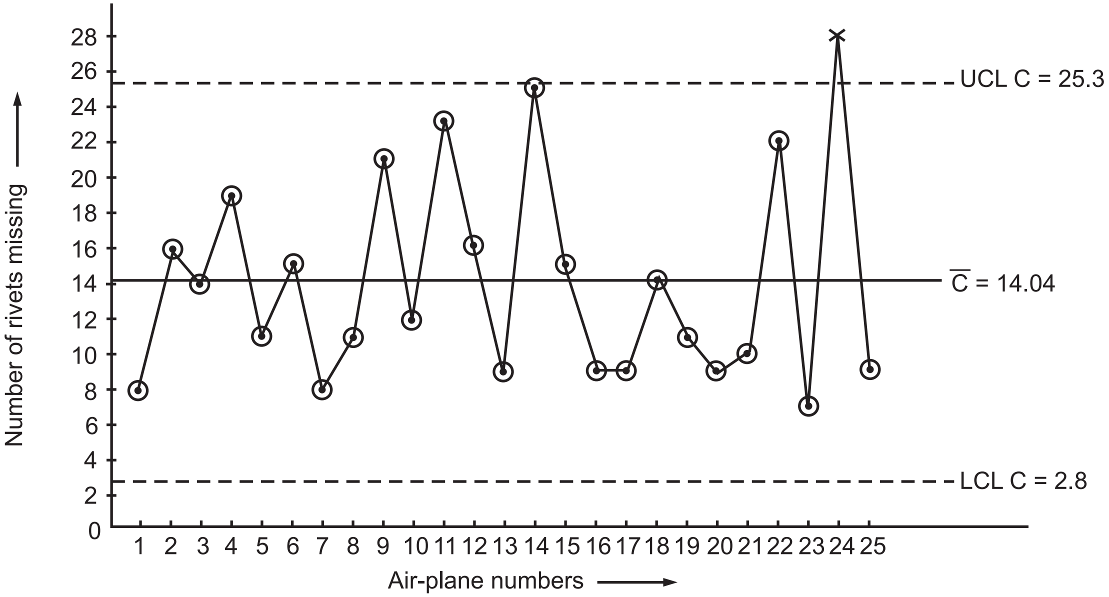


Fig. 12.23

(4) Conclusion from C chart:

- On inspecting all air planes to find number of missing rivets, we find that missing rivets are less than upper control limit given by UCL C = 25.3 except one air plane (Numbered as 24th). Number of missing rivets in 24th air plane is 28. It means that, the process used is capable and under control.

(5) Suggestion for values of C for subsequent period in future:

- From the drawn C chart, we observe that, there are huge variations in number of missing rivets found in consecutive air planes. For example: For air-plane number 13, 14 and 15, number of missing rivets are 9, 25 and 15 respectively. Therefore, it is very essential to maintain centering of process. A small deviation in process parameter may lead to more number of air-planes, in which, number of missing rivets are more than upper control limit.

- If it is difficult to maintain centering of process, then process may have to be improved, to avoid scattering of data away from central line $\bar{C}$. Values of missing rivets (C) should be lying in the range of 8 to 16.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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Chapter 13

ACCEPTANCE SAMPLING

About This Chapter …

This chapter has a weightage of 8 marks and assigned duration is 4 hours. In this chapter, we learn the concept of acceptance sampling, comparison with 100% inspection, different types of sampling plans along with their merits and demerits.

Statistical Analysis

Examination	Weightage of Chapter	Examination	Weightage of Chapter
W-08	10 Marks	S-09	08 Marks
W-09	15 Marks	S-10	18 Marks
W-10	16 Marks	S-11	18 Marks
W-11	16 Marks	S-12	10 Marks
W-12	10 Marks	S-13	06 Marks
W-13	10 Marks	S-14	18 Marks
W-14	–	S-15	14 Marks
W-15	12 Marks	S-16	18 Marks
W-16	08 Marks	S-17	12 Marks

13.1 ACCEPTANCE SAMPLING

QUESTIONS

1. What is the purpose of sampling inspection ? Explain. **(S-10)**
2. Explain acceptance sampling with its merits. **(W-09)**
3. Compare acceptance sampling with 100% inspection. **(W-11)**
4. Define: (i) Acceptance sampling and (ii) 100% inspection. **(S-14)**
5. Why 100% inspection is generally not preferred in the industry for mass production? **(W-16)**

- To take decision about any manufactured component or part, whether to be accepted or rejected, inspection is carried out at many stages in manufacturing. The part inspected may be in the form of raw material, semifinished part or finished part etc.

- Following are the two ways to carry out inspection activity:
    1. 100% inspection.
    2. Sampling inspection or Acceptance sampling.
- In **100% inspection**, all the parts are subjected to inspection, where as, in **sampling inspection**, only a 'sample' of few parts is drawn for inspection from the entire lot of parts.
- **Acceptance sampling** or Sampling inspection is defined as, '*the process of evaluating a sample containing a small quantity of products chosen from entire lot of products for the purpose of accepting or rejecting the lot on the basis of number of defective parts found in that sample.*
- If the number of defective parts does not exceed the predefined acceptance number level, the said lot is accepted, otherwise rejected.
- In brief, acceptance sampling is more practical, quick and economical method to control the quality of purchased as well as manufactured items.

13.1.1 Advantages and Disadvantages of Acceptance Sampling over 100% Inspection or Comparison between Acceptance Sampling and 100% Inspection

(W-15)

(A) Advantages of Acceptance Sampling as Compared to 100% Inspection

Sr. No.	Comparative Point	Acceptance Sampling	100% Inspection
(a)	**Cost of inspection**	Very less.	High.
(b)	**Time required to carry out inspection**	Less.	High.
(c)	**Inspection fatigue**	No.	Yes.
(d)	**Inspection error problem**	It can be minimised to great extent.	Not possible to minimise.
(e)	**Scheduling and dispatch dates**	As only few items undergo inspection, the accepted lot can be sent to market in least time. It improves scheduling and dispatch dates.	As all parts (100%) are inspected, this method takes more time to sort out non-defective products, which can be sent to market. So scheduling and dispatch dates cannot be improved.
(f)	**Effective pressure on quality improvement**	More.	Less.

(B) Disadvantages of Acceptance Sampling as compared to 100% Inspection

Sr. No.	Comparative Point	Acceptance Sampling	100% Inspection
(a)	**Loss of producer while rejecting a lot.**	A lot containing less defectives may be rejected due to more defectives found in sample. Producer will suffer the loss.	No loss except damage during transportation.
(b)	**Loss of consumer while accepting a lot.**	A lot containing more defectives may be accepted due to less number of defectives found in sample. Thus, the entire lot containing more number of defectives will be sent to market for sales. Then, many consumers will suffer due to defective articles received on purchase. Also, due to consumer complaints regarding replacement or repair of faulty products, the producer has to suffer loss, because of cost involved in transportation for replacing defective products and cost involved in repairing product at consumer's place. For retaining profit, the producer will pass on these additional expenses on consumer by raising price of product.	No loss of consumer, as all parts available in market are non-defectives, because of 100% inspection.
(c)	**Suitability for inspecting costly items.**	Not suitable, due to chances of wrong decision about acceptance / rejection of lot containing hundreds of finished products.	Suitable, because all the products undergo inspection to sort out defectives from non-defectives. Some of these defectives may become non-defectives by small repair or rework, since 100% inspection of any product gives detailed

Sr. No.	Comparative Point	Acceptance Sampling	100% Inspection
			information, which can be used to reduce number of defectives in a lot.
(d)	**Necessity of random sampling**	Yes.	No.

Note: Information regarding 'Advantages and Disadvantages of Acceptance Sampling and its Comparison with 100% Inspection' is combined in the above tabulated format for easy understanding of readers.

13.1.2 Factors Affecting Success of Sampling Inspection

(a) Random sampling.
(b) Proper sample size and lot size.
(c) Acceptance criteria.
(d) Quality characteristic to be measured.

13.2 RANDOM SAMPLING

- **Random sampling** is defined as, *"the process of selecting a sample in such a way that, each item in the given lot has an equal chance of being selected"*.
- Random sampling can also be defined as, "the act of drawing the sample from a lot on random basis.
- Since a judgment about the lot is to be made on the basis of only one sample, it is very important that, the sample truly represents the lot, from which, it is drawn.

Precautions to be taken for Random Sampling:

(a) Sample is collected from all sides and different depths of container containing the lot.
(b) Sample size is large enough.

13.3 SAMPLING PLANS

QUESTIONS

1. What are various sampling plans ? Explain any one sampling plan in detail. **(S-12)**
2. Enlist different sampling plans and explain double sampling plan. **(S-14; W-14)**
3. List down different types of sampling plans and explain one of them in brief. **(S.Q.P.)**
4. State various types of sampling methods. Explain any one in detail. **(S-17)**

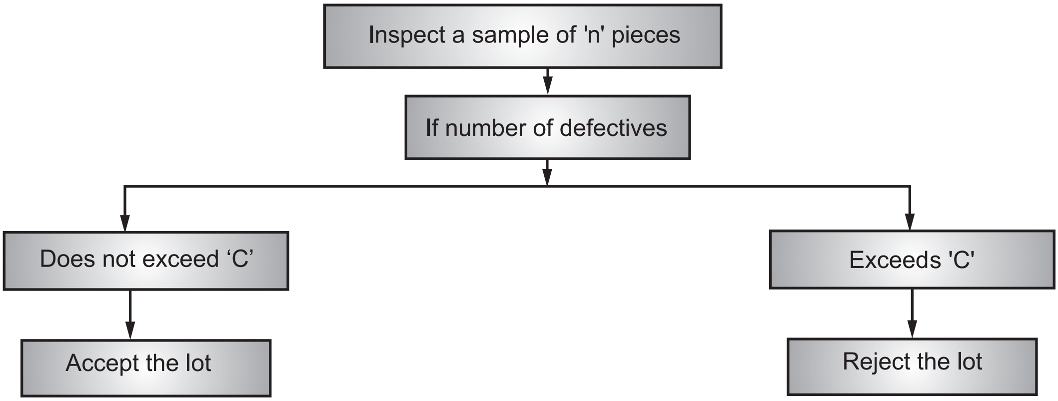
Types of Sampling plans:

(i) Single sampling plan,
(ii) Double sampling plan, and
(iii) Multiple sampling plan.

13.3.1 Single Sampling Plan

(S-14)

- When a decision of rejection or acceptance of lot is made on the basis of **only one sample**, the plan is known as *single sampling plan*. To understand the stepwise procedure, refer the chart.
- Lets consider following three **parameters**, in single sampling plan.
  1. N = Lot size,
  2. n = Sample size,
  3. C = Acceptance number = Maximum number of allowable defectives in sample of size 'n'.



Single sampling plan

13.3.2 Double Sampling Plan

(S-14, 15)

QUESTIONS

1. Discuss double sampling plan. (S-09, W-09, 10, 14)
2. Explain double sampling plan with respect to acceptance criteria. (S-10)
3. Explain the merits and demerits of double sampling plan. (W-11)
4. List types of sampling plan. Explain double sampling plan with block diagram. (W-13)

- When a decision of acceptance or rejection of lot is made on the basis of **two samples combined**, it is called as *double sampling plan*.
- A lot may be **accepted** at once, if the **first sample is good** enough and **rejected** at once, if **sample is bad** enough.
- If the first sample is neither good enough to accept the lot nor bad enough to reject the entire lot, then a second sample is drawn from same lot and decision is made on the basis of first and second sample combined.
- Refer the chart drawn to understand stepwise procedure of double sampling plan.
- **Parameters:**

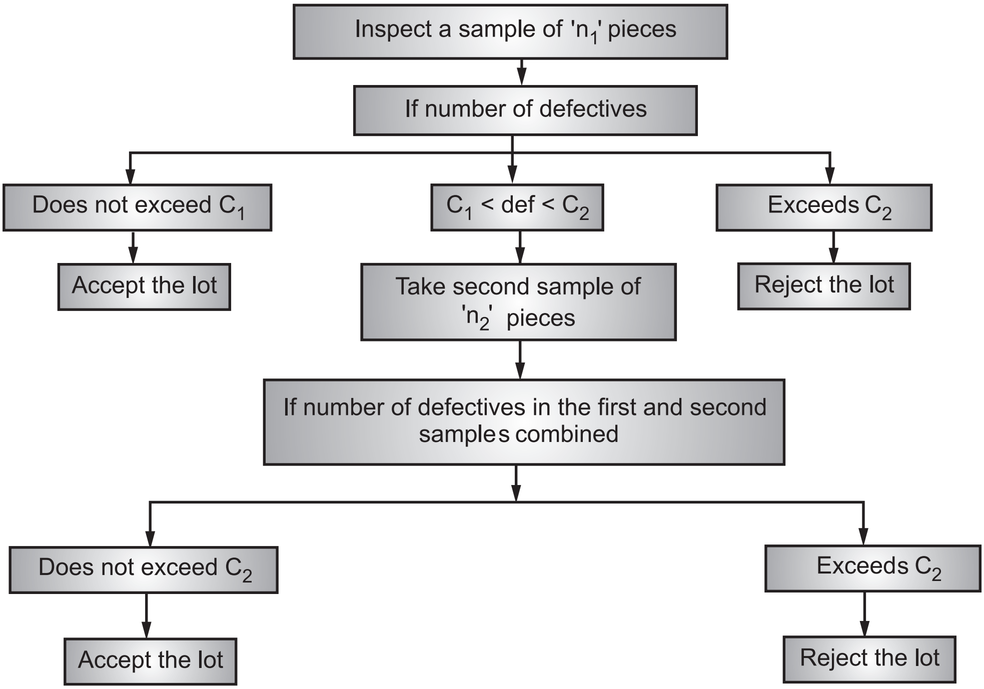
Let n_1 = Number of pieces in the first sample.

C_1 = Acceptance number for the first sample = Maximum number of defectives, that will permit the acceptance of lot on the basis of first sample.

n_2 = Number of pieces in the second sample.

$n_1 + n_2$ = Number of pieces in the two samples combined.

C_2 = Acceptance number for the two samples combined = Maximum number of defectives, that will permit the acceptance of lot on the basis of first and second sample combined.



Double sampling plan

Advantages/Merits of Double Sampling Plan:

1. It gives second chance to the producer. Therefore, it is much preferred and acceptable to producers.
2. Cost of administration is moderate.

Disadvantages/Demerits:

1. Economical loss, if
   (i) Samples do not represent the true picture of lot, and
   (ii) Acceptance criteria (number) is not selected properly.
2. More record keeping is required, since decision is made on two samples drawn and number of parameters stated are more.

13.3.3 Multiple Sampling Plans

- Multiple sampling plan is used, when three or more samples of stated size are drawn.
- Procedure of multiple sampling plan can be represented in a tabulated form as given below.

Table illustrating multiple sampling plan

Sample Number	Sample Size	For Combined Samples		
		Total Size of Samples	Acceptance Number	Rejection Number
First	n_1	n_1	C_1	r_1
Second	n_2	$n_1 + n_2$	C_2	r_2
Third	n_3	$n_1 + n_2 + n_3$	C_3	r_3
Fourth	n_4	$n_1 + n_2 + n_3 + n_4$	C_4	r_4
Fifth	n_5	$n_1 + n_2 + n_3 + n_4 + n_5$	C_5	$C_5 + 1$

(i) A first sample of n_1 pieces is drawn, the lot is accepted, if number of **defectives** are **less than C_1** and **rejected**, if **more than r_1**.

(ii) But, if **C_1 < defectives < r_1**, a **second sample** of n_2 pieces is drawn, the lot is **accepted**, if number of **defectives** are **less than C_2** in combined sample of **'$n_1 + n_2$'** and **rejected**, if **more than r_2**.

The procedure is continued in accordance with the above table.

(iii) If by the end of **fourth sample**, the lot is **neither accepted nor rejected**, a sample of n_5 pieces is drawn.

(iv) The lot is **accepted**, if the number of **defectives** in the **combined sample** of n_1, n_2, n_3, n_4, n_5 is **less than C_5** and rejected, if **more than $C_5 + 1$**.

13.3.4 Characteristics of Good Sampling Plan

A good sampling plan should have following characteristics/properties.

1. Simple to **operate**.
2. Economy of inspection i.e. **economical** inspection.
3. **Flexible** enough to reflect changes in size and quality of product submitted.
4. Plan should **protect** both **'producer and consumer'**.
5. **Less difficult** in training the inspectors about '*how to use sampling* plans'.

13.3.5 Factors to be Considered, while Selecting a Sampling Plan

(a) **Protection** to both, *'consumer and producer'*.
(b) **Cost** of inspection.
(c) **Availability** of *'inspectors and facilities'*.
(d) **Training inspectors** about '*how to use multiple sampling plans'* correctly.
(e) Need for **quick and reliable** estimates.
(f) **Administrative convenience.**

13.4 COMPARISON BETWEEN THREE SAMPLING PLANS

QUESTIONS

1. Define: Acceptance Sampling. Compare single, double and multiple sampling plan. **(W-08)**
2. Compare Single sampling plan with Double sampling plan. **(S-11, 13)**

Sr. No.	Feature	Single sampling plan	Double sampling plan	Multiple sampling plan
1.	**Average number of pieces inspected per lot.**	Generally large.	Inbetween single and multiple. It is preferred to take second sample of size twice the size of	Low.

Sr. No.	Feature	Single sampling plan	Double sampling plan	Multiple sampling plan
			first sample.	
2.	**Acceptability to producer.**	Poor, as it gives only one chance to decide, whether the lot is accepted or rejected	Most acceptable (Gives IInd chance).	Less acceptable, if indecision continues for a long period and more number of samples are drawn for making decision.
3.	**Cost of Administration**	Lowest.	In between.	Largest.
4.	**Information available about prevailing quality level.**	Largest.	In between.	Lowest.
5.	**Number of samples**	One	Two	Multiple.
6.	**Variability of inspection load [i.e. number of items undergoing inspection]**	Constant	Variable, depending upon behaviour of first sample.	Highly variable.
7.	**Estimation about quality of a lot**	Best	Intermediate	Difficult to estimate.
8.	**Decision of 'Acceptance' or 'Rejection' is based on**	One sample	Two samples combined.	Multiple samples combined.

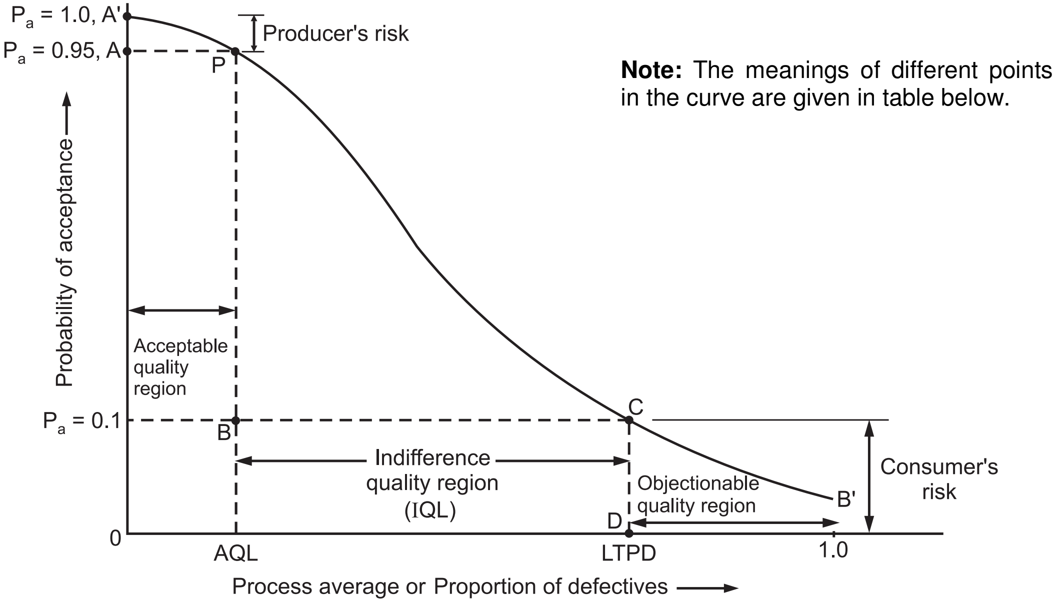
13.5 O.C. CURVE (S-15)

QUESTIONS

1. What is O.C. curve? How are they useful in selecting acceptance level? **(W-10)**
2. Draw a neat sketch of an O.C. curve. Show the different regions and explain the meaning of terms, (i) AQL, (ii) LTPD, (iii) IQL, (iv) Producer’s risk and Consumer’s risk. **(W-08, 12, S-14)**
3. What is O.C. curve? Draw ideal and actual O.C. curves and explain (i) Producer's risk, (ii) Consumer's risk. **(W-09, 11, 14)**
4. Sketch a labelled practical O.C. Curve. Explain (i) Producer’s risk, (ii) Consumer’s risk. **(S-10, W-11)**
5. Draw an O.C. curve. Indicate parameters on it and explain in brief. **(S-11)**
6. What is an O.C. curve? State step by step procedure for construction of an O.C. curve. State meaning and significance of important points located on O.C. curve. **(S.Q.P., W-15)**
7. What is meant by O.C. curve ? Draw ideal and actual O.C. curve and Explain. **(W-16)** (i) Producer’s risk, (ii) Consumer risk.
8. Explain Ideal and Actual O.C. curve with all significant points and regions. **(S-17)**

- **Operating characteristic curve** [O.C. curve] for an attribute-sampling plan is a graph of fraction defectives in a lot against the probability of acceptance.

- For fraction defective p' in a submitted lot, the O.C. curve shows the probability P_a, such that, the lot will be accepted by sampling plan.
- **O.C. curve** of an acceptable sampling plan shows the *ability of plan to distinguish between good lots and bad lots*.
- O.C. curve is used to **judge and compare** the **performance** of various sampling plans over a range of possible quality level of submitted product.
- **Shape of O.C. curve** depends upon following parameters.
  (a) N = Lot size, from which, samples are drawn.
  (b) n = Sample size
  (c) C = Acceptance number
- By changing the parameters **'N', 'n' and 'C'**, different sampling plans are obtained and for different sampling plans, the **O.C. curve** will differ.
- To **construct an O.C. curve**, we should know the *mathematical probability* of accepting the lots with *change in quantity of per cent defectives*. This can be obtained from the table of *Poisson's distribution*.
- Acceptance plan is designed in such a way that, its corresponding O.C. curve will pass through two stipulated points agreed upon by both, consumer and producer.
- Ideal O.C. curve is shown as APBCD in the figure 13.1. We observe that, if proportion of defectives is less than AQL, then probability of acceptance of lot will be 95%. But, if proportion of defectives are more than LTPD value, then $P_a = 0$.
- O.C. curve is said to be ideal, if all good lots are accepted and bad lots are rejected. But, no sampling plan can give ideal O.C. curve.
- Therefore, Ideal O.C. curve is not practically possible.
- Practically possible O.C. curve is called as actual O.C. curve shown by A'PCB'.
- The degree, to which, an actual O.C. curve approximates the ideal curve depends upon sample size (n) and acceptance number (C).



Note: The meanings of different points in the curve are given in table below.

Fig. 13.1: O.C. curve

Meanings of various points plotted in the figure 13.1.

Sr. No.	Point shown in figure	Probability of acceptance (P_a)	Description
1.	A'	100%	Zero defectives
2.	A	95%	5% defectives
3.	B'	0%	100% defectives
4.	B	10%	90% defectives
5.	AQL	Higher	Indicates "Acceptable quality level"
6.	IQL	50%	Indicates "Indifference quality level"
7.	LTPD	Lower	Indicates "Rejectionable quality level"
8.	Producer's risk	–	Indicates risk of rejecting a good lot, therefore, producer may suffer.
9.	Consumer's risk	–	Indicates risk of accepting a bad lot, therefore, consumer may suffer.

- Accordingly an O.C. curve can be divided into three regions.
  - (a) Acceptance quality region.
  - (b) Indifference quality region
  - (c) Objectionable quality region.
- Some of the **quality levels** are explained below.

QUESTIONS

1. Explain: (i) AQL, (ii) AOQL, (iii) IQL, (iv) LTPD. **(W-08, 09, S-10)**
2. Define the following terms in relation to sampling : **(W-13)**
   - (a) Acceptable Quality Level (AQL)
   - (b) Lot Tolerance Percent Defective (LTPD)
   - (c) Average Outgoing Quality Level (AOQL).

AQL:

- **AQL** represents *'the maximum proportion (%) of defectives, which the consumer finds definitely acceptable'.* It is a definition of satisfactory quality.
- As AQL is an 'acceptable quality level', the probability of acceptance should be high. Generally, it is taken as 95%. ∴ $\mathbf{P_a = 0.95}$.
- In fact, the **producer's safe point** is termed as AQL.

LTPD or RQL:

- LTPD is 'Lot tolerance per cent defective'. It can be called as RQL i.e. Rejectionable Quality Level. It is a definition of unsatisfactory quality.
- **LTPD** represents *'the proportion (%) of defectives, which the consumer finds definitely unacceptable'.*
- As RQL is unacceptable quality level, the probability of acceptance is very low.
- A probability of accepting a lot at LTPD represents **consumer's risk**.
- Consumer's risk is generally taken as 10%, such that, $\mathbf{P_a = 0.1}$.

IQL:

- IQL is called as 'Indifference quality level'.
- This is a quality level somewhat between AQL and LTPD. It can be referred as range or span between AQL and LTPD.
- Therefore, it is assumed to be a quality level having probability of acceptance as 50% for a given sampling plan. Therefore, $\mathbf{P_a = 0.5}$.

AOQ:

- AOQ is called as 'Average Outgoing Quality'.
- It represents a certain percentage of defectives remained in a lot after inspection.
- It represents the average % defective in the outgoing products after inspection, including all accepted lots and 100% inspected rejected lots to replace defectives by non-defectives. Therefore, rejected lots become accepted lots, because they do not have any defective.
- Therefore, AOQ will be less than p'.
- But, the lots accepted as a result of first sampling inspection will have a fraction defectives p'.
- It is given by,

$$AOQ = P_a \cdot p' \cdot \left(\frac{N - n}{n}\right)$$

where, P_a = Probability of acceptance

N = Lot size

n = Sample size

To understand the concept of AOQ, consider the following example.

- Let, Lot size (N) = 100, Number of lots = 100 and Sample size (n) = 15.
- Now, if 10 samples are drawn from randomly selected 10 lots out of 100 lots available, it means that, remaining 90 lots are not considered for acceptance sampling.
- Let us consider that acceptance number, C = 4 for all. 10 samples having sample size, n = 15 (each) are randomly selected from 10 lots, out of 100 lots.
- Now 10 samples having 15 items undergo acceptance sampling.
- Samples having 4 or less than 4 defectives are acceptable.
- If we find 7 samples acceptable and remaining 3 samples rejectionable it means, total number of accepted lots = 7.

  Let, total number of defectives in accepted lots = 20 (say).

  Let, total number of rejected lots = 3.

  Total number of defectives found in rejected lots = 16 (say).

  Therefore, total number of defectives found in accepted and rejected lots = 20 + 16 = 36. This value represents p'.
- The accepted 7 lots are passed on to consumer, even though they have 20 defective items.

- But, the rejected 3 lots are made to undergo 100% inspection and all the defectives (16) found are replaced by non-defective items. Therefore, total number of defectives in accepted lots and rejected lots will be, 20 + 0 = 20 defectives. This value of defectives represents AOQ, which is less than p'.

AOQL:

- It is called as 'Average Outgoing Quality Level'.
- For any sample size and acceptance number, there is a maximum value of AOQ beyond which, the average fraction defectives will not rise, no matter, how bad is the quality of lots, when they undergo sampling inspection to sort out acceptable lots and rejected lots, which is followed by 100% inspection of rejected lots to replace all defectives found in rejected lots by non-defectives. Therefore, AOQL can be referred as, *'maximum possible value of average percent defectives in the outgoing products after inspection and rectification'*.
- It means that, even if the incoming quality is bad, the sampling plan will cause all the lots to be rejected, 100% inspected and rectified. Therefore, the outgoing quality will be good.
- Therefore, even if the incoming quality is very good or very bad the outgoing quality will tend to be very good.
- Between these two lots, there will be a point, at which, the per cent of defectives will reach its maximum. This point is known as average outgoing quality level (AOQL).

13.5.1 Difference between AQL and AOQL

(S-11)

AQL	AOQL
1. It is acceptable quality level.	1. It is average outgoing quality level.
2. It is defined as 'the maximum per cent defectives, which can be considered as satisfactory for sampling inspection.	2. It is referred as 'maximum value of average per cent defectives in the outgoing products after inspection and rectification'.
3. It has high probability of acceptance upto 0.95.	3. Comparatively less.
4. It is the maximum proportion of defectives, which the consumer finds definitely acceptable.	4. It is the maximum value of AOQ, beyond which, the average per cent defectives cannot increase in the outgoing products, after inspection of all lots, followed by rectification of rejected lots.

13.5.2 Characteristics of O.C. Curve

QUESTION

1. State the important characteristics of O.C. curve. **(S-10)**

1. O.C. curve represents the ability of sampling plan to distinguish between good lots and bad lots.
2. With **fixed** values of **'acceptance number' (C) and 'sample size' (n)**, O.C. curves obtained for different values of **lot size (N)** do not differ considerably. It indicates that, sample size (n) is much more important as compared to lot size.
3. For large sample size (n), O.C. curve will give better discrimination between good lots and bad lots, if these two conditions are fulfilled, (i) value of N is fixed, and (ii) $C \propto n$ i.e. acceptance number is directly proportional to sample size.
4. Slope of O.C. curve will be more steeper for large values of sample size (n) and acceptance number (C). Steeper means slope of line, almost approaching vertical line, making an angle of 90° with the horizontal.

13.5.3 Significance of O.C. Curve

(W-10)

1. It compares the performance of various sampling plans over a range of possible quality levels of submitted products.
2. It provides a method for evaluating sampling plans.
3. It finds out the changing quality and condition of incoming materials.
4. It explains the risks, present compulsorily in a sampling plan at each level of quality. No sampling plan can be free from these inherent risks.

13.6 PRODUCER'S RISK AND CONSUMER'S RISK

QUESTION

1. Explain Producer's risk and Consumer's risk. **(W-09, 10,11,12; S-10, 11,14, 15)**

Producer's Risk:

- Producer's risk is 'the probability of rejecting a good lot, which otherwise, would have been selected (accepted)'. It means that, lot will be rejected, if the proportion of defectives found in a sample drawn from corresponding lot is more than acceptance number or set value, even though the maximum components of lot falls within an acceptance allowable range. The designated set value is generally AQL.
- Producer's risk is defined as 'the probability that a lot having AQL will be rejected'. This risk is generally taken as 5%, such that, $P_a = 1 - 0.05 = 0.95$.
- Even if quality is good, some lots are rejected due to results of sampling plan, then producer has to suffer.
- So producers should be protected against rejection of relatively better products.
- Producers can decrease risk by producing product at better quality level than specified AQL without much increase in production cost.

Example of Producer's Risk:

- In producer's risk, batch of materials is rejected, even though, the batch falls within an acceptable allowable range.
- **For example:** Manufacturer of pens rejects a lot of high quality pens due to more number of defective pens found in the sample drawn.

Consumer's Risk:

- Consumer's Risk is defined as 'the probability of accepting the defective lots, which otherwise would have been rejected'.
- Even if quality is bad, some lots are accepted due to results of sampling inspection, then consumer has to suffer.
- Saying that, $\mathbf{P_{a_{0.1}} = 2.5}$ means that, the consumer does not want a worse quality containing more than 2.5% defectives and he would, at the most accept, 10% of lots containing defectives is accepted less than 2.5%.
- Here, 10% of lots accepted is calculated by value 0.1 given in the above relation of Probability of acceptance. Multiply the given value 0.1 by 100 to obtain percentage of lots accepted, i.e. $0.1 \times 100\% = 10\%$.

Example of Consumer's Risk:

- In consumer's risk, a batch of materials is accepted, though it is defective and does not fall within an acceptable allowable range.
- For example: A purchased house of high quality indicates that, all the essential accessories for house are much durable, but, if plumbing is failed, then it becomes consumer's risk.
- The following table provides a **visual representation** of consumer's and producer's risks.

		Nature of Product	
		If non-defective ↓	If defective ↓
Final decision	If consumer accepts →	OK	Consumer's risk
	If consumer rejects →	Producer's risk	OK

13.7 ACCEPTANCE / REJECTION SCHEME

- The lots are subjected to sampling inspection.
- If the lot contains more than 'C' defectives, it is rejected, otherwise accepted.
- The AOQ will be either equal or more than given fraction defectives.

13.8 ACCEPTANCE / RECTIFICATION SCHEME

- The lots are subjected to sampling inspection and, if it contains defectives less than 'C', it is accepted.
- If the lot contains defectives more than 'C', it is called as rejected lot. This rejected lot is subjected to 100% inspection and defective articles are either repaired or replaced, before they are passed forward.

Important Points

- Inspection is carried out at many stages in manufacturing for acceptance purpose, and can be categorized into (a) 100% inspection, (b) Sampling inspection.
- The sampling plans used are single sampling plan, double sampling plan and multiple sampling plan.
- Selecting a sample in such a way that each item in a lot has an equal chance of being selected is called as *Random Sampling*.
- The operating characteristic curve for an attribute-sampling plan is a graph of fraction defectives in a lot against the probability of acceptance.
- Producer's risk is 'the probability of rejecting a good lot, which otherwise, would have been selected (accepted)'.
- Consumer's risk is 'the probability of accepting a defective lot, which otherwise, would have been rejected'.

Theory Questions for Practice

1. What is acceptance sampling? What are the advantages of sampling inspection over 100% inspection?
2. Give limitations of acceptance sampling.
3. What are the factors governing success of sampling inspection?
4. What are the types of sampling plans? Explain single sampling plan.
5. Write a short note on multiple sampling plans.
6. Give comparison between three sampling plans.
7. Draw OC curve and define (i) Producer's risk and (ii) Consumer's risk.
8. Define AOQ and AOQL with respect to OC curve.

MSBTE Questions and Answers (As Per G-Scheme)

Summer 2015

1. Enlist different sampling plans and explain double sampling plan. **(6M)**

Ans. Refer Articles 13.3 and 13.3.2.

2. What is an O.C. curve? Draw ideal and actual O.C. curve and explain: **(8M)**
   (i) Producer's risk
   (ii) Consumer's risk

Ans. Refer Articles 13.5 and 13.6.

Winter 2015

1. State merits and demerits of acceptance sampling. **(4M)**

Ans. Refer Articles 13.1.1.

2. What is an OC curve ? State the meaning and significance of important points on OC curve. **(8M)**

Ans. Refer Articles 13.5 and 13.5.3.

Summer 2016

1. Distinguish between the terms "Producer's risk" and "Consumer's risk". **(4M)**

Ans. Refer Article 13.6.

2. Compare single and double sampling plan. **(6M)**

Ans. Refer Article 13.4.

3. Draw a neat labelled sketch of O.C. curve. State the procedural steps of construction of O.C. curve. **(8M)**

Ans. Refer Article 13.5.

Winter 2016

1. Why 100% inspection is generally not preferred in the industry for mass production? **(4M)**

Ans. Refer Articles 13.1 and 13.1.1.

2. What is meant by O.C. curve ? Draw ideal and actual O.C. curve and Explain. **(8M)**
   (i) Producer’s risk.
   (ii) Consumer risk.

Ans. Refer Article 13.5 and 13.6.

Summer 2017

1. State various types of sampling methods. Explain any one in detail. **(4M)**

Ans. Refer Article 13.3 and 13.3.1.

2. Explain Ideal and Actual O.C. curve with all significant points and regions. **(8M)**

Ans. Refer Article 13.5.

Please Note: The questions of sample question paper, sample test papers as per 'G' scheme and MSBTE examination papers from W-08 to S-17 are incorporated with solutions in this edition.

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APPENDIX: FOR NUMERICAL TREATMENT OF SQC TECHNIQUES

Standard Table (A): Values of factor d_2 for corresponding sample size

Number of observations in sub-group (n) (Sample size)	**Value of d_2**
2	1.128
3	1.693
4	2.059
5	2.326
6	2.534
7	2.704
8	2.847
9	2.970
10	3.078
11	3.173
12	3.258
13	3.326
14	3.407
15	3.472
16	3.532
17	3.588
18	3.640
19	3.689
20	3.735
21	3.778
22	3.819
23	3.858
24	0.895
25	3.931
30	4.086
35	4.213
40	4.322
45	4.415
50	4.498
55	4.573
60	4.639
65	4.699
70	4.755
75	4.806
80	4.854
85	4.498
90	4.939
95	4.978
100	0.015

Standard Table B: Value of factors A_2, D_3 and D_4 for corresponding sample size

	Factor for $\bar{X}$ chart		Factors for R chart	
Number of observations (Sample size)	To calculate upper control limit $\left(\bar{\bar{X}} + A_2 \cdot \bar{R}\right)$	To calculate lower control limit $\left(\bar{\bar{X}} - A_2 \cdot \bar{R}\right)$	To calculate upper control limit $(D_4 \cdot \bar{R})$	To calculate lower control limit $(D_3 \cdot \bar{R})$
(n)	(A_2)		(D_4)	(D_3)
2	1.88		03.27	0
3	1.02		2.57	0
4	0.73		2.28	0
5	0.58		2.11	0
6	0.48		2.00	0
7	0.42		1.92	0.08
8	0.37		1.86	0.14
9	0.34		1.82	0.187
10	0.31		1.78	0.22
11	0.29		1.74	0.22
12	0.27		1.72	0.28
13	0.25		1.69	0.31
14	0.24		1.67	0.33
15	0.22		1.65	0.35
16	0.21		1.64	0.36
17	0.20		1.62	0.38
18	0.19		1.61	0.39
19	0.19		1.60	0.40
20	0.18		1.59	0.41

***

Winter 2017

1. (a) Attempt any THREE of the following: **(12)**

(i) Define comparator. State the working principle of mechanical comparator. **(4M)**

Ans. Refer Sections 2.14 and 2.15.

(ii) Define the following terms: (1) Tolerance, (2) Allowance, (3) Deviation, (4) Limits **(4M)**

Ans. Refer Sections 3.2, 3.7, 3.5 and 3.4.

(iii) "Sine bar is not used to measure angle more than 45°." Justify. **(4M)**

Ans. Refer Section 4.5.6.

(iv) Explain any four factors affecting the accuracy of measurement. **(4M)**

Ans. Refer Section 1.3.2.

(b) Attempt any ONE of the following:

(i) Explain the concept of cost of quality and value of quality by using suitable graph. **(6M)**

Ans. Refer Sections 9.13, 9.14 and 9.15.

(ii) Define TQM. Describe any 3 principal elements of TQM. **(6M)**

Ans. Refer Sections 10.1 and 10.2.

2. Attempt any FOUR of the following: **(16)**

(a) In the measurement of surface roughness heights of 18 successive peaks and valleys measured from a datum are as follows:

49, 27, 39, 24, 44, 26, 45, 27, 41, 25, 42, 28, 43, 26, 46, 29, 47, 28 the measurements were made over 18 mm.

Determine the CLA and RMS values of the surface. **(4M)**

Ans. Refer Similar Problem 7.2.

(b) [1°, 3°, 9°, 27°, 41°] [1', 3', 9', 27'] [3", 6", 18", 30"] and a square block.

Construct an angle of 116° 35' 6" using minimum number of angle gauges using standard angle gauge set. Draw the sketch of the arrangement. **(4M)**

Ans. Refer Similar Problem 4.3.

(c) Give the name of measuring instrument/method for following parameters of screw threads:
(i) Major diameter of external screw, (ii) Minor diameter of internal screw
(iii) Pitch of external screw, (iv) Effective diameter of external screw **(4M)**

Ans. Refer Section 5.4.

(d) Compare alignment test with performance test on any four parameters. **(4M)**

Ans. Refer Section 8.3.

(e) Compare acceptance sampling with 100% inspection. **(4M)**

Ans. Refer Section 13.1.1.

3. Attempt any FOUR of the following: **(16M)**

(a) State any four characteristics of good comparator. **(4M)**

Ans. Refer Section 2.14.2.

(b) Explain importance of surface finish in engineering applications. **(4M)**

Ans. Refer Section 7.1.

(c) Explain the principle of measurement of Parkinson's gear tester with a neat sketch. **(4M)**

Ans. Refer Section 6.9.

(d) Compare accuracy and precision. **(4M)**

Ans. Refer Section 1.4.

(e) Compare variable measurement and attribute measurement. **(4M)**

Ans. Refer Section 12.3.

4. (a) Attempt any THREE of the following: **(12M)**

(i) Explain with neat sketch, the procedure for squarness testing of drilling machine spindle. **(4M)**

Ans. Refer Section 8.19.4.

(ii) State the meaning of "Quality of Design" and "Quality of performance". **(4M)**

Ans. Refer Sections 9.8 and 9.10.

(iii) List the minimum number of slip gauges to be wrung together to produce an overall dimension of 63.875 mm using a set of 87 pieces. **(4M)**

Table No. 1: Slip Gauge Set M87

Range (mm)	Step (mm)	Pieces
1.005	–	01
1.001 to 1.009	0.001	09
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	09

Ans. Refer Similar Problem 2.2.

(iv) How major diameter is measured using floating carriage micrometer? **(4M)**

Ans. Refer Section 5.7.

(b) Attempt any ONE of the following: (6M)

(i) Enlist the types of sampling plans. Explain double sampling plan with suitable example. **(6M)**

Ans. Refer Sections 13.3 and 13.3.2.

(ii) What is LVDT? Explain its principle of working with neat sketch. **(6M)**

Ans. Refer Section 2.19.

5. Attempt any TWO of the following: (16M)

(a) Following are the inspection results of castings for a shift. Draw appropriate control chart and write your conclusion.
Given: $A_2 = 0.58$, $d_3 = 0$, $d_4 = 2.11$ (Refer Table No. 2) **(8M)**

Table No. 2

Time (Hrs.)	7 am to 8 am	8 am to 9 am	9 am to 10 am	10 am to 11 am	11 am to 12 pm	12 pm to 1 pm	1 pm to 2 pm	2 pm to 3 pm
Number of defective castings	08	07	09	06	04	05	04	06
Number of castings inspected	300	350	400	400	350	375	350	320

Ans. Refer Similar Problem 12.14.

(b) (i) Calculate the mean, mode and median for following observation data.
(Refer Table No. 3) **(4M)**

Table No. 3

Observation No.	1	2	3	4	5	6	7	8	9	10
Observations	4.11	4.18	4.19	4.22	4.25	4.15	4.16	4.18	4.18	4.20

Ans. Refer Similar Problem 12.2.

(ii) Explain the principle of measurement of gear tooth thickness, using a gear tooth vernier. **(4M)**

Ans. Refer Section 6.5.

(c) (i) What is six sigma statistical concept? Enlist its benefits. **(4M)**

Ans. Refer Sections 10.14 and 10.15.1.

(ii) Explain basic shaft and basic hole with neat sketch. **(4M)**

Ans. Refer Section 3.6.

6. Attempt any TWO of the following: (16M)

(a) Explain with neat sketch, construction and working of sigma comparator. **(8M)**

Ans. Refer Section 2.15.2.

(b) Draw a P-chart and comment on it. 25 samples of 100 items were inspected. They are as follows: **(8M)**

Sample Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Number of defectives	14	22	25	15	20	14	12	24	10	17	35	36	16	23

Sample Number	15	16	17	18	19	20	21	22	23	24	25
Number of defectives	14	6	7	33	17	34	11	16	25	36	18

Total number of defectives: 500.

Ans. Refer Similar Problem 12.10.

(c) (i) Draw O.C. Curve and explain the Producer's Risk and Consumer's Risk. **(4M)**

Ans. Refer Sections 13.5 and 13.6.

(ii) State and explain any four types of errors in gears. **(4M)**

Ans. Refer Section 6.12

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Summer 2018

1. (a) Attempt any THREE of the following: (12M)

(i) Define the terms: scientific metrology, industrial metrology and legal metrology. Give two applications of legal metrology. **(4M)**

Ans. Refer Section 1.1.4.

(ii) State and explain Taylors principle of gauge design. **(4M)**

Ans. Refer Section 3.19.

(iii) An angle of 32°50'54" is to be measured using following standards set of [1°, 3°, 9°, 27°, 41°, [1', 3', 9', 27'], [3", 6", 18", 30"]. Sketch the arrangement with minimum number of gauges. **(4M)**

Ans. Refer Problem 4.7.

(iv) Differentiate between Variable control chart and Attribute control chart based on any four parameters. **(4M)**

Ans. Refer Section 12.21.

(b) Attempt any ONE of the following: (6M)

(i) State, which comparator is most useful for measuring the roundness and taperness of cylinder bore? Explain its working. **(6M)**

Ans. Refer Section 2.17.

(ii) Write procedure to measure effective diameter of screw thread using two wire method.

Ans. Refer Section 5.9. **(6M)**

2. Attempt any FOUR of the following: (16M)

(a) Explain the need of inspection in industries. **(4M)**

Ans. Refer Section 9.18.

(b) Explain the following terms related to metrology and give one example:
(i) Selective assembly, (ii) Interchangeability **(4M)**

Ans. (i) Selective assembly: Refer Section 3.15.
(ii) Interchangeability: Refer Section 3.14.

(c) Sine bar is not preferred for measuring an angle more than 45°. State the reason.

Ans. Refer Section 4.5.6. **(4M)**

(d) Draw a neat sketch of gear tooth vernier caliper and write the formula for chordal depth and chordal thickness. **(4M)**

Ans. Refer Section 6.5.1.

(e) Compare 100% inspection with sampling inspection. **(4M)**

Ans. Refer Section 13.1.1.

3. Attempt any FOUR of the following: (16M)

(a) What is wringing of slip gauges? State the condition of wringing. **(4M)**

Ans. Refer Section 2.8.

(b) Suggest the instrument, which is used to measure the adjacent angle. Explain its principle. **(4M)**

Ans. Refer Section 4.6.

(c) State the importance of process capability study in solving quality problems. **(4M)**

Ans. Refer Section 12.16.1.

(d) Suggest the measuring instruments to measure the following features of external and internal threads:
(i) Minor diameter, (ii) Effective diameter, (iii) Pitch, (iv) Thread angle **(4M)**

Ans. Refer Section 5.4.

(e) List out the various techniques of qualitative analysis for surface finish. Explain any two. **(4M)**

Ans. Refer Section 7.10 (1).

4. (a) Attempt any THREE of the following: (12M)

(i) Explain, how the squareness of an axis of rotation with a given plane can be tested.

Ans. Refer Section 8.6 (a). **(4M)**

(ii) Define assignable causes and chance causes of variation. Give two causes for each of them. **(4M)**

Ans. Refer Sections 12.14.1 and 12.14.2.

(iii) Interpret the meaning of $40H_7i_7$ with respect to fit and basis system. **(4M)**

Ans. Refer Section 3.13.1.

(iv) State the factors to be considered for achieving a reliable design. **(4M)**

Ans. Refer Section 9.11.1.

(b) Attempt any ONE of the following: (6M)

(i) Explain the meaning of quality of design and quality of conformance. State the factors controlling the quality of design and quality of conformance. **(6M)**

Ans. Refer Sections 9.8 and 9.9.

(ii) Explain the double sampling plan with a suitable block diagram. **(6M)**

Ans. Refer Section 13.3.2.

5. Attempt any TWO of the following: (16M)

(a) With neat sketch, explain the principle of working of linear variable differential transformer. State its application. **(8M)**

Ans. Refer Sections 2.19 and 2.19.1.

(b) Explain with neat sketch, construction and working of Parkinson gear tester. **(8M)**

Ans. Refer Section 6.9.

(c) In the lot of 50 pieces, each subgroup is of 05 pieces and for 10 subgroups, $\bar{X}$ and R values for the length of pieces is as under. **(8M)**

Sr. No.	$\bar{X}$	**R**
01.	2.12	0.03
02.	1.99	0.01
03.	1.80	0.02
04.	2.00	0.04
05.	1.99	0.02
06.	2.45	0.01
07.	1.85	0.05
08.	1.70	0.04
09.	1.98	0.06
10.	2.30	0.03

Give Data: $A_2 = 0.577$, $D_3 = 0$, $D_4 = 2.11$, $d_2 = 2.362$.

By using general formulae, prepare $\bar{X}$ and R-chart and write the interpretation of chart.

6. Attempt any TWO of the following: (16M)

(a) Draw a neat sketch of O.C. curve, show the different regions and explain the meaning of four regions. **(8M)**

Ans. Refer Section 13.5.

(b) Explain the methodology of system improvement using six sigma. State various certifications used in six sigma. **(8M)**

Ans. Refer Sections 10.14 and 10.15.

(c) (i) State how surface finish is designated on drawing. **(4M)**

Ans. Refer Section 7.9.

(ii) Explain, how will you check flatness of work table on a horizontal milling machine. **(4M)**

Ans. Refer Section 8.18 (4).

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