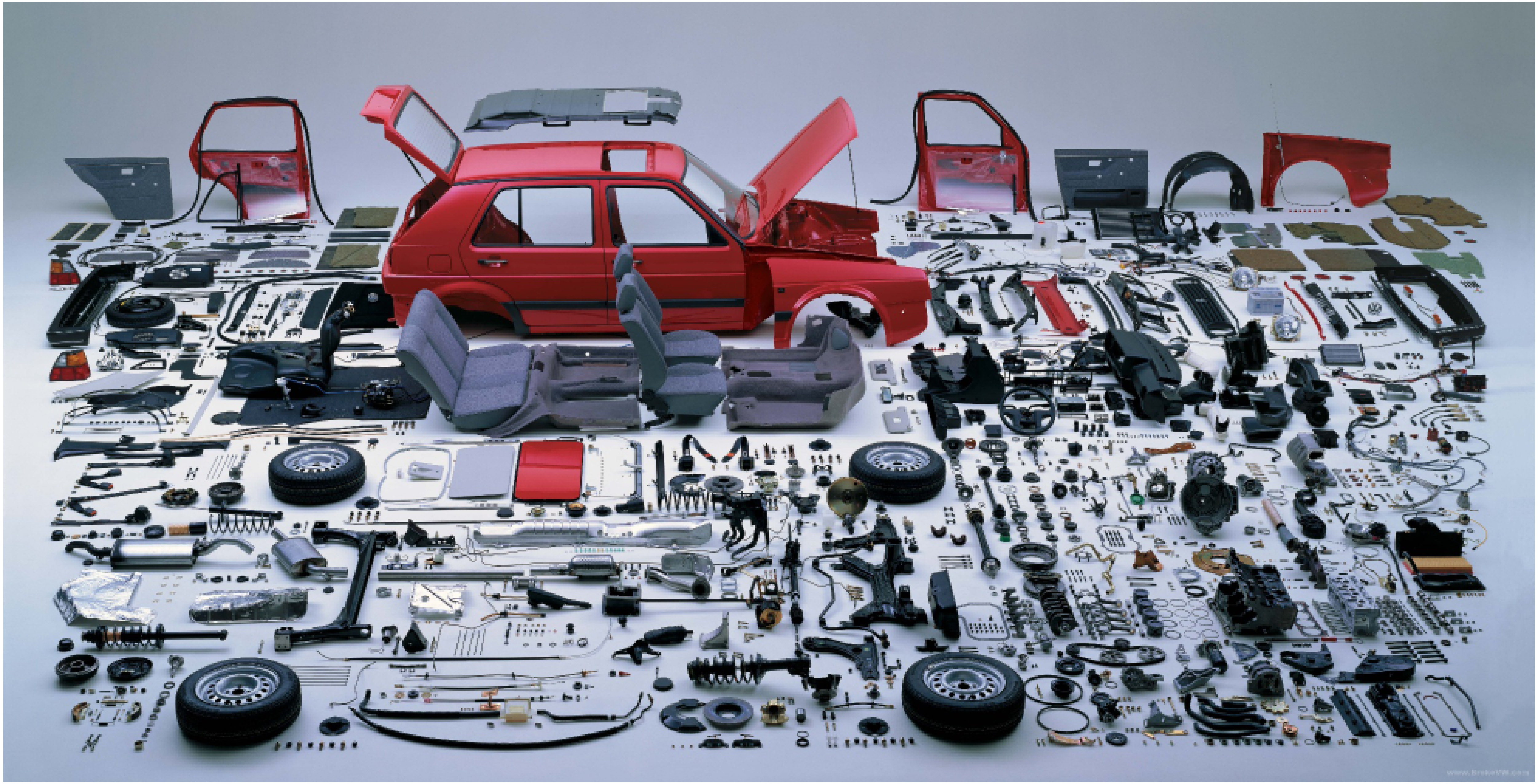
Module 2

SYSTEM OF LIMITS, FITS, TOLERANCES AND GAUGES

Apple iPhone 4

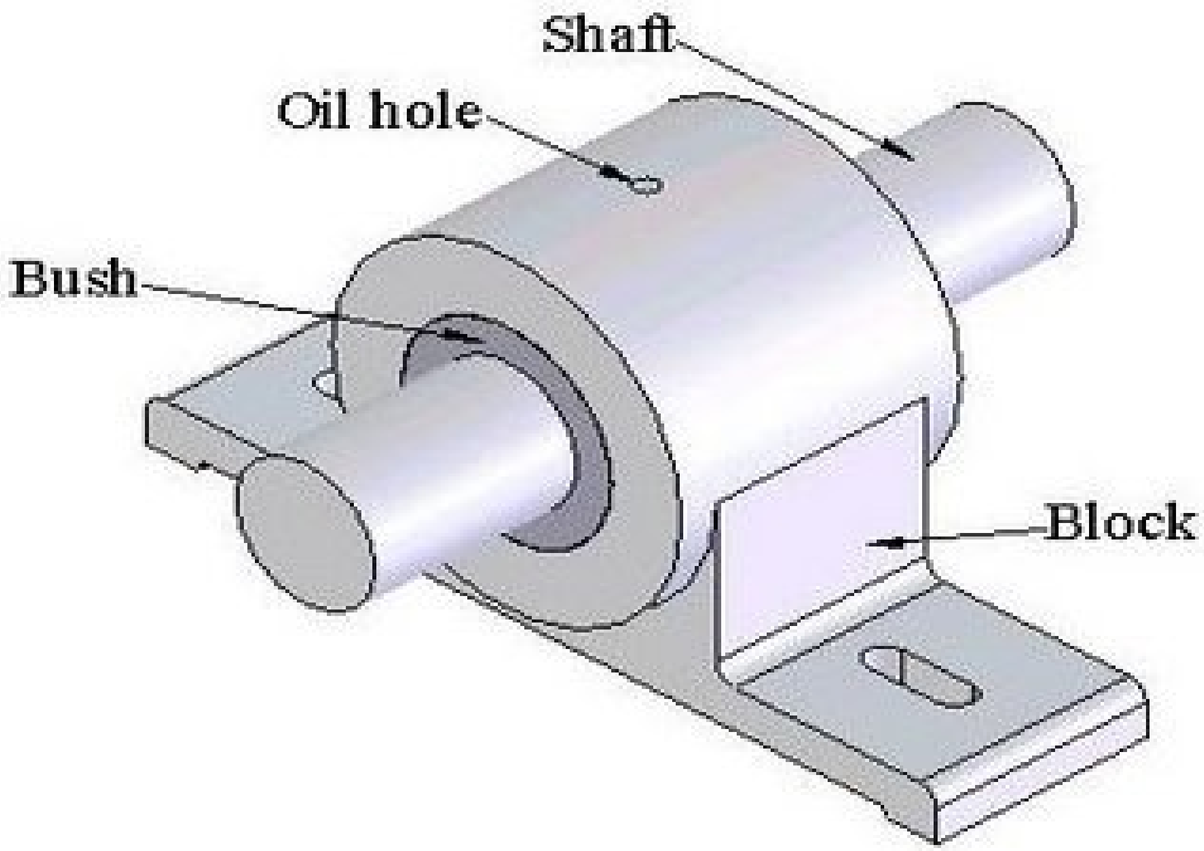


INTRODUCTION

- **It is a known fact that no two things can be similar in nature.**
- **Every process is a combination of three elements i.e., man, machine and material. A change in anyone of these will constitute a change in the process.**
- **All these three elements are subjected to inherent and characteristic variations.**
- **Hence, It is impossible to produce a part to an exact size and some allowance known as tolerance has to be allowed.**

- **This tolerance allowed depends on the functional requirements. In engineering practice any component manufactured is required to fit or match with some other component.**

- **For Example: If a shaft has to rotate in a bush there must be enough clearance between the shaft and bush (hole) to allow the lubricating oil film to be maintained. If the clearance is too small, excessive force would be required for rotating the shaft. On the other hand if the clearance is too wide, there would be vibrations and rapid wear.**


Shaft
Oil hole
Bush
Block

Terminology as per BIS

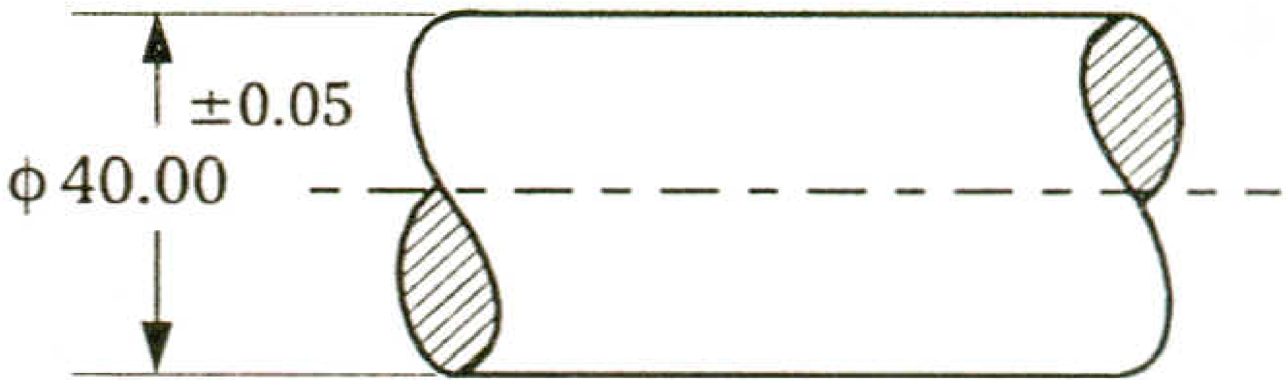
- **SIZE:-**
- **It is a number expressed in a particular unit in the measurement of length.**
- **BASIC SIZE:-**
- **It is the size based on which the dimensional deviations are given.**
- **ACTUAL SIZE:-**
- **It is the size of the component by actual measurement after it is manufactured. It should lie between the two limits of size.**
- **LIMITS OF SIZE:-**
- **These are the extreme permissible sizes within which the operator is expected to make the component.**

- **DEVIATION:-**
- **It is the algebraic difference between a size, to its corresponding basic size. It may be positive, negative or zero.**
- **UPPER DEVIATION:-**
- **It is the algebraic difference between maximum limit of size and its corresponding basic size.**
- **LOWER DEVIATION:-**
- **It is the algebraic difference between minimum limit of size and its corresponding basic size.**

- **FUNDAMENTAL DEVIATION:-**
- It is the deviation, either the upper or lower deviation, which is nearest one to zero line for either a hole or a shaft. It fixes the position of the tolerance zone in relation to the zero line.
- **ZERO LINE:-**
- In graphical representation of the above terms, the zero line represents the basic size. This line is also called as the line of zero deviation.

TOLERANCE

- Consider the dimensioning shown in the Fig.

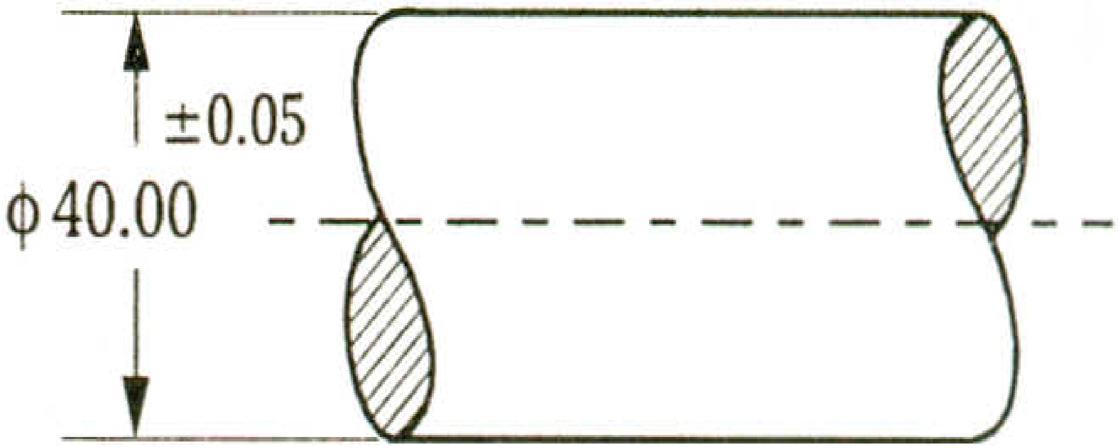


- When making the part we try to achieve a diameter of 40.00 mm. i.e. basic or nominal diameter.
- The shaft will be satisfactory if its diameter lies between 40.00 + 0.05= 40.05 mm and 40.00 - 0.05 = 39.95 mm.

- The dimension 40.05 mm is called the upper limit and the dimension 39.95 mm is called the lower limit.

- The difference between the upper and lower limits is called the tolerance.

- Tolerance in the above example is 40.05 - 39.95 = 0.10 mm.

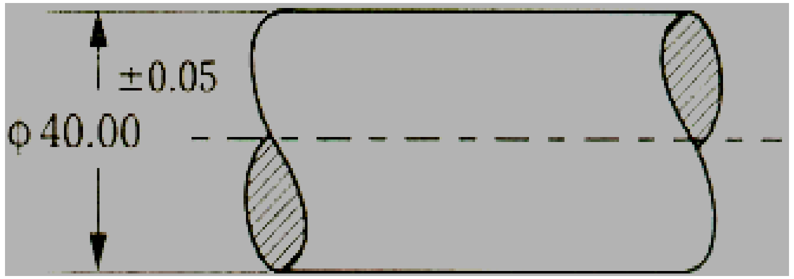


- **It is impossible to make anything to an exact size, therefore, it is essential to allow a definite tolerance or permissible variation on every specified dimension due to inevitability of human beings and machines.**
- **It is defined as the magnitude of permissible variation of a dimension or other measured or control criterion from the specified value.**

WHY TOLERANCE

1. **Variations in the properties of materials being machined that introduce errors**
2. **Inherent inaccuracies of the machine itself**
3. **Incapability of the operator while setting tools as well as operating**

- Tolerances on a dimension may be either unilateral or bilateral.
- A toleranced dimension is bilateral if the limit dimensions are given above and below the nominal size as shown.
- When the two limit dimensions are only above the nominal size (Fig. (a)) or only below the nominal size (Fig. (b)) then the tolerances are said to be unilateral.



Bilateral Tolerance

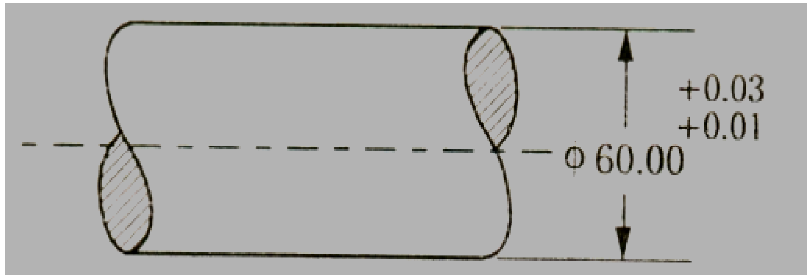


Fig. (a): Unilateral Tolerance

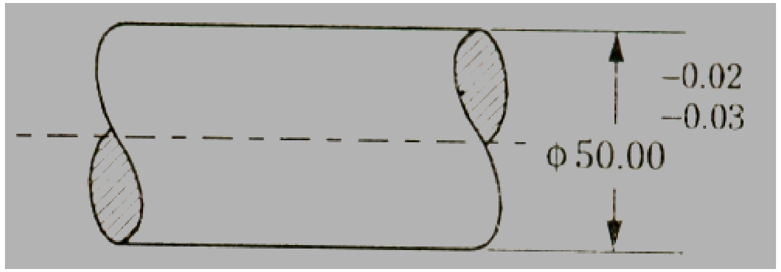
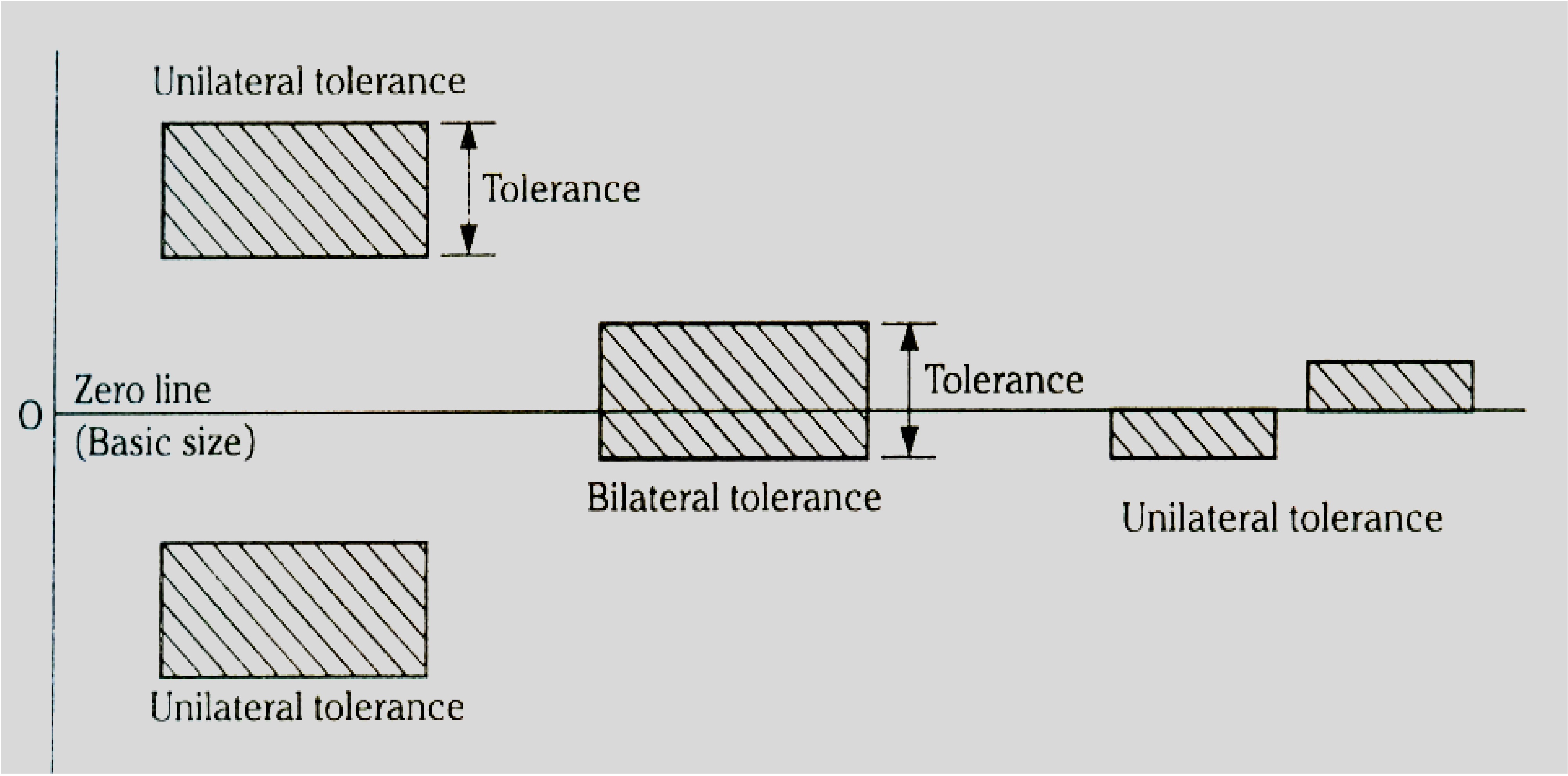


Fig. (b): Unilateral Tolerance

- **Unilateral tolerances are preferred over bilateral tolerances because the operator can machine to the upper limit of the shaft (or lower limit for a hole) still having the whole tolerance left for machining before the parts are rejected.**
- **For example: In drilling the dimensions are most likely to deviate in one direction only i.e., over size rather than undersize.**

- **Unilateral and bilateral tolerances can be schematically represented as shown below.**

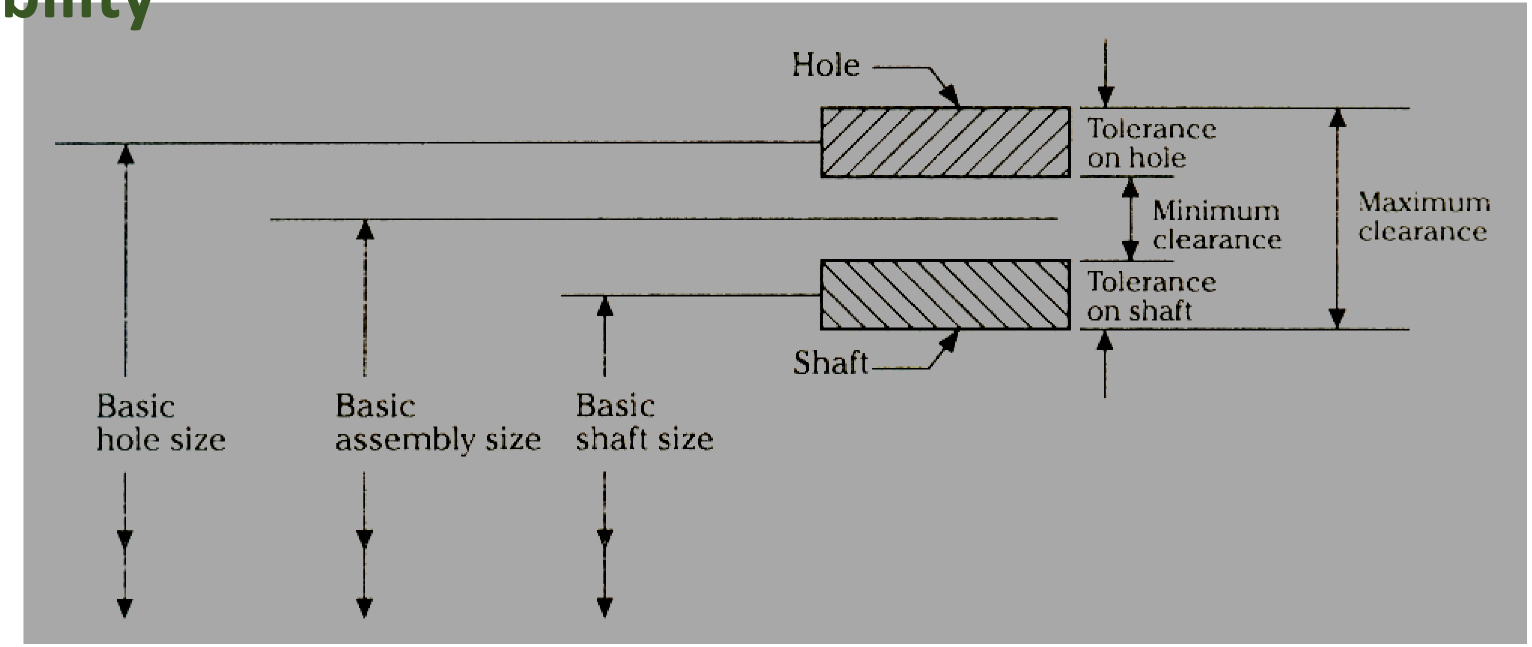


Specifying Tolerances in an Assembly:

- **The type of assembly or fit between the two mating parts will be decided based on the functional requirements. Accordingly tolerances on the shaft and hole are decided using the following two methods :**

(i) Complete interchangeability

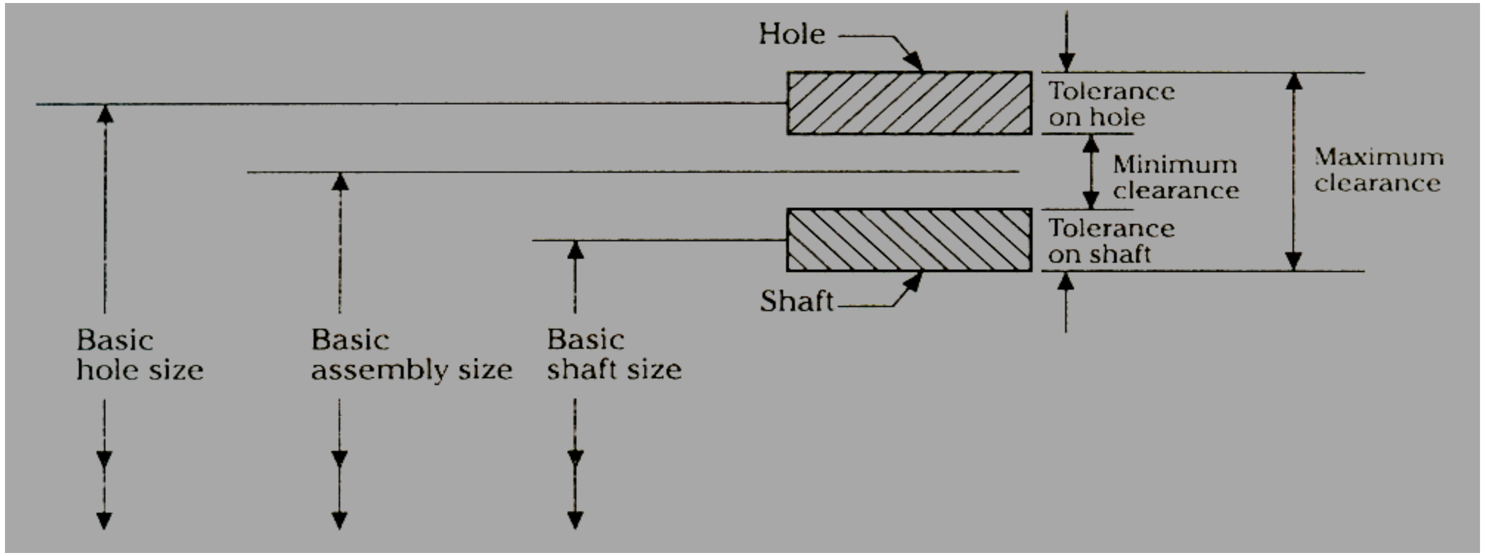
(ii) Statistical approach



Complete interchangeability:

- In this no risk is taken even for a single non-conforming assembly. If the fit between shaft and hole is clearance type as shown in the Fig., then for complete interchangeability.

- Tolerance on shaft = Tolerance on hole = Half the maximum clearance - Half the minimum clearance



The Statistical Approach :

- The statistical approach bases the permissible tolerances on the normal distribution curve, considering that only 0.3% of the parts would lie outside ± 3σ limits.

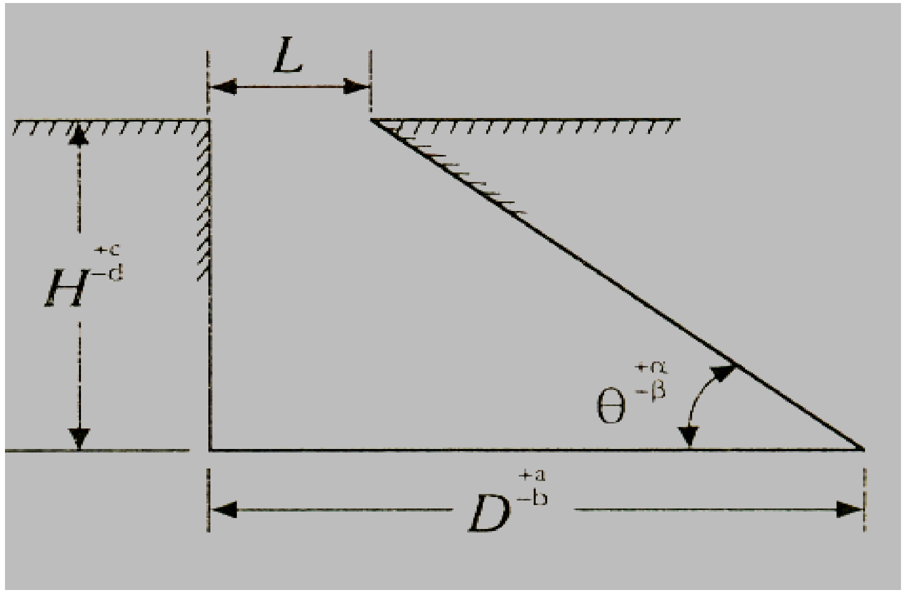
- This approach, obviously, allows wider tolerances and permits cheaper production methods especially in mass production.

- **If all the assignable causes of variation are fully controlled, then expected frequency curves of shafts and holes will be normal frequency curves, and accordingly the expected frequency of the clearances will also be a normal curve.**
- **It was estimated that about 33% more tolerance may be permitted by statistical approach compared to complete interchangeability.**

Tolerance Accumulation or Tolerance "Build-up”

- If a part comprises of several steps, each step having some tolerance over its length, then overall tolerance on complete length will be the sum of the tolerances on individual lengths as shown in the first Fig.
- The effect of accumulation of tolerances can be minimized by adopting progressive dimensioning from a common datum as shown in the second Fig.

Compound Tolerances



- A compound tolerance is one which is derived by considering the effect of tolerances on more than one dimension.
- For example, in this Fig. the tolerances on dimension 'L' are dependent on tolerances on D, H and ϴ.
- This compound tolerance on 'L' is the combined effect of all the three tolerances.
- The dimension L will be maximum when the base dimension is D + a, angle is ϴ + α and the vertical dimension is H - d. Similarly, L will be minimum when base dimension is D - b, angle is ϴ - β and the vertical dimension is H + c.

Interchangeability

- **When components are mass produced, unless they are interchangeable, the purpose of mass production is not fulfilled.**

- **By interchangeability, we mean that identical components, manufactured by different personnel under different environments, can be assembled and replaced without any further rectification during the assembly stage, without affecting the functioning of the component when assembled.**

- **Interchangeability occurs when one part in an assembly can be substituted for a similar part which has been made to the same drawing.**

- **For example there are 100 parts each with a hole, and 100 shafts which have to fit into any of the holes.**
- **If there is interchangeability then anyone of the 100 shafts should fit into any of the holes and the required kind of fit can be obtained. Hence, for the interchangeability of holes and shafts, we need a system of limits and fits which gives standard values for the limits on the hole and shaft, so that any particular type of fit can be obtained. Interchangeability is possible only when certain standards are strictly followed.**

- In universal interchangeability the mating parts are drawn from any two different manufacturing sources.
- Universal interchangeability is desirable and to achieve this all standards used by various manufactures should be traceable to a single source which will be an international standard. When all parts to be assembled are made in the same manufacturing unit, then local standards may be followed which is known as local interchangeability.
- The required type of fit in an assembly can be obtained either by universal or full interchangeability or by selective assembly.

SELECTIVE ASSEMBLY

- **In selective assembly the parts are graded according to the size and only matched grades of mating parts are assembled.**
- **This technique is most suitable where close fit of two component assembles are required.**
- **For Example: If some parts to be assembled are manufactured to a tolerance of 0.01 mm, then an automatic gauge can separate them into ten different groups with 0.001 mm limit for selective assembly of the individual parts. Thus parts with tolerances of 0.001 mm are obtained and both the conditions of high quality and low cost can be achieved by selective assembly technique.**

- **Selective assembly is often followed in aircraft, automobile and other industries where the tolerances are very narrow and are not possible by any sophisticated machine at reasonable costs.**
- **The selective assembly, however enables such tolerances to be achieved without actually being produced.**

LIMITS OF SIZE

- **In deciding the limits for a particular dimension it is necessary to consider the following:**
- **(i) Functional requirements - the intended function that a component should perform.**
- **(ii) Interchangeability - Replacement of the component in case of failure without difficulty.**
- **(iii) Economy in production time and cost.**

FIT

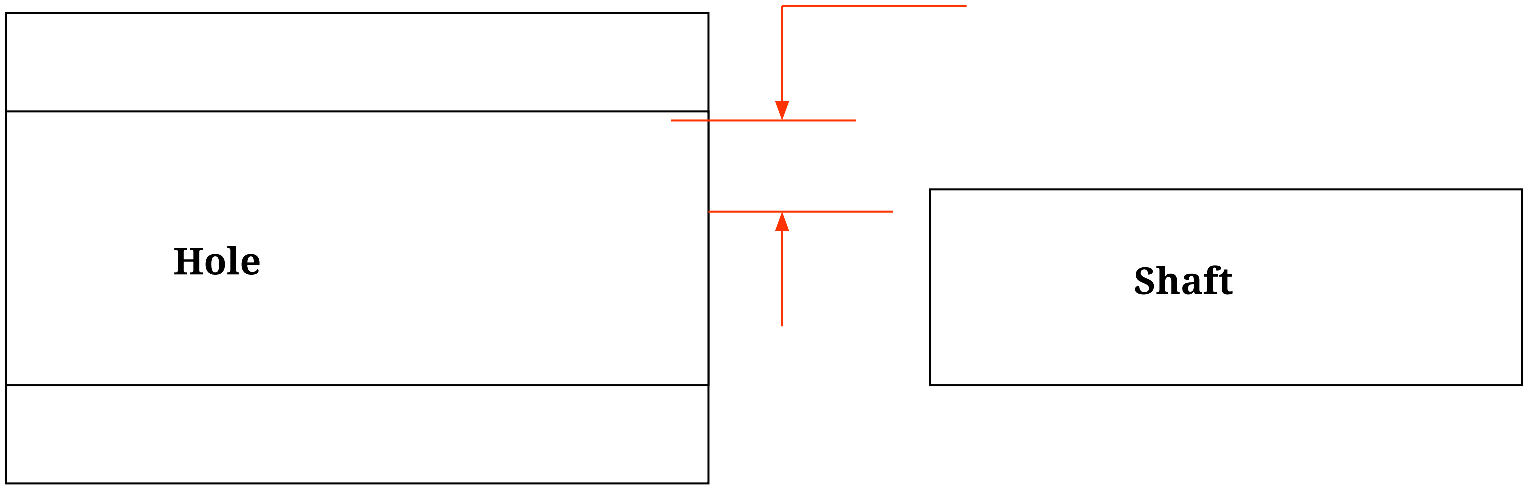
- When two parts are to be assembled, the relationship resulting from the difference between their sizes before assembly is termed as FIT
- Depending upon the actual limits of hole or shaft, the fit may be

1. A Clearance Fit
2. A Transition Fit
3. An Interference Fit

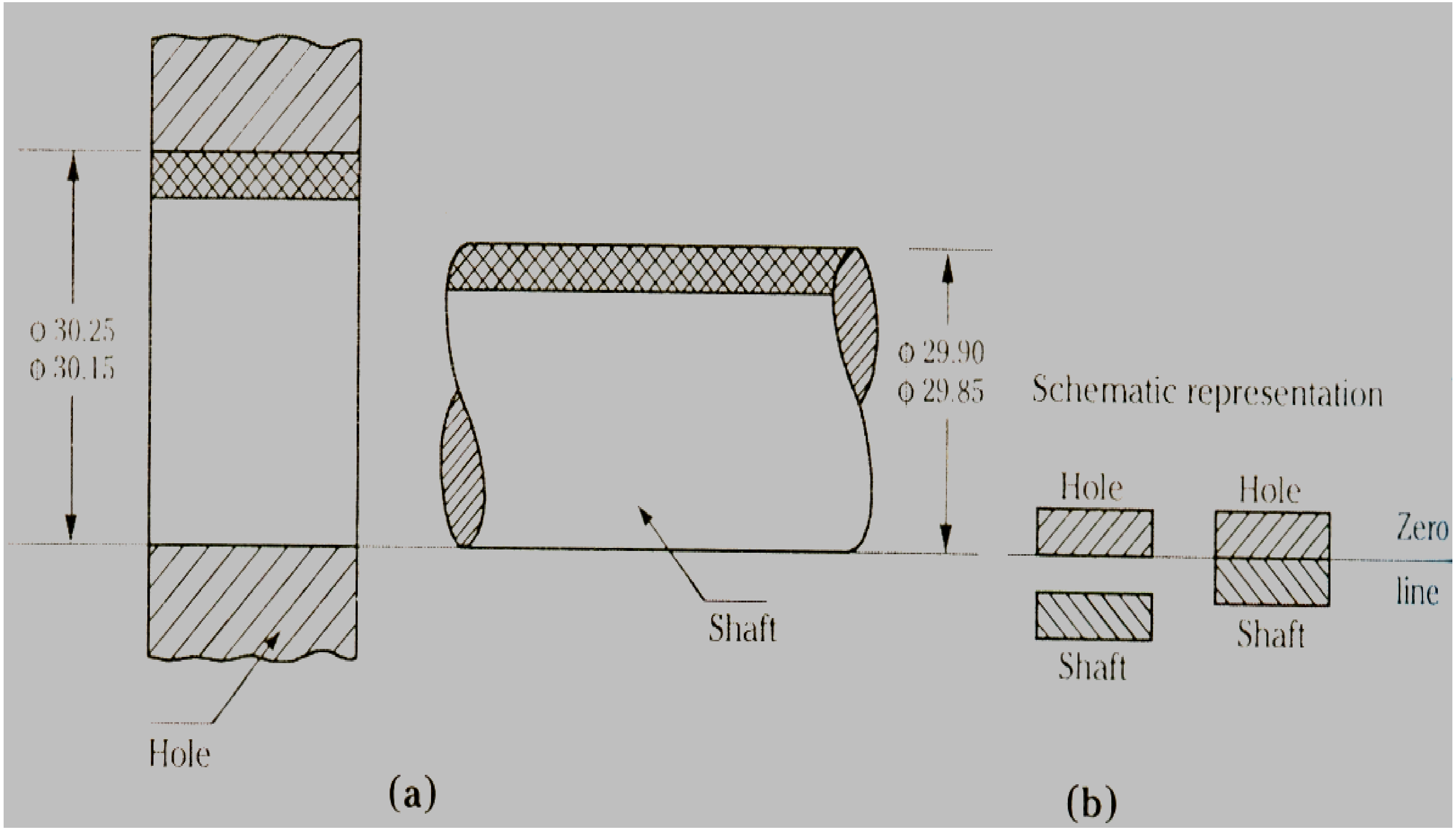
CLEARANCE FIT

Here the tolerance zone of the hole will be above the tolerance zone of the shaft. e.g. 20 H7/g6.

In other words the largest permitted shaft diameter is smaller than the diameter of the smallest hole, so that the shaft can rotate or slide through with different degrees of freedom.



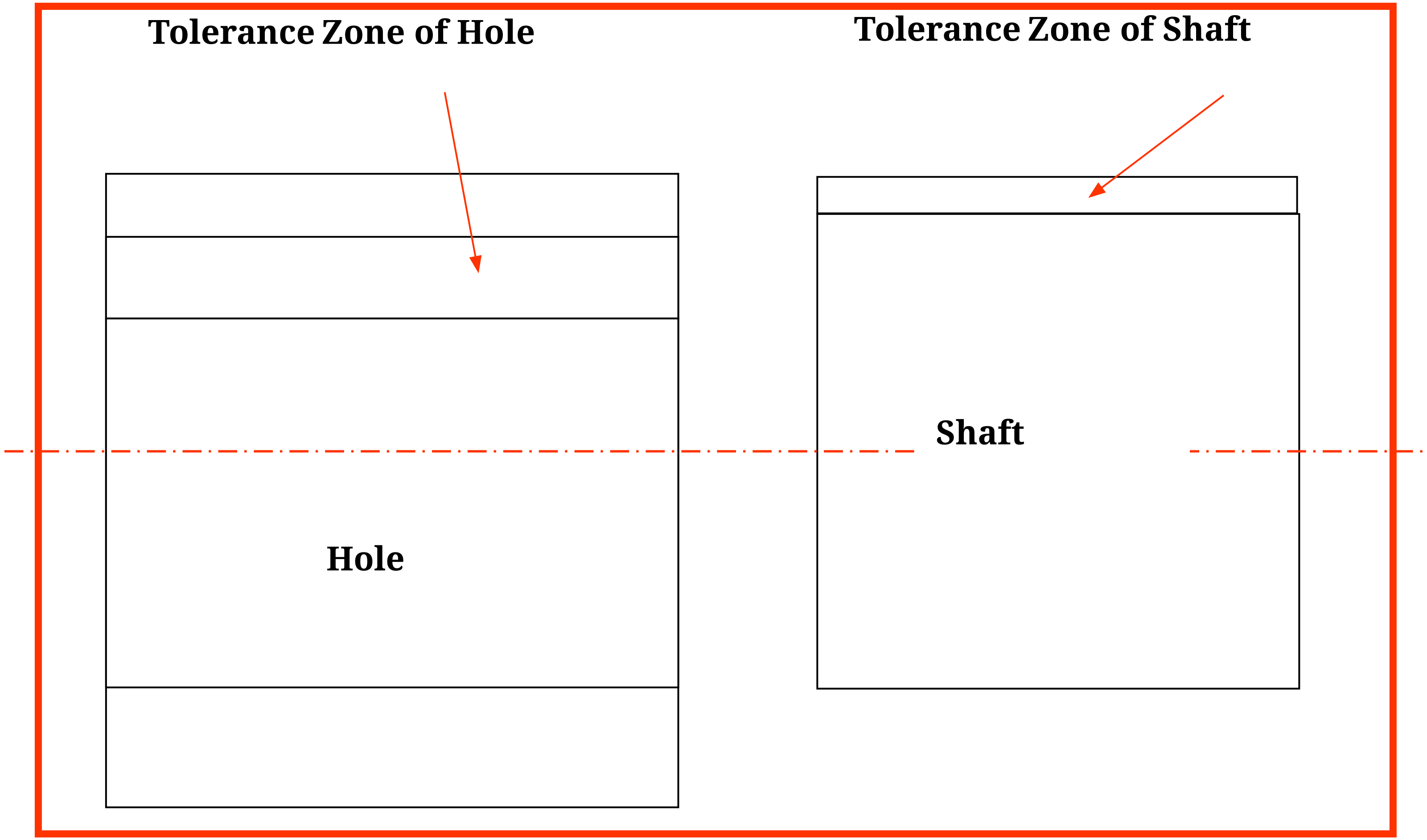
CLEARANCE FIT

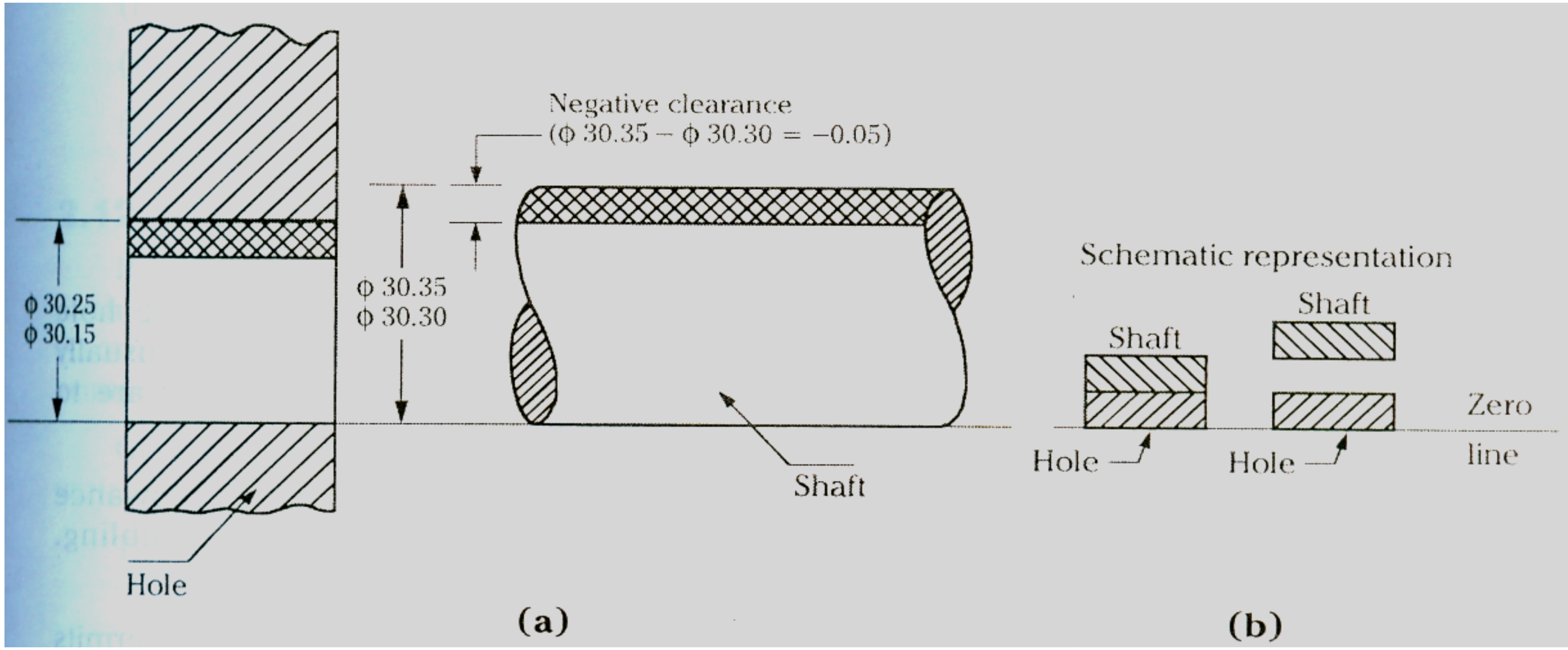


INTERFERENCE FIT

- In this type of fit , the minimum permitted diameter of the shaft is larger than the maximum allowable diameter of the hole.
- Here the tolerance zone of the hole will be below the tolerance zone of the shaft. e.g. 25 H7/p6.
- It is defined as the fit obtained when a negative clearance exist between the sizes of the hole and shaft.

INTERFERENCE FIT



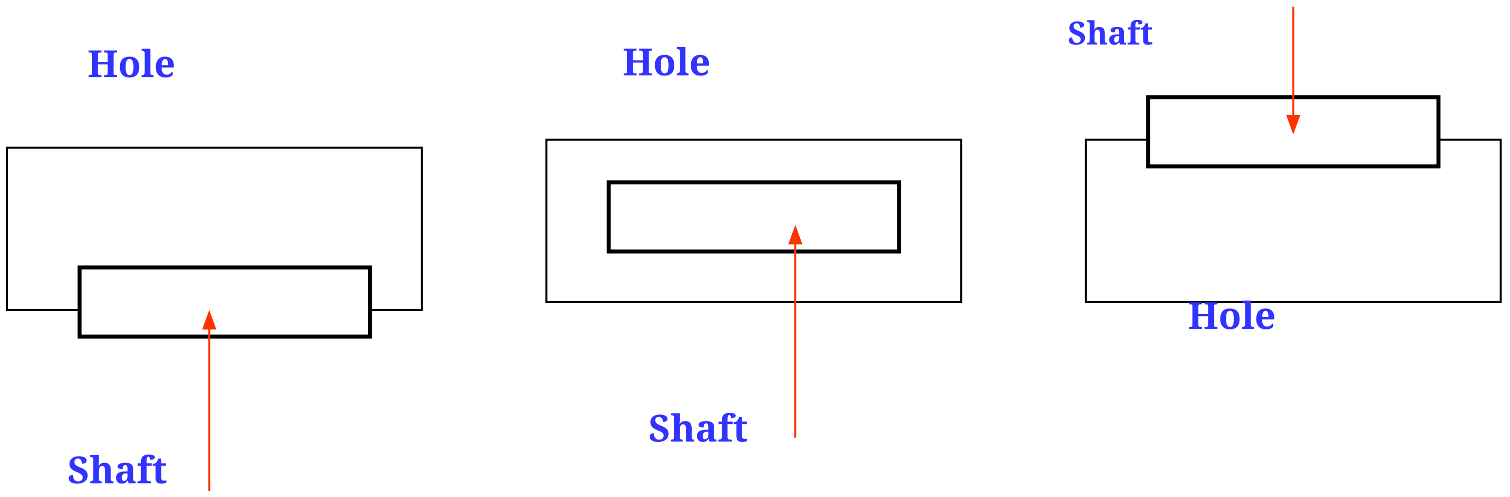


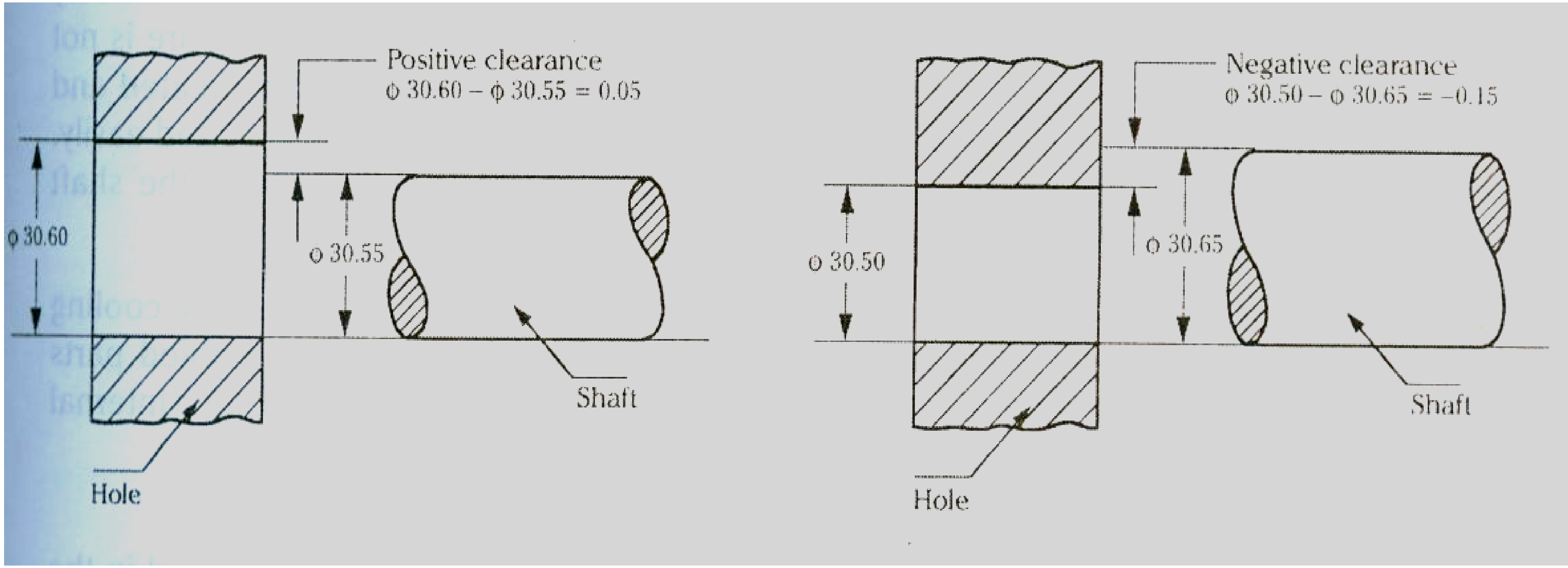
- Here the shaft and the hole members are intended to be attached permanently and used as solid.
- If during use, any one member is worn out, then it is required to force both the members to replace the part.
- Example: bush bearing

TRANSITION FIT

- **It is a fit which may sometimes provide clearance and sometimes interference.**
- **In this fit the diameter of the largest allowable hole is greater than that of the smallest shaft, but, the smallest hole is smaller than the largest shaft, so that small clearance between shaft and hole members are employable**
- **When this class of fit is represented graphically, the tolerance zone of the hole and shaft will overlap each other. e.g. 75 H8/j7.**

TRANSITION FIT





- **In this type of fit, a small positive or negative clearance exists between the shaft and the hole as shown in Fig.**
- **Example: Coupling rings, spigot in mating holes, etc.,**

SPECIFIC TYPES OF FIT

- **Following are some of the specific types of fits.**

a) Driving Fit

b) Forced or Pressed Fit

c) Push Fit or Snug Fit

d) Selective Fit

e) Shrinkage Fit

f) Freeze Fit

SPECIFIC TYPES OF FIT

- **DRIVING FIT: In driving fit, the shaft is made slightly larger than the hole such that the parts can be assembled by driving force. For assembling usually hydraulic presses are used. Driving fits are employed when the parts are to remain in a fixed position relative to each other.**
- **FORCED OR PRESSED FIT: It is similar to driving fit but has a lesser allowance than a driving fit, thereby, requires greater pressure for assembling.**
- **Examples : Crankpins, Car wheel axles etc..**

- **PUSH FIT or SNUG FIT:** This type of fit represents a closest fit which permits assembling of parts by hand.
- **SELECTIVE FIT:** Selective assembly is necessary when the objective is to make a shaft and hole with a finite fit and not a permissible range of fit. This kind of fit is generally used for tight or interference fits whenever it is desired to avoid extremes of maximum tightness or looseness.

- **SHRINKAGE FIT:** A shrinkage fit is obtained by making the shaft (internal member) slightly larger than the hole (external member).
- In shrinkage fit, pressure is not required for assembling but instead the hole (external member) is heated and expanded sufficiently to permit the shaft (internal member) to be inserted easily.
- Then the hole (external member) is cooled to shrink tightly around the shaft (internal member).

- **FREEZE FIT:** In freeze fit the shaft (internal member) is contracted by cooling and assembled with the hole (external member).
- When the assembled parts are exposed to the atmospheric temperature, the contracted shaft (internal member) expands and thus fit into the hole (external member).
- Example : Insertion of valve seat inserts in engine cylinder heads.
- Among the above, the force fit, shrink fit or freeze fit are widely used in the assembly of machine parts.

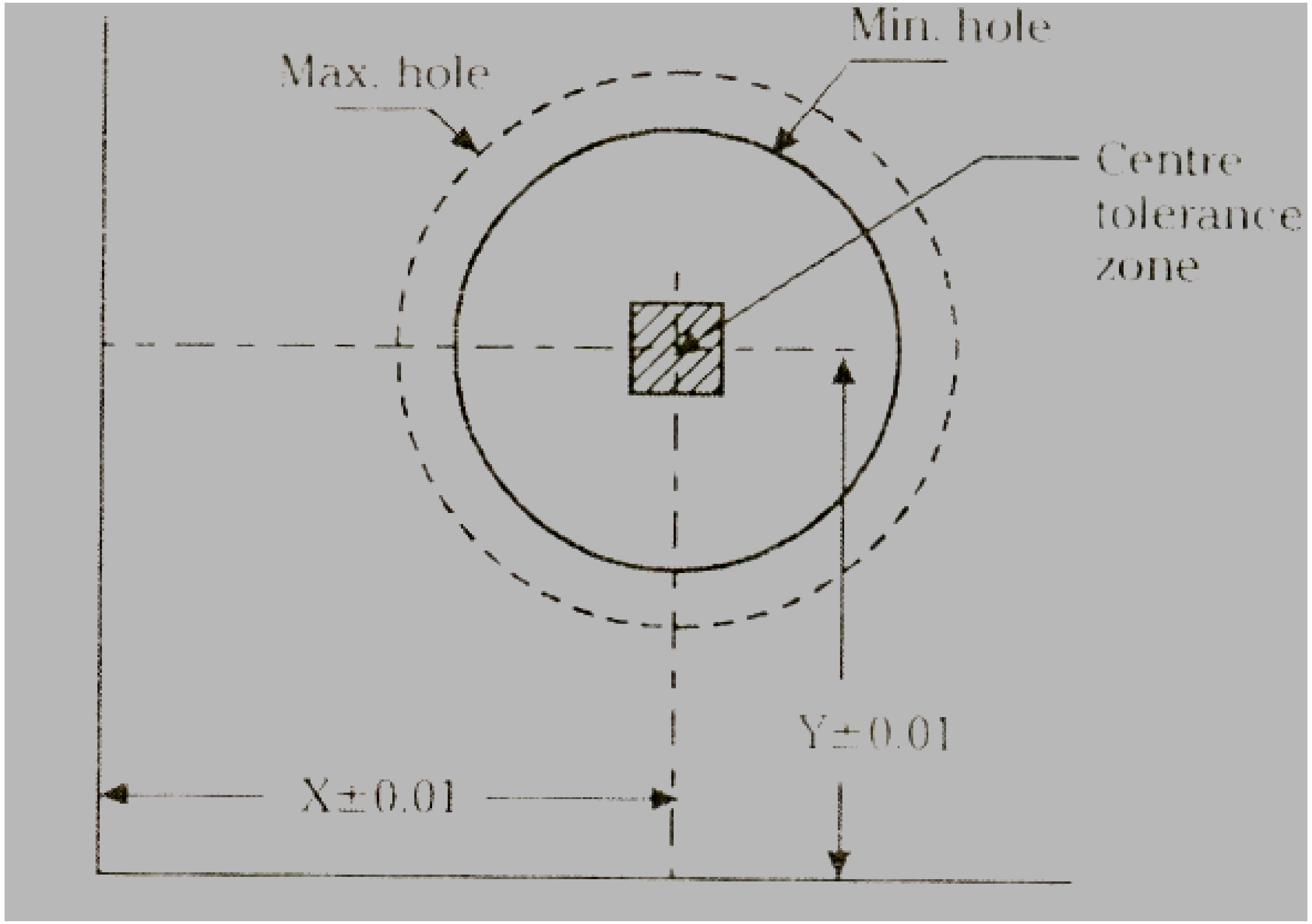
- The specific types of fits in terms of clearance, transition and interference fits are as follows :

1. Driving Fit - interference fit
2. Forced fit - interference fit
3. Push fit - transition fit
4. Selective fit - transition or interference fit
5. Shrinkage fit - interference fit
6. Freeze fit - interference fit

POSITIONAL TOLERANCES

- **The conventional method of giving a positional tolerance by tolerancing co-ordinates is as shown in the Fig. In the case of hole illustrated, it will be seen that the tolerance zone for the hole center is a square. If the tolerance co-ordinates are not equal then the zone would be rectangle.**
- **Thus the permissible error in position of center varies with the direction of error. But, in most of the cases the designer wishes to restrict the amount by which the hole may vary from its true position irrespective of the direction of error.**

POSITIONAL TOLERANCES



- **The same principles apply to the relative positions of two or more holes, spigots, pins or other similar types of location.**
- **Tolerance on concentricity or symmetry are exactly the same in principle, the only difference being that the two features have a common centre line instead of having their centre lines separated by a finite dimension.**
- **Incidentally, although the terms concentricity, symmetry, parallelism and so on are used it is quite illogical to do this.**

- **If two diameters of a shaft are not perfectly concentric, they are eccentric and the permissible tolerance is one of eccentricity.**
- **The word concentricity should be used only when the error is absolutely zero. However, these terms have become so widely used, although rather loosely, that they must be accepted and are generally understood.**

GEOMETRICAL TOLERANCES

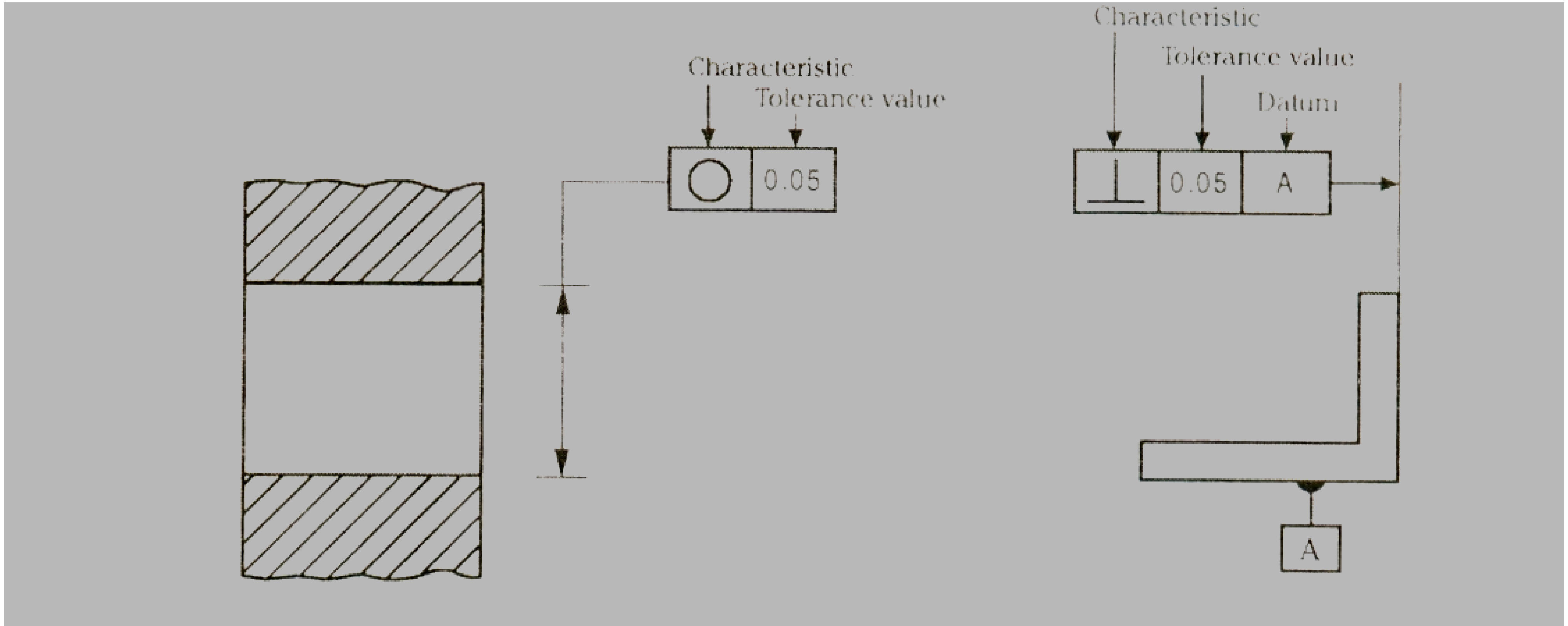
- It is necessary to specify and control the geometric features of a component, such as straightness, flatness, roundness etc., in addition to linear dimensions.
- Geometric tolerances are concerned with the accuracy of the relationship of one component to another, and it should be specified separately.
- Geometrical tolerance may be defined as the maximum permissible overall variation of form, or position of form, or position of a feature.

- **The characteristics to be geometrically tolerance are classified as :**

1. **Single features**
2. **Related features**

- **The table shows the symbols used to indicate the characteristics, the function of geometrical tolerances with typical examples.**

Comparison between single and related tolerance

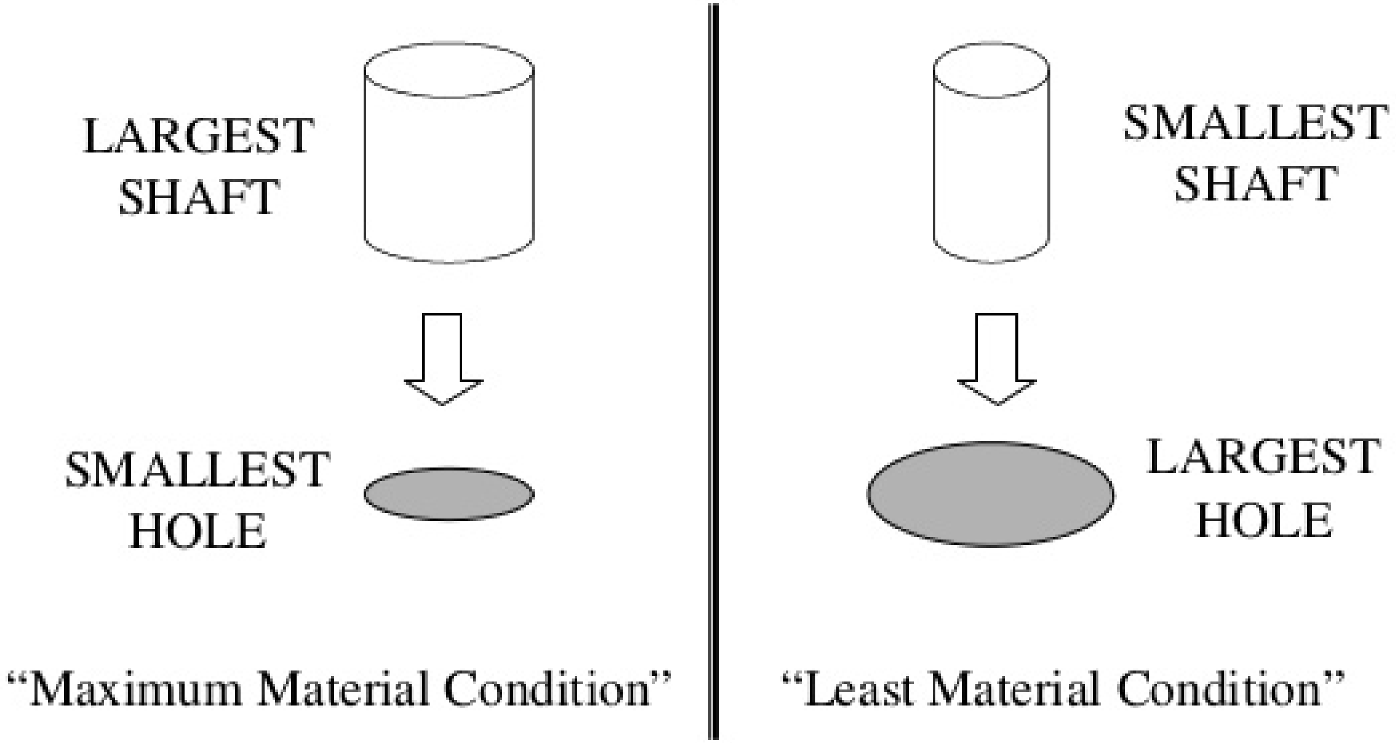


(a) Single tolerance (b) Related feature

Maximum and Minimum Metal Condition:

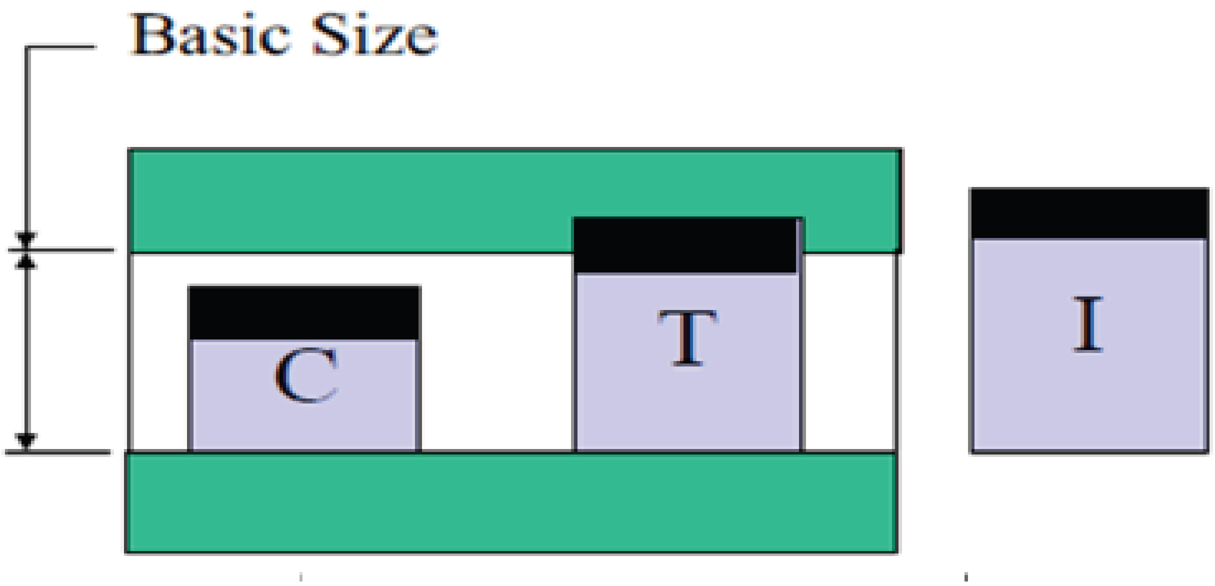
- **Maximum metal condition (MMC) corresponds to a condition in which a feature contains the maximum amount of material within the stated limits.**
- **For example maximum limit on shaft and minimum limit on the hole.**
- **Least Material Condition (LMC): The condition in which a feature contains the least amount of material within the stated limits. e.g. maximum hole diameter, minimum shaft diameter.**
- **MMC is important with regard to geometrical tolerances since it critically affects the interchangeability of manufactured parts.**

MMC vs. LMC

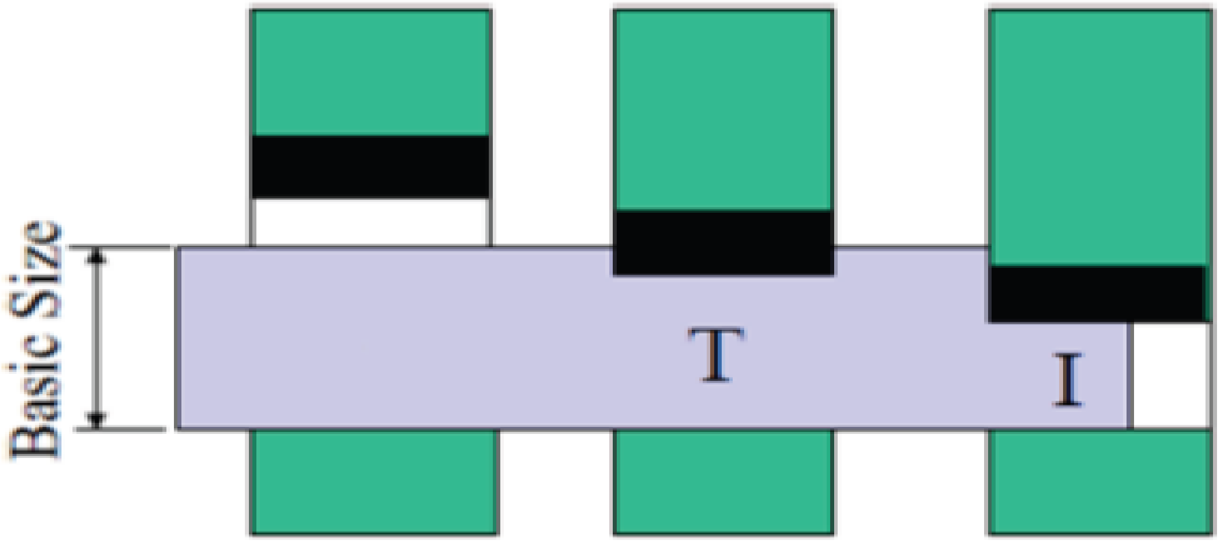

LARGEST
SHAFT
SMALLEST
HOLE
"Maximum Material Condition"
SMALLEST
SHAFT
LARGEST
HOLE
"Least Material Condition"

BASIS OF FITS

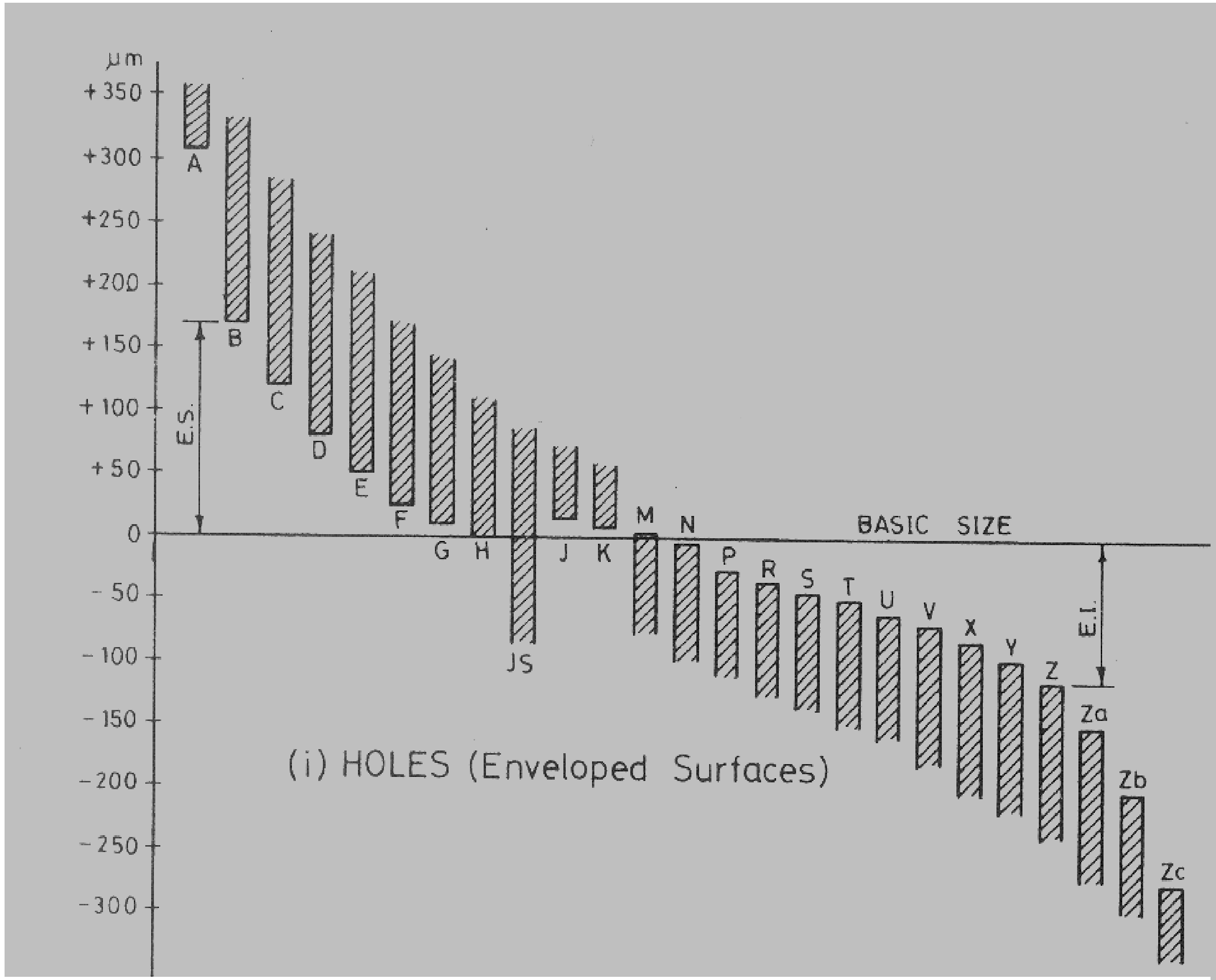
- **Hole Basis System:**
- **In this system, the basic size of the hole is kept constant while the shaft size is varied according to the type of fit.**
- **Lower deviation of the hole is zero.**

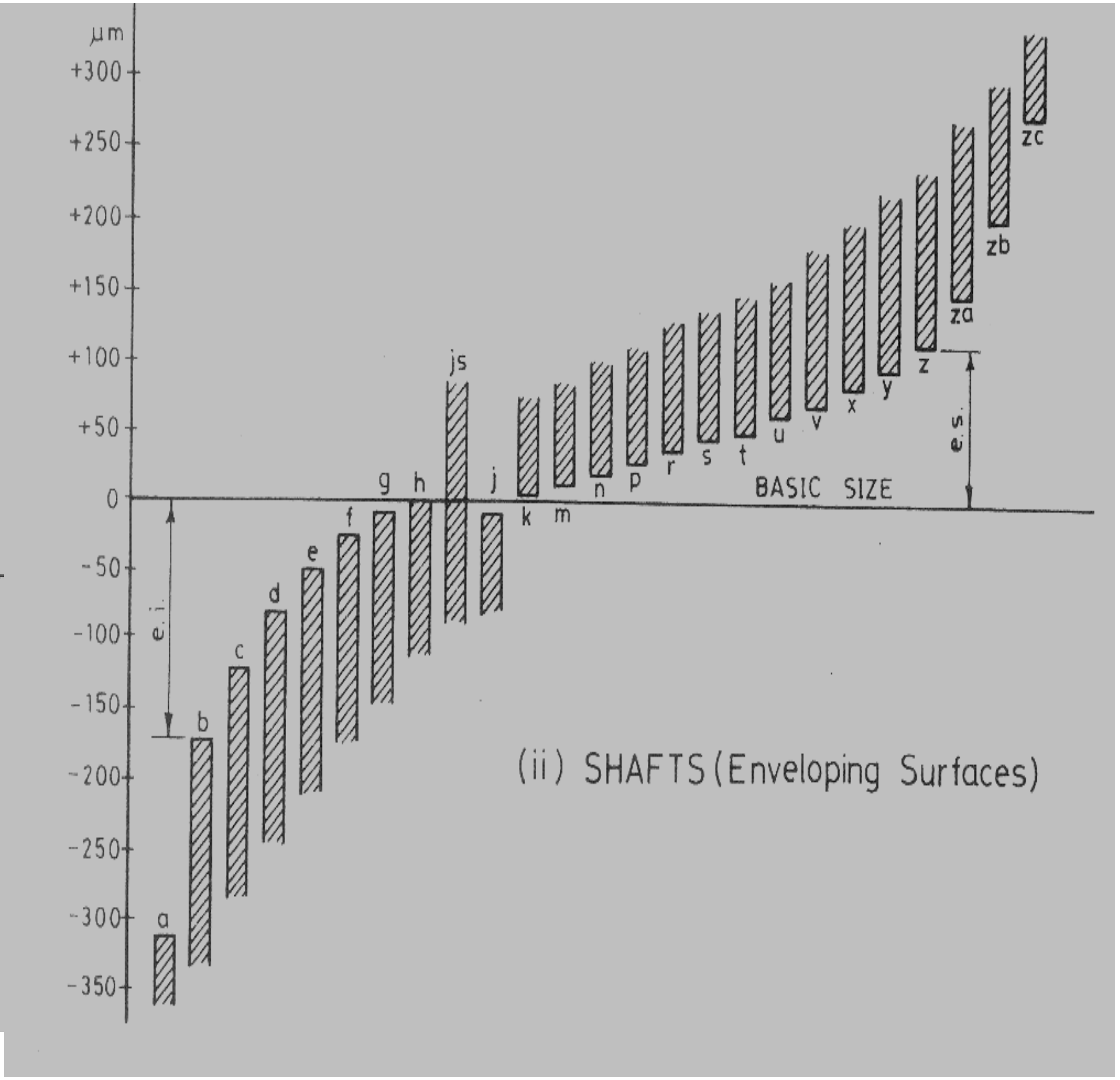


- **Shaft Basis System:**
- **In this system, the basic size of the shaft is constant while the hole size is varied according to the type of fit.**
- **Upper deviation of the shaft is zero.**



Symbols and terms used in IS 919-1965





- **Tolerance Grade**

Tol. 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
	7i	*10i*	*16i*	*25 i*	*40 i*	*64 i*	*100 i*	*160 i*	*250 i*	*400 i*	*640 i*	*1000 i*

- **Where,**
- **i is standard tolerance unit**
- **D is geometric mean diameter**

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

$$I = \ 0.004\ D + \ 2.1$$

Tolerance grade	Manufacturing process and applications	Machine required
IT01, IT0 IT1 to IT5	Super finishing process, such as lapping, diamond boring etc. Use: Gauges	Super finishing machines
IT6	Grinding	Grinding machines
IT7	Precision turning, broaching, honing	Boring machine, honing machine
IT8	Turning, boring and reaming	Lathes, capstan and automats
IT9	Boring	Boring machines
IT10	Milling, slotting, planing, rolling and extrusion	Milling machine, slotting machine, planing machine and extruders
IT11	Drilling, rough turning	Drilling machine, lathes
IT12, IT13, IT14	Metal forming processes	Presses
IT15	Die casting, stamping	Die casting machine, hammer machine
IT16	Sand casting	—

- **The value of tolerance grade is not calculated on the basis of actual size but is taken as geometric mean of upper and lower value of the range in which it falls.**
- **The various diameter steps specified by ISI are 1 – 3, 3 – 6, 6 – 10, 10 – 18, 18 – 30, 30 – 50, 50 – 80, 80 – 120, 120 – 180, 180 – 250, 250 – 315, 315 – 400 and 400 - 500 mm.**

SELECTION OF FITS

- It is easier to produce a shaft with a specified tolerance than a hole with the same tolerance due to the fixed character of hole producing tools.
- Therefore, it is common practice to follow the hole basis system.
- However, when shafts are made from drawing operation etc., shaft basis system has to be employed.
- Actually which system of fits to be selected depends upon many conditions such as nature of the product, the manufacturing methods, the condition of the raw material etc.

PLAIN GAUGES

- Gauges are inspection tools without a scale which serve to check the dimensions of the manufactured parts.
- Instead of measuring actual dimensions, the conformance of product with tolerance specifications can be checked by a "GO" and "NOT GO" gauges. These gauges represent the limit sizes of the work piece, as per the specified product tolerances.
- A "GO" gauge represents the maximum material condition of the product and conversely, a "NOT GO" gauge represents the minimum material condition

- **They do not indicate the actual value of the inspected dimensions on work, but ensure the size of the component being inspected lies within its specified limits.**
- **Plain gauges are used for checking plain (unthreaded) holes and shafts.**


T
16 H7
Z


GO
Brown&Holmes
NOGO

CLASSIFICATION OF PLAIN GAUGES

- They are classified:
- According to their type
  - (a) Standard gauges
  - (b) Limit gauges
- According to their purpose
  - (a) Workshop gauges
  - (b) Inspection gauges
  - (c) Reference or master gauges

- **According to the form of the tested surface**
  - **(a) Plug gauges for checking holes**
  - **(b) Snap and ring gauges for checking shafts**
- **According to their design**
  - **(a) Single limit and double limit gauges**
  - **(b) Single ended and double ended gauges**
  - **(c) Fixed and adjustable gauges.**

ADVANTAGES OF GAUGES

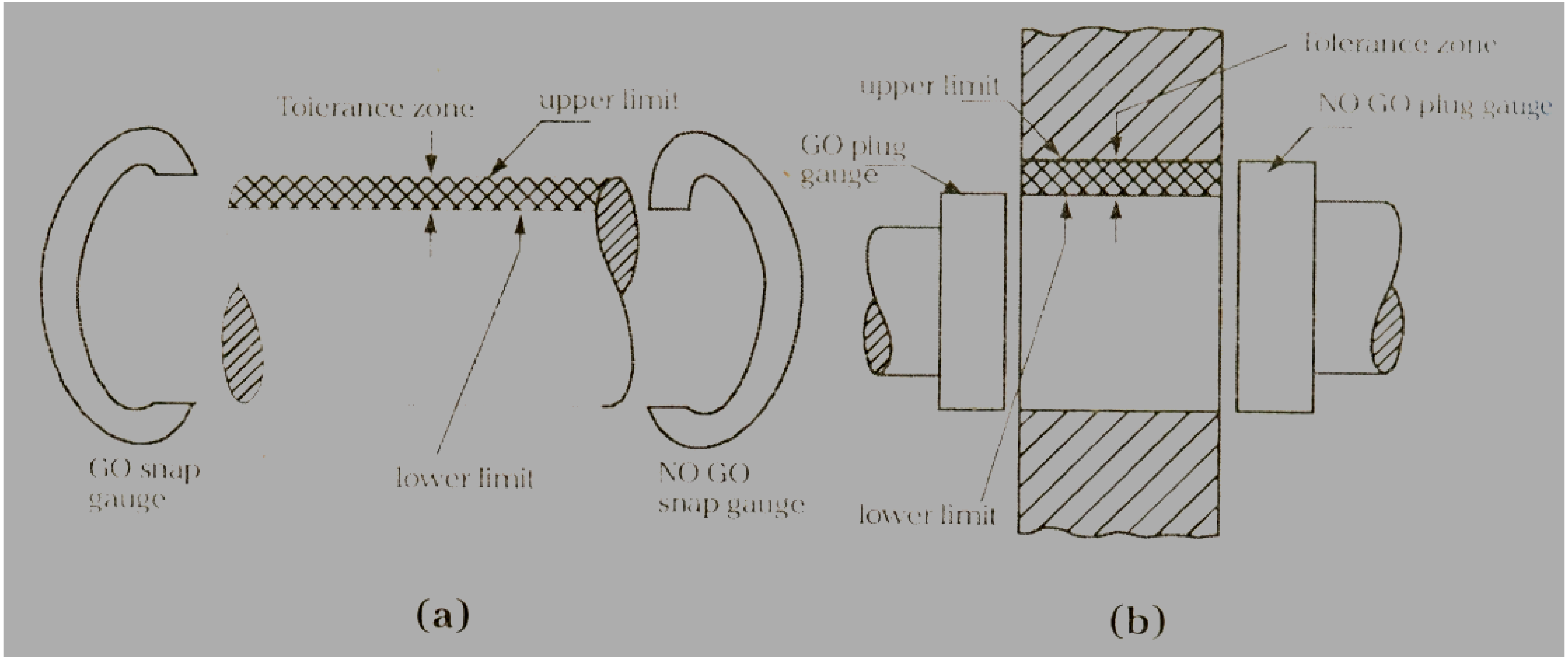
1. They are free from errors
2. They are portable and independent of power supply
3. They require no auxiliary equipments and set up
4. Various dimensions can be checked
5. They are inexpensive
6. They provide uniform standards

DISADVANTAGES

1. Some of the components which are within work tolerance limits may be rejected by the workshop gauges. Hence, they have to be checked again by inspection gauges and may be accepted after that.
2. Some components which are not within the work tolerance limits may be accepted when tested by inspection gauges.
3. The workshop and inspection gauges have to be made separately since their tolerance zones are different.

PRINCIPLE OF GAUGE DESIGN

- **Taylor's Principle of Gauge Design**
  - **According to Taylor "GO" and "NO GO" limit gauges should be designed to determine the maximum and minimum metal limits.**
  - **Go limit gauge : A GO gauge corresponds to maximum metal condition. For example upper limit of a shaft or lower limit of a hole as shown in Figures (a) and (b).**


Tolerance zone
upper limit
GO snap gauge
lower limit
NO GO snap gauge
(a)
tolerance zone
upper limit
NO GO plug gauge
GO plug gauge
lower limit
(b)

- **The 'GO' snap gauge corresponds to upper limit of the shaft, while the "GO" plug gauge corresponds to lower limit of the hole.**
- **The "GO" gauges should check all the possible elements of dimensions at a time (roundness, location size etc).**
- **A GO plug gauge must be of corresponding mating section and preferably to the full length of the hole so that straightness of the hole can be checked.**

- **NO GO limit gauge: A NO GO gauge corresponds to minimum metal condition.**
- **For example, lower limit of a shaft and the upper limit of a hole.**
- **It should check only one feature of the component at a time.**
- **The NOGO snap gauge corresponds to lower limit while the NOGO plug gauge corresponds to upper limit.**


3/4" - 1"


0 4H7 +0.012


0 9H7 +0.015

GAUGE TOLERANCE

- Gauges, like any other job requires a manufacturing tolerance. Therefore the theoretical gauge size as determined from the maximum and minimum metal limits of the component needs some modification to allow for reasonable imperfections in the workmanship of the gauge maker.
- This, tolerance on the gauges allowed for the workmanship of a gauge maker is known as Gauge maker's tolerances or gauge tolerances.
- This tolerance should be kept as small as possible. However, it will have an impact on the cost of making the gauge.
- The tolerance on each gauge whether GO or NO-GO is 1/10 of the work tolerance.

Methods of Gauge Maker's Tolerance

- **There are three methods of giving tolerance on snap and plug gauges.**

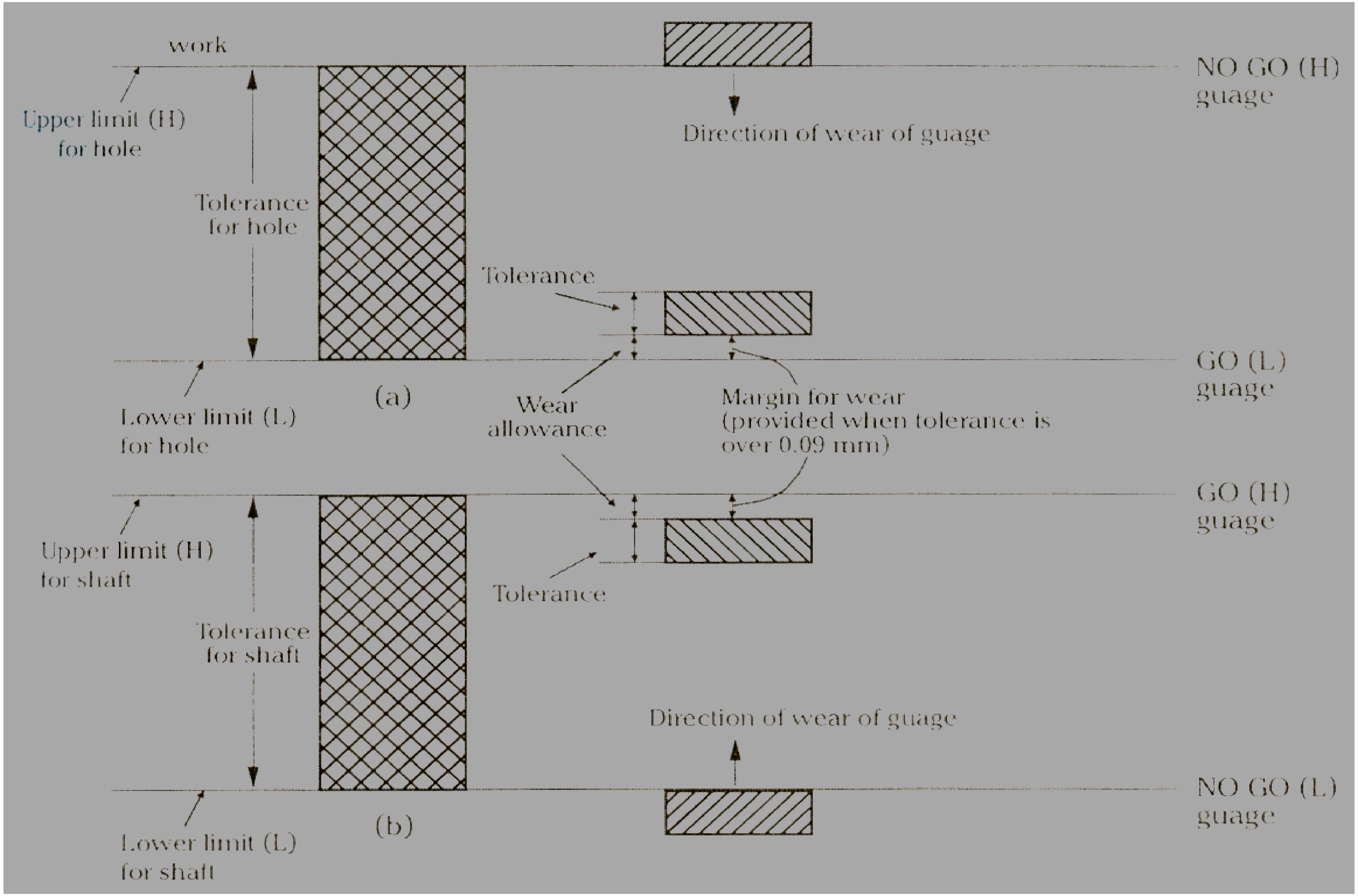
1. **First system (For Workshop and Inspection gauges)**
2. **Second System (Revised Gauge Limits)**
3. **Third System (Present British System)**

Third System (Present British System)

- In this system, following principles are followed along with Taylor's principle.

a) Tolerance will be as wide as consistent with satisfactory functioning, economical production and inspection.

b) No component will be accepted which lies outside the drawing specified limits.


work
Upper limit (H)
for hole
Tolerance
for hole
NO GO (H)
guage
Direction of wear of guage
Tolerance
GO (L)
guage
Lower limit (L)
for hole
(a)
Wear
allowance
Margin for wear
(provided when tolerance is
over 0.09 mm)
GO (H)
guage
Upper limit (H)
for shaft
Tolerance
Tolerance
for shaft
Direction of wear of guage
NO GO (L)
guage
Lower limit (L)
for shaft
(b)

- **This system gives the same tolerance limits on workshop and inspection gauges and the same gauges can be used for both purposes.**
- **The tolerance zone for the "GO" gauges will be placed within the work-limits while the tolerance zone for the "NOGO" gauges will be outside the work-limits as shown in Fig.**
- **Provision for wear of "GO" gauges is made by introducing a margin (called wear allowance) between the tolerance zone for the gauge and maximum metal limit of the work.**

- **Wear should not be permitted beyond the maximum metal limit of the work, when the limit is of critical importance. Its magnitude is 1/10 of the gauge tolerance.**
- **Thus, when work tolerance is less than 0.09 mm there is no need of giving allowance for wear. If work tolerance is more than 0.09 mm then 10% gauge tolerance is given only on "GO" gauge for wear.**

Wear Allowance Consideration on Gauges

- **The measuring surfaces of "GO" gauges which constantly rub against the surfaces of the parts during inspection are consequently subjected to wear and lose their initial size.**
- **Thus, due to wear, the size of "GO" plug gauges is reduced, while that of "GO" snap gauges is increased.**
- **But, it is desirable to prolong the service life of gauges and therefore a special allowance called wear allowance is added in a direction opposite to the wear.**
- **For this reason "GO' plug gauges are made with two positive deviations and "GO" snap gauges with two negative deviations from the nominal size.**

GAUGE MATERIALS

- Essential considerations in the selection of materials for gauges
  - Hardness to resist wear
  - Stability to preserve size and shape
  - Corrosion resistance
  - Machinability for obtaining the required degree of accuracy
  - Low coefficient of linear expansion to avoid temperature effect

MATERIALS USED FOR GAUGES

- **HIGH CARBON STEEL:** Cast steel (0.8 to 1.0% C) either water or oil hardened is relatively inexpensive and most commonly used material for gauges.
- Bigger sizes of plug gauges are made from case-hardening steels.

- **MILD STEEL:** These gauges are usually case hardened on the working surface.
- They are used for gauges of shapes which might cause cracking during hardening if made in other steels.
- Mild steel is easily machinable, stable and expensive.

- **CASE HARDENED STEEL:** Low carbon case-hardening steel is used for majority of small and medium sized gauges. It has the advantages of good Machinability, stability and the ability to be surface hardened to varying depths at any required position.
- **OIL HARDENED STEEL:** It is best suited where gauges are required in huge quantities.
- **CAST IRON:** It is often employed for the bodies or frames of large gauges, whose working faces are hard inserts of tool steel or cemented carbides.

- **PLATING, AND HARD ALLOYS:** Chromium plating have led to its increasing use for gauges. It renders the surface of the gauges very hard coupled with resistance to abrasion and corrosion. Chromium plating also proved a useful method of reclaiming the worn out gauges. Hard alloys of the tungsten carbide type are finding increasing applications in gauges.
- **INVAR:** Invar containing 36% nickel has low coefficient of expansion but is unsuitable over a long period.

- † **GLASS :** Glass gauges in spite of their good wear qualities have not gained much popularity because if dropped or heavily knocked they may get damaged. Glass gauges have the advantage of eliminating the corrosive effects due to perspiration from hands.

- Their dimensions are not affected by temperature changes due to their low coefficient of expansion. Further when a glass gauge is scratched or chipped, no burn is left on the gauge.

PLUG GAUGES

- **These are the limit gauges for a hole and consists of two cylindrical wear resisting steel plugs whose sizes are made to the limiting values of the hole dimension.**
- **The plug made to the lower limit of the hole is known as "GO" gauge, and this will obviously enter any hole which is not smaller than the lower limit allowed.**
- **The plug made to the upper limit is known as "NOT-GO" or "NO-GO" gauge, and will not enter any hole which is smaller than the upper limit allowed. GO and NO-GO plugs are arranged at either end of a common handle.**

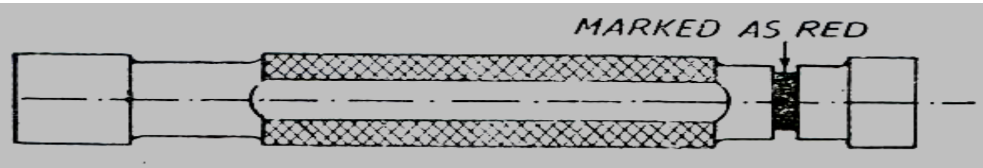


Fig. 4.29

(*ii*) 'Go' and 'No Go' plain plug gauges for sizes over 10 and upto 30 mm (Taper Inserted type). (Refer Fig. 4.30)

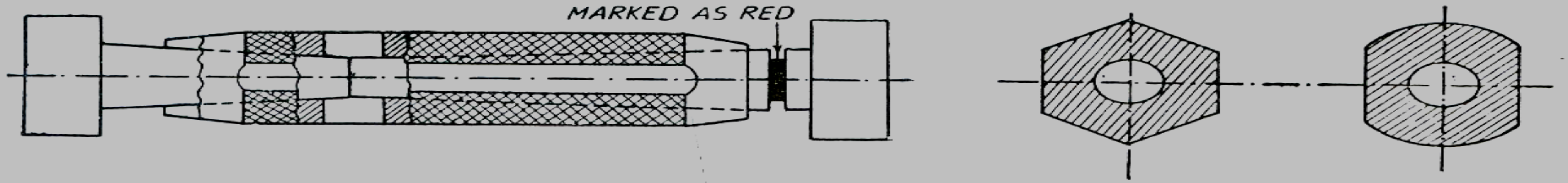


Fig. 4.30. Section of Handle.

(*iii*) 'Go' and 'No Go' plain plug gauges for sizes over 30 mm and upto 63 mm (Fastened type), (Refer Fig. 4.31).

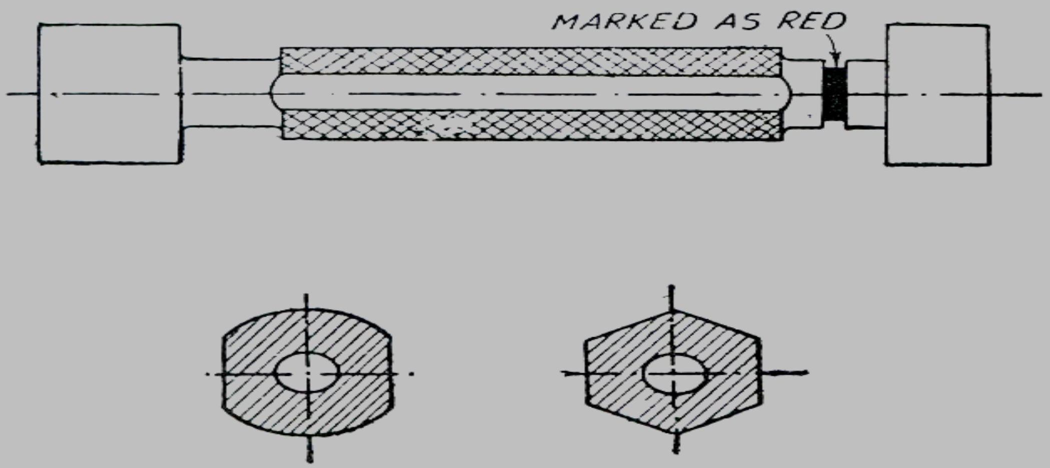


Fig. 4.31. Section of Handle.

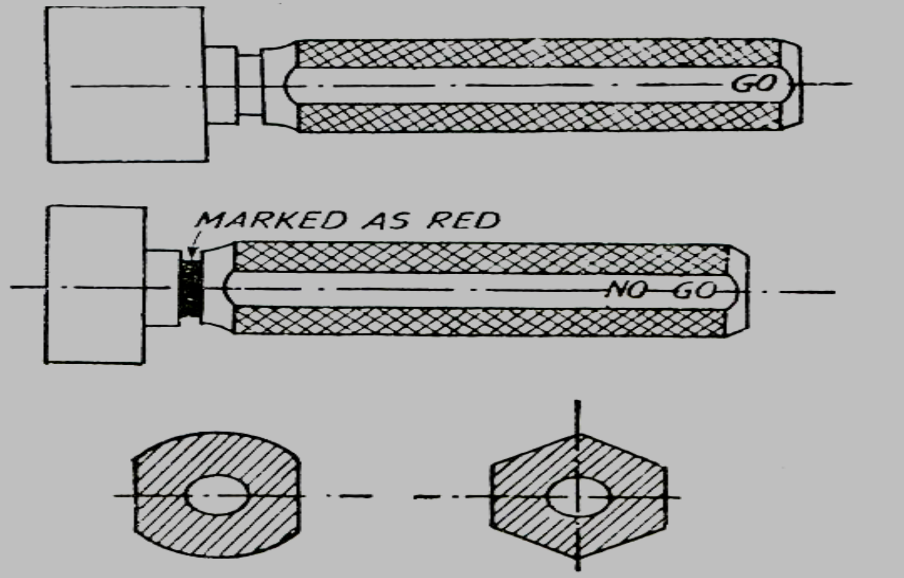
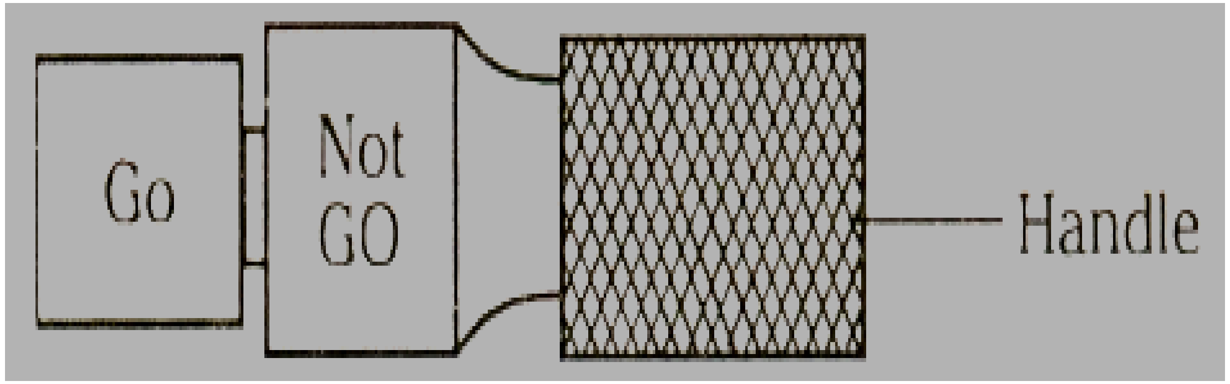


Fig. 4.32. Section of Handle.

PROGRESSIVE FORM OF PLUG GAUGE

- For smaller through holes, a progressive form of plug gauge as shown in Fig. is used.
- In this both the GO and NOGO gauges are on the same side separated by a small distance.
- First the GO portion is inserted into the hole. Further entry will be obstructed by the portion if NOGO of the hole is within the tolerance limits.



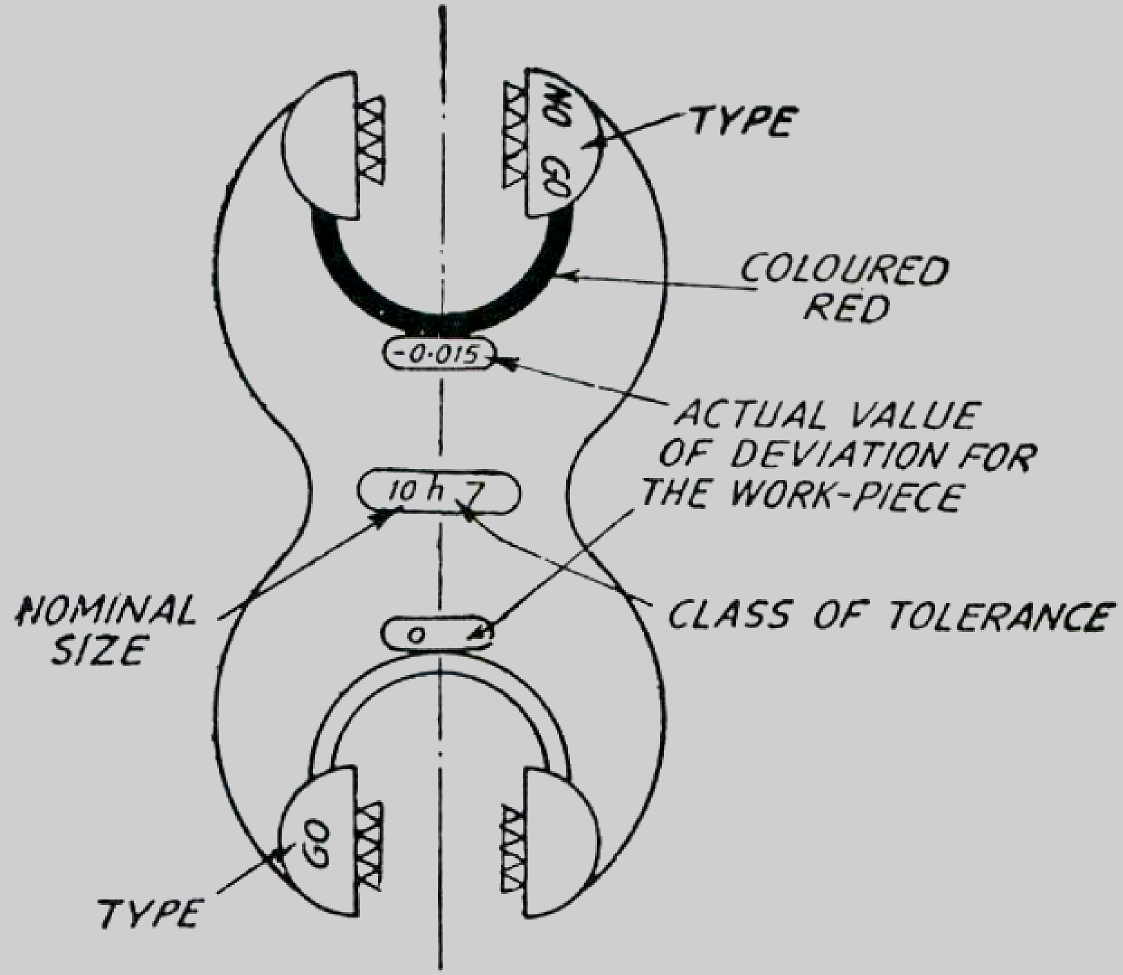

0
10 H7 工
+0.015
BAA94


GSG

SNAP GAUGES or GAP GAUGES

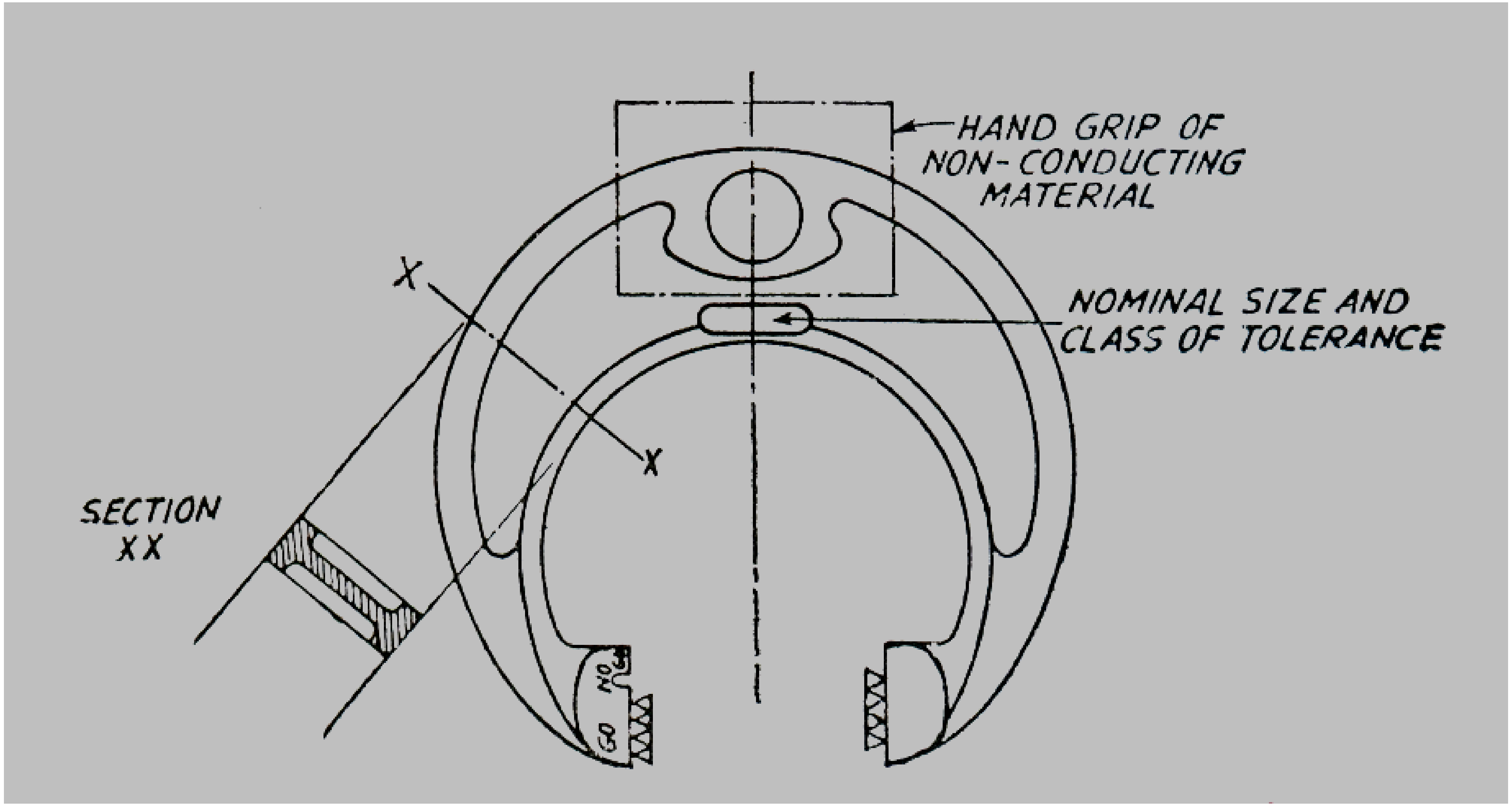
- In these gauges the gauging anvils can be adjusted endwise to suit any particular limit dimension required.
- Snap gauges are used for both cylindrical as well as non cylindrical work as compared to ring gauges which are conventionally used only for cylindrical work.
- Double ended snap gauges as shown in Fig. can be used for sizes ranging from 3 to 100 mm. For the sizes above 100 to 250mm a single ended progressive type snap gauge is used.

SNAP GAUGES or GAP GAUGES



'Go' and 'No Go' snap gauges for sizes over 3 mm and upto 100 mm.
Fig. 4.41

SNAP GAUGES or GAP GAUGES

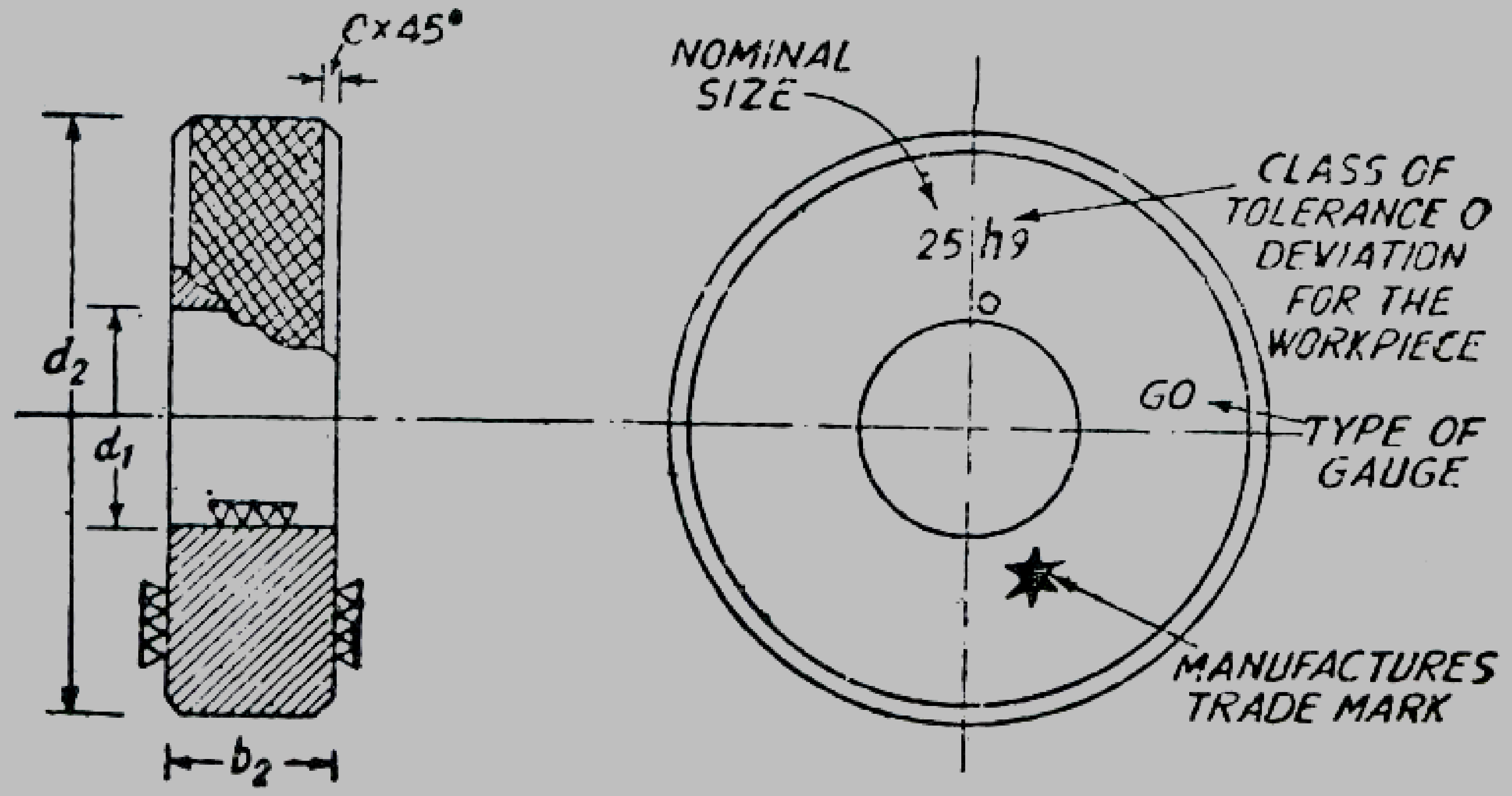


SNAP GAUGES

RING GAUGES

- These are used to check the dimensions of shafts
- They are in the form of a ring made with wear resistant steel and hardened to about 720HV
- These are available in two forms, GO and NO GO type

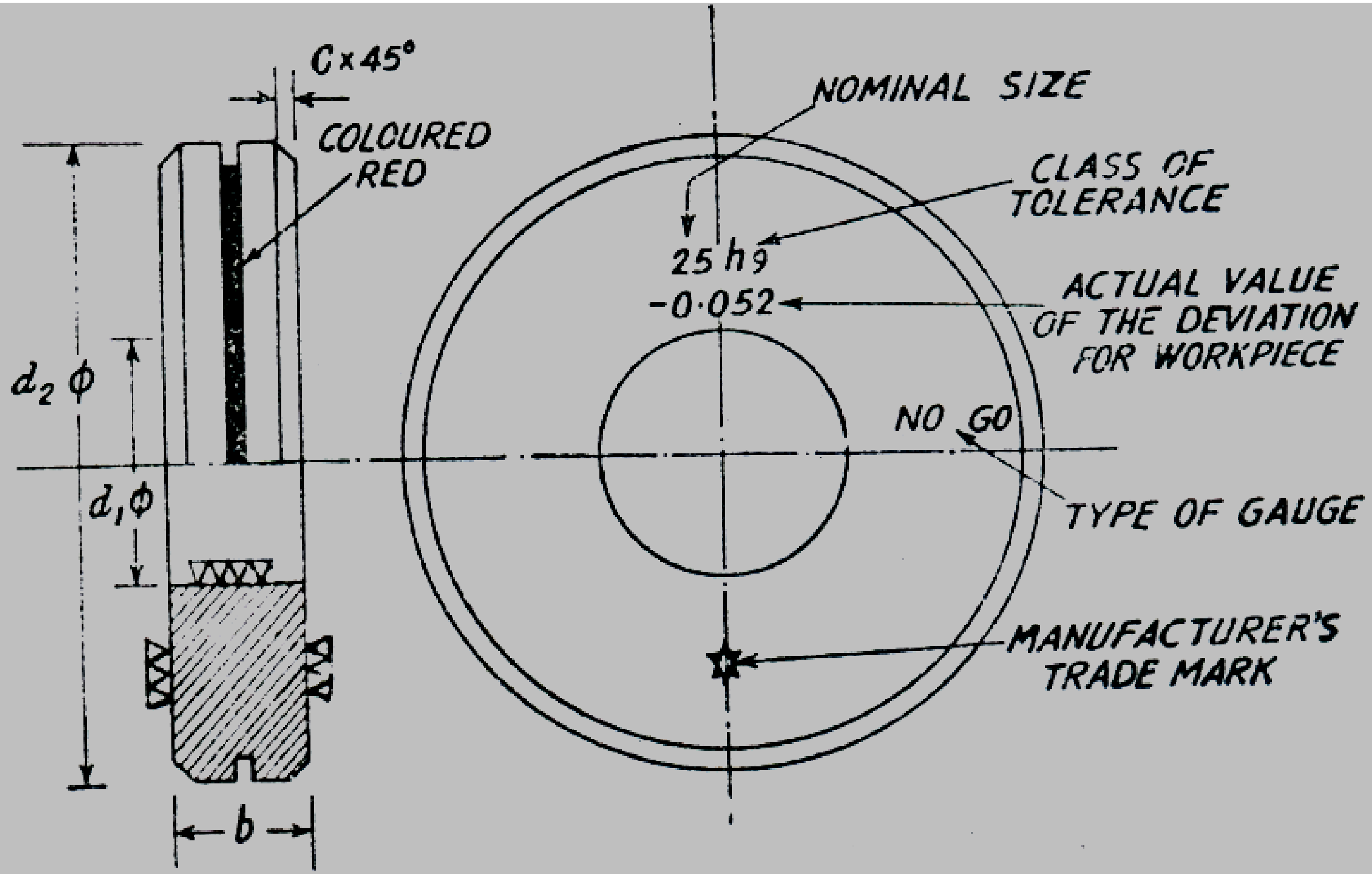
RING GAUGES



'Go' plain ring gauge for dimension d_1 from 3 to 70 mm in 10 steps

Fig. 4.37

RING GAUGES



'No Go' plain ring gauge for dimension d_1 varying from 3 to 70 mm in 10 steps.

RING GAUGES

INTRODUCTION TO COMPARATORS

- **All measuring instruments are comparators, ranging from a simple scale to a complex instrument.**
- **A comparator works on relative measurement, i.e. it gives only dimensional differences in relation to a basic dimension**
- **A comparator is an instrument used for the measurement of diameters or lengths on gauges and components, using slip gauge as a standard.**

- **All comparators irrespective of their type, usually consists of three basic features.**
  - **A sensing device which faithfully senses the input signal.**
  - **A magnifying or amplifying system to increase the signal to a suitable magnitude. Mechanical, optical, pneumatic, hydraulic and electronic methods are used for this purpose.**
  - **A display system (usually a scale and pointer) which utilizes the amplified signal to provide a suitable read out.**

NEED FOR A COMPARATOR

- Comparator is required in mass production and mass production would be impossible if component parts could not be produced to close dimensional tolerances.
- Where dimension must be checked with high degree of precision and speed in the mass production.
- Example : Piston
- When many dimensions are to be checked, in a very short time.
- For inspecting the newly purchased gauges

In short, Comparator is a device which

(1) Picks up small variations in dimensions.

(2) Magnifies it.

(3) Displays it by using indicating devices, by which comparison can be made with some standard value.

Characteristics of Good Comparators:

1. **It should be compact.**
2. **It should be easy to handle.**
3. **It should give quick response or quick result.**
4. **It should be reliable, while in use.**
5. **There should be no effects of environment on the comparator.**
6. **Its weight must be less.**
7. **It must be cheaper.**

8. It must be easily available in the market.

9. It should be sensitive as per the requirement.

10. The design should be robust.

11. It should be linear in scale so that it is easy to read and get uniform response

12. It should have less maintenance.

13. It should have hard contact point, with long life.

Characteristics or Basic Requirements of Comparators

1. The instrument must be of robust design and construction so as to withstand the effect of ordinary usage without impairing its measuring accuracy.

2. The indicating devices must be such that readings are obtained in least possible time.

3. The system should be free from backlash, wear effects and the inertia should be minimum.

4. Provision for maximum compensation to temperature effects.

5. **The scale must be linear and must have straight line characteristics.**

6. **The instrument must be versatile i.e., its design must be such that it can be used for a wide range of measurements.**

7. **The measuring pressure should be low and constant.**

8. **The indicator (pointer, liquid column etc) should be clear and free from oscillations.**

CLASSIFICATION OF COMPARATORS

- **Based on the design used for amplifying and recording the variations, the comparators are classified as**

1. **Mechanical comparators :** It works on gears pinions, linkages, levers, springs etc.
2. **Optical comparators :**Optical comparator works by using lens, mirrors, light source etc.
3. **Electrical and Electronic comparators :** Works by using step up, step down transformers and by b using amplifier, digital signal etc.
4. **Pneumatic comparators :** Pneumatic comparator works by using high pressure air, valves, back pressure etc.

1. **Fluid displacement comparators**

- Further the combination of magnifying principles has resulted in the development of following comparators

1. Mechanical - Optical comparators
2. Electro - Mechanical comparators
3. Multi - check comparators

- In addition, comparators of high sensitivity and magnification are as follows

1. The Brookes level comparator
2. The Eden - Rolt "millionth" comparator

MECHANICAL COMPARATORS

- **It is self controlled and no power or any other form of energy is required. It employs mechanical means for magnifying the small movement of the measuring stylus. The movement is due to the difference between the standard and the actual dimension being checked**

- **In mechanical comparators, the required magnification is obtained by using mechanical linkages, levers, gearing and other mechanical devices.**

- **Example of mechanical type of comparators:**
  - **Dial gauge**
  - **Reed comparator**
  - **Johansson Mikrokator**
  - **Sigma comparator**
  - **Eden-Rolt millionth comparator etc.,**

System of displacement amplifications used in Mechanical Comparators

1. **Rack and pinion:** **Measuring spindle integral with the rack, engages a pinion which amplifies the movement of plunger through a gear train.**

2. **Cam and gear train:** **In this case the measuring spindle acts on a cam which transmits the motion to the amplifying gear train**

3. **Lever with toothed sector:** **Here the lever with a toothed sector at its end engages a pinion in the hub of a crown gear sector which further meshes with a final pinion to produce the indication**

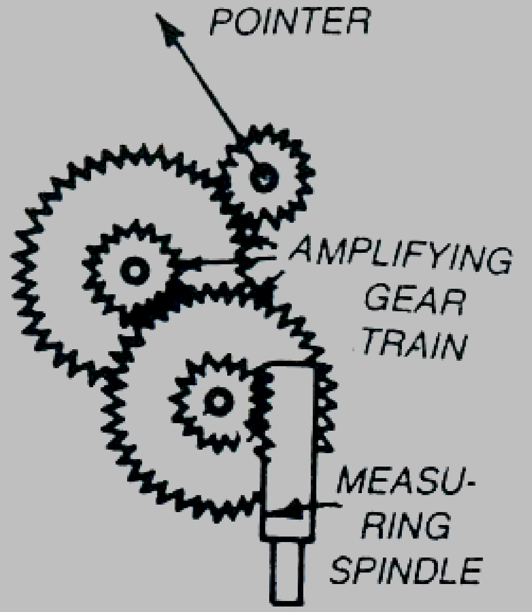


Fig. 5.1. Rack and pinion.

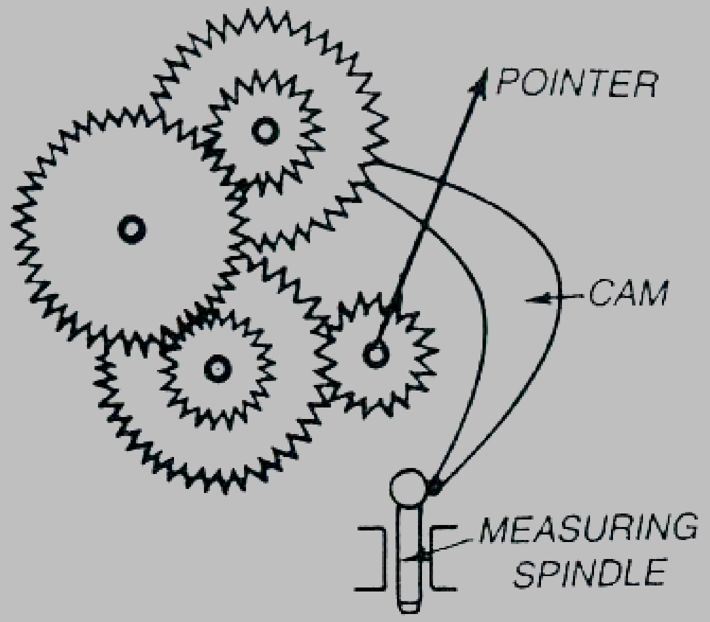


Fig. 5.2. Cam and gear train.

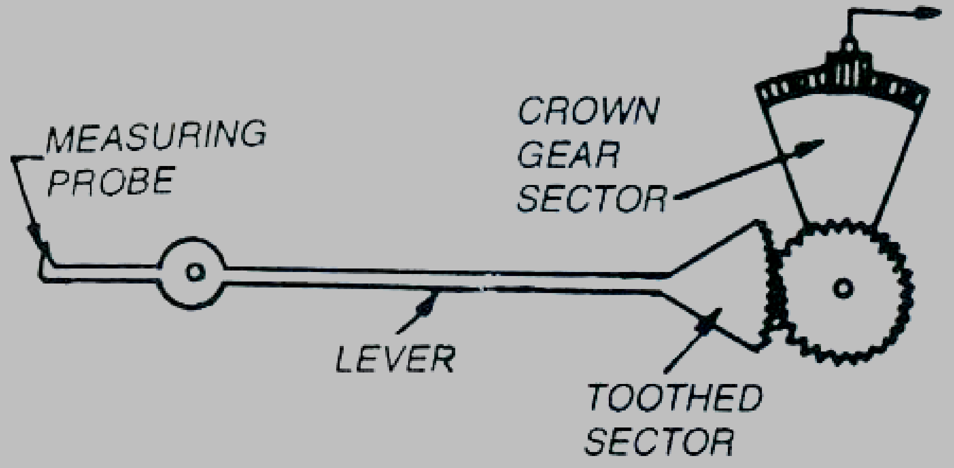


Fig. 5.3. Lever with toothed gear.

4. **Compound levers:** In this type the lever forming a couple with compound action are connected through segments and pinion to produce the final pointer movement

5. **Twisted taut strip:** The movement of the measuring spindle tilts the knee causing straining which further causes the twisted taut band to rotate proportionally.

6. **Lever combined with band wound around drum:** In this case the movement of the measuring spindle tilts the hinged block, causing the swing of the fork which induces the rotation of the drum

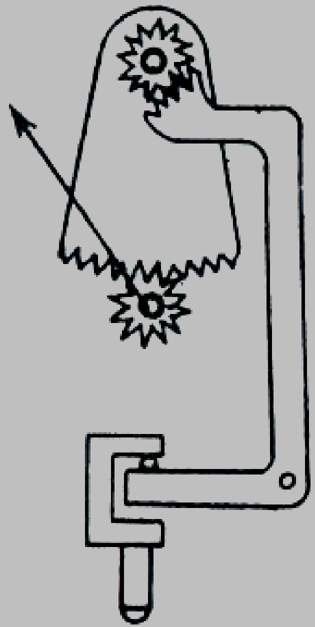


Fig. 5.4. Compound levers.

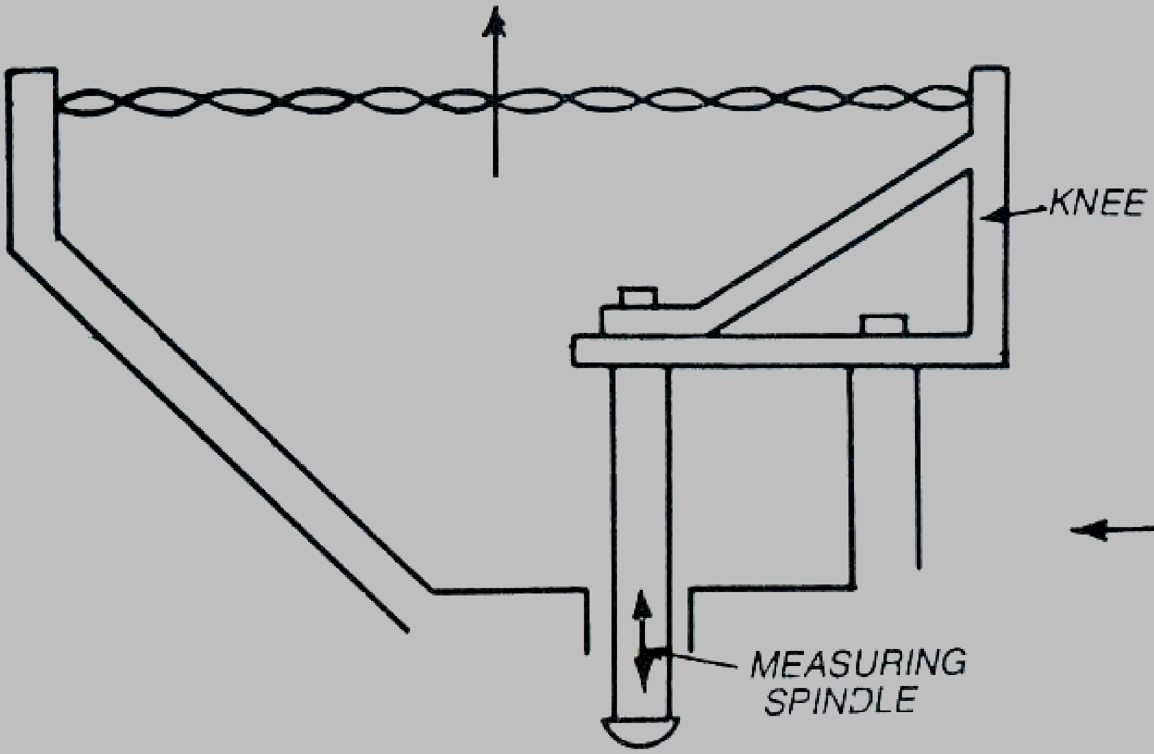


Fig. 5.5. Twisted taut strip.

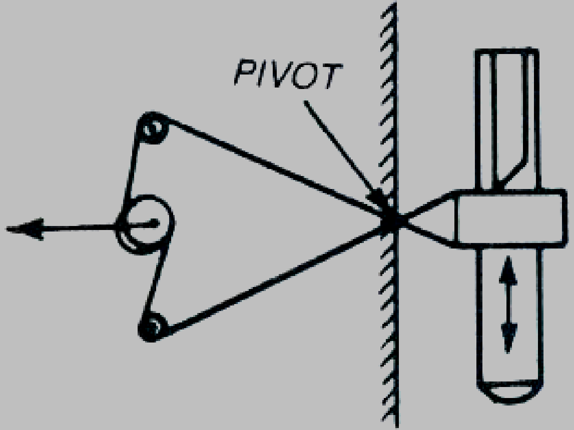


Fig. 5.6. Lever combined
with band wound around drum

JOHANSSON MIKROKATOR (ABRAMSON'S MOVEMENT)

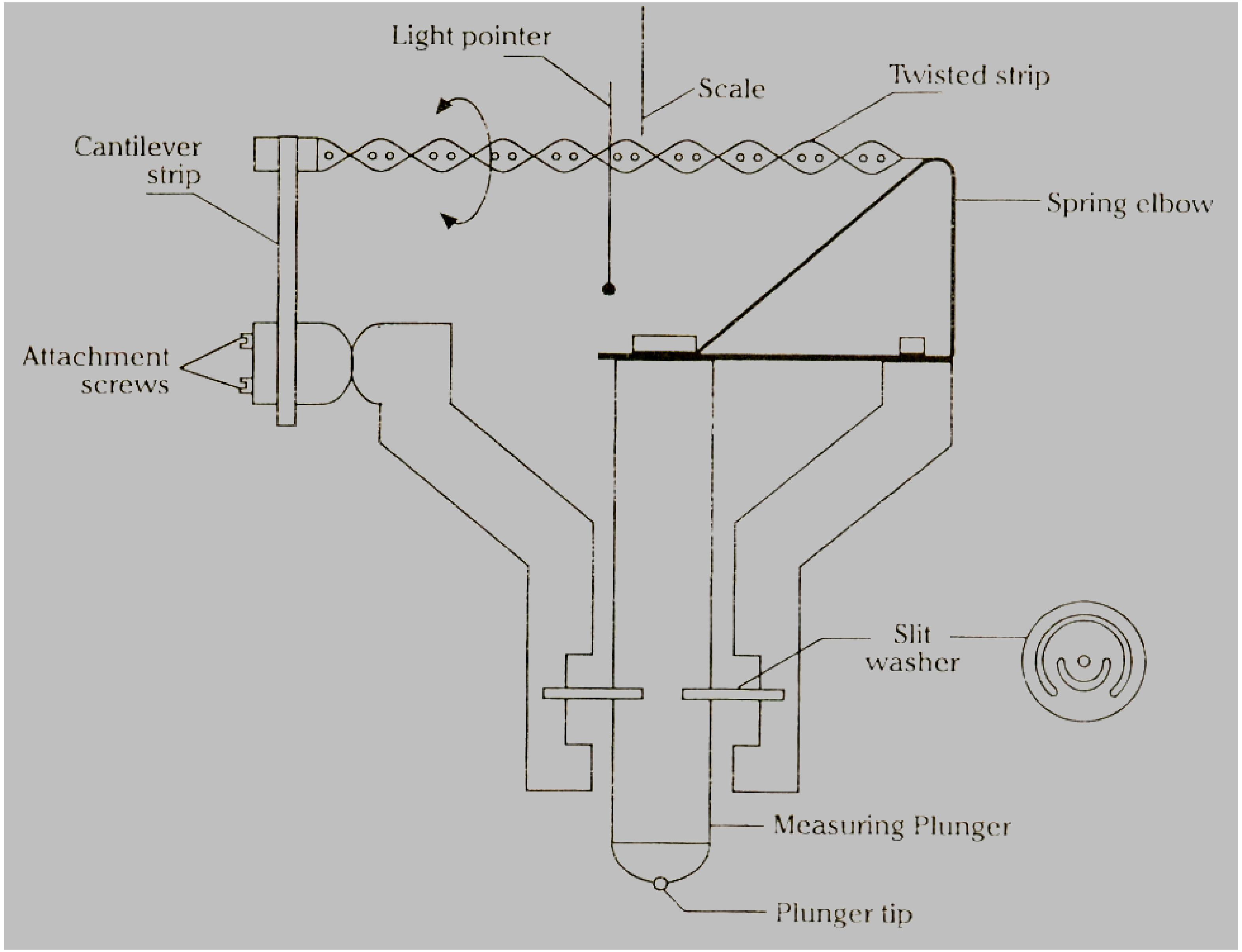
- This comparator uses the simplest and most smart method of obtaining the mechanical magnifications designed by H. Abramson.
- It works on the principle of a button spinning on a loop of string.
- A twisted thin metal strip carries a very light pointer made of thin glass at the centre of its length.
- The two halves of the strip from the centre are twisted in opposite directions so that any pull on the strip will cause the centre to rotate.

- **One end of the strip is fixed to an adjustable cantilever strip and the other end is anchored to the spring elbow, one arm of which is carried on the measuring plunger.**

- **As the measuring plunger moves either upwards or downwards, the elbow acts as bell crank lever and causes twisted strip to change its length thus making it further twist or untwist.**

- **Thus, the pointer at the centre of the twisted strip rotates by an amount proportional to the change in length of the strip and hence proportional to the plunger movement.**

- **The spring elbow is formed of flexible strips with a diagonal which is relatively stiff.**
- **The length of cantilever can be varied to adjust the magnification of the instrument.**
- **Since the centre line of the strip is straight even when twisted, therefore it is directly stretched by the tension applied to the strip.**
- **In order to prevent excessive stress on the central portion, the strip is perforated along the centre line.**
- **A slit washer is used for lower mounting of the plunger.**

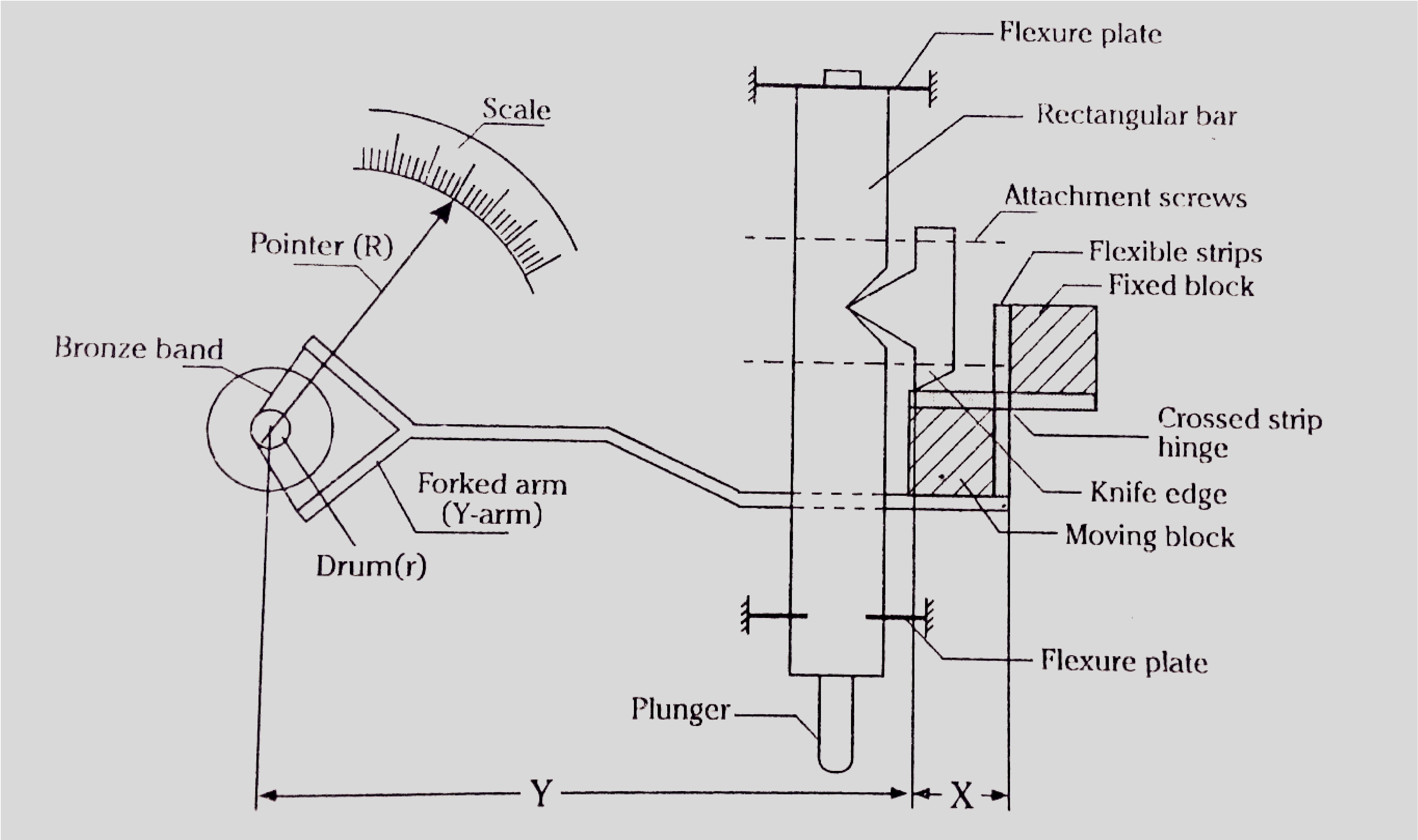

Light pointer
Scale
Twisted strip
Cantilever strip
Spring elbow
Attachment screws
Slit washer
Measuring Plunger
Plunger tip

- **The amplification of this comparator is given by,**
  - $d\theta/dl \;\alpha\; l/w^2n$
- **where,**
- θ is the twist at mid-point of the strip with respect to the ends
- l is the length of twisted strip measured along its neutral axis
- w is the width of the twisted strip and
- n is the number of turns
- **In order to increase the amplification of the instrument, a very long thin rectangular strip must be used.**
- **The magnification of this instrument is of the order of X5000.**

SIGMA COMPARATOR

- **Sigma comparator is an example of a mechanical comparator with magnifications in the range of X300 to X5000.**
- **The plunger is attached to a rectangular bar which is supported at its upper and lower ends by flexure plates.**
- **A knife edge is fixed to the side of the rectangular bar which stands on a moving block.**

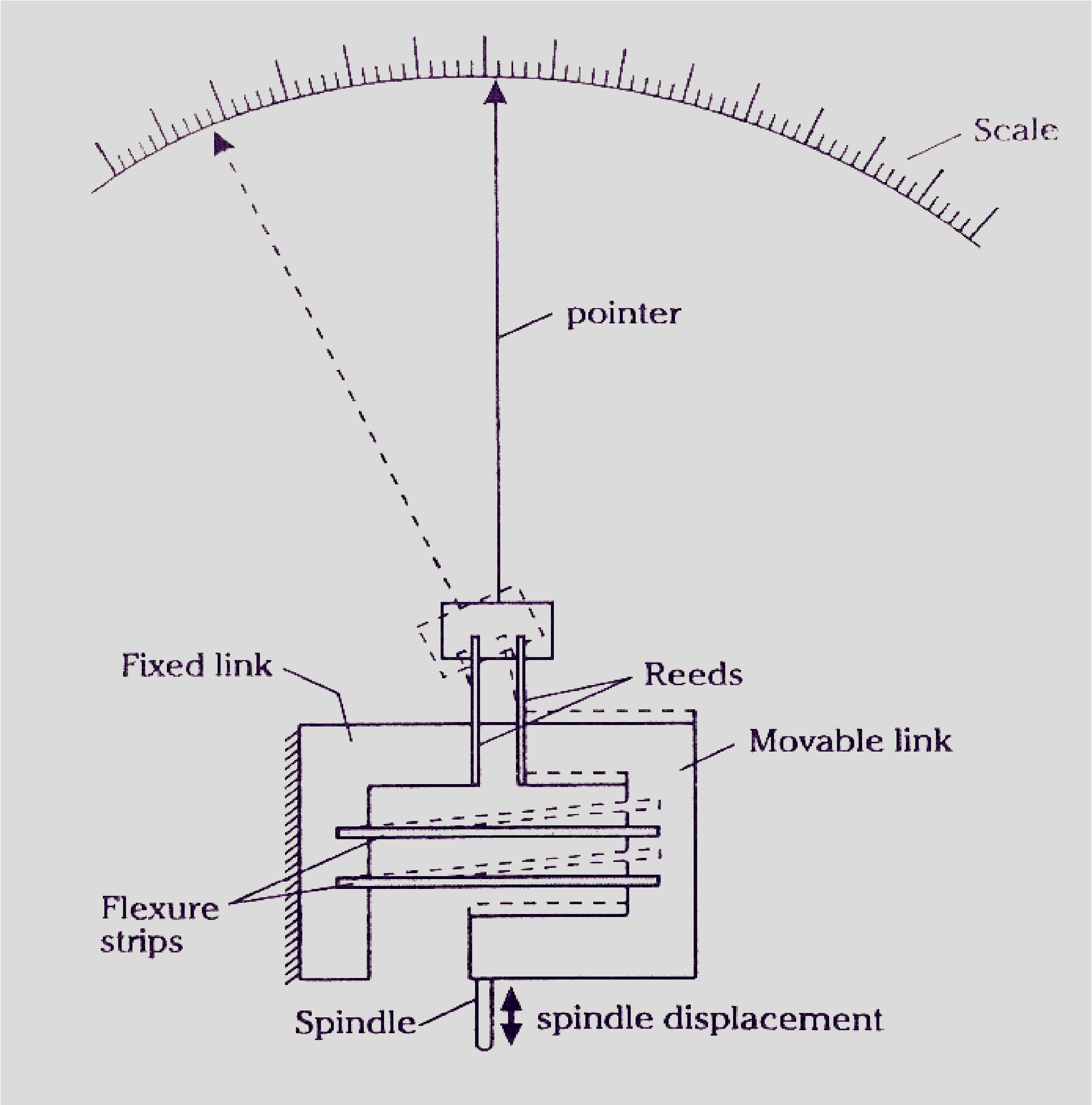
- **The moving block and the fixed block are connected by flexible strips at right angles to each other.**
- **If an external force is applied to the moving block, it would pivot about the line of intersection of the strips.**
- **This hinge is suitably pre-tensioned to allow it to rotate within the range of the instrument scale.**
- **A forked arm or Y-arm attached to the moving block transmits rotary motion to the indicator driving drum through a bronze band wrapped around the drum.**



Flexure plate
Scale
Rectangular bar
Attachment screws
Pointer (R)
Flexible strips
Fixed block
Bronze band
Crossed strip hinge
Forked arm (Y-arm)
Knife edge
Moving block
Drum(r)
Flexure plate
Plunger
Y
X

- **Magnification**: If Y is the length of the forked arm and "X" is the distance from the knife edge to the hinge, then the first stage magnification is Y/ x.
- If the pointer length is "R" and radius of the drum is "r" then the second stage of magnification is R/r.
- Hence the total magnification is given by
- M = Y/x * R/r
- The magnification preset by the manufacturer may be varied by adjusting the knife edge attachment screws.
- And another way to produce instrument of different magnification is to use drum of different radii "r" with a suitable strip.

REED TYPE MECHANICAL COMPARATOR



- **The reed mechanism is frictionless device for magnifying small motions of spindle.**
- **It consists of a fixed block A which is rigidly fixed to the gauge head case.**
- **The moving block B carries the input spindle and is connected to block A by reeds or flexible strips C.**
- **A vertical reed D attached to both blocks A and B carries a pointer.**

A linear motion of the spindle moves the moving block B vertically causing the vertical reed D to slide.

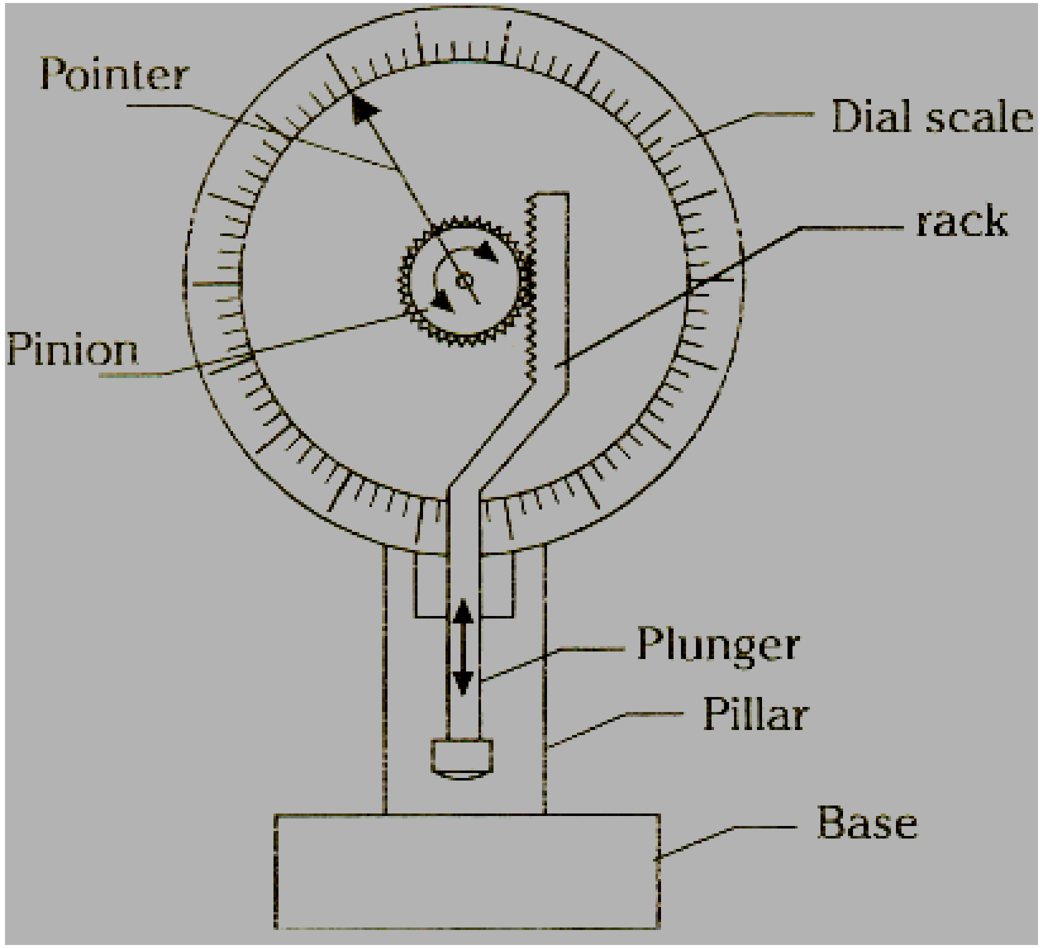
This movement causes the pointer to swing over the scale proportional to spindle movement and very much magnified.

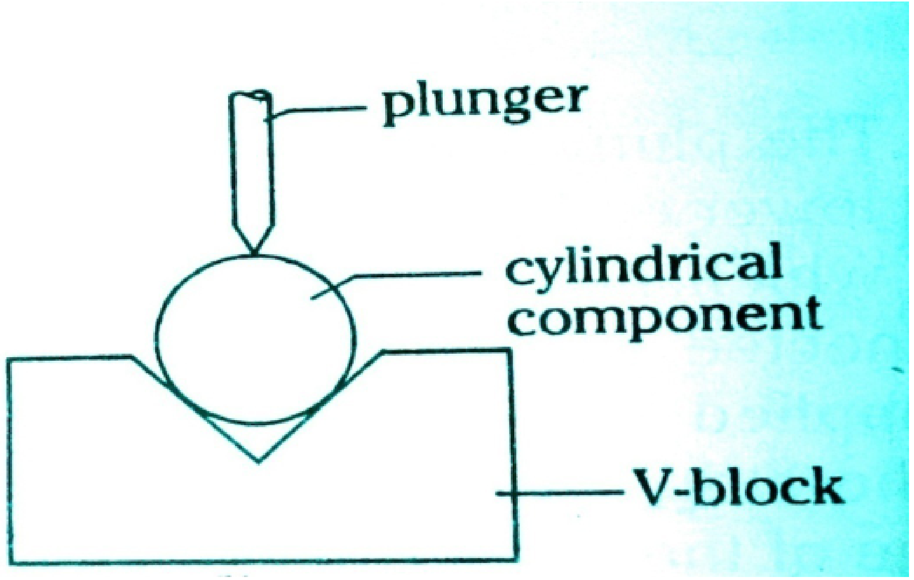
Reed comparators may have sensitivities of the order of 0.25 micron.

DIAL INDICATOR

- **It consists of a robust base whose surface is perfectly flat and a pillar carrying a bracket in which is incorporated a spindle fitted with a pinion and a dial scale.**
- **The linear movement of the plunger is magnified by means of a rack and pinion train into sizable rotation of the pointer on the dial scale.**
- **The dial scale is set to zero by the use of slip gauges representing the basic size of the part.**

- **This is generally used for inspection of small precision machined parts.**
- **This type of comparator can be used with various attachments so that it may be used for large number of works.**
- **For example, with a V-block attachment, it can be used for checking out-of-roundness of a cylindrical component.**


Pointer
Dial scale
rack
Pinion
Plunger
Pillar
Base


plunger
cylindrical component
V-block

Advantages of Mechanical Comparators

- **Mechanical comparators are usually cheaper when compared to other amplifying devices.**
- **Mechanical comparators do not require any external sources such as electricity.**
- **Usually the mechanical comparators have linear scale.**
- **They are robust and easy to handle.**

Disadvantages

- The mechanisms used in mechanical comparators have more inertia and this may cause them to be sensitive to vibrations.
- Any wear, play, backlash or dimensional faults in the mechanical devices used will also be magnified.
- The range of these instruments is limited, because the pointer moves over a fixed scale.
- It is very difficult to incorporate an arrangement for adjusting the magnification.

Optical Comparators

- These obtain large magnifications by the use of optical principles.
- All optical comparators works on one of the following two main principles
    - The use of the optical lever
    - The use of enlarged image
- Optical comparators are capable of giving high degree of measuring precision.

- **Due to the reduction of moving members they possess better wear resistance qualities than mechanical types.**
- **Also the inherent disadvantages found with the mechanical comparators, such as weight, bending properties, friction etc., are overcome by optical comparators.**

Principle of Optical Lever

- If a beam of light is directed on to a mirror, it will be reflected onto the screen at 0 as a dot.
- The angle θ at which the beam strikes the mirror is equal to the angle θ at which the beam is reflected from the mirror.
- When the plunger moves upwards vertically, causing the mirror to tilt by an angle 'α' , then the reflected light beam moves through an angle "2α" which is twice the angle of tilt produced by the plunger movement.
- The illuminated dot moves to "B" thus a linear movement "h" of the plunger produces a movement of the dot equivalent to the distance OB on the screen.
- It is also clear that as the distance of the screen from the tilting mirror increases, greater will be the magnification and is called the principle of enlarged image.

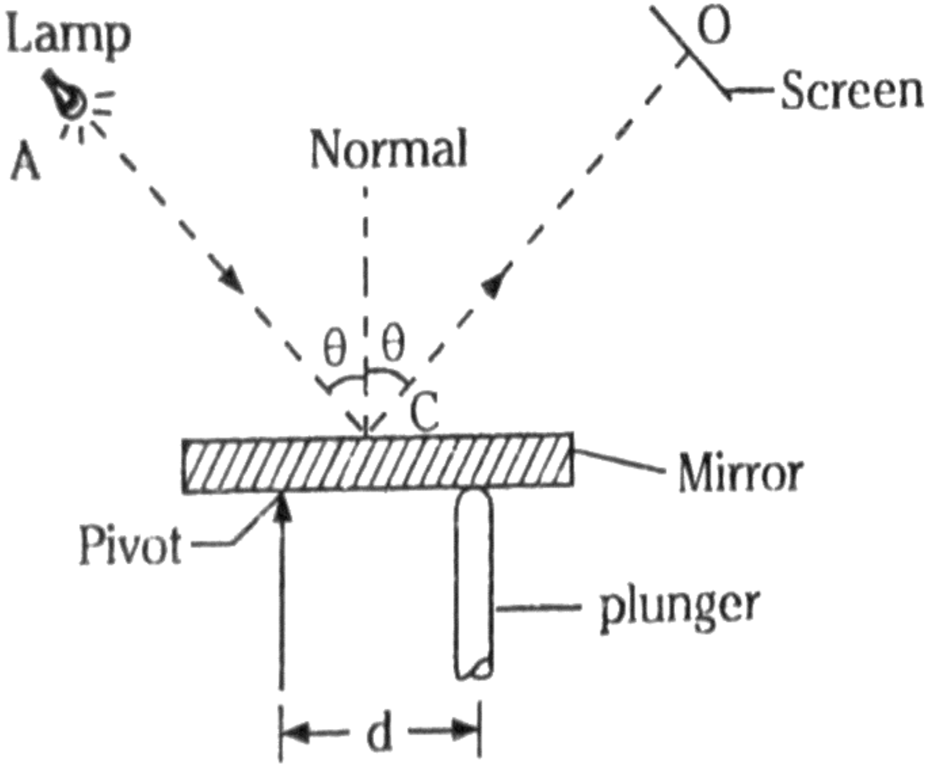

Lamp
A
Normal
O
Screen
θ
θ
C
Mirror
Pivot
plunger
d

Fig. (a)

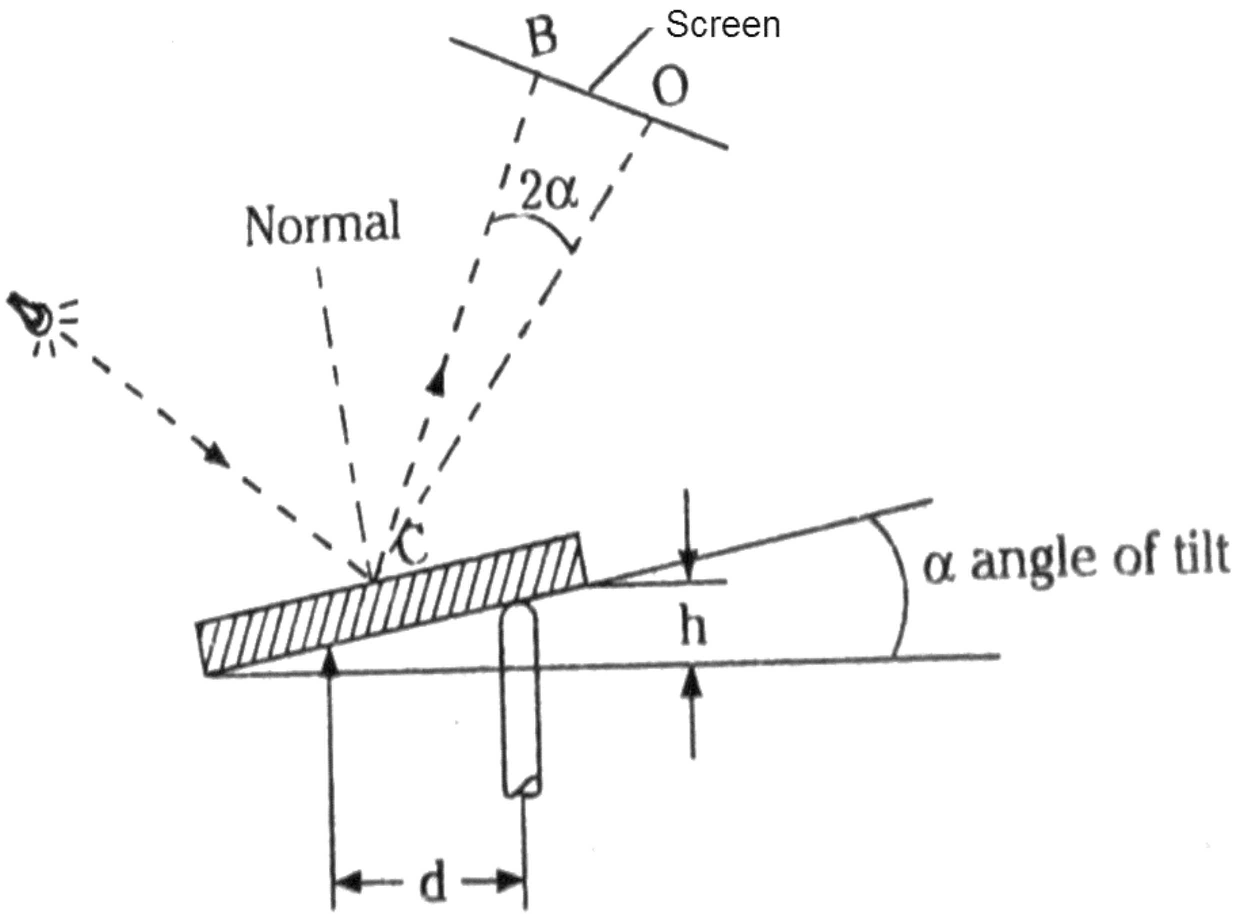

B
Screen
O
2α
Normal
C
α angle of tilt
h
d

Fig. (b)

- **In mechanical - optical comparators as shown, small displacements of the measuring plunger are amplified first by a mechanical lever.**
- **The amplified mechanical movement is further amplified by an optical system involving the projection of an image.**
- **The mechanical lever causes the mirror to tilt about mirror pivot and the image of the index is projected on a scale on the inner surface of a glass screen.**
- **The overall magnification of this system = $2 \times (l_2/l_1)(l_4/l_3)$**

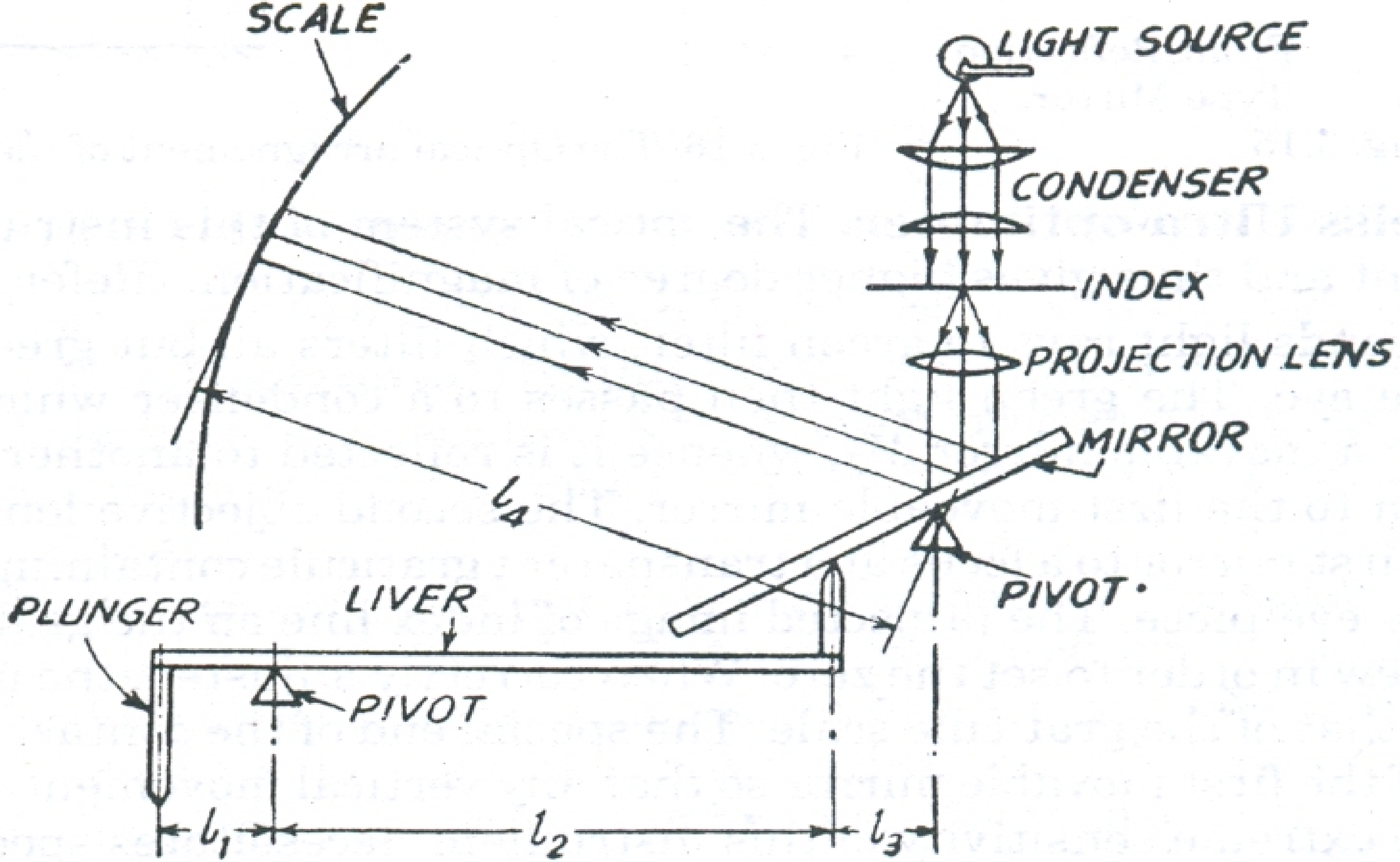


Fig. 5.14. Principle of Optical Comparator.

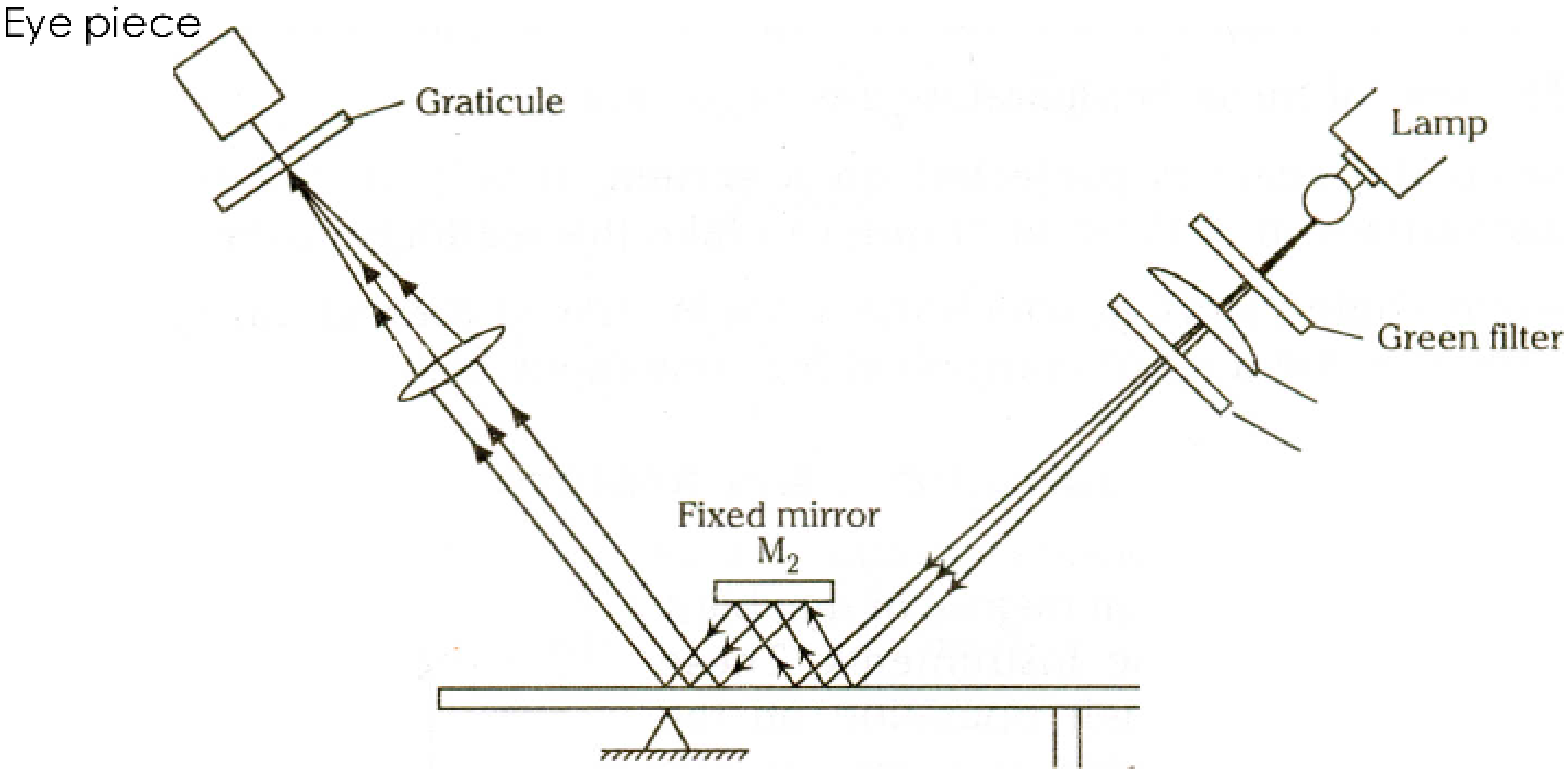

DORSEY
METROLOGY INTERNATIONAL
BENCHMARK 16H
Made in USA
X -0.3570
Y 0.1995
Q 0°00'
DORSEY
Made in USA


DELTRONIC

Zeiss Ultra - Optimeter

- **The optical system of this instrument involves double reflection of light and thus gives higher degree of magnification.**
- **A lamp sends light rays through green filter to filter all rays except green light, which causes less fatigue to eye.**
- **The green light then passes through a condenser which via an index mark projects it on to a movable mirror M1.**
- **It is then reflected to another fixed mirror M2 and back again to the first movable mirror M1.**
- **The objective lens brings the reflected beam from the movable mirror to a focus at a transparent graticule containing a precise scale which is viewed by the eye-piece.**

- **The projected image of the index line on the graticule can be adjusted by means of a screw in order to set the initial zero reading.**
- **When correctly adjusted, the image of the index line is seen against that of the graticule scale.**
- **The end of the contact plunger rests against the other end of the first movable mirror so that any vertical movement of the plunger will tilt the mirror.**
- **This causes a shift in the position of the reflected index line on the eye piece graticule scale, which in turn measures the displacement of the plunger.**



Eye piece
Graticule
Lamp
Green filter
Fixed mirror
M2

Advantages of Optical Comparators

- Optical comparators have few moving linkages and hence are not subjected to friction and consequent wear and tear. This results in high accuracy of measurement.
- The scale can be made to move past a datum line and thus have high range of measurements and no parallax error.
- The magnification is usually high.
- Optical lever is weightless

Disadvantages

- **Heat from the source of light, transformers etc., may cause the setting to drift.**
- **An electric supply is necessary to operate these type of comparators.**
- **The size of these comparators are large, and costly.**
- **Since the scale is projected on a screen, it is essential to use these instruments in dark room in order to take the readings easily.**
- **Some comparators in which the scale is viewed through an eye piece of a microscope are not convenient for continuous use.**

ELECTRICAL COMPARATORS

- These possess a minimum number of moving parts and hence a high degree of reliability can be expected from these instruments.
- These comparators depend for their operation on the principle of Wheatstone bridge
- For the bridge to balance, the ratio of the resistances in each pair of arms must be equal
- In D.C circuit, electrical resistance in each arm is caused by a change of balance of the displacement of an armature relative to the arm under the action of measuring plunger
- But if alternating current is applied to such a bridge, the inductance and capacitance of the arms must be taken into account in addition to their resistances.

- **In the actual measuring instruments as shown, one pair of inductances takes the form of a pair of coils in the measuring head of the instrument.**
- **An iron armature inside these coils moves along with the measuring plunger, and, if the circuit is already balanced, upsets this balance and causes a deflection of the pointer of the meter.**
- **The meter is calibrated directly in linear units corresponding to the plunger movement.**
- **Commonly used instruments of this type are electro limit, electricator, electrigage etc.**
- **Magnifications of the order of 30,000 are possible with these systems.**

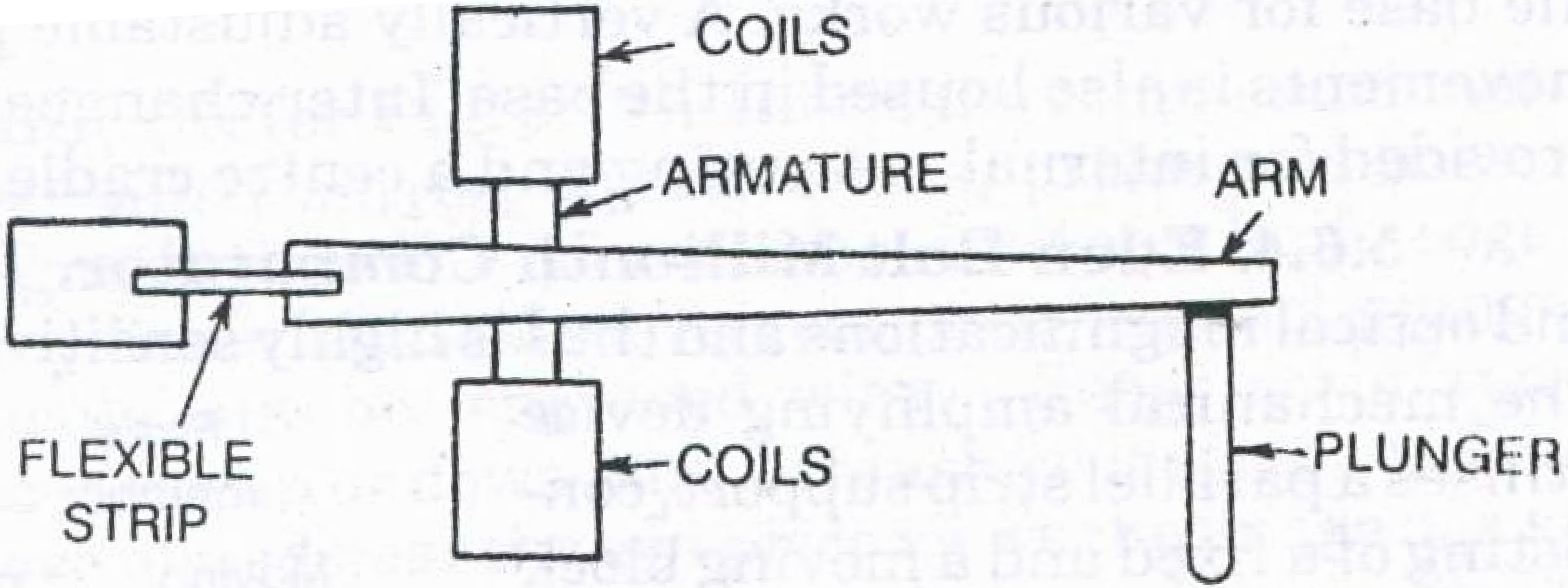


Fig. 5.20. Electrical comparator based on a.c. bridge.

Advantages of Electrical and Electronic Comparators

- **The measuring unit can be remote from the indicating instrument.**
- **These comparators have high magnifications with less number of moving parts.**
- **The mechanism carrying the pointer is very light and not sensitive to vibration.**
- **The measuring unit is compact and can have several magnifications.**

Disadvantages

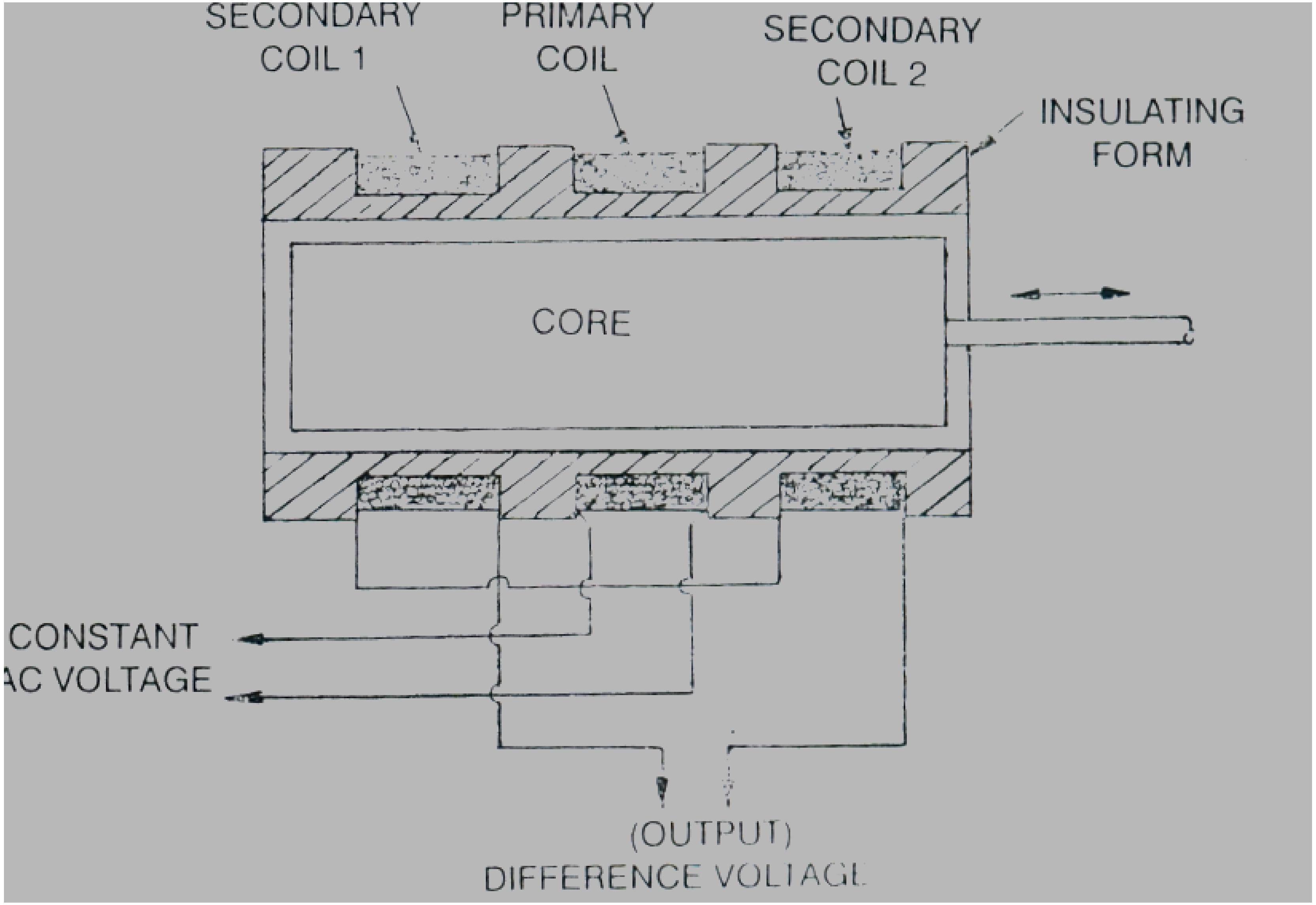
- **These comparators require an external source of energy to operate i.e., an A.C electric supply. Thus, the fluctuations in voltage or frequency of electric supply may affect the results.**
- **Heating of coils in the measuring unit may cause zero drift and alter the calibration.**
- **If a fixed scale is used with a moving pointer, then with high magnifications a very small range of measurement results.**
- **Electrical and Electronic comparators are more expensive than mechanical comparators**

Linear Variable Differential Transformer (LVDT)

- Linear variable differential transformer is the most popular electro-mechanical device used to convert mechanical displacement into electrical signal.
- In effect, it is a differential transformer consisting of three symmetrically spaced coils.
- It works on the principle of mutual inductance.

- **The centre coil is energized from an external A.C power source and the two end coils are connected together in phase opposition which in turn are used as pick up coils.**
- **The output amplitude and phase depends on the relative coupling between the two pick up coils and the power coil.**
- **The relative coupling is in turn depends upon the position of the core. If the core is centered in the middle of the two secondary windings, then the voltage induced in each secondary winding will be identical, 180 degree out of phase and net output will be zero.**

- **If the core is moved off the middle position then the mutual inductance of the primary with the secondary will be greater than the other and the differential voltage will appear across the secondary in series.**
- **A typical differential transformer characteristics obtained by plotting the output voltages Vs core displacements.**
- **With in the limits on either side of the null position, the core displacements results in a proportional output.**
- **The linear range depends upon the length of the secondary coils.**



SECONDARY COIL 1
PRIMARY COIL
SECONDARY COIL 2
INSULATING FORM
CORE
CONSTANT AC VOLTAGE
(OUTPUT) DIFFERENCE VOLTAGE

Advantages

- It can be used as a primary detector transducer, since it converts a mechanical displacement into electrical voltage.
- LVDT can't be over loaded mechanically since the core is completely separable from the rest of the equipment.
- It is relatively insensitive to high or low temperatures and to temperature changes.
- It provides a comparatively high output which can be used without intermediate amplification.
- It is reusable and of reasonable cost.

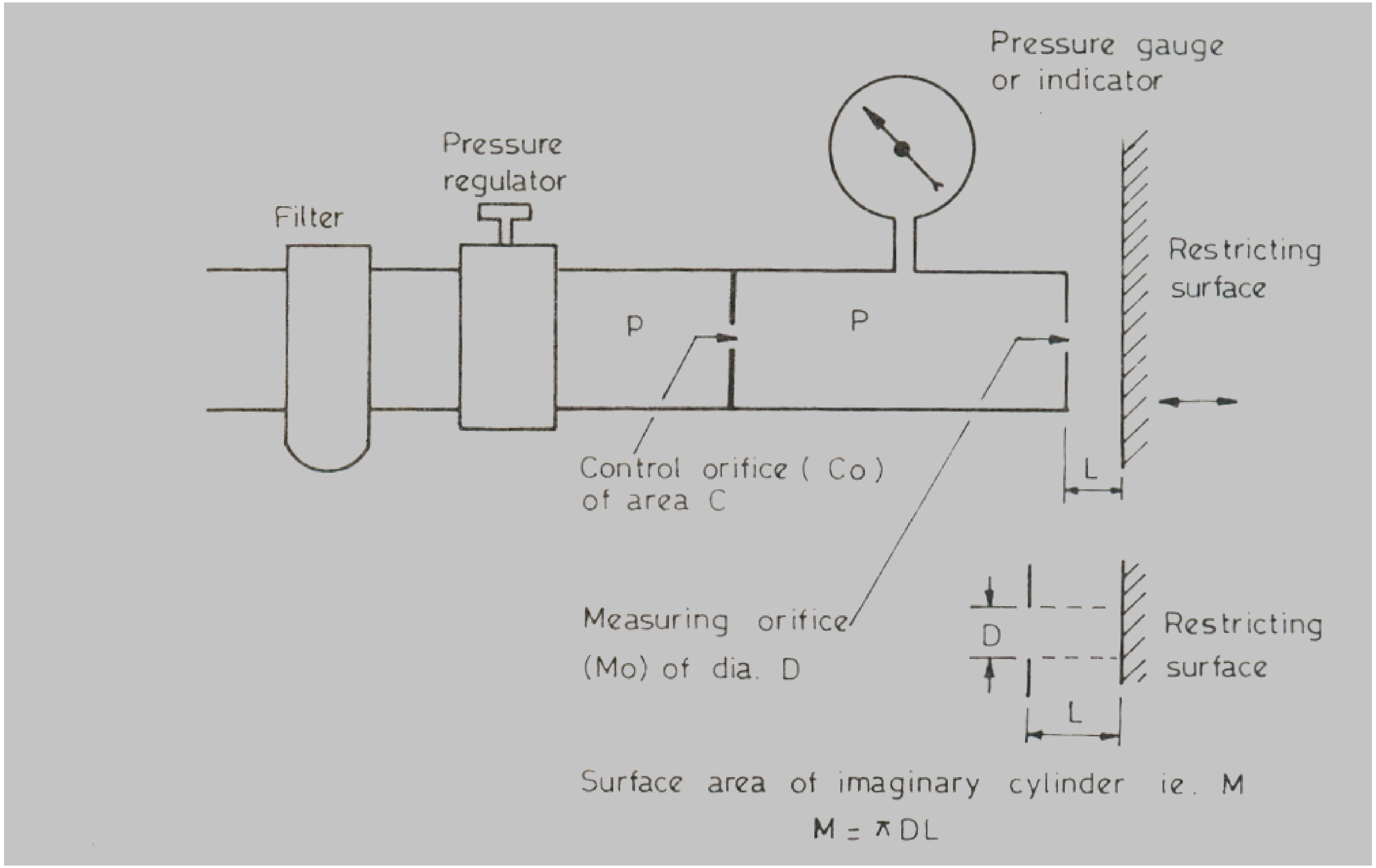
Disadvantages

- **It can't be widely used in the area of dynamic measurement since the core is of appreciable mass compared with the mass of a strain gauge.**
- **If 60 cps supply voltage is used then it becomes a limiting factor as for as dynamic measurement is concerned.**
- **If the direction from the null point is to be indicated then the advantage of sample circuit arrangement is lost.**

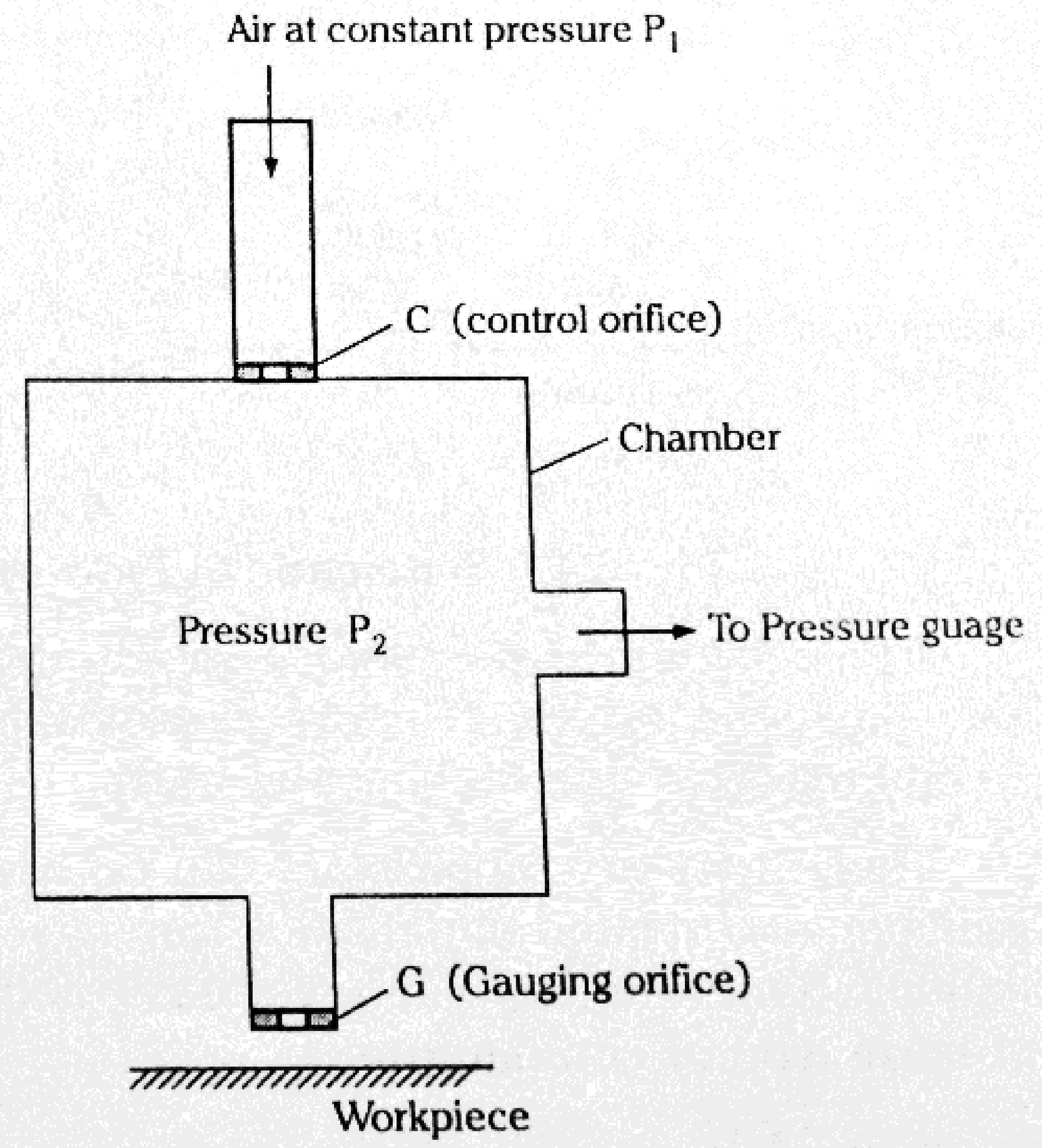
PNEUMATIC COMPARATORS

- **In pneumatic comparators air is used as a means of magnification.**
- **Pneumatic comparators works on the principle of an air jet.**
- **When air jet is in close proximity with a surface, the flow of air out of that jet will be restricted. This will result in a change of pressure in the system, supplying the jet.**

- **A chamber is fitted with control orifice C and a measuring orifice D, through which the air flows from a supply at constant pressure P_1.**
- **If the size of the control orifice C remains constant, any variation in the size of the gauging orifice D will cause an alteration in the pressure P_2 in the chamber.**
- **This pressure variation is measured by a pressure gauge of suitable sensitivity, which may be a manometer, Bourdon-type gauge or bellows, and graduated to read in linear units.**
- **The size of the gauging orifice (D) varies as the distance of the workpiece from the gauging orifice (D) alters.**



Pressure gauge
or indicator
Pressure
regulator
Filter
Restricting
surface
P
P
Control orifice (Co)
of area C
L
Measuring orifice
(Mo) of dia. D
D
Restricting
surface
L
Surface area of imaginary cylinder ie. M
M = π DL


Air at constant pressure P1
C (control orifice)
Chamber
Pressure P2
To Pressure guage
G (Gauging orifice)
Workpiece


HX601D精密数字压力表
00000
(0~60)MPa
0
1
2
3
4
5
6
MPa
MC
天津万达德斯特

Systems of Pneumatic Comparators

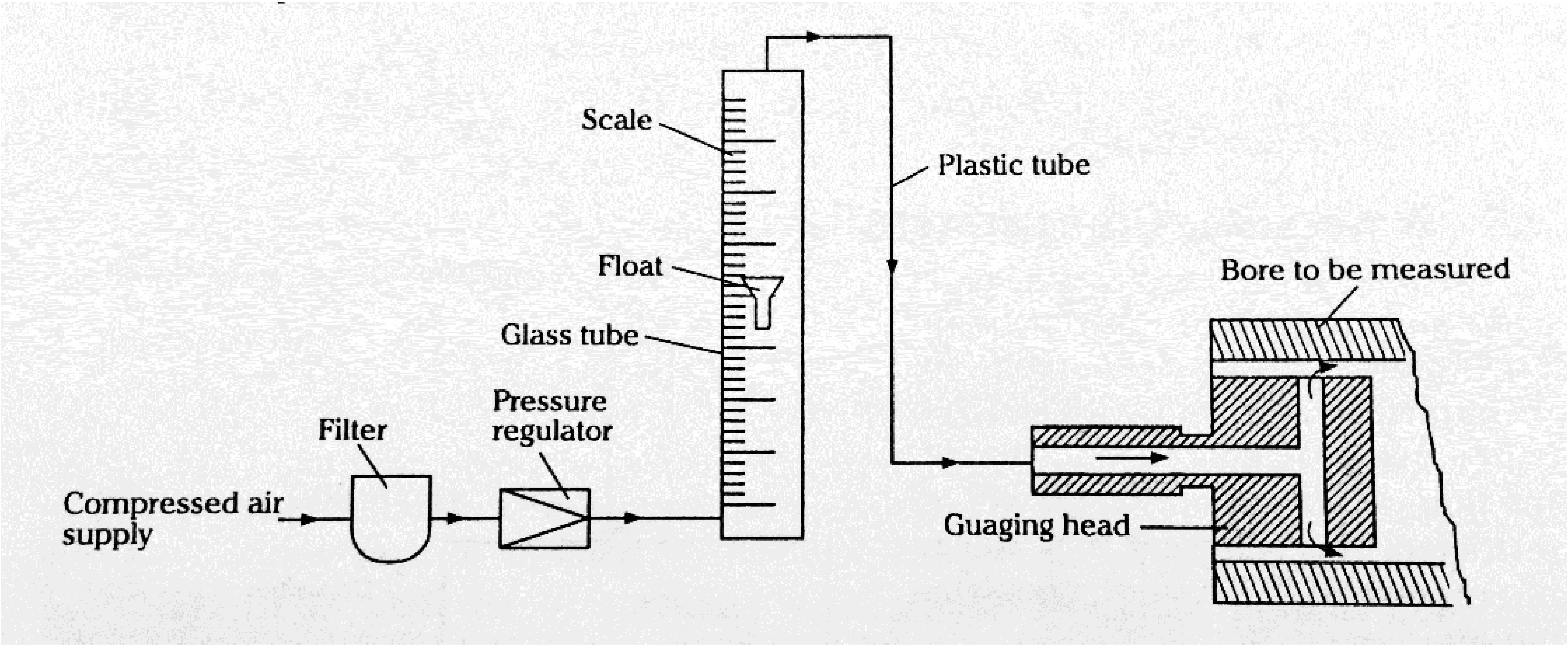
Based on the physical phenomenon on which the pneumatic comparators works, they are classified as,

(a) **Flow or velocity type**

(b) **Back pressure type**

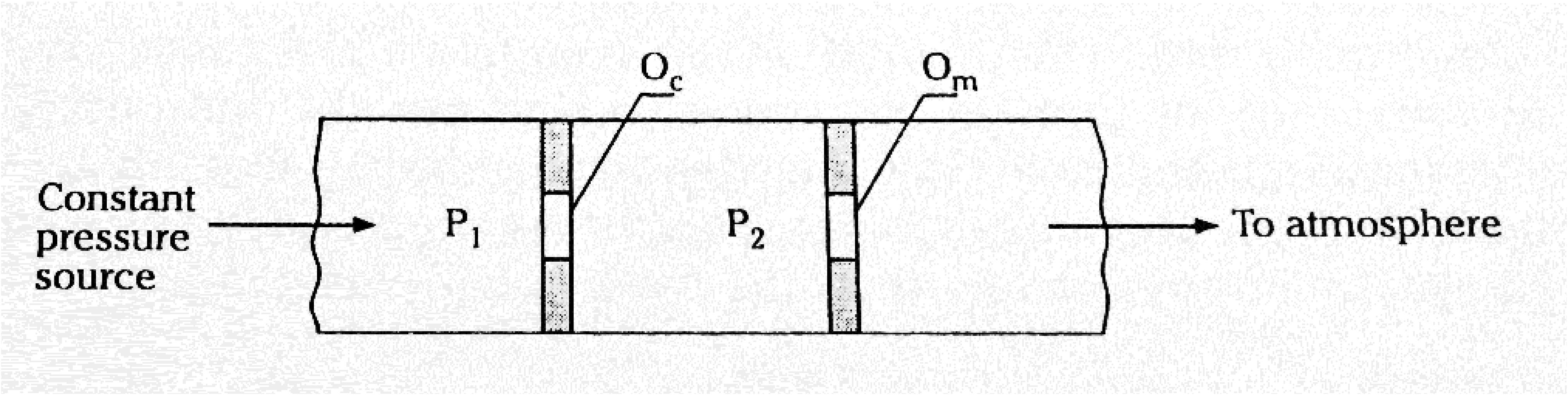
Flow or Velocity Type Comparator

- **Flow or velocity type of pneumatic comparators operate by sensing and indicating the momentary rate of air flow.**
- **In this case the compressed air after the filtering and pressure regulating unit flows through a glass tube containing a small metal float**
- **The compressed air then flows through a plastic tube to the gauge head having two diametrically opposite orifices for the air to escape.**
- **The position of the float depends upon the amount of air flowing through the gauge head, which in turn depends upon the clearance between the bore to be measured and the gauging head.**

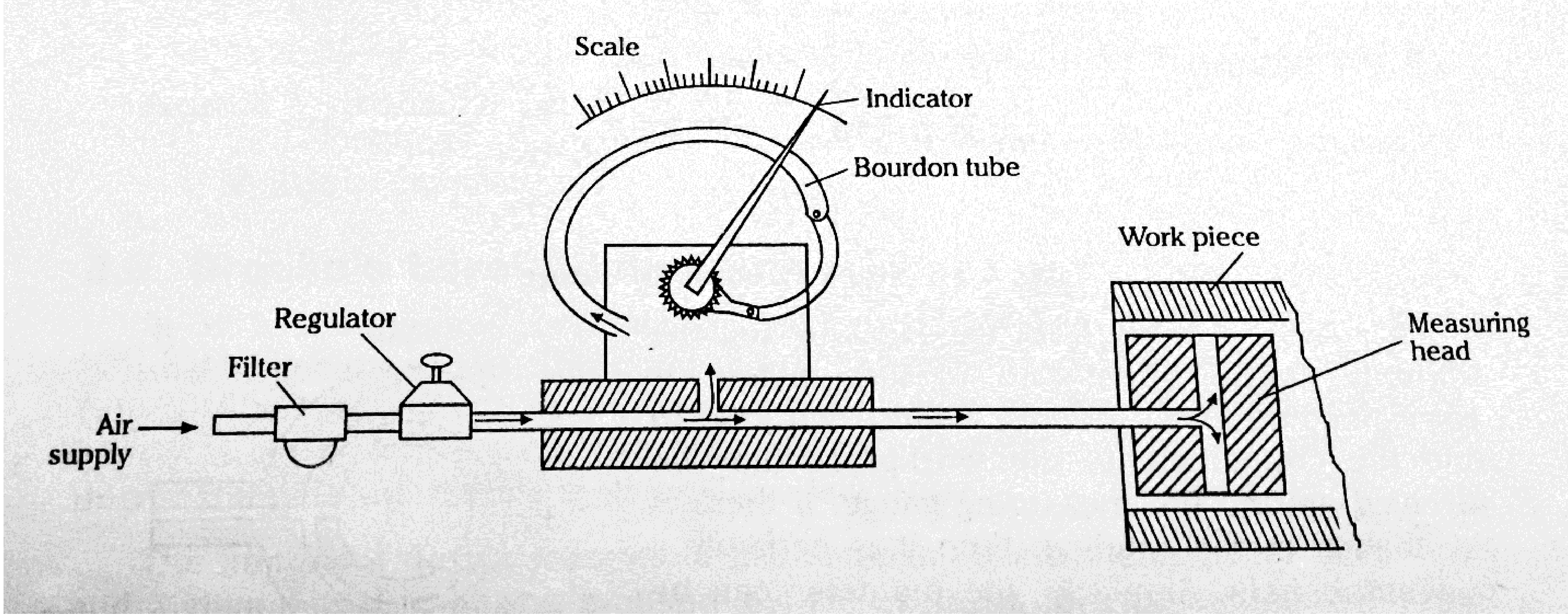

Scale
Plastic tube
Float
Glass tube
Bore to be measured
Pressure
regulator
Filter
Compressed air
supply
Guaging head

Back Pressure Type Pneumatic Comparators

- **The principle of pneumatic gauging in the back pressure type comparator is as follows**
- **Air from a constant pressure source flows to the atmosphere through two orifices O_c and O_m as shown in the figure.**
- **P_1 is the pressure on the upstream of the first orifice and P_2 is the pressure between the two orifices.**
- **The relationship between P_1 and P_2 depends upon the relative sizes of the two orifices.**
- **P_2 becomes equal to P_1 when O_m is blocked and tends to zero as O_m is increased indefinitely.**



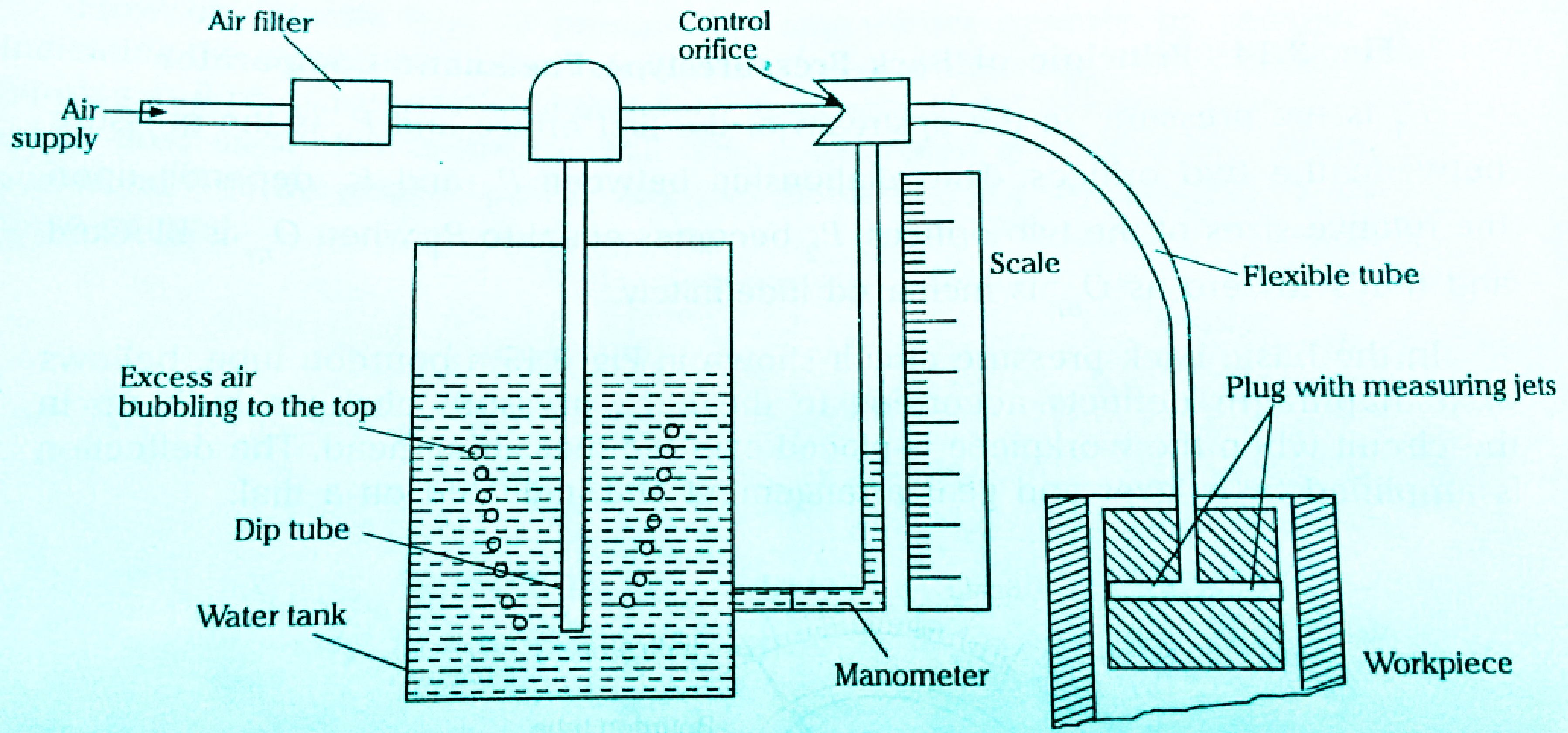
- **In the basic back pressure circuit shown a bourdon tube, bellows or a diaphragm deflects according to the back pressure changes built up in the circuit when the workpiece is placed over the measuring head.**
- **The deflection is amplified by a lever and gear arrangement and indicated on a dial.**


Scale
Indicator
Bourdon tube
Work piece
Measuring head
Regulator
Filter
Air supply

Solex Pneumatic Gauge

- **The solex company has marketed a device employing a water manometer for the indication of back pressure.**
- **It consists of a water tank in which water is filled up to a certain level and a dip tube is immersed into it up to a depth corresponding to the air pressure required.**
- **Since air is sent at high pressures than the required, some air will escape from the dip tube and bubbles to the top of the water tank.**
- **Thus the air moving towards the control orifice will be at the desired constant pressure.**

- **Then, the air at this pressure passes through the control orifice and escapes from the measuring jets.**
- **The back pressure in the circuit is indicated by the head of water displaced in the manometer tube.**


Air filter
Control orifice
Air supply
Scale
Flexible tube
Excess air bubbling to the top
Plug with measuring jets
Dip tube
Water tank
Manometer
Workpiece

- **The pressure in the manometer is regulated by the relative rates of escape of air through the control orifice and the measuring jets.**
- **If the measuring jets are completely closed, the manometer level is depressed to the bottom of the tube.**
- **The tube is graduated linearly to show changes in the pressures resulting from changes in internal diameter of the work being measured.**

Advantages of Pneumatic Comparators

- **The gauging member does not come in contact with the part to be measured and hence practically no wear takes place on the gauging member.**
- **It has very less number of moving parts and thus the accuracy is more due to the absence of friction and lower inertia.**
- **It is possible to have a very high degree of magnification.**
- **It is a suitable device for measuring diameter of holes where the diameter is small compared with the length.**
- **It is the best method for determining the quality and taperness of the circular holes.**
- **Measuring pressure is very small and the jet of air helps in cleaning the dust, if any, from the part to be measured.**

Disadvantages

- **It requires elaborate auxiliary equipments such as accurate pressure regulator, compressor etc.,**
- **The scale is generally not linear.**
- **When indicating device is glass tube, then high magnification is necessary in order to avoid the parallax errors.**
- **The apparatus is not easily portable and is rather elaborate for many industrial applications.**