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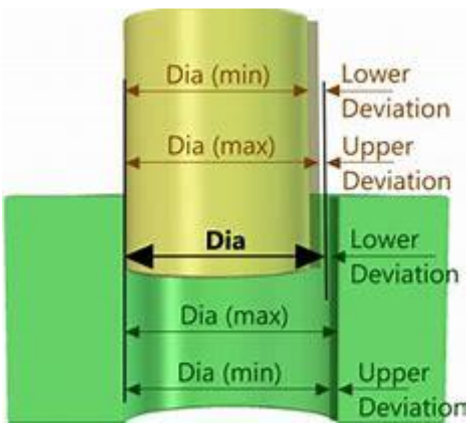
Ch-2
System of Limits, Fits, Tolerance and Gauging



Subject:- MMM Code:-3141901	**Prepared by:** Asst.Prof.Chirag Mevada (Mechanical Department,ACET)	AMIRAJ COLLEGE OF ENGINEERING & TECHNOLOGY

2	**System of Limits, Fits, Tolerance and Gauging:** Definition of tolerance, Specification in assembly, Principle of interchangeability and selective assembly, limits of size, Indian standards, concept of limits of size and tolerances, definition of fits, hole basis system, shaft basis system, types of fits and their designation (IS 919-1963), geometric tolerance, position-tolerances. Classification of gauges, brief concept of design of gauges (Taylor's principles), Wear allowance on gauges, Types of gauges-plain plug gauge, ring gauge, snap gauge, limit gauge and gauge materials. **Comparators:** Functional requirements, classification, mechanical- Johnson Mikrokator, sigma comparators, dial indicator, electrical- principles, , LVDT, Pneumatic- back pressure gauges, Solex comparators and optical comparators- Zeiss ultra-optimeter.	12

Interchangeability

- The term **interchangeability** is normally employed for the mass production of identical items within the prescribed limits of sizes.
- A little consideration will show that in order to maintain the sizes of the part within a close degree of accuracy, a lot of time is required. But even then there will be small variations. If the variations are within certain limits, all parts of equivalent size will be equally fit for operating in machines and mechanisms.
- Therefore, certain variations are recognised and allowed in the sizes of the mating parts to give the required fitting. This facilitates to select at random from a large number of parts for an assembly and results in a considerable saving in the cost of production.
- In order to control the size of finished part, with due allowance for error, for interchangeable parts is called **limit system**.
- It may be noted that when an assembly is made of two parts, the part which enters into the other, is known as ***enveloped surface*** (or shaft for cylindrical part) and the other in which one enters is called ***enveloping surface*** (or hole for cylindrical part).

Notes:

1. The term ***shaft*** refers not only to the diameter of a circular shaft, but it is also used to designate any external dimension of a part.

2. The term ***hole*** refers not only to the diameter of a circular hole, but it is also used to designate any internal dimension of a part.

Important Terms used in Limit System

- The following terms used in limit system (or interchangeable system) are important from the subject point of view:

1. **Limits of sizes:** There are two extreme permissible sizes for a dimension of the part as shown in Fig. 3.1. The largest permissible size for a dimension of the part is called upper or high or maximum limit, whereas the smallest size of the part is known as lower or minimum limit.

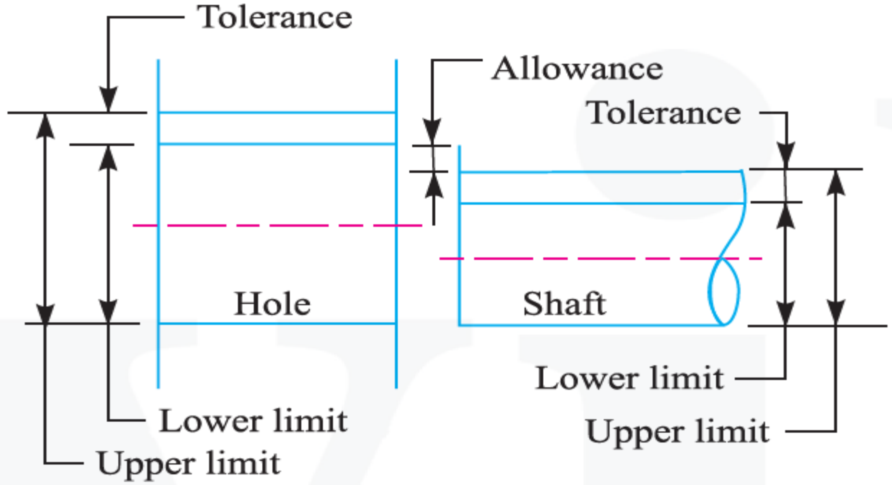


Fig. 3.1. Limits of sizes.

2. **Allowance:** It is the difference between the basic dimensions of the mating parts. The allowance may be positive or negative. When the shaft size is less than the hole size, then the allowance is positive and when the shaft size is greater than the hole size, then the allowance is negative.

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Important Terms used in Limit System

3. **Nominal size:** It is the size of a part specified in the drawing as a matter of convenience.

4. **Basic size:** It is the size of a part to which all limits of variation (i.e. tolerances) are applied to arrive at final dimensioning of the mating parts. The nominal or basic size of a part is often the same.

5. **Actual size:** It is the actual measured dimension of the part. The difference between the basic size and the actual size should not exceed a certain limit, otherwise it will interfere with the interchangeability of the mating parts.

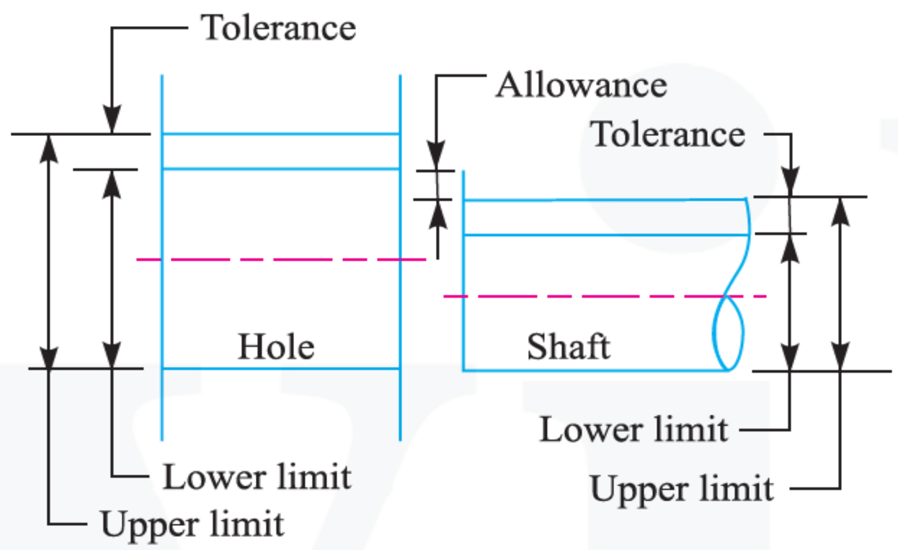


Fig. 3.1. Limits of sizes.

Important Terms used in Limit System

6. **Tolerance:** It is the difference between the upper limit and lower limit of a dimension. In other words, it is the maximum permissible variation in a dimension. The tolerance may be unilateral or bilateral. When all the tolerance is allowed on one side of the nominal size, e.g. $20^{+0.000}_{-0.004}$, then it is said to be unilateral system of tolerance. The unilateral system is mostly used in industries as it permits changing the tolerance value while still retaining the same allowance or type of fit.

- When the tolerance is allowed on both sides of the nominal size, e.g. $20^{+0.002}_{-0.002}$, then it is said to be bilateral system of tolerance. In this case + 0.002 is the upper limit and – 0.002 is the lower limit.
- The method of assigning unilateral and bilateral tolerance is shown in Fig. 3.2 (a) and (b) respectively.

(*a*) Unilateral tolerance. (*b*) Bilateral tolerance.

Fig. 3.2. Method of assigning tolerances.

Important Terms used in Limit System

7. **Tolerance zone:** It is the zone between the maximum and minimum limit size, as shown in Fig. 3.3.

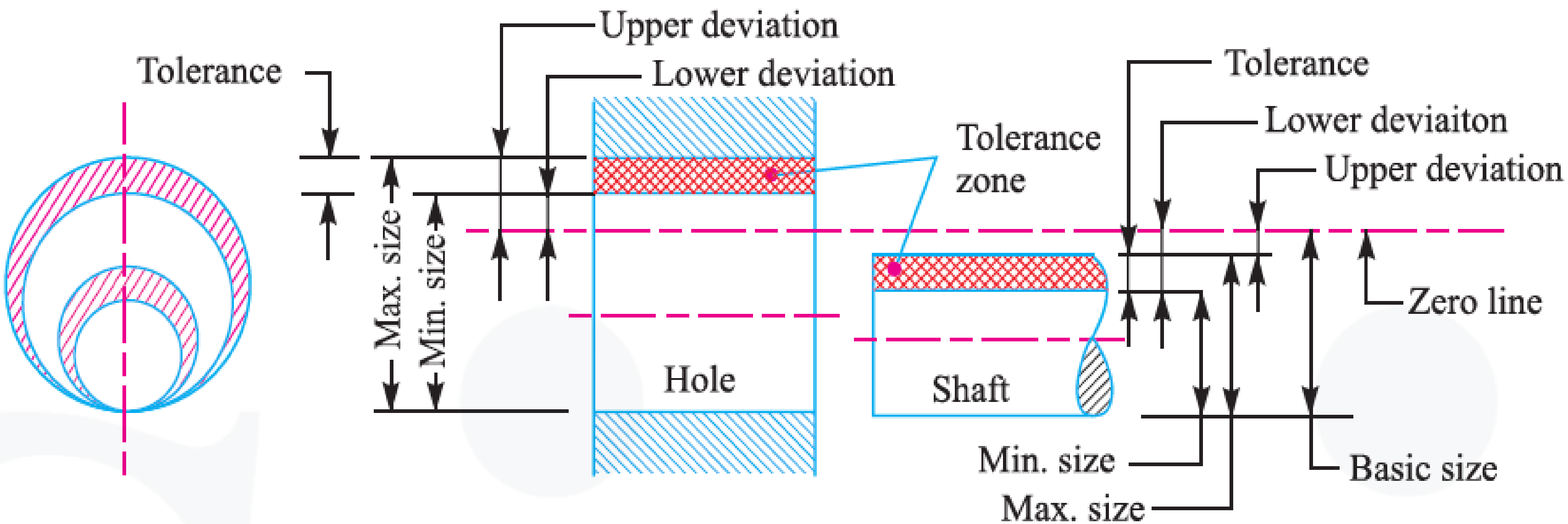


Fig. 3.3. Tolerance zone.

8. **Zero line:** It is a straight line corresponding to the basic size. The deviations are measured from this line. The positive and negative deviations are shown above and below the zero line respectively.

Important Terms used in Limit System

9. **Upper deviation:** It is the algebraic difference between the maximum size and the basic size. The upper deviation of a hole is represented by a symbol ES (Ecart Superior) and of a shaft, it is represented by es.

10. **Lower deviation:** It is the algebraic difference between the minimum size and the basic size. The lower deviation of a hole is represented by a symbol EI (Ecart Inferior) and of a shaft, it is represented by ei.

11. **Actual deviation:** It is the algebraic difference between an actual size and the corresponding basic size.

12. **Mean deviation:** It is the arithmetical mean between the upper and lower deviations.

13. **Fundamental deviation:** It is one of the two deviations which is conventionally chosen to define the position of the tolerance zone in relation to zero line, as shown in Fig. 3.4.

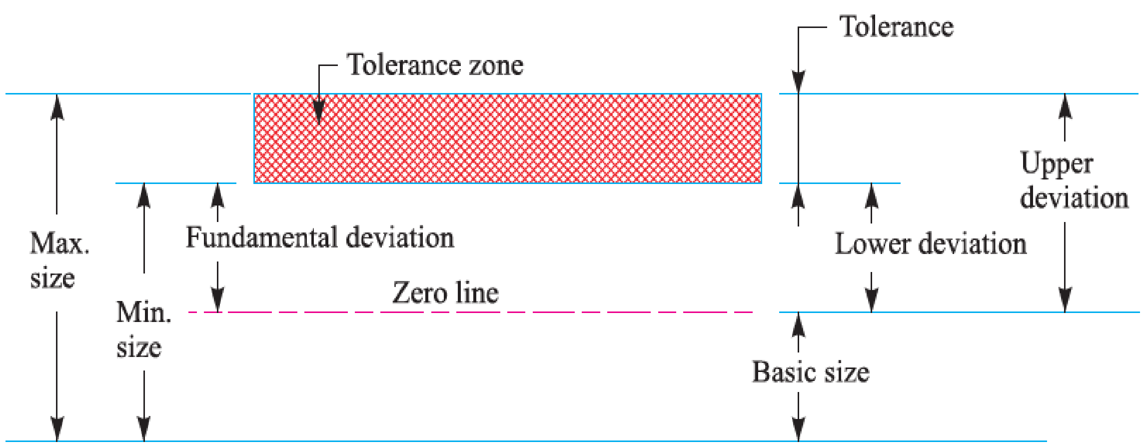


Fig. 3.4. Fundamental deviation.

Fits

- The degree of tightness or looseness between the two mating parts is known as a ***fit*** of the parts. The nature of fit is characterised by the presence and size of clearance and interference.
- The ***clearance*** is the amount by which the actual size of the shaft is less than the actual size of the mating hole in an assembly as shown in Fig. 3.5 (a).
- In other words, the ***clearance*** is the difference between the sizes of the hole and the shaft before assembly. The difference must be ***positive***.

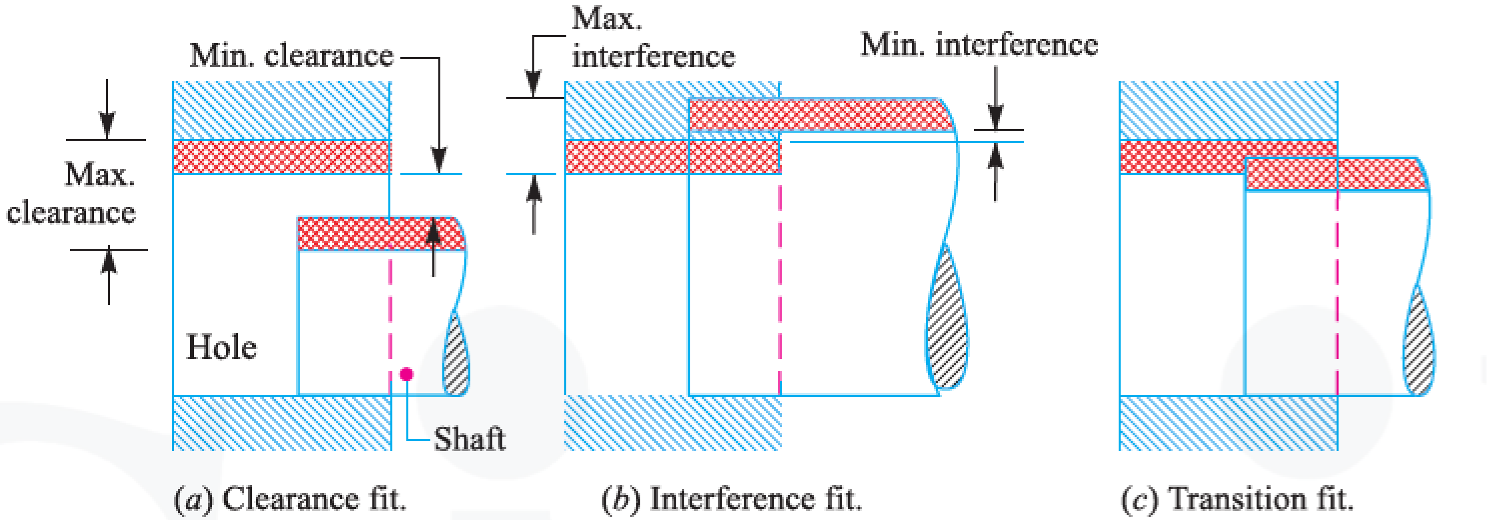
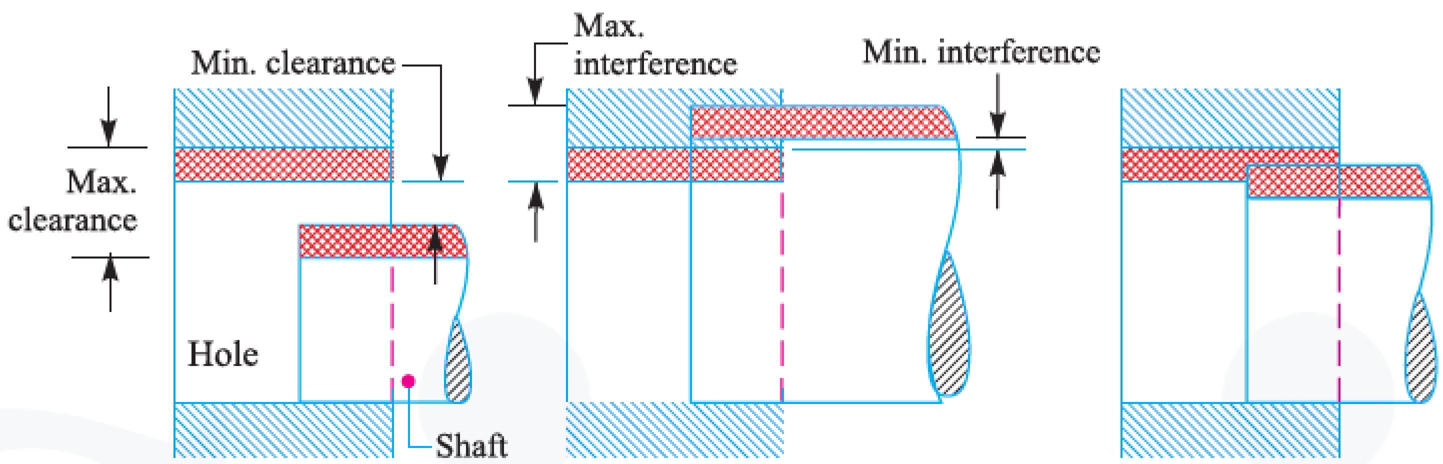


Fig. 3.5. Types of fits.

Fits

- The ***interference*** is the amount by which the actual size of a shaft is larger than the actual finished size of the mating hole in an assembly as shown in Fig. 3.5 (b).
- In other words, the ***interference*** is the arithmetical difference between the sizes of the hole and the shaft, before assembly. The difference must be ***negative***.



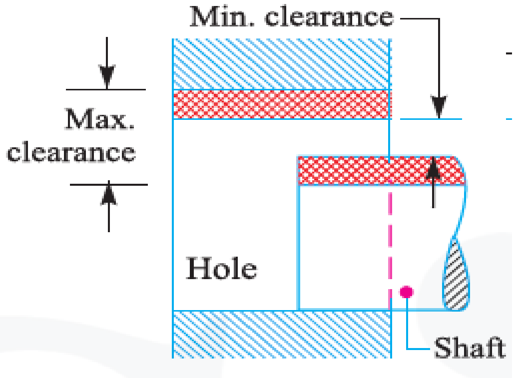
(*a*) Clearance fit. (*b*) Interference fit. (*c*) Transition fit.

Fig. 3.5. Types of fits.

Types of Fits

- According to Indian standards, the fits are classified into the following three groups :

1. **Clearance fit:** In this type of fit, the size limits for mating parts are so selected that clearance between them always occur, as shown in Fig. 3.5 (a). It may be noted that in a clearance fit, the tolerance zone of the hole is entirely above the tolerance zone of the shaft.



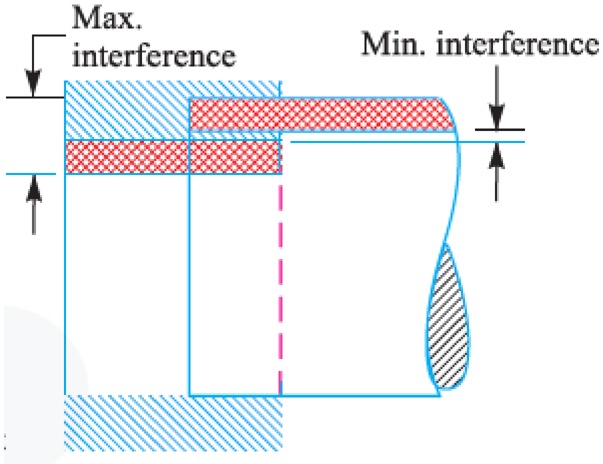
(*a*) Clearance fit.

- In a clearance fit, the difference between the minimum size of the hole and the maximum size of the shaft is known as minimum clearance whereas the difference between the maximum size of the hole and minimum size of the shaft is called maximum clearance as shown in Fig. 3.5 (a).
- The clearance fits may be slide fit, easy sliding fit, running fit, slack running fit and loose running fit.

Types of Fits

2. Interference fit. In this type of fit, the size limits for the mating parts are so selected that interference between them always occur, as shown in Fig. 3.5 (b). It may be noted that in an interference fit, the tolerance zone of the hole is entirely below the tolerance zone of the shaft.

- In an interference fit, the difference between the maximum size of the hole and the minimum size of the shaft is known as minimum interference, whereas the difference between the minimum size of the hole and the maximum size of the shaft is called maximum interference, as shown in Fig. 3.5 (b).
- The interference fits may be shrink fit, heavy drive fit and light drive fit.



(b) Interference fit.

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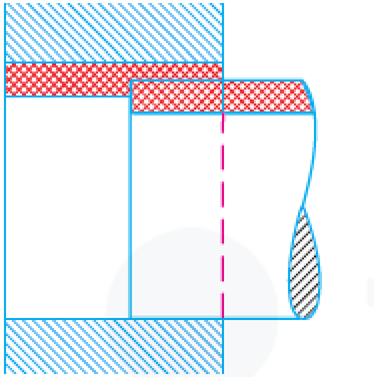
Types of Fits

3. Transition fit: In this type of fit, the size limits for the mating parts are so selected that either a clearance or interference may occur depending upon the actual size of the mating parts, as shown in Fig. 3.5 (c). It may be noted that in a transition fit, the tolerance zones of hole and shaft overlap.

- The transition fits may be force fit, tight fit and push fit.

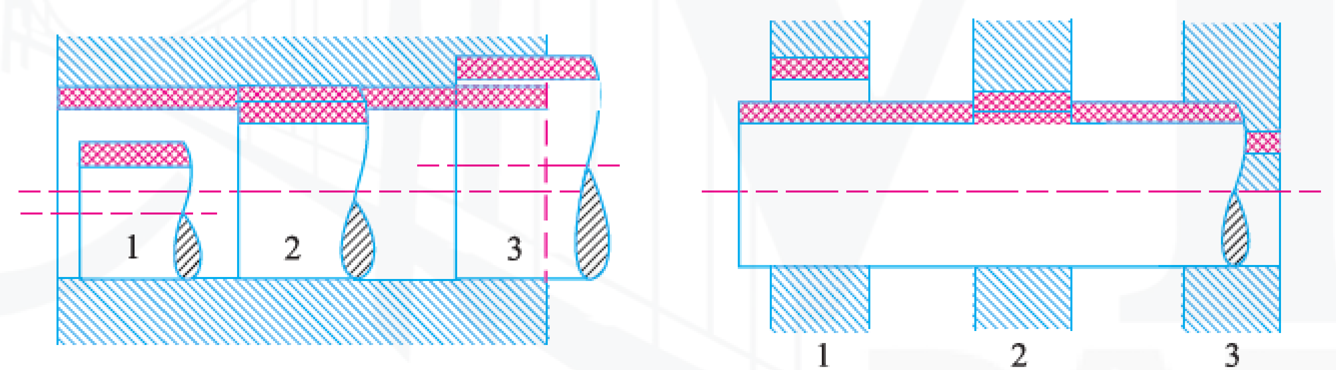


(*c*) Transition fit.

Basis of Limit System

- The following are two bases of limit system:

1. **Hole basis system:** When the hole is kept as a constant member (i.e. when the lower deviation of the hole is zero) and different fits are obtained by varying the shaft size, as shown in Fig. 3.6 (a), then the limit system is said to be on a hole basis.
2. **Shaft basis system:** When the shaft is kept as a constant member (i.e. when the upper deviation of the shaft is zero) and different fits are obtained by varying the hole size, as shown in Fig. 3.6 (b), then the limit system is said to be on a shaft basis.



1. Clearance fit. 2. Transition fit. 3. Interference fit.

(*a*) Hole basis system. (*b*) Shaft basis system.

Fig. 3.6. Bases of limit system.

Basis of Limit System

- The hole basis and shaft basis system may also be shown as in Fig. 3.7, with respect to the zero line.
- It may be noted that from the manufacturing point of view, a hole basis system is always preferred.
- This is because the holes are usually produced and finished by standard tooling like drill, reamers, etc., whose size is not adjustable easily. On the other hand, the size of the shaft (which is to go into the hole) can be easily adjusted and is obtained by turning or grinding operations.

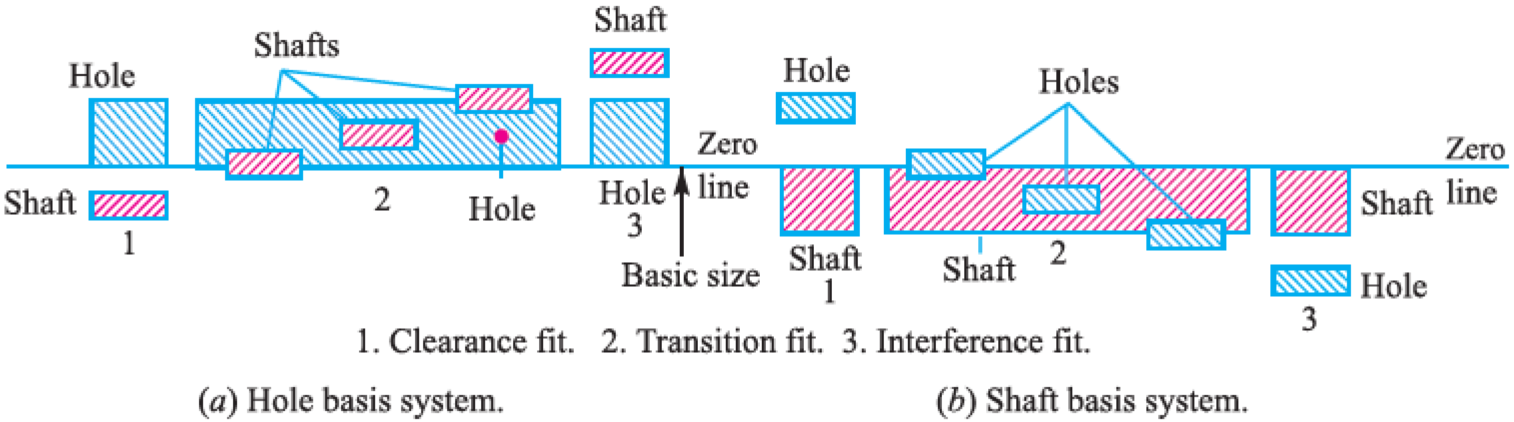


Fig. 3.7. Bases of limit system.

Indian Standard System of Limits and Fits

- According to Indian standard [IS : 919 (Part I)-1993], the system of limits and fits comprises 18 grades of fundamental tolerances i.e. grades of accuracy of manufacture and 25 types of fundamental deviations indicated by letter symbols for both holes and shafts (capital letter A to ZC for holes and small letters a to zc for shafts) in diameter steps ranging from 1 to 500 mm.
- A unilateral hole basis system is recommended but if necessary a unilateral or bilateral shaft basis system may also be used.
- The 18 tolerance grades are designated as IT 01, IT 0 and IT 1 to IT 16. These are called standard tolerances.
- The standard tolerances for grades IT 5 to IT 7 are determined in terms of standard tolerance unit (i) in microns, where

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

- where D is the size or geometric mean diameter in mm.

Indian Standard System of Limits and Fits

- The following table shows the relative magnitude for grades between IT 5 and IT 16.

Table 3.2. Relative magnitude of tolerance grades.

Tolerance grade	IT 5	IT 6	IT 7	IT 8	IT 9	IT 10	IT 11	IT 12	IT 13	IT 14	IT 15	IT 16
Magnitude	7 *i*	10 *i*	16 *i*	25 *i*	40 *i*	64 *i*	100 *i*	160 *i*	250 *i*	400 *i*	640 *i*	1000 *i*

- The values of standard tolerances corresponding to grades IT 01, IT 0 and IT 1 are as given below:
- For IT 01, i (microns) = 0.3 + 0.008 D,
- For IT 0, i (microns) = 0.5 + 0.012 D, and
- For IT 1, i (microns) = 0.8 + 0.020 D,
- where D is the size or geometric mean diameter in mm.
- The tolerance values of grades IT 2 to IT 4 are scaled approximately geometrically between IT 1 and IT 5.

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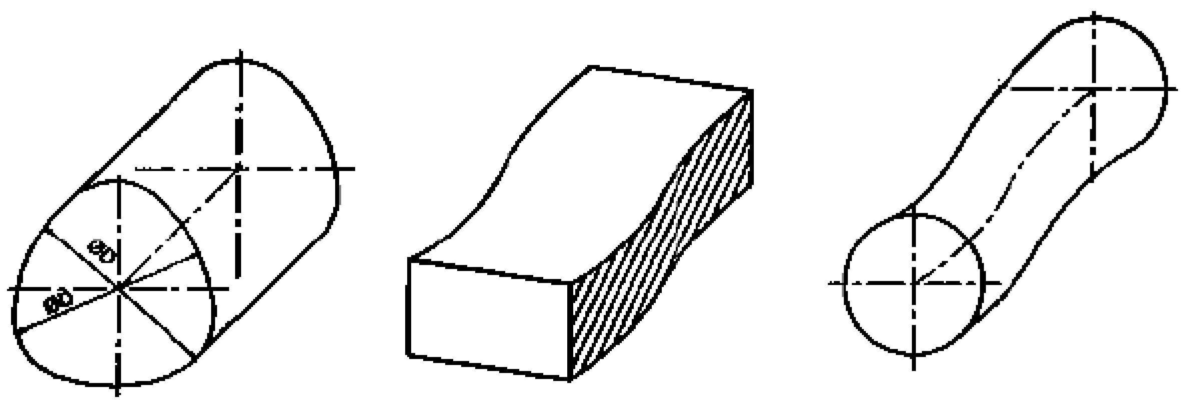
Indian Standard System of Limits and Fits

- For hole, H stands for a dimension whose lower deviation refers to the basic size.
- The hole H for which the lower deviation is zero is called a basic hole.
- Similarly, for shafts, h stands for a dimension whose upper deviation refers to the basic size.
- The shaft h for which the upper deviation is zero is called a basic shaft.
- A fit is designated by its basic size followed by symbols representing the limits of each of its two components, the hole being quoted first.
- For example, 100 H6/g5 means basic size is 100 mm and the tolerance grade for the hole is 6 and for the shaft is 5.

Geometric tolerances

- In certain circumstances, tolerances of size, which was discussed in previous point are not sufficient to provide the required control of form or not sufficient to ensure the acceptance of component.
- For example, in fig (a) the shaft has same diameter in all possible position but is not a circular.
- Similarly, in fig.(b) the rib has the same thickness throughout but it is not a flat. Also in fig. (c) The component i.e. circular shaft is circular in all cross-section but it is not a straight.



(a) (b) (c)

Fig.9.9 geometrical variations

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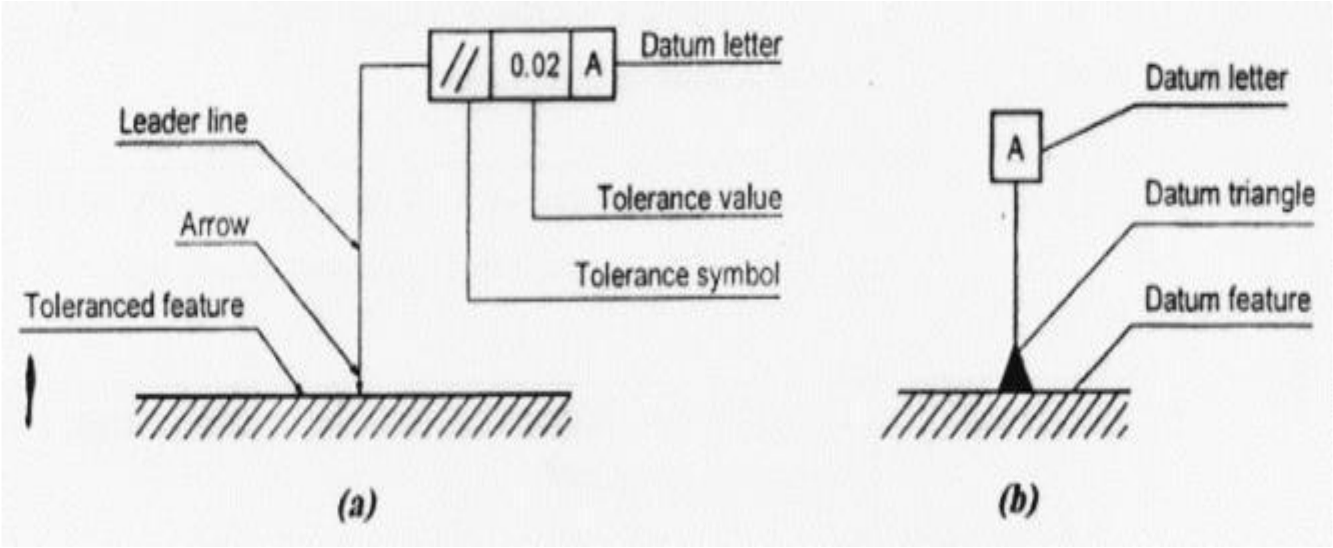
Geometric tolerances

- All above parts are unacceptable if they were checked only for dimensional variation, thus here another tolerance come into picture which controls the shape or form of component i.e. geometrical tolerance.
- Thus the geometrical tolerances are defined as the maximum permissible overall variation of form or position of a feature.
- The geometrical tolerances are used:

1. To specify the required accuracy in controlling the form of component.
2. To ensure correct function position of components.
3. To ensure interchangeability of components.
4. To facilitate the assembly of mating of components.

Terms used in Geometric tolerances

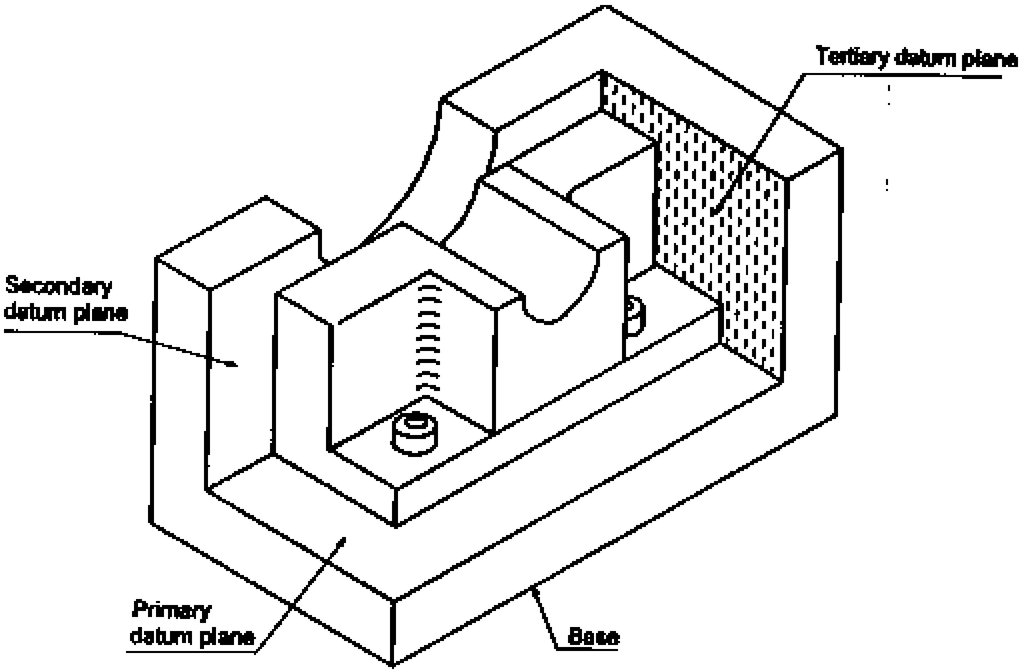
- **Datum:** It is theoretically exact geometric reference such as axes, planes, straight lines, etc. to which the tolerance features are related.
- **Datum features:** A datum feature is a feature of a part, such as an edge, surface or a hole, which forms the basis for a datum or is used to establish its location.
- **Datum triangle:** The datum is indicated by a leader line, terminating in a filled or an open triangle as shown in fig.



- **Datum latter:** To identify a datum for reference purposes, ca capital latter is enclosed in a frame, connected to the datum triangle.

Terms used in Geometric tolerances

- **Datum system:** Datum system is a group of two or more separated datums, used a combined reference for tolerance features. In this case, the sequence of datums referred, has considerable influence on the result.



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Indication of Geometric tolerances on a drawing

- To eliminate the need to descriptive notes, geometrical tolerances are indicated on drawings by symbols, tolerances and datums, all contained in components of a rectangular frame as shown in fig.

❖Advantages of using geometrical tolerances:

- Geometric tolerances convey very briefly and precisely, the complete geometrical requirements on engineering drawings.
- The use of symbols and boxes eliminates the need for lengthy descriptive notes and corresponding dimensions, because of which the drawings are much clearer to read.
- The symbols used are internationally recommended.
- One type of geometrical tolerance can control another form. For instance, sureness can correct flatness and straightness.

Indication of feature controlled

- The feature controlled by geometrical tolerance is indicated by an arrow head at the end of a leader line, from the tolerance frame. The tolerance frame is connected to the tolerance feature by a leader line, terminating with an arrow in the following ways.
- On the outline of the feature, on extension of the outline, but not a dimension line, when the tolerance refers to the line or surface itself.
- The following table shows the symbols representing the characteristics to be tolerance.

Indication of feature controlled

Characteristics to be toleranced		*Symbols*
Form of single features	Straightness	⏤
	Flatness	⏥
	Circularity (roundness)	○
	Cylindricity	⌭
	Profile of any line	⌒
	Profile of any surface	⌓
Orientation of related features	Parallelism	//
	Perpendicularity (squareness)	⊥
	Angularity	∠
Position of related features	Position	⌖
	Concentricity and coaxiality	◎
	Symmetry	⌯
	Run-out	↗

Examples

1) **In bush and pin assembly, pin of 30 mm diameter rotates in a bush. The tolerance for pin is 0.025 mm while for bush is 0.04 mm. If allowance is 0.1 mm, determine dimensions of pin and bush considering hole-basis system.**

Given Data:-

Basic size = 30 mm, Allowance = 0.1 mm, Tolerance for pin = 0.025 mm, Tolerance for bush = 0.04 mm Hole basis system To find: Dimension of pin & bush.

Solution:-

Step: -1 Calculate the dimension of bush.

For hole basis system, fundamental deviation of bush is zero.

Lower limit of bush = Basic size + fundamental deviation = 30 + 0 = 30 mm.

Upper limit of bush = Lower limit of bush + Tolerance for bush = 30 + 0.04 = 30.04 mm.

Step: -2 Calculate the dimension of pin.

With positive allowance, it is a clearance fit.

Allowance = Lower limit of bush – Upper limit of pin = 30 – Upper limit of pin

Upper limit of pin = 29.9 mm.

Lower limit of pin = Upper limit of pin – Tolerance for pin = 29.9 - .025 = 29.875 mm.

Dimension of bush = 30 +0.04 +0.00 mm.

Dimension of pin = 30 -0.100 -0.125 mm.

Examples

2) A journal of nominal diameter 79 mm rotates in a bearing. The upper and lower deviations in hole diameter are respectively +0.05 mm and 0.00 mm, while those for shaft are respectively -0.03 mm and -0.07 mm. Calculate: (i) Extreme diameters for hole and shaft, (ii) Tolerances for hole and shaft and (iii) maximum and minimum clearance.

Given Data

Nominal Diameter = Ø 79 mm. Hole - Upper Deviation = + 0.05 mm. Lower Deviation = 0.00 mm. Shaft - Upper Deviation = - 0.03 mm. Lower Deviation = - 0.07 mm.

Solution

Upper Deviation = Max limit – Basic size. Max limit = Upper Deviation + Basic size.

For hole Max limit = + 0.05 + 79 = 79.05 mm.

For shaft Max limit = - 0.03 + 79 = 78.97 mm.

Lower Deviation = Min limit – Basic size. Min limit = Lower Deviation + Basic size.

For hole Min limit = 0.00 + 79 = 79.00 mm.

For shaft Min limit = - 0.07 + 79 = 78.93 mm.

Tolerance = Max limit – Min limit.

Tolerance for hole = Max limit – Min limit = 79.05 – 79 = 0.05 mm.

Tolerance for shat = Max limit – Min limit = 78.97 – 78.93 = 0.04 mm.

Min Clearance = Min hole – Max shaft = 79 – 78.97 = 0.03 mm.

Max Clearance = Max hole – Min shaft = 79.05 – 78.93 = 0.12 mm.

Examples

3) Find the tolerances, maximum interference and type of fit for the data for the following given data: Hole ϕ50+0.25-0.10 and Shaft ϕ50+0.20-0.20.

Given Data

Hole Ø 50 + 0.25 -0.10, Shaft Ø 50 + 0.20 -0.20.

Solution

Upper Deviation = Max limit – Basic size.

Max limit = Upper Deviation + Basic size.

For hole Max limit = + 0.25 + 50 = 50.25 mm.

For shaft Max limit = + 0.20 + 50 = 50.20 mm.

Lower Deviation = Min limit – Basic size.

Min limit = Lower Deviation + Basic size.

For hole Min limit = - 0.10 + 50 = 49.90 mm.

For shaft Min limit = - 0.20 + 50 = 49.80 mm.

Tolerance = Max limit – Min limit.

Tolerance for hole = Max limit – Min limit = 50.25 – 49.90 = 0.35 mm.

Tolerance for shat = Max limit – Min limit = 50.20 – 49.80 = 0.40 mm.

Max Interference = Max shaft – Min hole = 50.20 – 49.90 = 0.30 mm.

Type of fit is Interference.

LIMIT GAUGES

- Gauges are inspection tools which serve to check the dimensions of the manufactured pmts. Limit gauges ensure the size of the component lies within the specified limits.
- They are non-recording and do not determine the size of the part. Gauges are generally classified as:

1. **Standard gauges** are made to the nominal size of the part to be tested and have the measuring member equal in size to the mean permissible dimension of the part to be checked.
2. **Limit Gauges are also called 'GO' and 'NO GO' gauges**. These are made to the limit sizes of the work to be measured. One of the sides or ends of the gauge is made to correspond to maximum and the other end to the minimum permissible size. The function of limit gauges is to determine whether the actual dimensions of the work are within outside the specified limits.

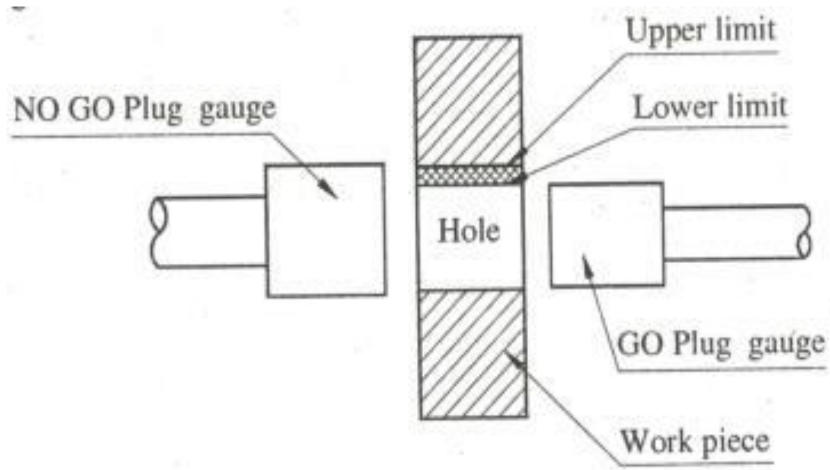
- A GO-NO GO gauge is a measuring tool that does not return a size in the conventional sense, but instead returns a state. The state is either acceptable (the part is within tolerance and may be used) or it is unacceptable (and must be rejected).
- They are well suited for use in the production area of the' factory as they require little skill or interpretation to use effectively and have few, if any, moving parts to be damaged in the often hostile production environment.

Why limit gauges necessary?

- In the manufacturing firm, the components are manufactured as per the specified tolerance limits, upper limit and lower limit. The dimension of each component should be within this upper and lower limit.
- If the dimensions are outside these limits, the components will be rejected. If we use any measuring instruments to check these dimensions, the process will consume more time.
- Also, in mass production, we are not interested in knowing the amount of error in dimensions. It is just enough whether the size of the component is within the prescribed limits or not. For this purpose, limit gauges are used.
- A limit gauge is not a measuring gauge; this gives the information about the products which may be either within the prescribed limit or not. By using limit gauges report, the control charts of P and C charts are drawn to control invariance of the products.
- This procedure is mostly performed by the quality control department of each and every industry. Limit gauge are mainly used for checking for cylindrical holes of identical components with a large numbers in mass production.

Basic concept of Gauge Design (Taylor's Principle)

- According to Taylor, 'GO' and 'NOGO' gauges should be designed to check maximum and minimum material limits.
- The terms minimum metal condition, and maximum metal condition are used to describe the tolerance state of a work piece. The GO gauge is made near the maximum metal condition.
- The GO gauge must be able to slip inside/over the feature without obstruction. For example plug gauge (for checking hole size), as shown in Fig. having exactly the GO limit.



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Basic concept of Gauge Design (Taylor's Principle):

- Diameter and a length equal to the engagement length of the fit to be made for checking the GO limit of the work piece and this gauge must perfectly assemble with the work piece to be inspected.
- The NO GO gauge is made near the minimum metal condition. NO GO gauge which contacts the work piece surface only in two diametrically opposite points and at those points it should have exactly NO GO limit diameter.
- The NO GO gauge must not be able to slip inside/over the work piece in any consecutive position in various diametric directions on the work piece length.

TYPES OF LIMIT GAUGES

1. **According to their purpose:**

a) **Work shop gauges:** Working gauges are those used at the bench or machine in gauging the work as it being made.

b) **Inspection gauges:** These gauges are used by the inspection personnel to inspect manufactured parts when finished.

c) **Reference or Master Gauges:** These are used only for checking the size or condition of other gauges.

2. **According to form of tested surfaces:**

a) **Plug gauges:** They check the dimensions of a hole.

b) **Ring gauges:** They check the dimensions of a shaft.

c) **Snap gauges:** They also check the dimensions of a shaft. Snap gauges can be used for both cylindrical as well as non-cylindrical work as compared toting gauges which are conveniently used only for cylindrical work.

3. **According to their design:**

a) Single limit & double limit gauges

b) Single ended and double ended gauges

c) Fixed & adjustable gauges

Plug gauges

- Plug gauges are used for checking holes and consist of two cylindrical wear resistant plugs. The plug made to the lower limit of the hole is known as 'GO' end and this will enter any hole which is not smaller than the lower limit allowed.
- The plug made to the upper limit of the hole is known as 'NO GO' end and this will not enter any hole which is smaller than the upper limit allowed. The plugs are arranged on either ends of a common handle.
- The ends are hardened and accurately finished by grinding. One end is the GO end and the other end is NO GO end. If the size of the hole is within the limits, the GO end should go inside the hole and NO GO end should not go.
- If the GO end does not go, the hole is under size and also if NO GO end goes, the hole is over size. Hence, the components are rejected in both the cases.

Plug gauges

➢ The GO end and NO GO end are arranged on both the ends of the plug as shown in Fig. 2.32. This type has the advantage of easy handling and are called double ended plug gauges.

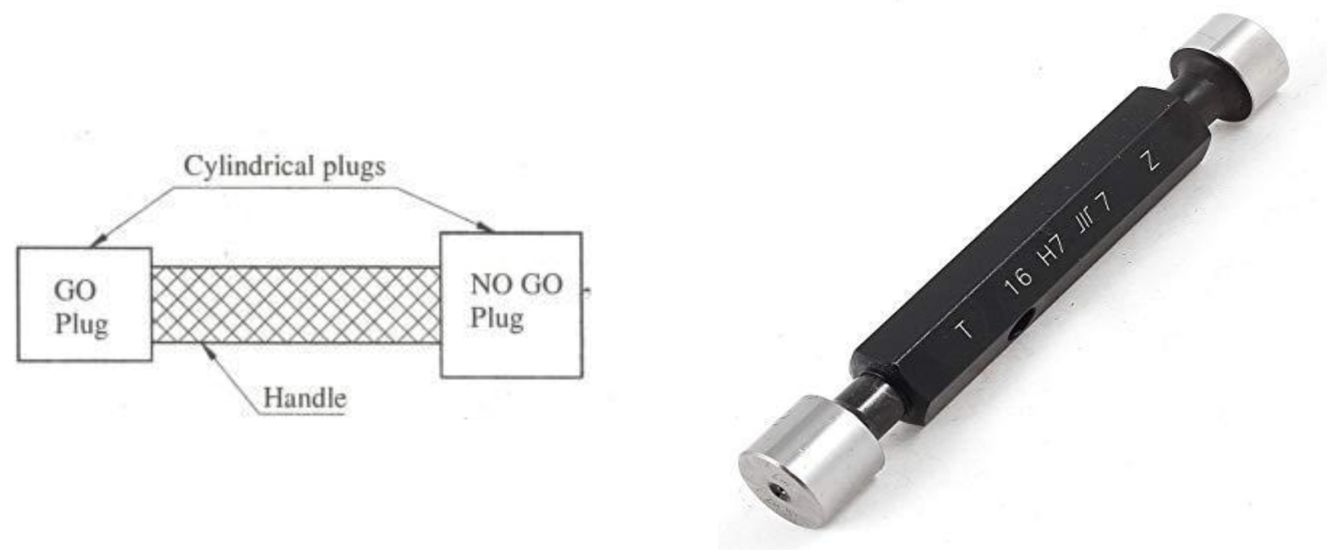

Figure 2.32 Double ended plug gauge

Plug gauges

- In case of progressive type of plug gauges as shown in the Fig. 2.33 both the GO end and NO GO end are arranged in the same side of the plug. We can use the plug gauge ends progressively one after the other while checking the hole. It saves time.
- Generally, the GO end is made longer than the NO GO end in plug gauges.

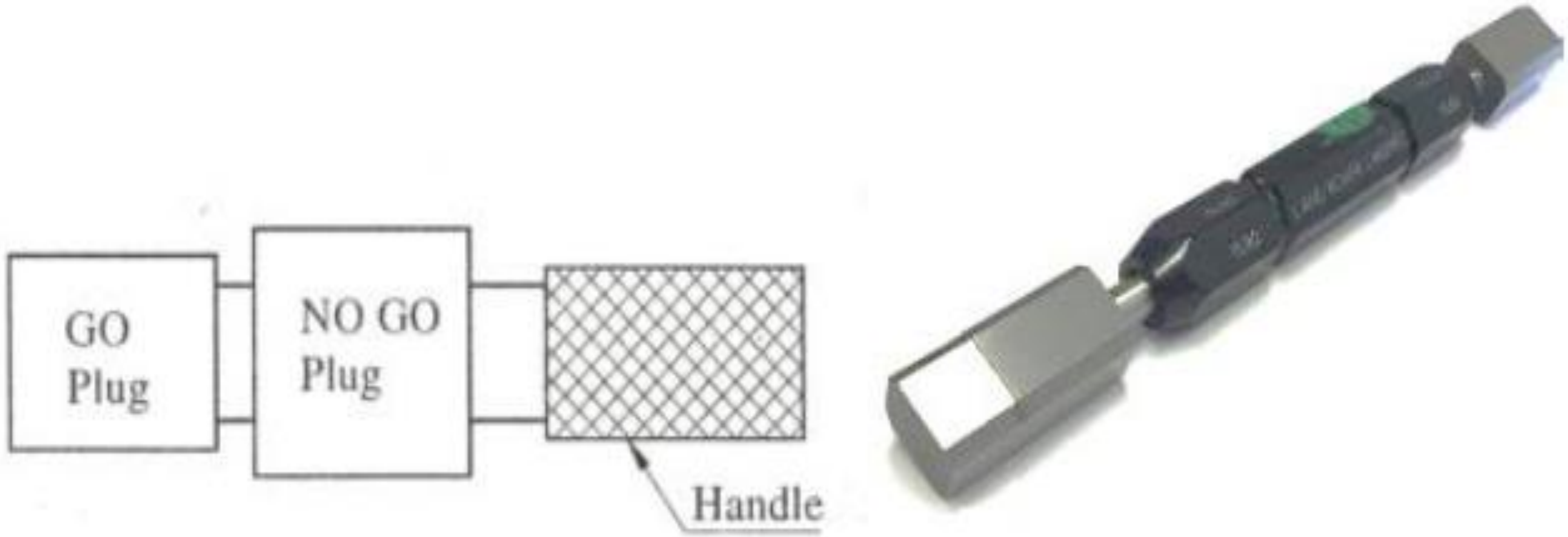

Figure 2.33 Progressive plug gauge

Plug gauges

- As shown in Fig. 2.34 taper plug gauges are used to check tapered holes. It has two check lines, one is a GO line and another is a NO GO line. During the checking of work, NO GO line remains outside the hole and GO line remains inside the hole. They are various types taper plug gauges are available as taper plug gauge- plain, taper plug gauge- tanged, taper ring gauge- plain and taper ring gauge- tanged.

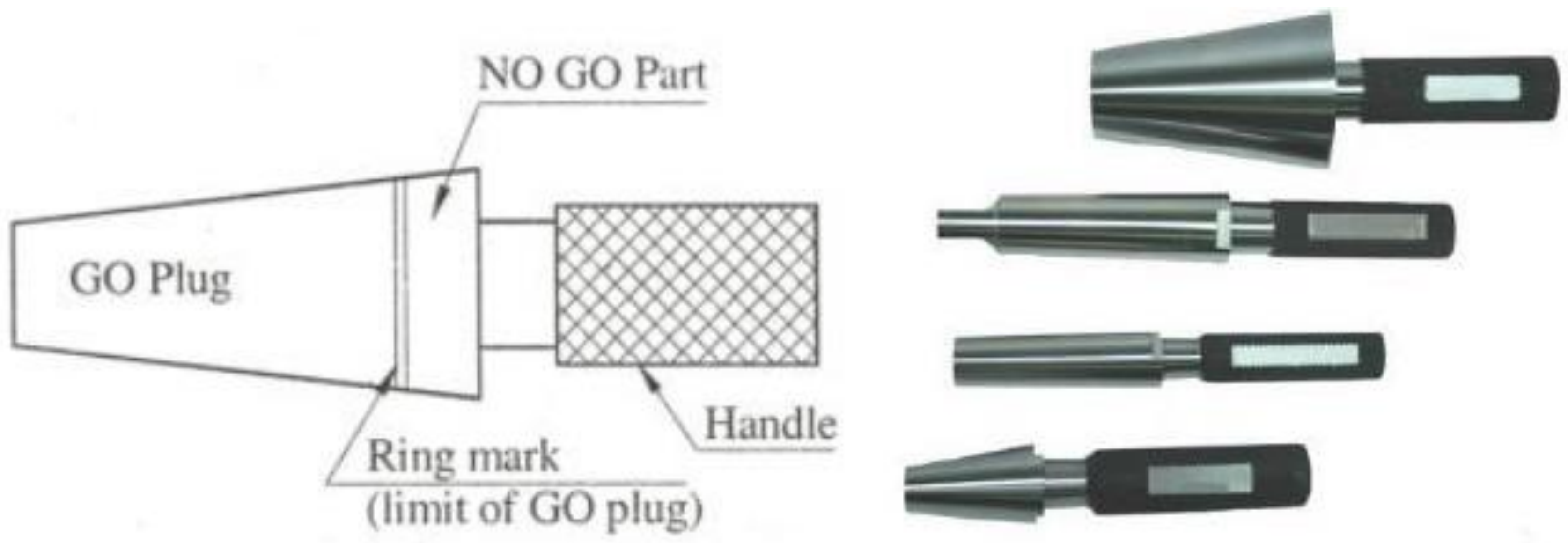

Figure 2.34 Taper plug gauge

Ring gauge

- Ring gauges are used for checking the diameter of shafts. They are used in a similar manner to that of GO and NO GO plug gauges. A ring gauge consists of a piece of metal in which a hole of required size is bored as shown in Fig. 2.35.

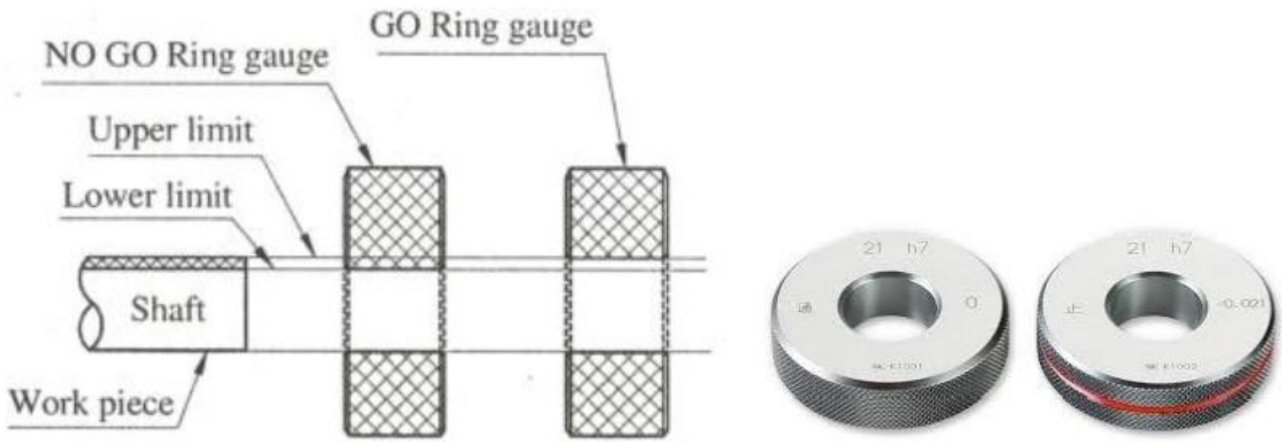

Figure 2.35 Ring gauges

- The hole or bore is accurately · finished by grinding and lapping after taking hardening process. The hole of GO ring gauge is made to the. Upper limit size of the shaft and NO GO for the lower limit.
- The periphery of the ring is knurled to give more grips while handling the gauges.
- Nominally, the GO ring gauge and NO GO ring gauge are separately used to check the shaft.
- Generally, NO GO made with a red mark or a small groove cut on its periphery in order to identify NO GO gauge.

Snap gauge

- Snap gauges are used for checking external dimensions. They are also called as gap gauges. A snap gauge usually consists of a plate or frame with a parallel faced gap of the required dimension.
- Snap gauges can be used for both cylindrical as well as non-cylindrical work as compared to ring gauges which are conveniently used only for cylindrical work.
- A double ended snap gauge as shown in Fig. 2.36 is having two ends in the form of anvils. The GO anvil is made to lower limit and NO GO anvil is made to upper limit of the shaft. This snap gauge is also known as solid snap gauges.

Figure 2.36 Double ended snap gauge

Snap gauge

- If both GO and NO GO anvils are form at the same end as shown in Fig. 2.37 then it is called progressive snap gauge. It is mainly used for checking large diameters up to 100 mm.
- The GO anvil should be at the front and NO GO anvil at the rear. So, the diameter of the shaft is checked progressively by these two ends. This type of gauge is made of horse shoe shaped frame with I section to reduce the weight of the snap gauges. This snap gauge is also called caliper gauge.

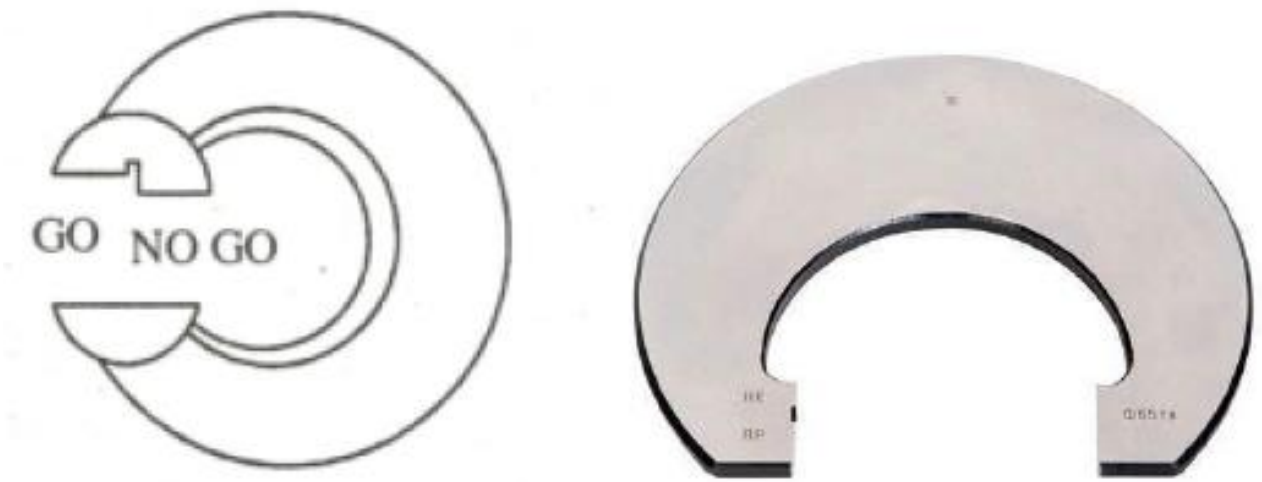

Figure 2.37 Progressive snap gauge

Snap gauge

- An adjustable snap gauges as shown in Fig. 2.37 consists of one fixed anvil and two small adjustable anvils. The distance between the two anvils is adjusted by adjusting the adjustable anvils by means of set screws. This adjustment can be made with the help of slip gauges for specified limits of size. They are used for checking large size shafts.

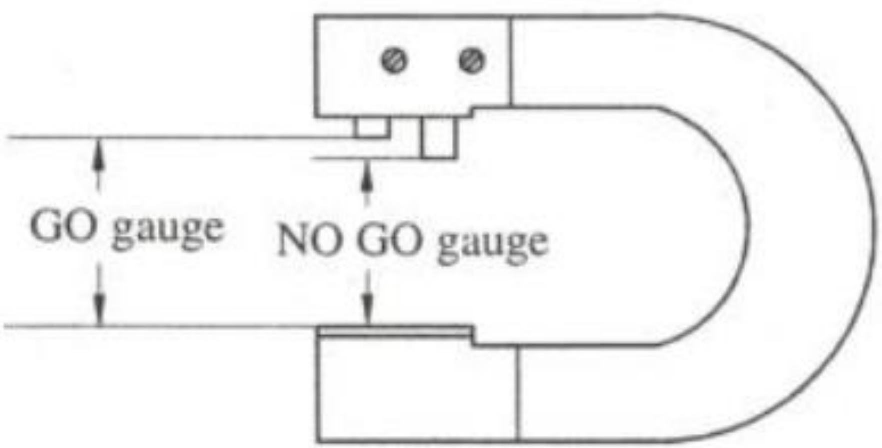

Figure 2.38 Adjustable snap gauges

Comparator

Metrology

NEED OF COMPARATORS

- In mass production identical component parts are produced on a very large scale.
- To achieve inter changeability these parts should be produced to a dose dimensional tolerances.
- As a result, inspection is often more concerned with the dimensional variation from the standard or basic dimension of the part. To this extent inspection becomes a process of comparing manufactured part to the master part envisaged by the designer.
- The use of vernier caliper, micrometer etc. will not be feasible because of the skill involved and the time required to measure the dimension. Use of comparator requires little or no skill for the operator, eliminates human element for taking measurement and gives quick and highly consistent results.

BASIC PRINCIPLE AND OPERATION OF COMPARATORS

- The comparator is first adjusted to zero on its dial or recording device with a gauge block in position.
- The gauge block is of dimension which the workpiece should have. The workpiece to be checked is then placed in position and the comparator gives the difference in dimension in relation to the gauge block.
- The dimension of the workpiece may be less than, equal to or greater than the standard dimension.
- If the dimension is less or greater than the standard, the difference will be shown on the dial or the recording device of the comparator. Thus, a comparator does not give the dimension of a workpiece, but only gives the difference between the standard and the actual dimension of the workpiece.
- In comparators, this difference is shown as magnified on the dial or the recording device.
- For example, if a comparator has a magnification of 1000, and if the difference between the standard and the actual dimensions of a. workpiece is 0.02 mm, it will result in pointer movement of 20 mm on the dial or recording device of the comparator.

ESSENTIAL CHARACTERISTICS OF A GOOD COMPARATOR

1) **Robust design and construction:** The design and construction of the comparator should be robust so that it can withstand the effects of ordinary uses without affecting its measuring accuracy.
2) **Linear characteristics of scale:** Recording or measuring scale should be linear and uniform (straight line characteristic) and its indications should be clear.
3) **High magnification:** The magnification of the comparator should be such that a smallest deviation in size of component can be easily detected.
4) **Quick in results**: The indicating system should be such that the readings are obtained in least possible time.
5) **Versatility:** Instruments should be designed that it can be used for wide range of measurements.
6) **Minimum wear of contact point:** The measuring plunger should have hardened steel contact or diamond to minimize wear effects.
7) **Contact pressure:** It should be low and uniform.

USES OF COMPARATOR

1) **Laboratory Standards:** Comparators are used as laboratory standards from which working or inspection gauges are set and co-related.
2) **Working Gauges:** They are also used as working gauges to prevent work spoilage and to maintain required tolerance at all important stages of manufacturer.
3) **Final Inspection Gauges:** Comparators may be used as final inspection gauges where selective assembly, of production parts is necessary.
4) **Receiving Inspection Gauges:** AE receiving inspection gauges comparators are used for checking parts received from outside sources.
5) **For checking newly purchased gauges:** The use of comparators enables the checking of the parts (components in mass production at a very fast rate.)

CLASSIFICATION OF COMPARATORS

- A wide variety of comparators are commercially available at present.
- They are classified according to the method used for amplifying and recording the variations measured in to the following types.

1) Mechanical comparators

a) Dial indicators

b) Read type comparators

c) Sigma comparators

d) Johansson mikrokator

2) Mechanical optical comparators

a. Optical lever

b. Zeiss optimeter

c. Zeiss ultra optimeter

d. Zeiss optotest comparators

3) Electrical and electronics comparators

4) Pneumatic comparators

5) Fluid displacement comparators

6) Projection comparators

7) Multi-check comparators

8) Automatic gauging machine

9) Electro-mechanical comparators

10) High sensitive comparators

a. Brookes level comparators

b. Eden-Rolt millionth comparators

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MECHANICAL COMPARATORS

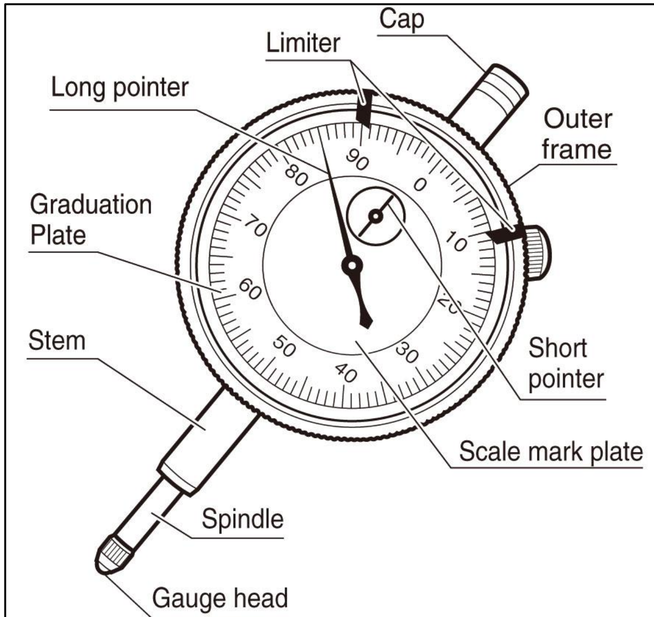
- **Principle of workings:** A mechanical comparator employs mechanical means for magnifying the small movement of the measuring stylus, brought about due the difference between the standard and the actual dimension being checked.
- In these comparators the magnification of the small stylus movement is obtained by means of levers, gear trains, rack and pinion or a combination.
- The usual magnification obtained by these comparators ranges from about 250 to 1000, mechanical comparators are of the following types:

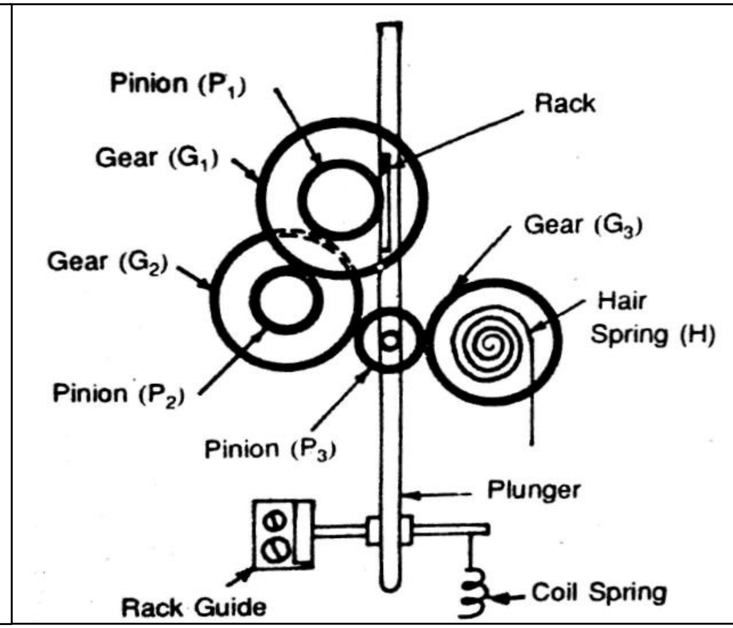
1. Dial indicator (Dial gauge)
2. Read type mechanical comparator
3. Johansson Mikrokator
4. Sigma comparator

Dial Indicator (Dial gauge)

- The simplest type of mechanical comparator is a dial indicator. It consists of a base with a rigid column rising from its rear. An arm is mounted on this column and it carries a dial gauge at its outer end.
- The arm can be adjusted vertically up and down along the e column. An anvil or a worktable is mounted on the base, which provides a reference on which workpieces are placed during measuring operation.
- Such a simple comparator is ideal for the checking of components with a tolerance of say ± 0.05 millimeters. In its operation, the indicator is set to zero by the use of slip gauges representing the basic size of the part. The part to be checked is then placed below the measuring plunger of the indicator.
- The linear movement of the plunger is magnified by means of a gear and pinion train in to sizable rotation of the pointer. The variation in dimension of the part from the basic size is indicated on the dial.
- Dial indicator is generally used for inspection of small precision machined parts.
- The dial indicator with various attachments may be used for large number of works; with V-block attachment it can be used for checking out of roundness of a cylindrical part.

Dial Indicator (Dial gauge)





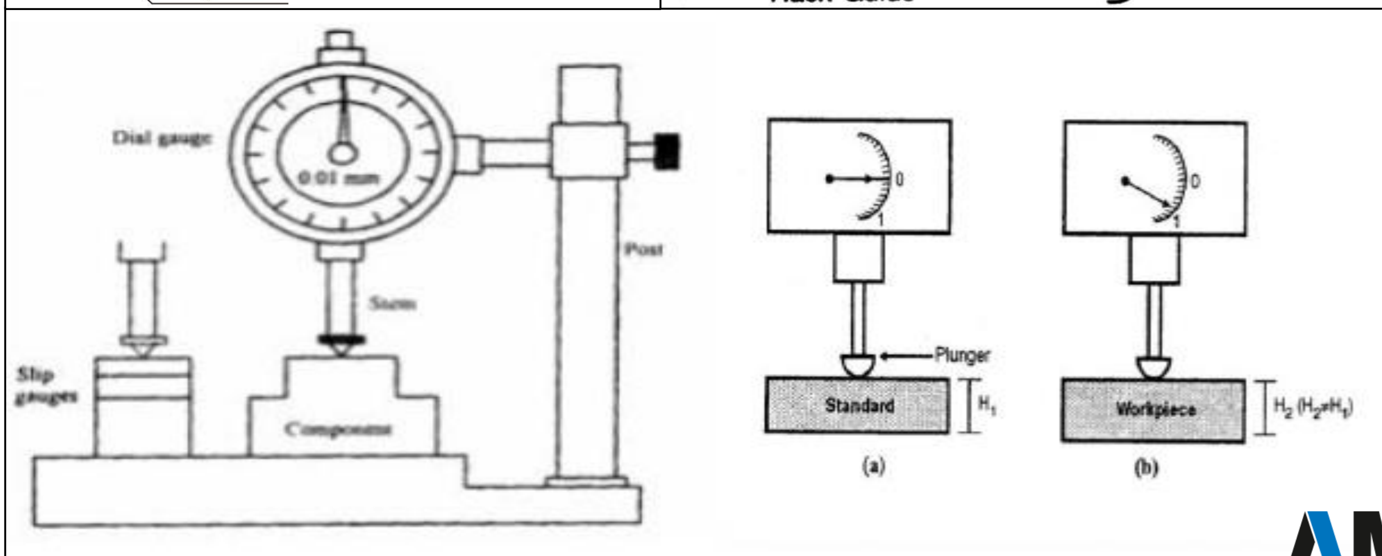


Figure 9.1 Dial comparator

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The Johansson Mikrokator

- This instrument was first devised by m/s C.F. Johansson and hence the name. It uses a twisted strip to convert small linear movement of a plunger into a large circular movement of a pointer.
- It is therefore, also called as twisted strip comparator. It uses the simplest method for obtaining the mechanical magnification designed by H. Abramson which is known as 'Abramson, movements.
- A twisted thin metal strip carries at the centre of its length a very light pointer made of thin glass. One end of the strip is fixed to the adjustable cantilever strip and the other end is anchored to the spring elbow, one arm of which is carried on measuring plunger.
- The spring elbow acts as a bell crank lever. The construction of such a comparator is shown in Fig.9.2
- A slight upward movement of plunger will make the bell crank lever to rotate. Due to this a tension will be applied to the twisted strip in the direction of the arrow.
- This causes the strip to untwist resulting in the movement of the point.

The Johansson Mikrokator

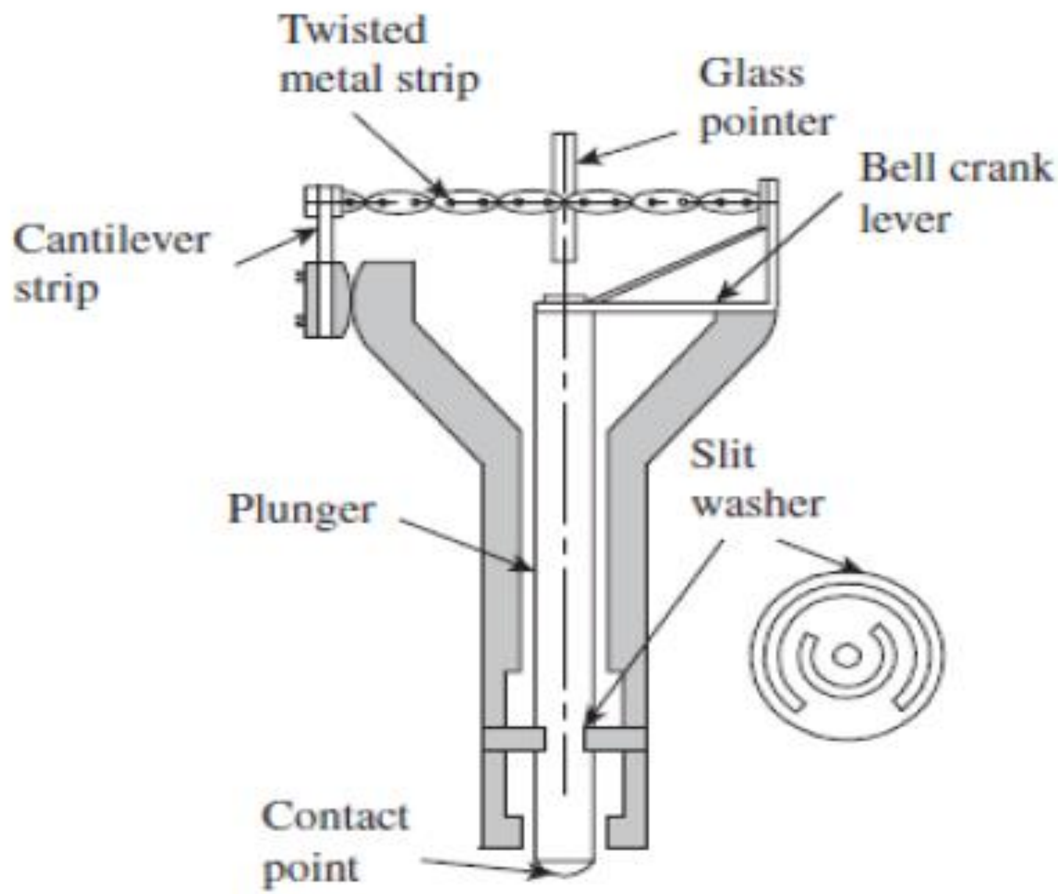

Figure 9.2 Johansson Mikrokator comparator

The Johansson Mikrokator

- The spring will ensure that the plunger returns when the contact pressure between the bottom tip of the plunger and the workpiece is not there, that is, when the workpiece is removed from underneath the plunger.
- The length of the cantilever can be varied to adjust the magnification. In order to prevent excessive stress on the central portion, the strip is perforated along the centre line by performation as shown in Fig. 5.2.
- The magnification of the instrument is approximately equal to the ratio of rate of change of pointer movement to rate of change in length of the strip, i.e. dQ/dL.It can be shown that the magnification of the instrument

$$\frac{dQ}{dL} \alpha \frac{L}{w^2 n}$$

- Where, Q = twist of mid-point of strip with respect to the end
- L = length of twisted strip measured along its neutral axis
- w = width of twisted strip and,
- n = number of turns.
- It is thus obvious that in order to increase the magnification of the instrument a very thin rectangular strip must be used.

Reed Type Mechanical Comparator

➢ In reed type mechanical comparator, the gauging head is usually a sensitive, high quality, dial indicator. The dial indicator is mounted on a base supported by a sturdy column. Fig. 9.3 shows a read type mechanical comparator the reed mechanism is frictionless device for magnifying small motions of the spindle.

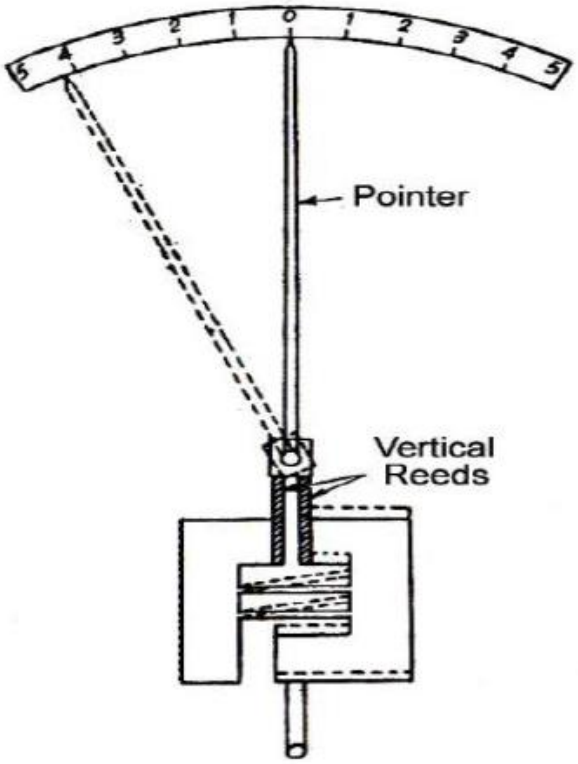

Fig.9.3. Reed Type Mechanical Comparator

Reed Type Mechanical Comparator

- It consists of a fixed block. Which is rigidly fastened to the gauge head case, and floating block B, which carries the gauging spindle and is connected horizontally to the fixed block by reed C. A vertical reed is attached to each block with upper ends joined together.
- These vertical reeds are indicated by D. Beyond this joint extends a pointer. A linear motion of the spindle moves the free block vertically causing the vertical reed on the floating block to slide past the vertical reed on the fixed block.
- However, as the vertical reeds are joined at the upper end, instead of slipping, the movement causes both reeds swing through an arc. The scale may be calibrated by means of gauge block to indicate any deviation from an initial setting.
- The mechanical amplification is usually less than 100 but it is multiplied by the optical lens system. It is available in amplification ranging from 500 to 1000.

Sigma comparators

- This is a mechanical comparator providing magnification in the range of 300 to 5000.
- It consists of a plunger mounted on two flat steel strings (slit diaphrams).this provides a frictionless linear movement for the plunger.
- The plunger carries a knife edge, which bears upon the face of the mounting block of a cross-strip hinge. The cross strip hinge is formed by pieces of flat steel springs arranged at right angles and is a very efficient pivot for smaller angular movements.
- The moving block carries a light metal ¥forked arms. A thin phosphor bronze ribbon is fastened to the ends of the forked arms and wrapped around a small drum, mounted on a spindle carrying the pointer.

Sigma comparators

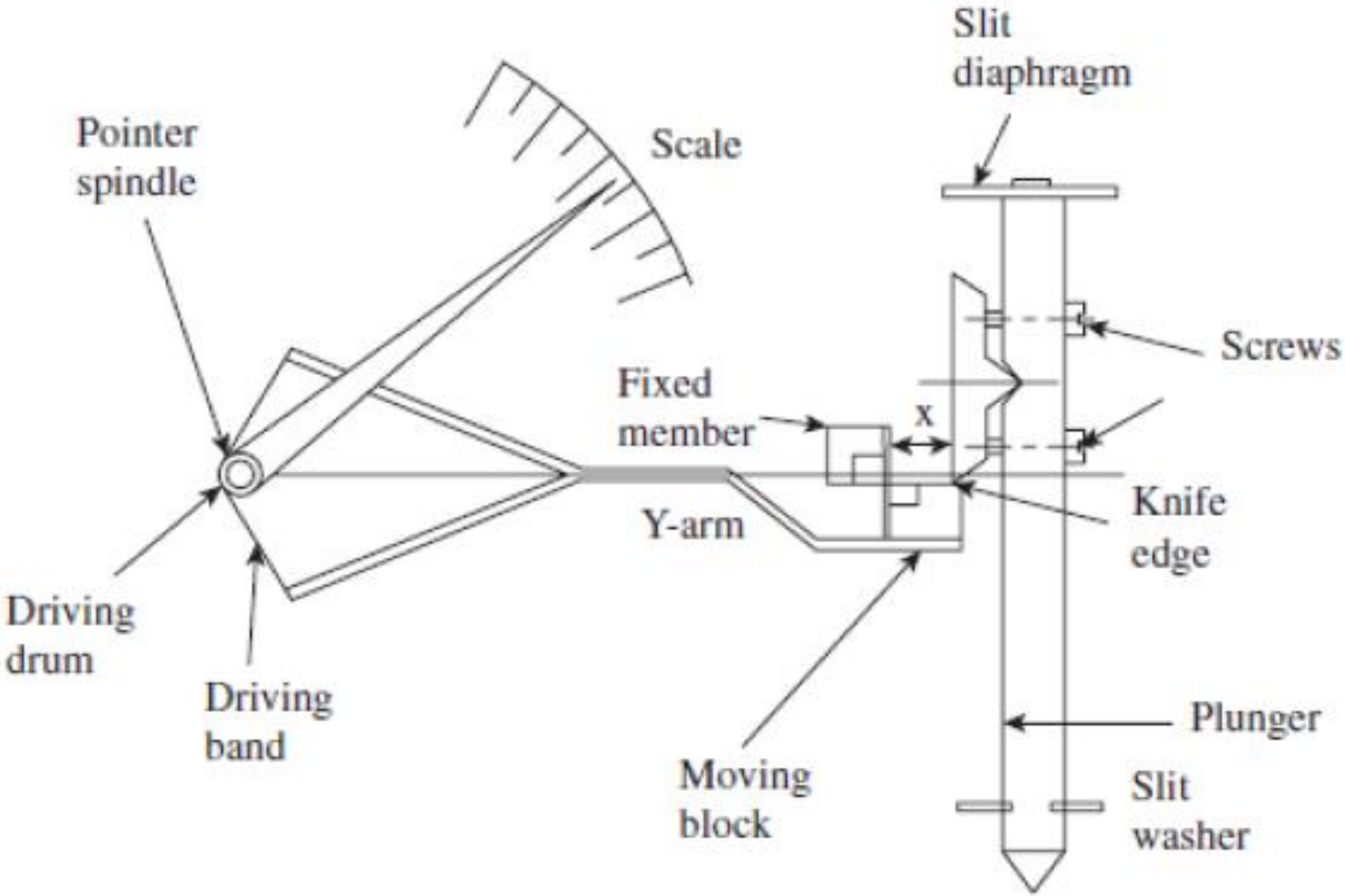

Figure 9.4 Sigma Comparator

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Sigma comparators

- Any vertical displacement of the measuring plunger and hence that of the knife edge makes the moving block of the cross strip liver to pivot. This causes the rotation of the Y-arms.

- The metallic band attached to the arms makes the driving drum and hence the pointer to rotate. The ratio of the effective length (L) of the arm and the distance (a) of the knife edge from the pivot 'gives the first stage magnification and the ratio of the pointer length (l) and radius (r) of the driving drum gives second stage magnification of the instrument.

- Total magnification of the instrument is thus $\frac{l}{a} \times \frac{l}{r}$.The magnification of instrument can be varied by changing the distance (a) of Knife edge of tightening or slackening of then adjusting screws:

- The range of instruments available provides magnifications of x 300 to X 5000, the most sensitive models allowing scale estimation of the order of 0.0001 mm to be made.

Sigma comparators

❖Advantages

1. **Safety:** As the knife edge moves away from the moving member of the hinge and is followed by it, therefore, if too robust movement of the plunger is made due to shock load that will not be transmitted through the movement.
2. **Dead beat Readings:** By mounting nonferrous disc on the pointer spindle and making it move in field of a permanent magnet, dead beat reading can be obtained.
3. **Parallax:** The error due to Parallax is avoided by having a reflective strip on the scale.
4. **Constant pressures:** The constant measuring pressure over the range of the instrument is obtained by the use of magnet plunger. On the frame
5. Fine adjustments are possible

❖Disadvantages

1. Due to motion of the parts there is a wear in the moving parts.
2. It is not sensible as optical comparator due to friction of the moving parts.

Advantages of Mechanical Comparators

1. **Cheaper :** Mechanical comparators are less costly as compared to other amplifying devices.

2. **No need of external agency :** These instruments do not require any external agency such as electricity or air and as such the variations in outside supply do not affect the accuracy.

3. **Linear Scale :** Usually the-mechanical comparators have linear scale.

4. **Robust and compact :** These instruments are robust and compact in design and easy to handle.

5. **Portable :** For ordinary workshop conditions, these instruments are very suitable and being portable can be issued from the stores.

Disadvantages of Mechanical Comparators

1. **Less accuracy** (a) Due to more moving parts, the friction is more which reduces the accuracy (b) Any slackness in moving parts also reduces the accuracy considerably.
2. **Sensitive to vibrations:** The mechanisms in mechanical comparators have more inertia and this may cause them to be sensitive to vibrations.
3. **Faults magnified:** Any wear backlash o;: dimensional faults in the mechanical devices used will also be magnified.
4. **Limited range:** The range of the instrument is limited as the pointer moves over a fixed scale.
5. **Parallax error:** Error due to Parallax are more likely with these instruments as the pointer moves over a fixed scale.

Mechanical Optical Comparators

❖ **Working principle:** In these comparators, use is made of a **fundamental optical law** and instead of a printer, the edge of the shadow is projected on to a curved graduated scale to indicate the comparison measurement.

➢ The optical principle adopted is that of, optical lever, which is shown in Fig.9.5. If a ray of light OA strikes a mirror, it is reflected as ray AB such that,

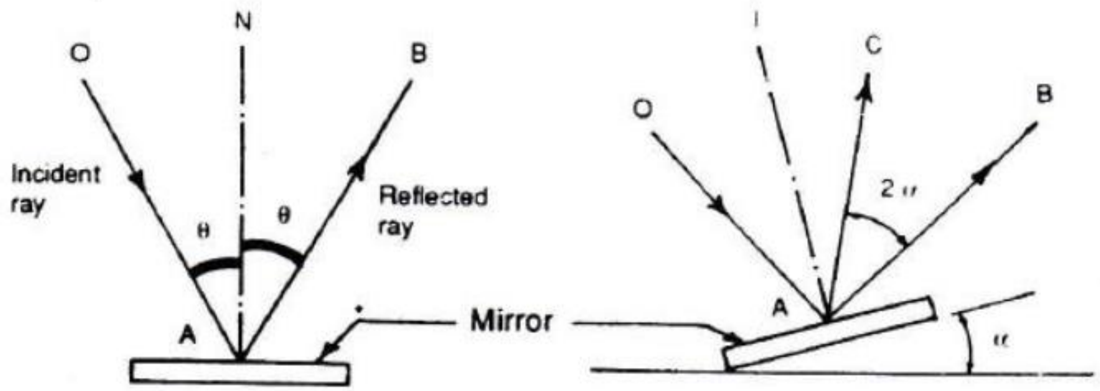

Figure 9.5 Optical principle

$\angle OAN = \angle NAB$

➢ Now, if the mirror is titled through an angle α reflected ray of light has moved through an angle 2α. In optical comparators, the mirror is tilted by the measuring plunger movement and the movement of the reflected light is recorded as an image on a screen.

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Mechanical-optical Comparators

- In mechanical optical comparators, small displacement of the measuring plunger are amplified first by a mechanical system consisting of pivoted levers. The amplified mechanical movement is further amplified by a single optical system involving the projection of an image.
- As shown in fig.9.6 the mechanical system causes a plane reflector to tilt about an axis and the image of an index is projected on a scale on the inner surface of a ground glass screen.

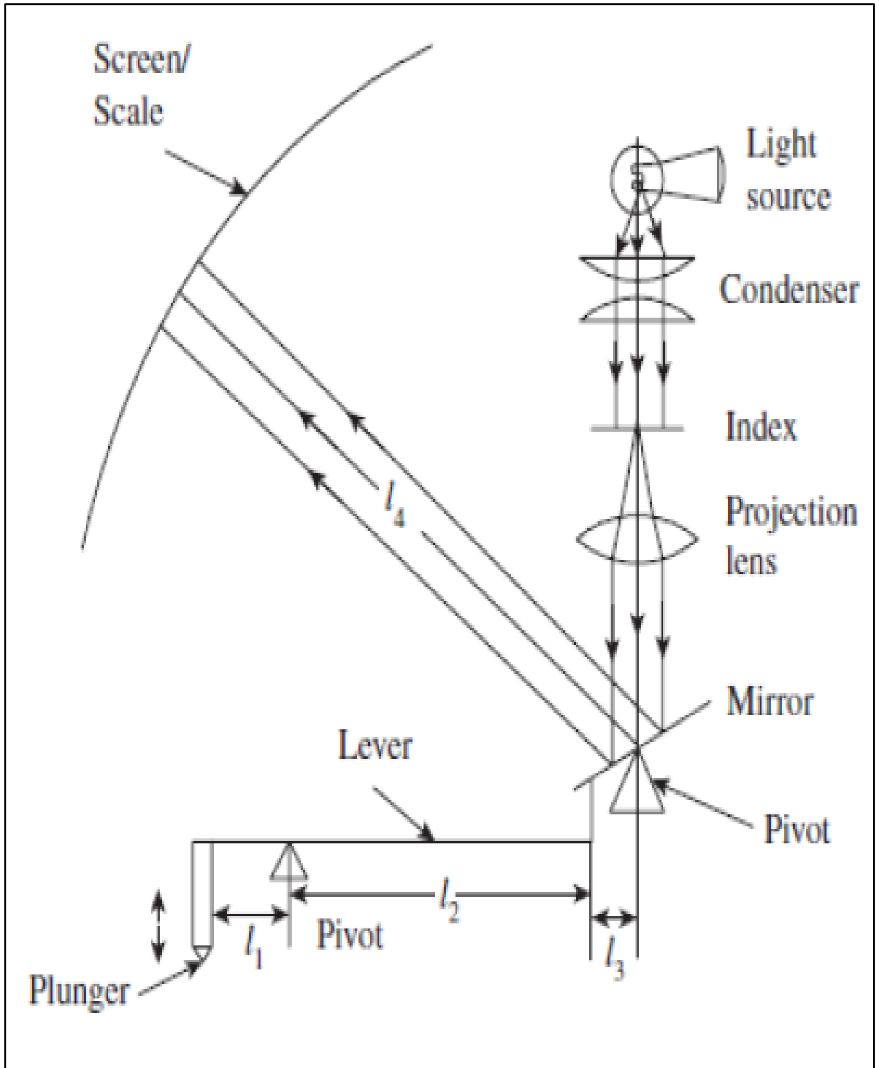


Figure 9.6 Mechanical optical comparator

Mechanical-optical Comparators

- Mechanical amplification = $\frac{L_2}{L_1}$ (by lever principle)
- Now, if the movement of the plunger causes the mirror to tilt by angle α, then the image, will be tilted by 2α.
- Therefore optical amplification = $2 \times \frac{L_4}{L_3}$
- Thus overall magnification of this system = $2\,\frac{L_2}{L_1} \times \frac{L_4}{L_3}$

Zeiss Ultra Optimeter

- The optical system of Zeiss ultra optimeter involves of light and thus double reflection gives higher degree of magnification. Fig.9.7. shows the optical system of this type of comparator.
- The light rays from the lamps falls on the green filter. The green filter filters all and green light pass to a condenser, which projects is on to a movable mirror M1.It is then reflected to another fixed mirror M2 and then back again to first movable mirror.
- The objective lens brings the reflected beam from the first mirror to a focus at a transparent graticule containing a precise scale which is viewed by an eye-piece.

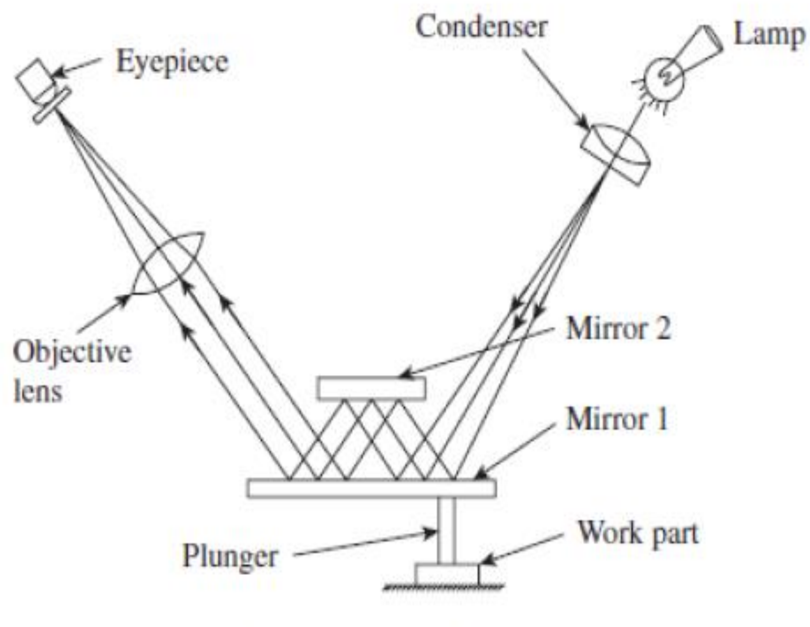


Figure 9.7 Zeiss ultra optimer

Zeiss Ultra Optimeter

- Magnification: If the distance from the plunger centre line to the first mirror pirot is x and the plunger moves a height then angler movement of the mirror $\delta\theta = \frac{h}{x}$ if f be the focal lens, then the movement of scale is 2f.δθ i.e.

$$2f \times \frac{h}{x}$$

- Therefore, magnification = $2f \times \frac{h}{xh} = \frac{2f}{x}$
- Overall magnification = $\frac{2f}{x} \times$ Eyepiece magnification

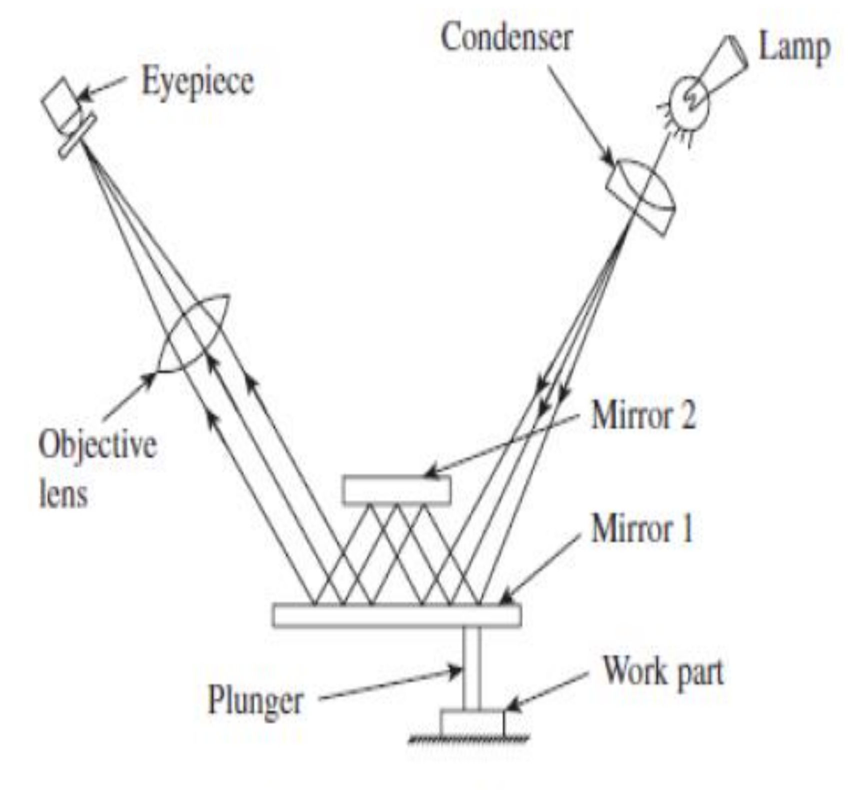


Figure 9.7 Zeiss ultra optimer

optical comparators

ADVANTAGES

1. **High accuracy:** These comparators have very few moving parts and hence gives higher accuracy.
2. **No parallax Error:** The scare can be made past a datum line and thus have high range and no parallax error.
3. **High magnification:** Hence suitable for precision measurements.
4. Optical lever is weightless.
5. **Illuminated scale:** since scare is illuminated, it enables readings to be taken irrespective of room lighting conditions.

DISADVANTAGES

1. As the magnification is high, heat from the lamp, transformers, etc. may cause the setting the drift.
2. Depends on external electrical power supply.
3. Apparatus is usually bulky and expensive.
4. When scale is projected on a screen, the instrument is to be used in dark room.
5. Instrument is inconvenient for continuous use, because the scale is to be viewed through eyepiece.

Pneumatic Comparators

- **Working Principle :** When air passes through the narrow constant space between nozzle and the work piece the pressure of air remains constant. If the space between nozzle and workpiece changes, it causes change in the pressure of the air. This change in pressure is utilized to measure the deviation of the dimension being measured from the standard dimension.

- This technique offers the high magnification. The magnification pneumatic comparator may be 30,000 : 1 or more.

- The pneumatic comparator is normally used to determine the roundness of the job.

Solex Pneumatic Comparators

- As shown in fig. solex pneumatic comparator consists of vertical metal cylinder contains water to a predefined level and a dip tube immersed into it upto a depth corresponding to air pressure required.

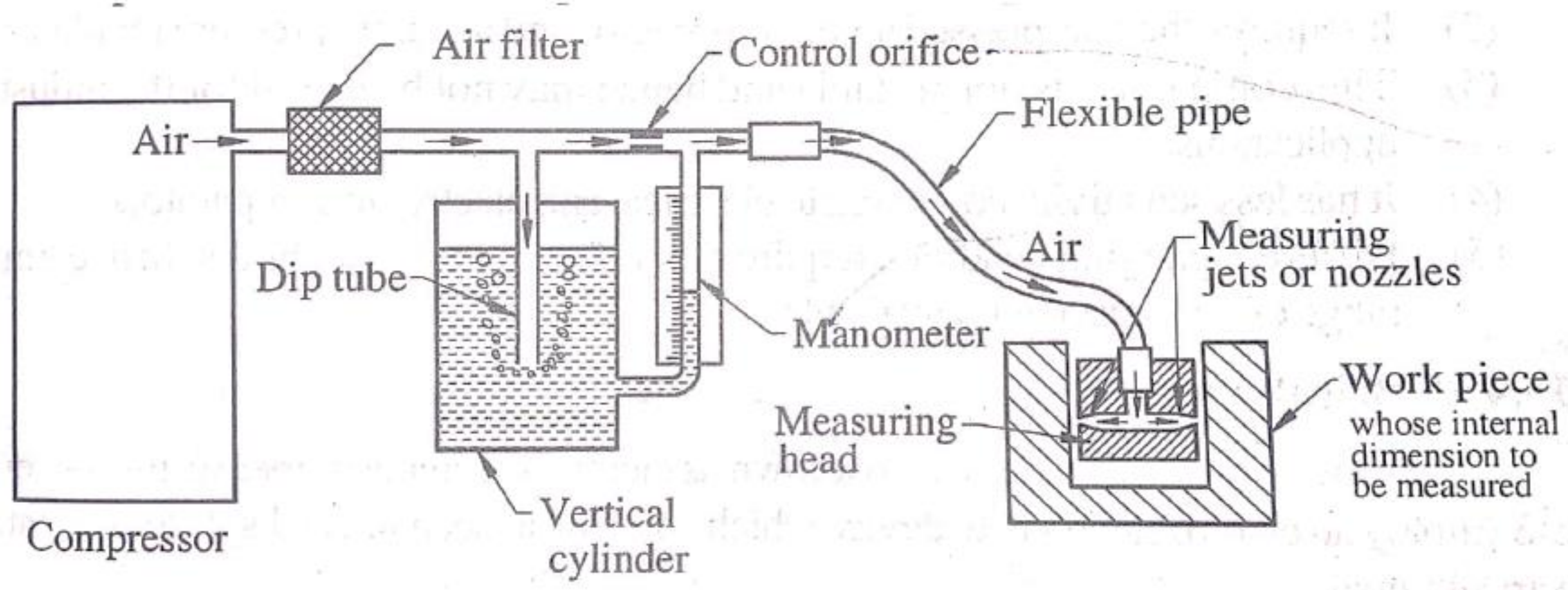


Fig. 2.42 Solex pneumatic comparator

Solex Pneumatic Comparators

- A calibrated manometer tube is connected between the vertical cylinder and control orifice. The flexible pipe is used to connect the measuring jet and cylinder-control orifice-manometer unit. The certain pressure air is supplied from the air compressor.
- The system designed in order to supply air at constant pressure to the measuring jets. If the pressure of the air supplied is higher than the predefined pressure, some air will bubble out from the bottom of the dip tube and air moving to control orifice will be at predefined constant pressure.
- The constant pressure air then passes through control orifice and escape from the measuring jets when there is no restriction provided by workpiece to the escape of air, the level of water in the manometer tube will same as level of water in cylinder.
- But when restriction is provided at the measuring jets, resulting increases the back pressure and level of water in the manometer fall down which vary the height of water in manometer tube, a calibrated scale being set beside this tube.
- In other word the restriction to the escape of air depends upon the variations in the dimensions to be measured.

Advantages Pneumatic Comparators

1. There is no direct contact between the comparator measuring head and workpiece, hence no wear takes place on the measuring head.
2. They have less number of moving parts hence less friction, wear and inertia.
3. The indicating instrument can be remote from measuring unit.
4. The measuring pressure is very small and the jet of air helps in cleaning the dust if any from the part to be measured.
5. Very high magnification can be achieved.
6. This type of comparator is best for determining the ovality and taperness of circular bores.
7. They are very suitable for measuring diameters of holes where diameter is small compared to length.

Disadvantages Pneumatic Comparators

1. Scale is generally not uniform.
2. It requires the compressed air or compressor and accurate pressure regulator.
3. This comparator is not portable and hence may not be useful for the industrial applications.
4. It has less sensitivity compared to electrical and electronic comparators.
5. Different gauging heads are required for different dimensions and hence limited range of measurement is available.

Electrical Comparators

- Electrical comparators are also known as electro-mechanical measuring system as these employ an electromechanical device which converts a mechanical displacement into an electrical signal.
- Linear Variable Differential Transformer (LVDT) is the most common electro-mechanical device used to convert mechanical displacement into electrical signal.

LVDT Construction

- LVDT consists of three coils wound on a single non-magnetic tube. There is one primary winding (P) fed with a.c. supply and two secondary windings (S1 and S2) as shown in fig.
- The secondary windings are symmetrically placed, are identical (equal number of turns) and are connected in series opposition.
- A ferromagnetic core (called armature) attached to the moving part which freely move inside the non-magnetic tube.
- The movable core is coupled with spindle or contact point.

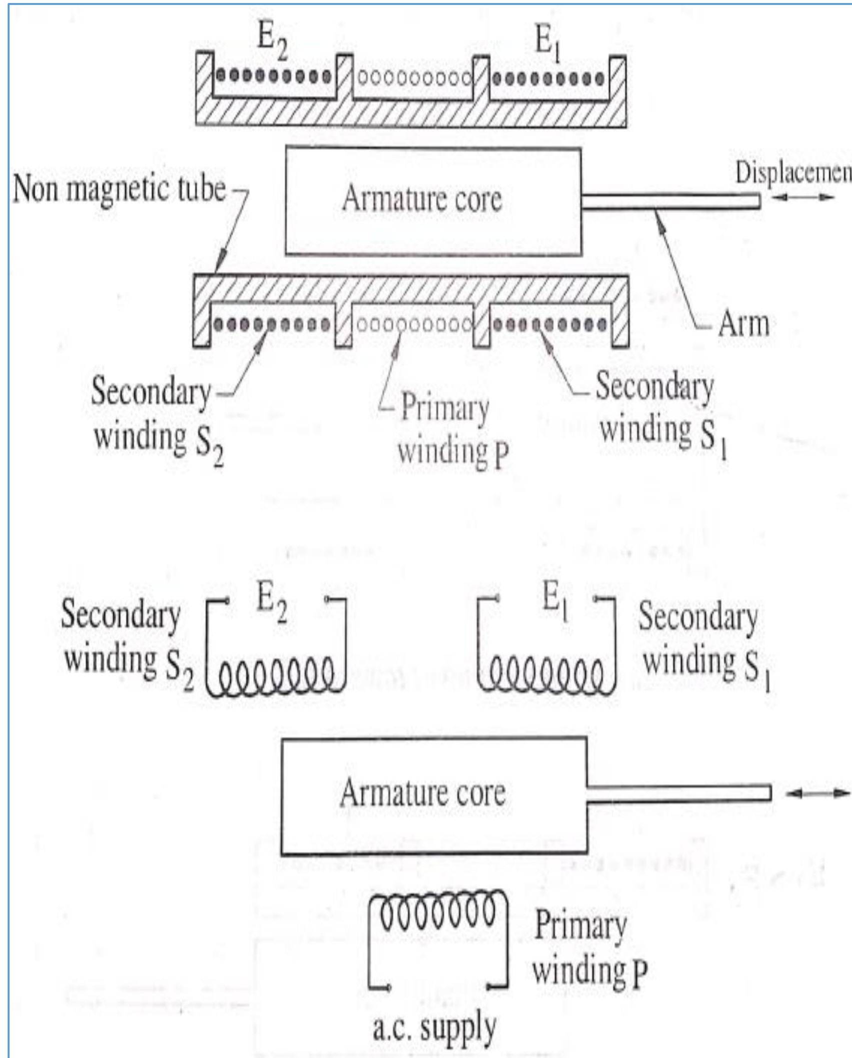
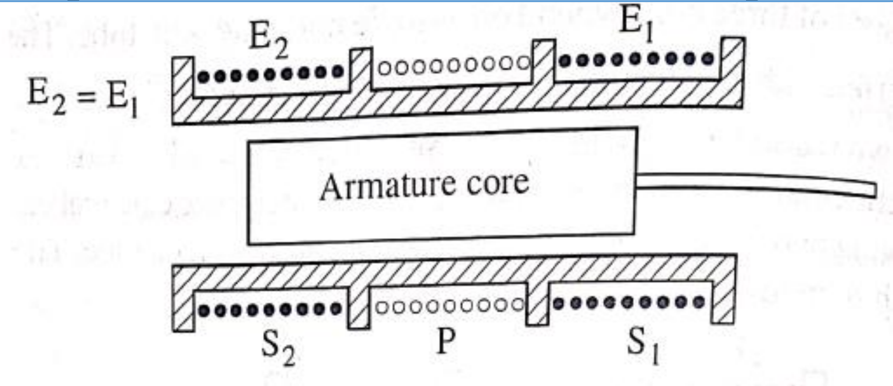


Fig. LVDT - Linear variable differential transformer

LVDT Working

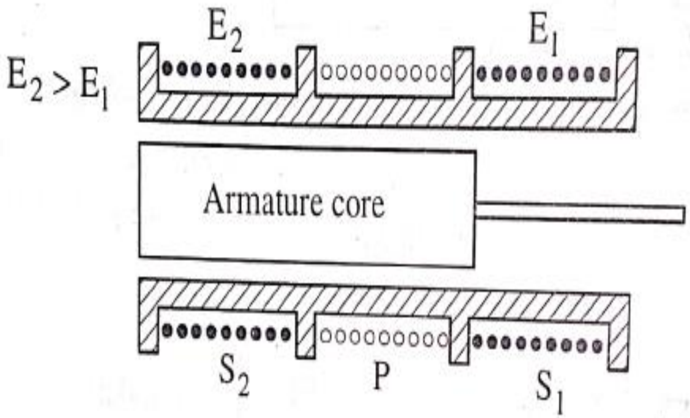
- When a.c. current is supplied to primary winding, the magnetic flux generated by the coil is distributed by the armature (ferromagnetic core) so that voltages are induced in the secondary windings.
- The secondary windings are identical, symmetrically placed and are connected in phase opposition so that voltage induced in the secondary windings are opposite when armature is at reference position (armature centre). The position of the magnetic core (armature) determines the flux linkages with each winding.
- When the core is placed centrally, at reference position as shown in fig. (a), equal and opposite voltages are induced in secondary windings. Hence net output (voltage) from transformer equals to zero, since $E_2 = E_1$. $\therefore E_2 - E_1 = 0$.
- This is called the null position of armature or balance point.



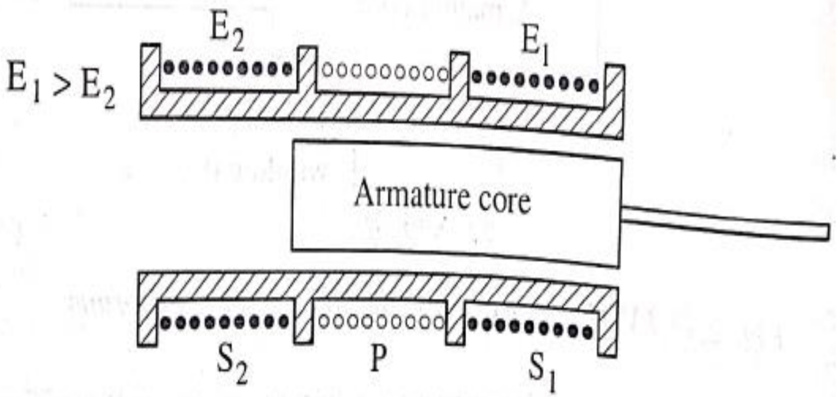
(a) Null position of armature

LVDT Working

- A variation in the position of the armature from its null position produces an output in terms of voltages.
- As the armature moves towards left, as shown in fig. (b) E_2 (voltage of secondary winding S_2) increases and E_1 (voltage of secondary winding S_1) decreases.
- The net voltage available is $V_0 = E_2 - E_1$ and is in phase with E_2.
- Similarly, as armature moves towards right as shown in fig. (c), E_1 increases and E_2 decreases. The net voltage available is $V_0 = E_1 - E_2$ and is phase with E_1.
- It is observed that the magnitude of V_0 is a function of the distance moved by the armature and its polarity or phase indicates as to in which direction it has moved.
- Hence, pressure acting against the elastic element like bourdon tube, bellows, or diaphragm can be measured in terms of unbalance voltage V_0 between two secondary windings.



(b) Armature moves toward left



(c) Armature moves toward right

Thank You

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