## 5.1 FINISHING PROCESSES

Finishing is an abrasive process utilizing either a bonded abrasive or loose abrasive for improving surface finish, reduce irregularities and waviness.

## 5.2 Theory of grinding

**ABRASIVE PROCESSES: GRINDING**

Grinding is the most common form of abrasive machining. The art of grinding goes back many centuries. Over 5000 years ago the Egyptians abraded and polished building stones to hairline fits for the pyramids. Grinding is a metal cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as grit. These grits are characterized by sharp cutting points, high hot hardness, wear resistance and chemical stability. The grits are held together by a suitable bonding material to give shape of an abrasive tool. Simply it is a metal removal process in which the metal is removed with the help of rotating grinding wheel. Fig. 4.1 illustrates the cutting action of abrasive grits of disc type grinding wheel similar to cutting action of teeth of the cutter in slab milling.

**Applications of grinding**

- To remove small amount of metal from work pieces and finish then to close tolerances. To obtain a better surface finish.
- To machine hard surfaces that cannot be machined by high-speed steels. Grinding of tools and cutters and resharpening of the same.
- Grinding of threads.
- Stock removal (abrasive milling) finishing of flat as well as cylindrical surface. Slitting and parting.
- Descaling and deburring.

**Advantages of grinding**

- Dimensional accuracy and good surface finish. Good form and locational accuracy.
- Applicable to both hardened and unhardened material.

**GRINDING WHEELS**

Grinding wheel consists of hard abrasive grains called grits, which perform the cutting or material removal, held in the weak bonding matrix. A grinding wheel commonly identified by the type of the abrasive material used. The conventional wheels include Aluminium Oxide ($Al_2O_3$) and Silicon Carbide (SiC) wheels while diamond and CBN (Cubic Boron Nitride) wheels fall in the category of super abrasive wheel. Thus, it forms a multi-edge cutter.

**Grinding wheel and work piece interaction**

The bulk grinding wheel-work piece interaction as illustrated in Fig. 4.2 can be divided into the following:

1. Grit-work piece (forming chip).
2. Chip-bond.
3. Chip-work piece.
4. Bond-work piece.



Exceptthegrit-workpieceinteractionwhichisexpectedtoproducechip,theremainingthree undesirably increases the total grinding force and power requirement. Therefore, efforts should always be made to maximize grit-work piece interaction leading to chip formation and to minimize the rest for best utilization of the available power.

**5.3 Reconditioning & Truing of grinding wheel**

Truing is the act of regenerating the required geometry on the grinding wheel, whether the geometry is a special form or flat profile. Therefore, truing produces the macro-geometry of the grinding wheel.

Truing is also required on a new conventional wheel to ensure concentricity with specific mounting system. In practice the effective macro-geometry of a grinding wheel is of vital importance and accuracy of the finished work piece is directly related to effective wheel geometry.

**Truing tools**

There are four major types of truing tools:

**Steel cutter**: These are used to roughly true coarse grit conventional abrasive wheel to ensure freeness of cut. Steel or carbide crash roll: It is used to crush-true the profile on vitrified bond grinding wheel. Vitrified abrasive stick and wheel: It is used for off hand truing of conventional abrasive wheel. These are used for truing resin bonded super abrasive wheel.

**Diamond truing tool:**

Single point diamond truing tools. [shown in Fig. 4.5]

Multi stone diamond truing tools. [shown in Fig. 4.6]

Impregnated diamond truing tools. [shown in Fig. 4.7]

Rotary powered diamond truing wheels. [shown in Fig. 4.8] Surface set truing wheels.

Impregnated truing wheels.

Electroplated truing tools.

Diamond form truing blocks. [shown in Fig. 4.9]

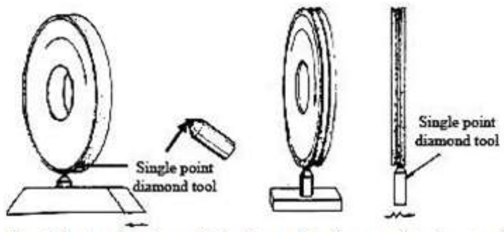
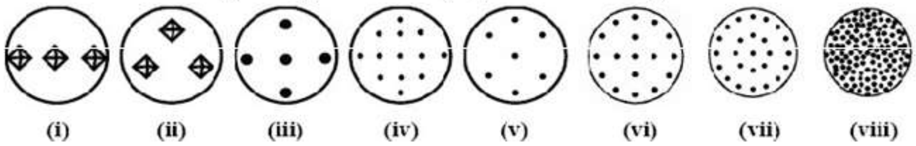



Fig. 4.5 Application of single point diamond truing tool




| Distribution of diamond | Diamond weight (carat) | Distribution of diamond | Diamond weight (carat) |
|---|---|---|---|
| (i) 1 layer - 3 stone | 10 | (v) 5 layer - 7 stone | 50 |
| (ii) 2 layer - 3 stone | 10 | (vi) 5 layer - 17 stone | 10 |
| (iii) 3 layer - 5 stone | 10 | (vii) 5 layer - 25 stone | 250 |
| (iv) 5 layer - 13 stone | 25 | (viii) throughout | 50 |

### 5.3.1 Dressing of grinding wheel

Dressing is the conditioning of the wheel surface which ensures that grit cutting edges are exposed from the bond and thus able to penetrate into the work piece material. Also, in dressing attempts are made to splinter the abrasive grains to make them sharp and free cutting and also to remove any residue left by material being ground. Dressing therefore produces micro-geometry. The structure of micro-geometry of grinding wheel determines its cutting ability with a wheel of given composition. Dressing can substantially influence the condition of the grinding tool.

Truing and dressing are commonly combined into one operation for conventional abrasive grinding wheels, but are usually two distinctly separate operation for super abrasive wheel.

**Dressing of super abrasive wheel**

Dressing of the super abrasive wheel is commonly done with soft conventional abrasive vitrified stick, which relieves the bond without affecting the super abrasive grits. However, modern technique like electrochemical dressing has been successfully used in metal bonded super abrasive wheel. The wheel acts like an anode while a cathode plate is placed in front of the wheel working surface to allow electrochemical dissolution.

Electro discharge dressing is another alternative route for dressing metal bonded super abrasive wheel. In this case a dielectric medium is used in place of an electrolyte. Touch-dressing, a new concept differs from conventional dressing in that bond material is not relieved. In contrast the dressing depth is precisely controlled in micron level to obtain better uniformity of grit height resulting in improvement of work piece surface finish.

## 5.4 Classification of grinding machines

Conventional grinding machines can be broadly classified as:

a. Surface grinding machine
b. Cylindrical grinding machine
c. Internal grinding machine
d. Tool and cutter grinding machine

### 5.4.1 Surface grinding machine:

This machine may be similar to a milling machine used mainly to grind flat surface. However, some types of surface grinders are also capable of producing contour surface with formed grinding wheel. Basically there are four different types of surface grinding machines characterized by the movement of their tables and the orientation of grinding wheel spindles as follows:

- Horizontal spindle and reciprocating table
- Vertical spindle and reciprocating table
- Horizontal spindle and rotary table
- Vertical spindle and rotary table

### 5.4.2 Horizontal spindle reciprocating table grinder

Figure 29.1 illustrates this machine with various motions required for grinding action. A disc type grinding wheel performs the grinding action with its peripheral surface. Both traverse and plunge grinding can be carried out in this machine as shown in Fig. 29.2

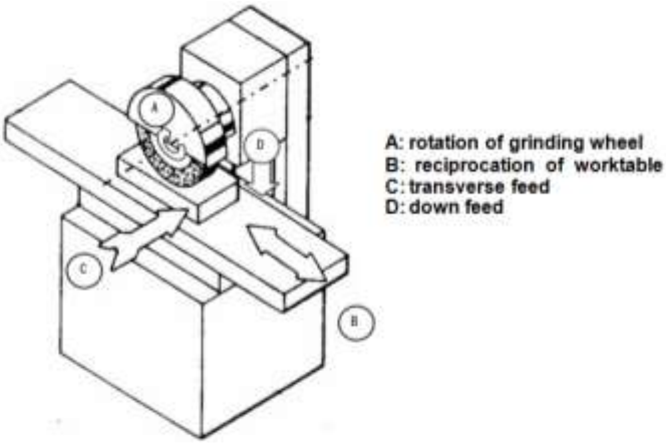



Fig.29.1: Horizontal spindle reciprocating table surface grinder

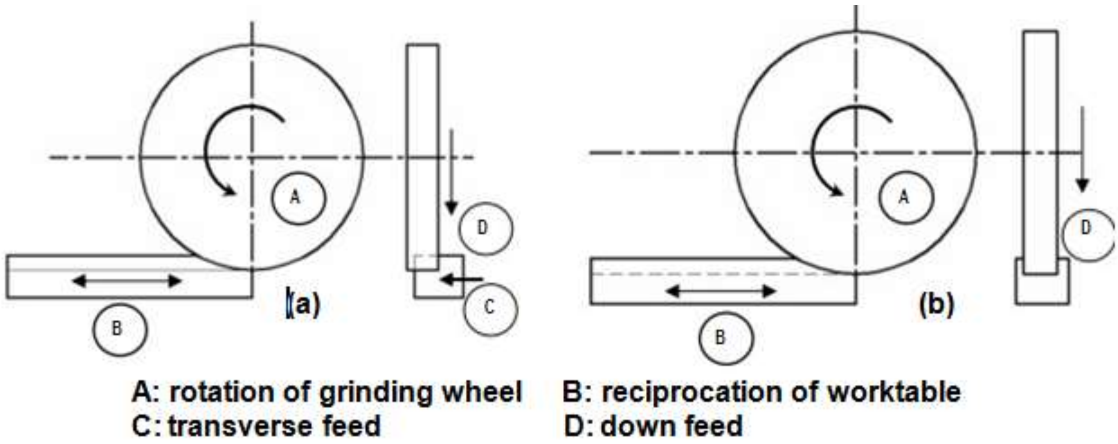



Fig. 29.2 Surface grinding (a) traverse grinding (b) plunge grinding

### 5.4.3 Vertical spindle reciprocating table grinder

This grinding machine with all working motions is shown in Fig. 29.3. The grinding operation is similar to that of face milling on a vertical milling machine. In this machine a cup shaped wheel grinds the workpiece over its full width using end face of the wheel as shown in Fig. 29.4. This brings more grits in action at the same time and consequently a higher material removal rate may be attained than for grinding with a peripheral wheel.

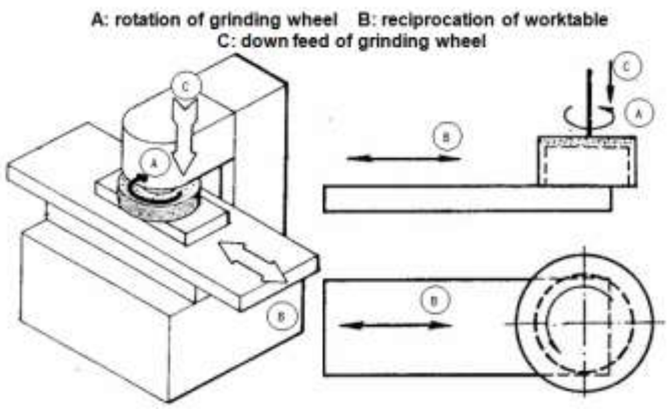



Fig. 29.3 Vertical spindle reciprocating table surface grinder

Fig. 29.4 Surface grinding in Vertical spindle reciprocating table surface grinder



### 5.4.4 Horizontal spindle rotary table grinder

Surface grinding in this machine is shown in Fig.29.5. In principle the operation is same as that for facing on the lathe. This machine has a limitation in accommodation of workpiece and therefore does not have wide spread use. However, by swivelling the worktable, concave or convex or tapered surface can be produced on individual part as illustrated in Fig. 29.6

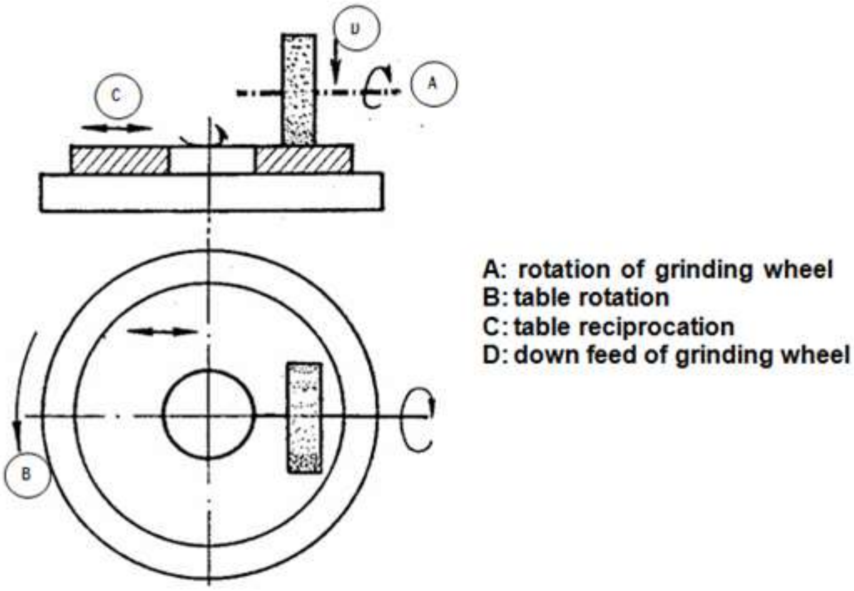



Fig. 29.5 Surface grinding in Horizontal spindle rotary table surface grinder

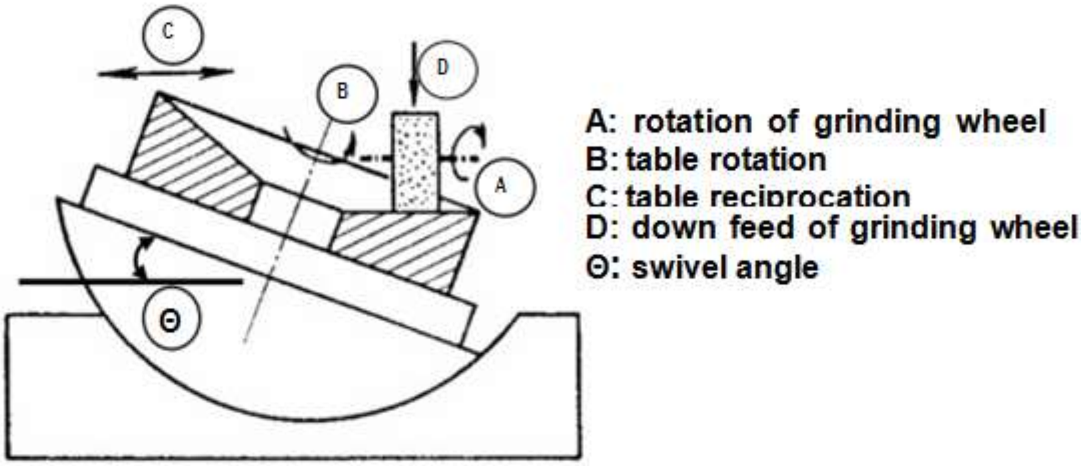



Fig. 29.6 Grinding of a tapered surface in horizontal spindle rotary table surface grinder

### 5.4.5 Vertical spindle rotary table grinder

The principle of grinding in this machine is shown in Fig. 29.7. The machine is mostly suitable for small workpieces in large quantities. This primarily production type machine often uses two or more grinding heads thus enabling both roughing and finishing in one rotation of the work table.

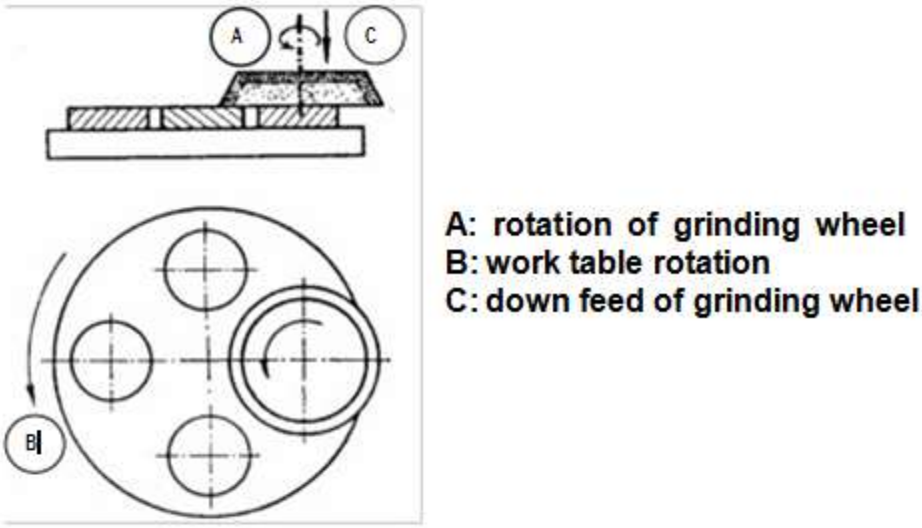



*Fig. 29.7 Surface grinding in vertical spindle rotary table surface grinder*

### 5.4.6 Creep feed grinding machine:

This machine enables single pass grinding of a surface with a larger downfeed but slower table speed than that adopted for multi-pass conventional surface grinding. This machine is characterised by high stiffness, high spindle power, recirculating ball screw drive for table movement and adequate supply of grinding fluid. A further development in this field is the creep feed grinding centre which carries more than one wheel with provision of automatic wheel changing. A number of operations can be performed on the workpiece. It is implied that such machines, in the view of their size and complexity, are automated through CNC.

### 5.4.7 High efficiency deep grinding machine:

The concept of single pass deep grinding at a table speed much higher than what is possible in a creep feed grinder has been technically realized in this machine. This has been made possible mainly through significant increase of wheel speed in this new generation grinding machine.

### 5.5 Cylindrical grinding machine

This machine is used to produce external cylindrical surface. The surfaces may be straight, tapered, steps or profiled. Broadly there are three different types of cylindrical grinding machine as follows:

1. Plain centre type cylindrical grinder
2. Universal cylindrical surface grinder
3. Centre less cylindrical surface grinder

### 5.5.1 Plain centre type cylindrical grinder

Figure 29.8 illustrates schematically this machine and various motions required for grinding action. The machine is similar to a centre lathe in many respects. The workpiece is held between head stock and tailstock centres. A disc type grinding wheel performs the grinding action with its peripheral surface. Both traverse and plunge grinding can be carried out in this machine as shown in Fig.29.9.



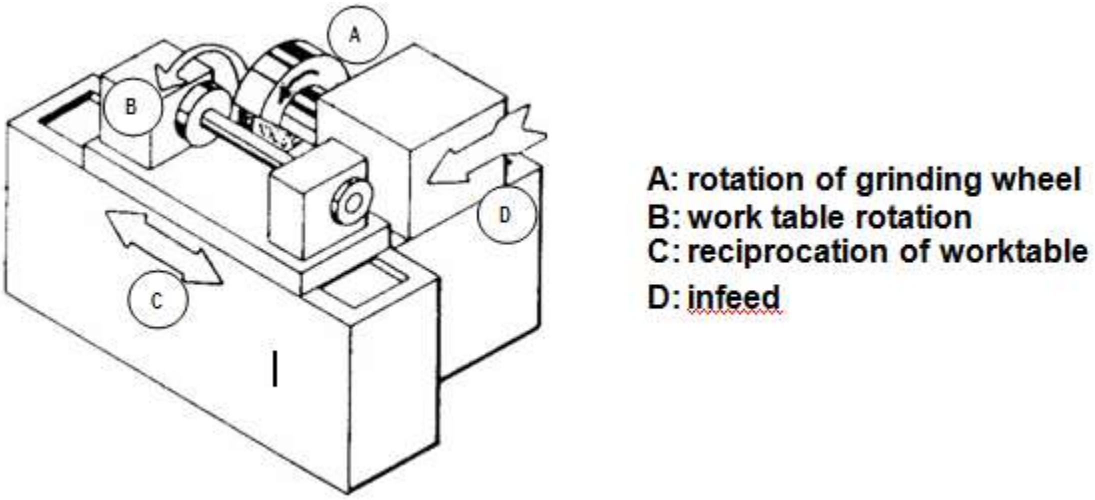



*Fig. 29.8 Plain centre type cylindrical grinder*

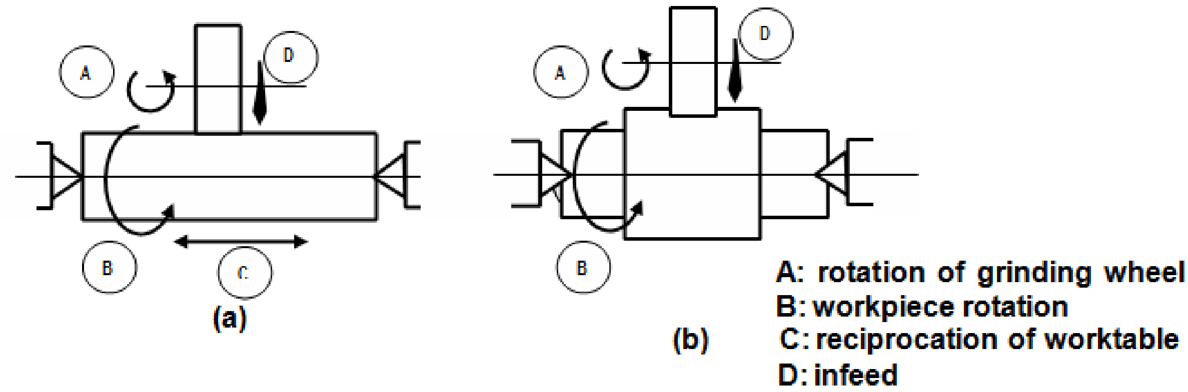



*Fig. 29.9 cylindrical (a) traverse grinding and (b) plunge grinding*

### 5.5.2 Universal cylindrical surface grinder

Universal cylindrical grinder is similar to a plain cylindrical one except that it is more versatile. In addition to small worktable swivel, this machine provides large swivel of head stock, wheel head slide and wheel head mount on the wheel head slide.

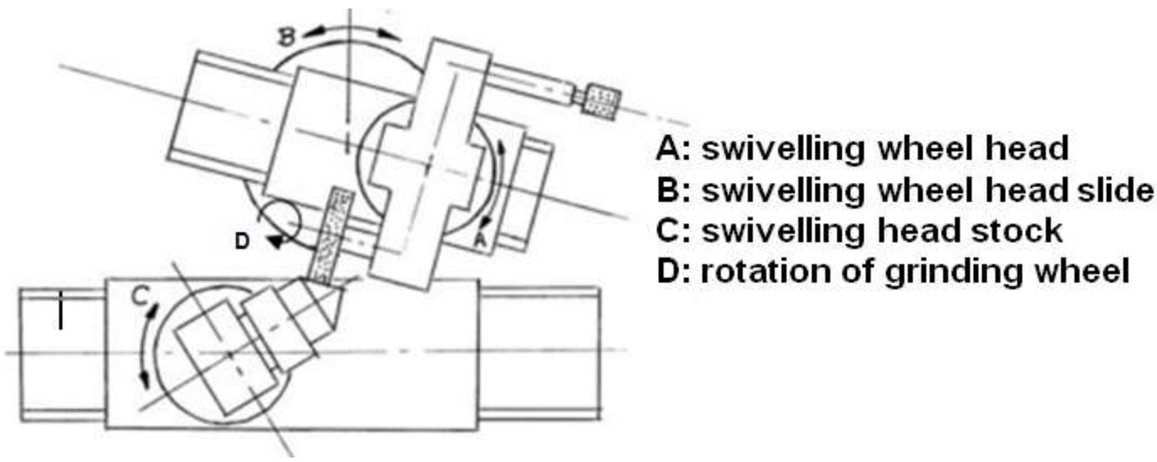



*Fig. 29.10 important features of universal cylindrical grinding machine*



This allows grinding of any taper on the workpiece. Universal grinder is also equipped with an additional head for internal grinding. Schematic illustration of important features of this machine is shown in Fig.29.10.

### 5.5.3 External centreless grinder

This grinding machine is a production machine in which outside diameter of the workpiece is ground. The workpiece is not held between centres but by a work support blade. It is rotated by means of a regulating wheel and ground by the grinding wheel.

In through-feed centreless grinding, the regulating wheel revolving at a much lower surface speed than grinding wheel controls the rotation and longitudinal motion of the workpiece. The regulating wheel is kept slightly inclined to the axis of the grinding wheel and the workpiece is fed longitudinally as shown in Fig. 29.14.

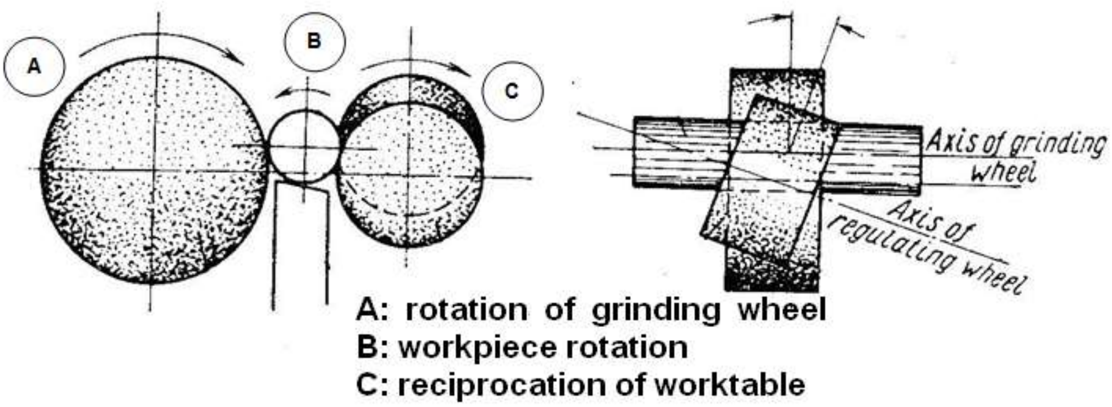



*Fig.29.14: Centreless through feed grinding*

Parts with variable diameter can be ground by centreless in feed grinding as shown in Fig. 29.15(a). The operation is similar to plunge grinding with cylindrical grinder. End feed grinding shown in Fig. 29.15 (b) is used for workpiece with tapered surface.

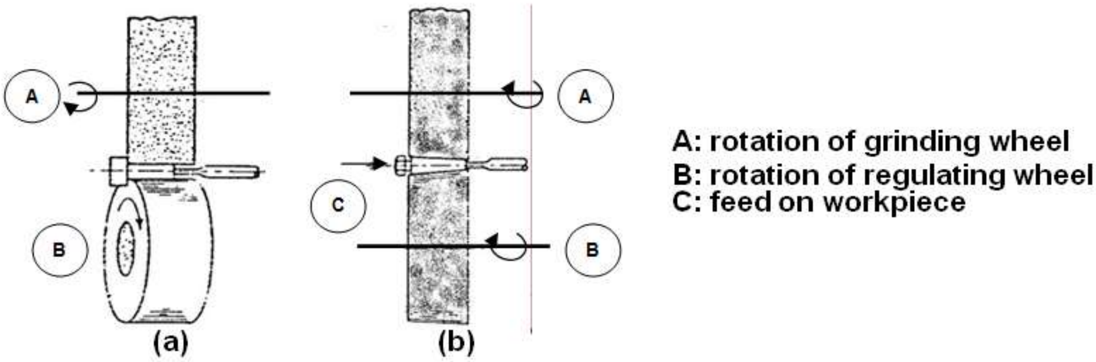



*Fig. 29.15 Centreless (a) infeed and (b) end feed grinding*

The grinding wheel or the regulating wheel or both require to be correctly profiled to get the required taper on the workpiece.

### 5.5.4 Centreless internal grinder

This machine is used for grinding cylindrical and tapered holes in cylindrical parts (e.g. cylindrical liners, various bushings etc). The workpiece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel as illustrated in Fig. 29.19



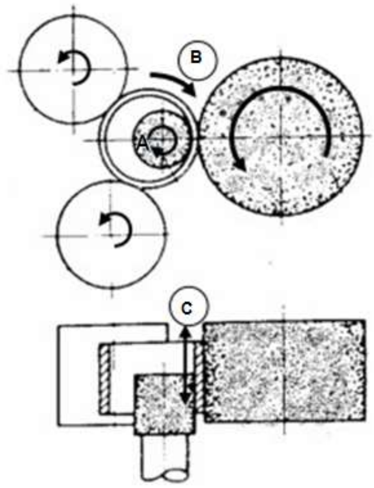



*Fig. 29.19 Internal centreless grinding*

**5.6 Tool and cutter grinding machines**

**5.7 Different types of abrasives, bonds**

**5.7.1 Types of abrasives**

Abrasives may be classified into two types:

1. Natural abrasives
    a. Emery (50 - 60 % crystalline $Al_2O_3$ + Iron Oxide),
    b. Sandstone or Solid Quartz,
    c. Corundum (75 - 90 % crystalline $Al_2O_3$ + Iron Oxide) and
    d. Diamond.
2. Artificial abrasives
    a. Aluminium Oxide(Al2O3),
    b. Silicon Carbide(SiC),
    c. Artificial diamond,
    d. Boron Carbide and
    e. Cubic Boron Nitride (CBN).

The abrasives that are generally used are

1. Aluminum Oxide. ($Al_2O_3$)
2. Silicon Carbide. (SiC)
3. Diamond.
4. Cubic Boron Nitride. (CBN)

**1. Aluminium oxide ($Al_2O_3$):**

Aluminium oxide may have variation in properties arising out of differences in chemical composition and structure associated with the manufacturing process. Pure $Al_2O_3$ grit with defect structure like voids leads to unusually sharp free cutting action with low strength and is advantageous in fine tool grinding operation, and heat sensitive operations on hard, ferrous materials. Regular or brown aluminium oxide (doped with $TiO_2$) possesses lower hardness and higher toughness than the white $Al_2O_3$ and is recommended heavy duty grinding to semi finishing. $Al_2O_3$ alloyed with chromium oxide (<3%) is pink in colour. Monocrystalline $Al_2O_3$ grits make a balance between hardness and toughness and are efficient in medium pressure heat sensitive operation on ferrous materials.



Microcrystalline $Al_2O_3$ grits of enhanced toughness are practically suitable for stock removal grinding. $Al_2O_3$ alloyed with zirconia also makes extremely tough grit mostly suitably for high pressure, high material removal grinding on ferrous material and are not recommended for precision grinding. Microcrystalline sintered $Al_2O_3$ grit is the latest development particularly known for its toughness and self sharpening characteristics. Trade names: Alundum, Aloxide, corundum, emery, etc.

**2. Silicon carbide (SiC)**

Silicon carbide is harder than alumina but less tough. Silicon carbide is also inferior to Al2O3 because of its chemical reactivity with iron and steel. Black carbide containing at least 95% SiC is less hard but tougher than green SiC and is efficient for grinding soft nonferrous materials. Green silicon carbide contains at least 97% SiC. It is harder than black variety and is used for grinding cemented carbide. Trade names: Carborundum, Crystolon, Electrolon, etc.

**3. Diamond**

Diamond grit is best suited for grinding cemented carbides, glass, sapphire, stone, granite, marble, concrete, oxide, non-oxide ceramic, fiber reinforced plastics, ferrite, graphite. Natural diamond grit is characterized by its random shape, very sharp cutting edge and free cutting action and is exclusively used in metallic, electroplated and brazed bond.

Monocrystalline diamond grits are known for their strength and designed for particularly demanding application. These are also used in metallic, galvanic and brazed bond. Polycrystalline diamond grits are more friable than monocrystalline one and found to be most suitable for grinding of cemented carbide with low pressure. These grits are used in resin bond.

**4. Cubic Boron Nitride (CBN)**

Diamond though hardest is not suitable for grinding ferrous materials because of its reactivity. In contrast, CBN the second hardest material, because of its chemical stability is the abrasive material of choice for efficient grinding of HSS, alloy steels, HSTR alloys.

Presently CBN grits are available as monocrystalline type with medium strength and blocky monocrystals with much higher strength. Medium strength crystals are more friable and used in resin bond for those applications where grinding force is not so high. High strength crystals are used with vitrified, electroplated or brazed bond where large grinding force is expected.

Microcrystalline CBN is known for its highest toughness and auto sharpening character and found to be best candidate for HEDG and abrasive milling. It can be used in all types of bond.

**5.7.2 Bonds**

It is an adhesive substance which holds the abrasive grains together to form the grinding wheel. Types of bonds - Bonds are classified into two types:

1. Organic - Resinoid, Rubber, Shellac & Oxychloride
2. Non – Organic - Metallic, Vitrified & Silicate

**Vitrified bond (V)**

Vitrified bond is suitable for high stock removal even at dry condition. It can also be safely used in wet grinding. It can not be used where mechanical impact or thermal variations are like to occur. This bond is also not recommended for very high speed grinding because of possible breakage of the bond under centrifugal force.

**Rubber bond (R)**

Its principal use is in thin wheels for wet cut-off operation. Rubber bond was once popular for finish grinding on bearings and cutting tools.



**Silicate bond (S)**

Silicate wheels are made by mixing abrasive grains with silicate of soda. The mixture is moulded in a mould and dried for several hours. After drying, the moulded material is kept in a furnace at about $260^0$ C for 20 to 80 hours. Silicate bonded wheels are light grey in colour. These wheels are having a fairly high tensile strength.

**Metal bond (M)**

Metal bond is extensively used with super abrasive wheels. Extremely high toughness of metal bonded wheels makes these very effective in those applications where form accuracy as well as large stock removal is desired.

**Shellac bond (E)**

Shellac bonded grinding wheels are relatively strong but not rigid. At one time this bond was used for flexible cut off wheels. At present use of shellac bond is limited to grinding wheels engaged in fine finish of rolls.

**Oxychloride bond (O)**

It is less common type bond, but still can be used in disc grinding operation. It is used under dry condition. It is produced by mixing abrasive grains with oxide and chloride of magnesium.

**Resinoid bond (B)**

Conventional abrasive resin bonded wheels are widely used for heavy duty grinding because of their ability to withstand shock load. This bond is also known for its vibration absorbing characteristics and finds its use with diamond and CBN in grinding of cemented carbide and steel respectively.

Resin bond is not recommended with alkaline grinding fluid for a possible chemical attack leading to bond weakening. Fiber glass reinforced resin bond is used with cut off wheels which requires added strength under high speed operation.

**Electroplated bond**

This bond allows large (30-40%) crystal exposure above the bond without need of any truing or dressing. This bond is specially used for making small diameter wheel, form wheel and thin super abrasive wheels. Presently it is the only bond for making wheels for abrasive milling and ultra-high speed grinding.

**Brazed bond**

This is relatively a recent development, allows crystal exposure as high 60-80%. In addition grit spacing can be precisely controlled. This bond is particularly suitable for very high material removal either with diamond or CBN wheel. The bond strength is much greater than provided by electroplated bond. This bond is expected to replace electroplated bond in many applications.

**5.8 Specification and selection of a grinding wheel**

Specification of a grinding wheel ordinarily means compositional specification. Conventional abrasive grinding wheels are specified encompassing the following parameters.
The type of grit material.
The grit size.
The bond strength of the wheel, commonly known as wheel hardness.
The structures of the wheel denoting the porosity i.e. the amount of inter grit spacing. The type of bond material.
Other than these parameters, the wheel manufacturer may add their own identification code prefixing or suffixing (or both) the standard code.



## 13.21. SELECTION OF GRINDING WHEELS

Selection of a proper grinding wheel is a vital necessity to obtain the best results in grinding work. A wheel may be required to perform various different functions like quick removal of stock material, give a high class surface finish, maintain close dimensional tolerances and a single wheel will fail to meet all the requirements. It is necessary, therefore, that proper grain size, bond, grade, strength, shape and size of the wheel should be selected to meet the specific requirements of a job. The factors upon which the above selection will depend are as follows :

1. Properties of the material to be machined, *i.e.*, its hardness, toughness, strength, etc.
2. Quality of surface finish required.
3. Grinding allowance provided on the workpiece, *i.e.*, the amount of stock to be removed.
4. Dimensional accuracy required.
5. Method of grinding, *i.e.*, wet or dry.
6. Rigidity, size and type of machine.
7. Relative sizes of wheel and job.
8. Type of grinding to be done.
9. Speed and feed of the wheel.

The Indian Standard Institution (*see* IS : 1249-1958) has recommended the use of the following grinding wheels for different materials and operations.

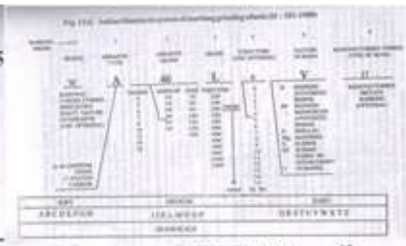
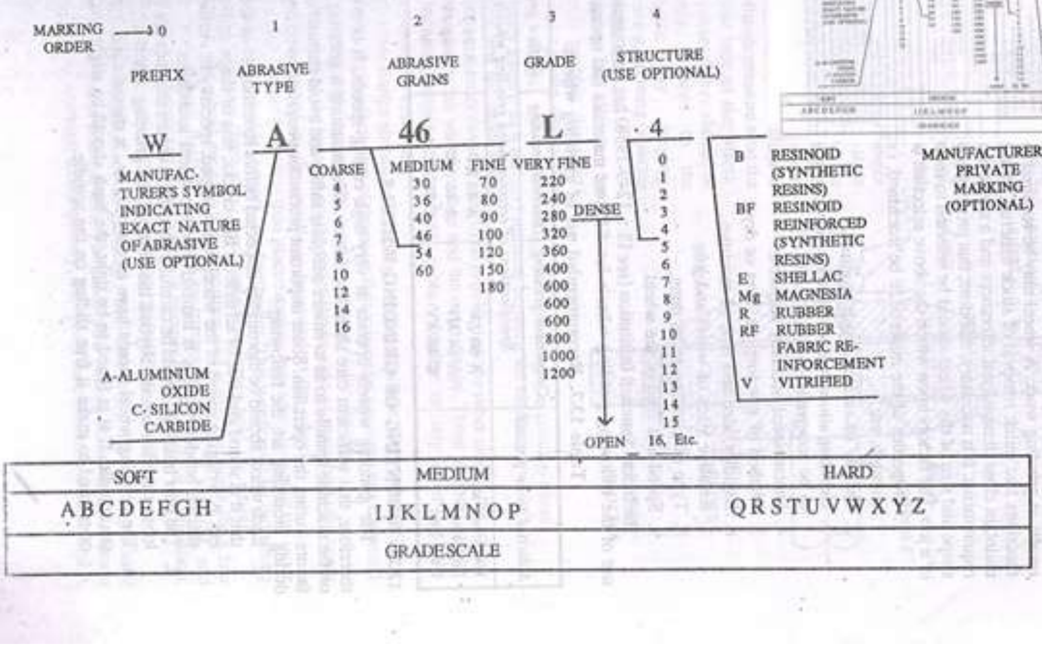


Fig. 13.6. Indian Standards system of marking grinding wheels (IS : 55



**Marking system for conventional grinding wheel**

The standard marking system for conventional abrasive wheel can be as follows:

| | | | | | | |
|---|---|---|---|---|---|---|
| 51 | A | 60 | K | 5 | V | 05 |

where

The number '51' is manufacturer's identification number indicating exact kind of abrasive used. The letter 'A' denotes that the type of abrasive is Aluminium Oxide (Al2O3). In case of Silicon Carbide (SiC) the letter 'C' is used.

The number '60' specifies the average grit size in inch mesh. For a very large size grit this number may be as small as 6 where as for a very fine grit the number may be as high as 600.

The letter 'K' denotes the hardness of the wheel. The letter symbol can range between 'A' and 'Z', 'A' denoting the softest grade and 'Z' denoting the hardest one.

The number '5' denotes the structure or porosity of the wheel. This number can assume any value between 1 to 20, '1' indicating high porosity and '20' indicating low porosity.

The letter code 'V' means that the bond material used is vitrified.

The number '05' is a wheel manufacturer's identifier.

**Marking system for super abrasive grinding wheel**

Marking system for super abrasive grinding wheel is somewhat different as illustrated below:

| | | | | | | |
|---|---|---|---|---|---|---|
| R | D | 120 | N | 100 | M | 4 |

where

The letter 'R' is manufacture's code indicating the exact type of super abrasive used.

The letter 'D' denotes that the type of abrasive is Diamond. In case of Cubic Boron Nitride (CBN) the letter 'B' is used.

The number '120' specifies the average grain size in inch mesh. However, a two number designation (e.g. 120/140) is utilized for controlling the size of super abrasive grit.

Like conventional abrasive wheel, the letter 'N' denotes the hardness of the wheel. However, resin and metal bonded wheels are produced with almost no porosity and effective grade of the wheel is obtained by modifying the bond formulation.

The number '100' is known as concentration number indicating the amount of abrasive contained in the wheel. The number '100' corresponds to an abrasive content of 4.4 carats/cm3. For diamond grit, '100' concentration is 25% by volume. For CBN the corresponding volumetric concentration is 24%.

The letter 'M' denotes that the type of bond is metallic. The other types of bonds used in super abrasive wheels are resin, vitrified or metal bond, which make a composite structure with the grit material. However, another type of super abrasive wheel with both diamond and CBN is also manufactured where a single layer of super abrasive grits are bonded on a metal perform by a galvanic metal layer or a brazed metal layer

**Indian standard marking system**

| | | | | | | |
|---|---|---|---|---|---|---|
| W | A | 36 | K | 5 | R | 17 |

Where

W - Manufacture's symbol indicating exact kind of abrasive, (optional use).

A - Abrasive type: A for Al2O3, C for SiC, D for Diamond.

36 - Grain size.

K - Grade.

5 - Structure.

R - Bond type.

17 - Private marking to identify the wheel, (optional use).

**5.9 Lapping operations**

Lapping is regarded as the oldest method of obtaining a fine finish. Lapping is basically an abrasive process in which loose abrasives function as cutting points finding momentary support from the laps. Figure schematically represents the lapping process. Material removal in lapping usually ranges from .003 to .03 mm but many reach 0.08 to 0.1mm in certain cases.

***Characteristics of lapping process:***

Use of loose abrasive between lap and the workpiece

Usually lap and workpiece are not positively driven but are guided in contact with each other

Relative motion between the lap and the work should change continuously so that path of the abrasive grains of the lap is not repeated on the workpiece.

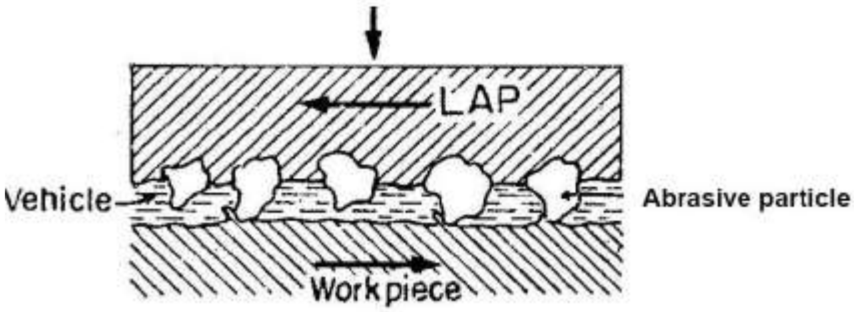



**Fig. 30.1** *Scheme of lapping process*

Cast iron is the mostly used lap material. However, soft steel, copper, brass, hardwood as well as hardened steel and glass are also used.

*Abrasives of lapping:*

$Al_2O_3$ and SiC, grain size 5~100μm

$Cr_2O_3$, grain size 1~2 μm

Diamond, grain size 0.5~5 V

*Vehicle materials for lapping*

Machine oil

Rape oil

grease

*Technical parameters affecting lapping processes are:*

Unit pressure

The grain size of abrasive

Concentration of abrasive in the vehicle



***Lapping speed***

Lapping is performed either manually or by machine. Hand lapping is done with abrasive powder as lapping medium, whereas machine lapping is done either with abrasive powder or with bonded abrasive wheel.

**Hand lapping**

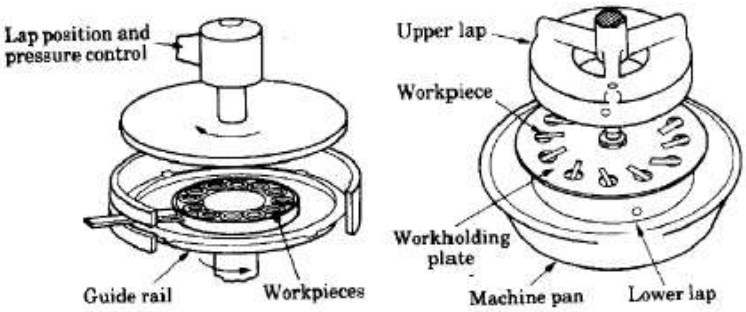
Hand lapping of flat surface is carried out by rubbing the component over accurately finished flat surface of master lap usually made of a thick soft close-grained cast iron block. Abrading action is accomplished by very fine abrasive powder held in a vehicle. Manual lapping requires high personal skill because the lapping pressure and speed have to be controlled manually.

Laps in the form of ring made of closed grain cast iron are used for manual lapping of external cylindrical surface. The bore of the ring is very close to size of the workpiece however, precision adjustment in size is possible with the use of a set screw as illustrated in Fig. To increase range of working, a single holder with interchangeable ring laps can also be used. Ring lapping is recommended for finishing plug gauges and machine spindles requiring high precision. External threads can be also lapped following this technique. In this case the lap is in the form of a bush having internal thread.

Solid or adjustable laps, which are ground straight and round, are used for lapping holes. For manual lapping, the lap is made to rotate either in a lathe or honing machine, while the workpiece is reciprocated over it by hand. Large size laps are made of cast iron, while those of small size are made of steel or brass. This process finds extensive use in finishing ring gauges.

**Lapping Machine**

Machine lapping is meant for economic lapping of batch qualities. In machine lapping, where high accuracy is demanded, metal laps and abrasive powder held in suitable vehicles are used. Bonded abrasives in the form wheel are chosen for commercial lapping. Machine lapping can also employ abrasive paper or abrasive cloth as the lapping medium. Production lapping of both flat and cylindrical surfaces is illustrated in Fig.  In this case cast iron plate with loose abrasive carried in a vehicle can be used. Alternatively, bonded abrasive plates may also be used. Centre less roll lapping uses two cast iron rolls, one of which serves as the lapping roller twice in diameter than the other one known as the regulating roller. During lapping the abrasive compound is applied to the rolls rotating in the same direction while the workpiece is fed across the rolls. This process is suitable for lapping a single piece at a time and mostly used for lapping plug gauges, measuring wires and similar straight or tapered cylindrical parts.




*Production lapping on (a) flat surface (b) cylindrical surface*

The bonded abrasive lapping wheel as well as the regulating wheel is much wider than those used in centreless grinding. This technique is used to produce high roundness accuracy and fine finish, the workpiece requires multi-pass lapping each with progressively finer lapping wheel. This is a high production operation and suitable for small amount of rectification on shape of workpiece.

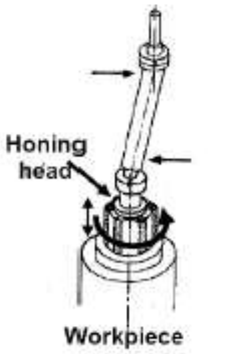
Therefore, parts are to be pre-ground to obtain substantial straightness and roundness. The process finds use in lapping piston rings, shafts and bearing races.

Machines used for lapping internal cylindrical surfaces resemble honing machines used with power stroke. These machines in addition to the rotation of the lap also provide reciprocation to the workpiece or to the lap. The lap made usually of cast iron either solid or adjustable type can be conveniently used.

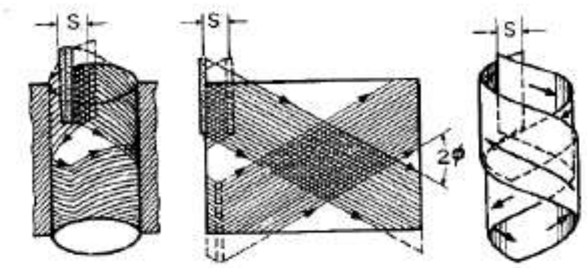
### 5.10 Honing operations

Honing is a finishing process, in which a tool called hone carries out a combined rotary and reciprocating motion while the workpiece does not perform any working motion. Most honing is done on internal cylindrical surface, such as automobile cylindrical walls. The honing stones are held against the workpiece with controlled light pressure. The honing head is not guided externally but, instead, floats in the hole, being guided by the work surface. It is desired that

1. Honing stones should not leave the work surface
2. Stroke length must cover the entire work length.



*Honing tool*



*Lay pattern produced by combination of rotary and oscillatory motion*

The honing stones are given a complex motion so as to prevent every single grit from repeating its path over the work surface. The critical process parameters are:

1. Rotation speed
2. Oscillation speed
3. Length of the stroke
4. Honing stick pressure

With conventional abrasive honing stick, several strokes are necessary to obtain the desired finish on the work piece. However, with introduction of high performance diamond and CBN grits it is now possible to perform the honing operation in just one complete stroke.

### 5.11 Broaching operations

#### 5.11.1 Basic principles of broaching

Broaching is a machining process for removal of a layer of material of desired width and depth usually in one stroke by a slender rod or bar type cutter having a series of cutting edges with gradually increased protrusion as indicated in Fig. 4.51 (b). In shaping, attaining full depth requires a number of strokes to remove the material in thin layers step-by-step by gradually infeeding the single point tool as illustrated in Fig. 4.51 (a). Whereas, broaching enables remove the whole material in one stroke only by the gradually rising teeth of the cutter called broach. The amount of tooth rise between the successive teeth of the broach is equivalent to the infeed given in shaping.

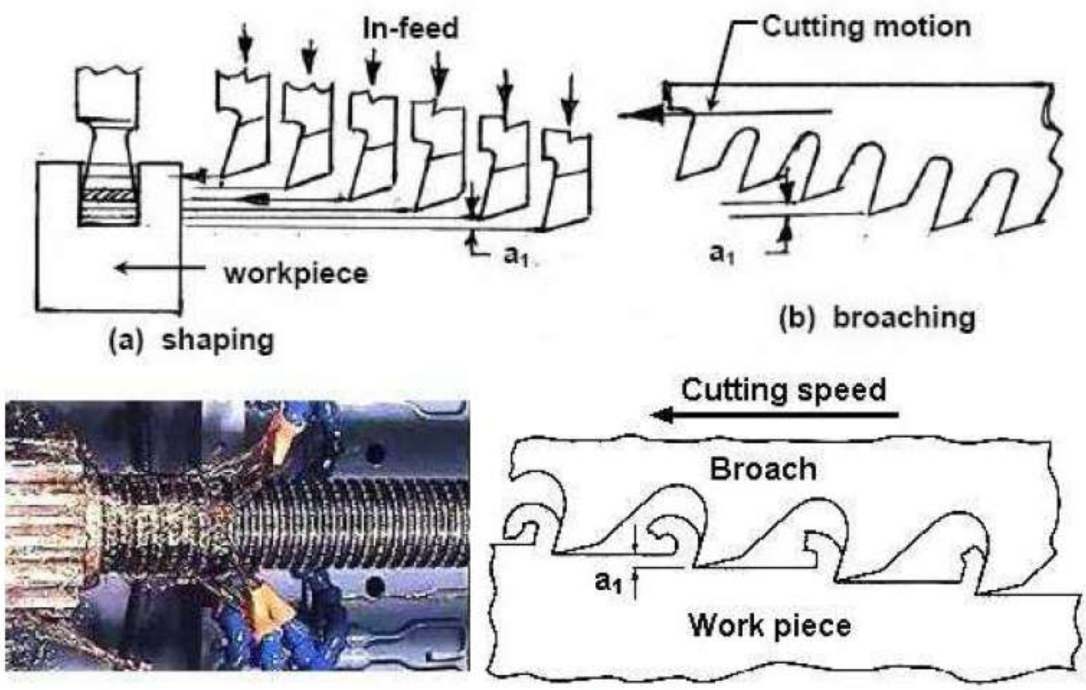



Fig. 4.51 Basic principle of broaching

Machining by broaching is preferably used for making straight through holes of various forms and sizes of section, internal and external through straight or helical slots or grooves, external surfaces of different shapes, teeth of external and internal splines and small spur gears etc. Fig. 4.52 schematically shows how a through hole is enlarged and finished by broaching

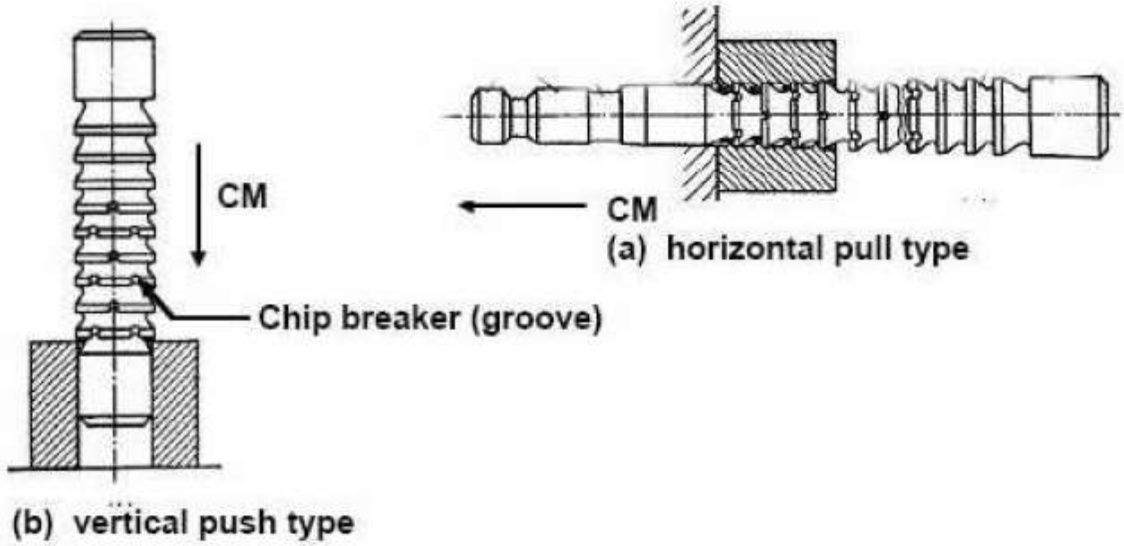



Fig. 4.52 Schematic views of finishing hole by broaching

The cutting tool is called a broach, and the machine tool is called a broaching machine. The shape of the machined surface is determined by the contour of the cutting edges on the broach, particularly the shape of final cutting teeth. Broaching is a highly productive method of machining. Advantages include good surface finish, close tolerances, and the variety of possible machined surface shapes, some of them can be produced only by broaching. Owing to the complicated geometry of the broach, tooling is expensive. Broaching is a typical mass production operation.

Productivity improvement to ten times or even more be not uncommon, as the metal removal rate by broaching is vastly greater. Roughing, semi finishing and finishing of the component is done just in one pass by broaching, and this pass is generally accomplished in seconds.

Broaching can be used for machining of various integrate shapes which can not be otherwise machined with other operations. Some of the typical examples of shapes produced by internal broaching are shown in Fig. 4.53.

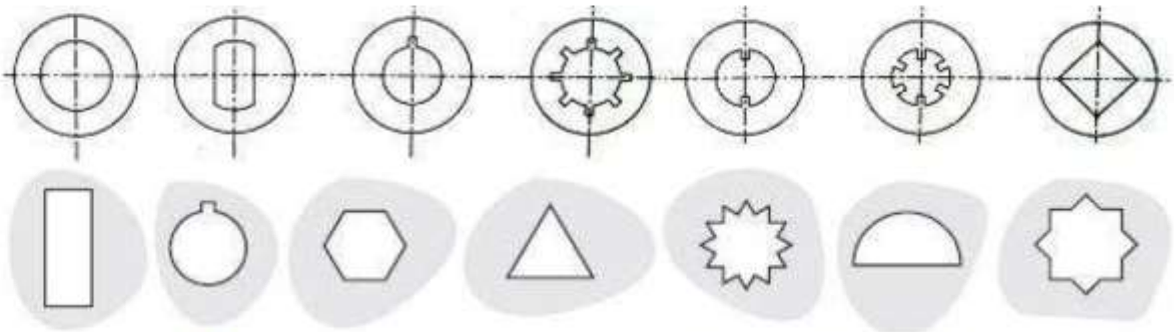


Fig. 4.53 Typical examples of shapes produced by internal broaching

4.20.2 Different types of broaches and their applications

Broaching is getting more and more widely used, wherever feasible, for high productivity as well as product quality. Various types of broaches have been developed and are used for wide range of applications. Broaches can be broadly classified in several aspects such as:

Internal broaching or external broaching.

Pull type or Push type.

Ordinary cut or Progressive type.

Solid, Sectional or Modular type.

Profile sharpened or form relieved type.

Internal broaching and broaches

Internal broaching tools are used to enlarge and finish various contours in through holes

preformed by casting, forging, rolling, drilling, punching etc. Internal broaching tools are mostly pull

type but may be push type also for lighter work. Pull type internal broaching tools are generally provided

with a set of roughing teeth followed by few semi-finishing teeth and then some finishing teeth which

may also include a few burnishing teeth at the end. The wide range of internal broaching tools and their

applications include:

Through holes of different form and dimensions. [Fig. 4.54] Non-circular holes and internal slots. [Fig. 4.54]

Internal keyway and splines. [Fig. 4.54]

Teeth of straight and helical fluted internal spur gears. [Fig. 4.54]

External broaching and broaches

External surface broaching competes with milling, shaping and planing and, wherever feasible, outperforms those processes in respect of productivity and product quality. External broaching tools may be both pull and push type. Major applications of external broaching are:

Un-obstructed outside surfacing; flat, peripheral and contour surfaces. [Fig. 4.55 (a)] Grooves, slots, keyways etc. on through outer surfaces of objects. [Fig. 4.55 (a)] External splines of different forms.

Teeth of external spur gears or gear sectors as shown in Fig. 4.55 (b).

External broaching tools are often made in segments which are clamped in fixtures for operation.

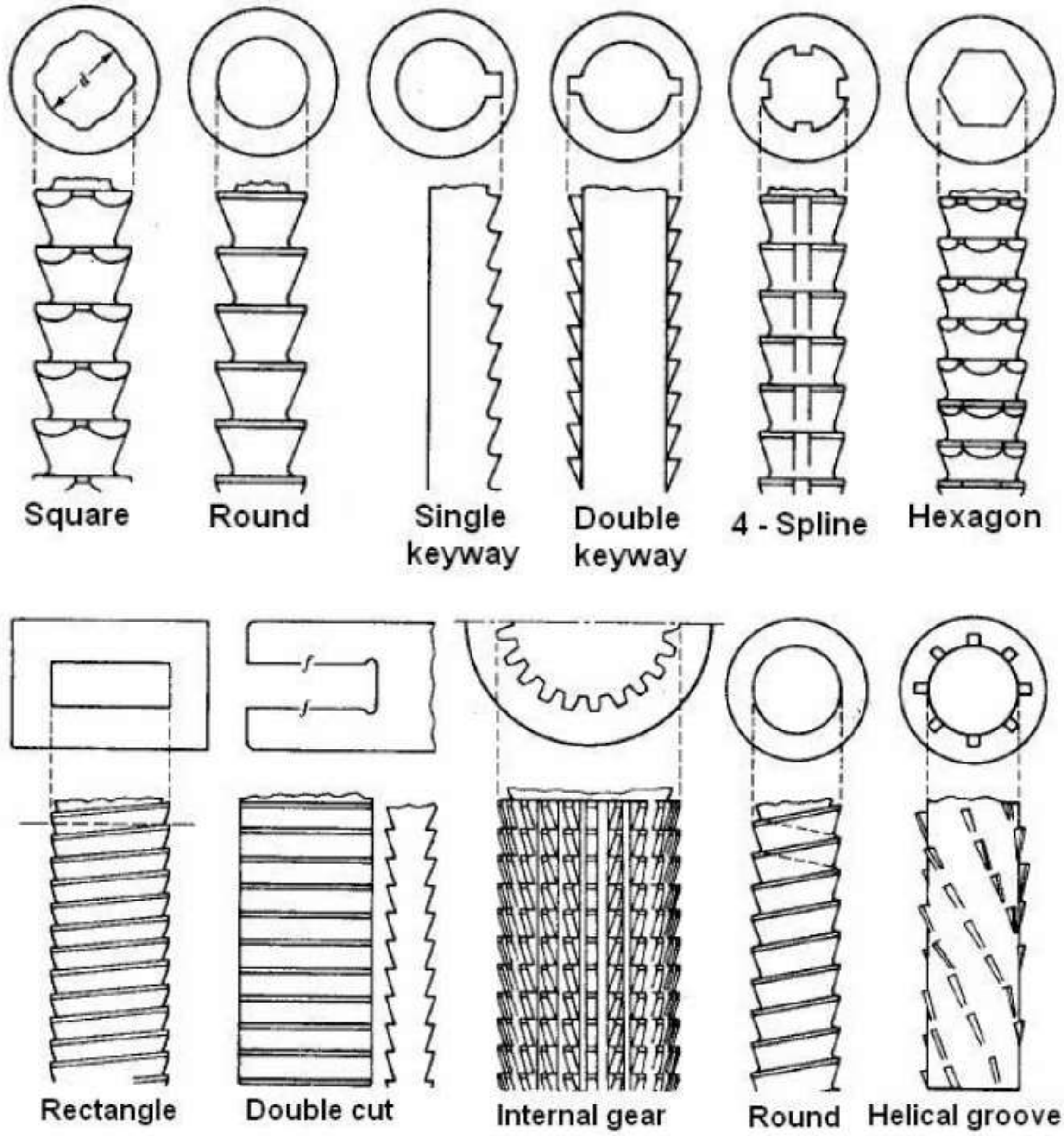



Fig. 4.54 Internal broaching – tools and applications

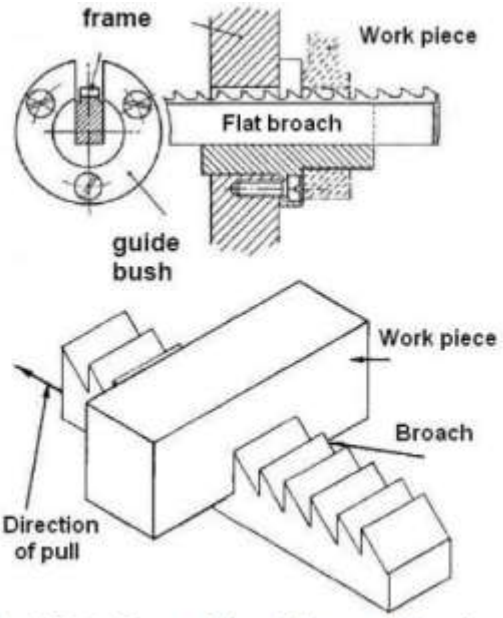



Fig. 4.55 (a) External broaching – making slot

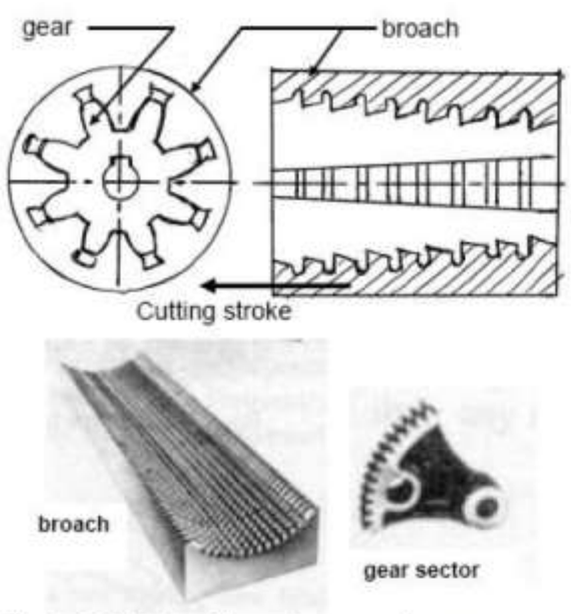



Fig 4.55 (b) Broaching of gears and gear sectors

Pull type and push type broaches

During operation a pull type broach is subjected to tensile force, which helps in maintaining alignment and prevents buckling. Pull type broaches are generally made as a long single piece and are more widely used, for internal broaching in particular. Push type broaches are essentially shorter in length (to avoid buckling) and may be made in segments. Push type broaches are generally used for external broaching, preferably, requiring light cuts and small depth of material removal.

Ordinary cut or progressive type broach

Most of the broaches fall under the category of Ordinary - cut type where the teeth increase in height or protrusion gradually from tooth to tooth along the length of the broach. By such broaches, work material is removed in thin layers over the complete form. Whereas, Progressive cut type broaches have their teeth increasing in width instead of height. Fig. 4.56 shows the working principle and configuration of such broach.

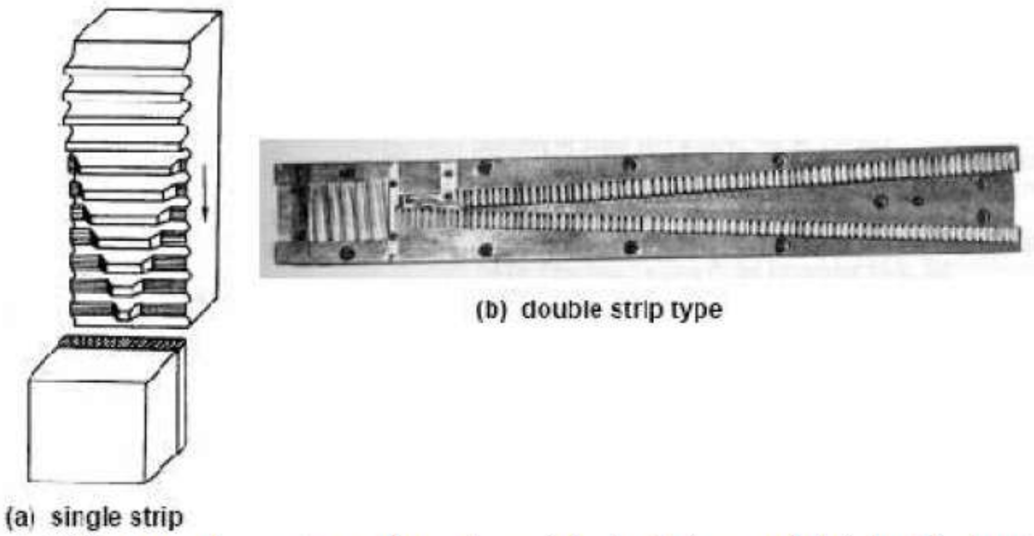



Fig. 4.56 Progressive cut type broaches; (a) single bar and (b) double bar type

Solid, Sectional and module type broaches

Broaches are mostly made in single pieces especially those used for pull type internal broaching. But some broaches called sectional broaches, are made by assembling several sections or cutter-pieces in series for convenience in manufacturing and resharpening and also for having little flexibility required by production in batches having interbatch slight job variation. External broaches are often made by combining a number of modules or segments for ease of manufacturing and handling. Fig. 4.57 typically shows solid, sectional and segmented (module) type broaches.

Profile sharpened and form relieved type broaches

Like milling cutters, broaches can also be classified as:

Profile sharpened type broaches - Such cutters have teeth of simple geometry with

same rake and clearance angles all over the cutting edge. These broaches are generally designed and used for machining flat surface(s) or circular holes.

Form relieved type broaches - These broaches, being used for non-uniform profiles

like gear teeth etc., have teeth where the cutting edge geometry is more complex and varies point

- to - point along the cutting edges. Here the job profile becomes the replica of the tool form. Such broaches are sharpened and resharpened by grinding at their rake faces unlike the profile sharpened broaches which are ground at the flank surfaces.

4.20.3 Advantages and limitations of broaching

Major advantages

Very high production rate (much higher than milling, planing, boring etc.). High dimensional and form accuracy and surface finish of the product. Roughing and finishing in single stroke of the same cutter.

Needs only one motion (cutting), so design, construction, operation and control are simpler. Extremely suitable and economic for mass production.

Since all the machining parameters are built into the broach, very little skill is required from the operator.

Any type of surface, internal or external can be generated with broaching.

Limitations

Only through holes and surfaces can be machined.

Usable only for light cuts, i.e. low chip load and unhard materials. Cutting speed cannot be high.

Defects or damages in the broach (cutting edges) severely affect product quality.

Design, manufacture and restoration of the broaches are difficult and expensive.

Separate broach has to be used when the size, shape and geometry of the job changes. Economic only when the production volume is large.

**5.12 Comparison to grinding.**

# UNIT-4

## SYSTEMS OF LIMITS AND FITS

**Introduction:-**

Metrology is derived from a Greek word which means "measurement". It is the science of measurement and measurement is the language of science. But, for engineering purposes it has limited to the measurement of length, angles and other quantities that can be expressed in linear and angular terms. It is concerned with the methods execution and estimation of accuracy of measurements.

Metrology plays a vital role in the field of engineering for the designing and manufacturing of various engineering products. It is used for measuring the size, shape, etc. The products obtained should be in the limits of the specification with dimensional accuracy. In order to improve the process of manufacturing, it is required to develop the means of measurement. Every type of quantity measured must be followed by the units, which gives the correct meaning to the quantity measured.

**Significance of Metrology:**

(a) Metrology is very helpful in the scientific investigation of our dynamic world.

(b) It plays a critical role in the fields of chemistry, nanotechnology, etc.

(c) Metrology provides an infrastructure not only for physical and natural sciences but also exceeds to comprise environment, medicine, agriculture and food.

(d) Various higher level studies demonstrate the impact of measurement to the society.

**LIMITS:-**

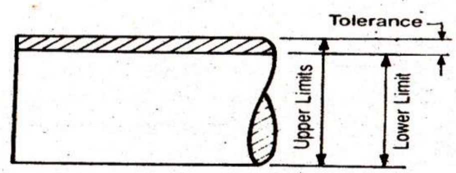
Limits can be defined as the permissible variation in dimension that is permitted to account for variability. Manufacturing process is a combination of three elements man, materials and machine. A change in any one or all of these will result in changes in sizes of manufactured parts. Usually in mass production, large number of components are to be made by different operators on different machines. So, it is impossible to make all components with exact dimensions.

The difference in dimensions vary from machine to machine, operator to operator and quality of the components. The dimension of the manufactured part can thus only be made to lie between two limits, maximum and minimum. The maximum limit is the maximum size permitted for the component whereas the minimum limit is the minimum size permitted for the component.

**TOLERANCE:-**

The permissible variation in size or dimension is called tolerance. Thus, the word tolerance indicates that a worker is not expected to produce the part to the exact size, but a definite small size error is permitted. The difference between the upper limit (high. limit) and the lower limit of a dimension represents the margin for variation in' workmanship, and is called a ‘tolerance Zone'.

Tolerance can also be defined as the amount by which the job is allowed to go away from accuracy and perfectness without causing any functional trouble, when assembled with its mating part and put into actual service.




**Tolerance**

**For example, a shaft of 25 mm basic size may be written as 25 ± 0.02.**
**The maximum permissible size (upper limit) = 25.02 mm and the minimum permissible size (2000 limit) = 24.98 mm**

**Then, Tolerance = Upper limit – Lower limit**
**= 25.02 – 24.98 = 0.04 mm.**

**<u>Systems of Writing Tolerances:-</u>**

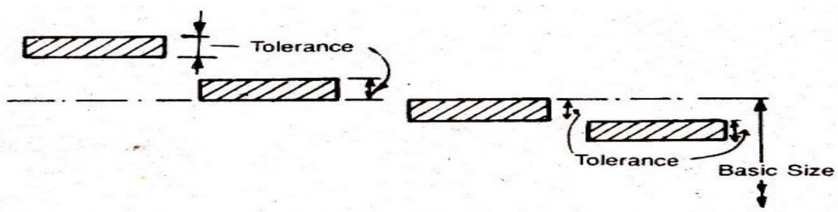
There are two systems of writing tolerances:

(i) Unilateral system

(ii) Bilateral system

**(i) Unilateral System**

In this system, the dimension of a part is allowed to vary only on one side of the basic size i.e., tolerance lies wholly on one side of the basic size either above or below it.



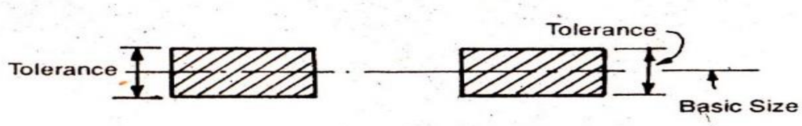

**Unilateral Tolerance**

**Examples of unilateral tolerance are :**

$25^{+0.02}_{+0.01}$, $25^{+0.02}_{-0.00}$, $25^{-0.01}_{-0.02}$, $25^{+0.00}_{-0.02}$ etc.

**(ii) Bilateral system**

In this system, the dimension of the part is allowed to vary on both the sides of the basic size i.e., the limits of tolerance lie on either side of the basic size; but may not be necessarily equally disposed about it.




**Bi-lateral tolerance**

*e.g.*, $25^{\pm 0.02}$, $25^{+0.02}_{-0.01}$

In this system it is not possible to retain the same fit when tolerance is varied and .the basic size of one or both of the mating parts is to be varied. This system is used in mass production where machine setting is done for the basic size.

**Advantages of Unilateral Dimensioning System**

1. Unilateral system of dimensioning is the most easiest and simplest method to find the deviations.

2. It can standardize the 'Go' gauge ends Without any difficulty.

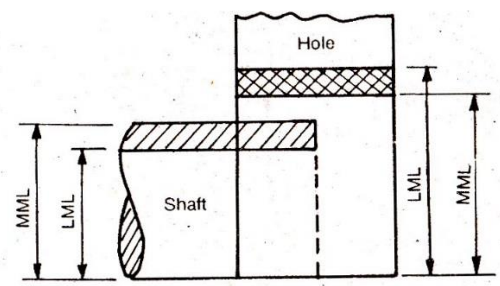
3. While machining the mating parts, the tolerance under this system facilitates the operator to a higher extent.

**Advantage of Bilateral Dimensioning System**

This system is used in mass production, as the setting of machine for basic size is the main criteria.

**Maximum and Minimum Metal Limits (or conditions):-**

If the tolerance for the shaft is given as $25^{\pm 0.05}$, the upper limit will be 25.05 mm and the lower limit will be 24.94 mm. The Shaft is said to have Maximum Metal Limit (MML) of 25.05 mm, since at this limit the shaft has maximum possible amount of metal. The limit of 24.95 will then be the minimum or "Least Metal Limit" (LML) because at this limit the shaft will have the least possible amount of metal.

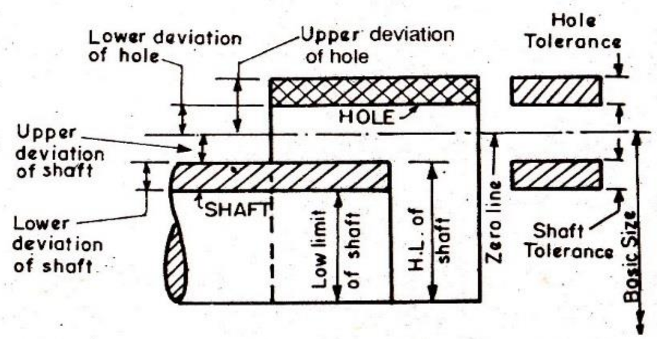



MML and LML

Similarly, if the hole is designated as $30^{\pm 0.05}$mm, the upper limit will be 30.05 mm and the lower limit will be 29.95 mm. Then, the Maximum Metal Limit (MML) of hole will be equal to 29.95, since at this lower limit the hole has the maximum possible amount of metal; while the upper limit of 30.05 mm will be the minimum of 'Least Metal Limit' (LML) of hole as, at this limit the hole will have the least possible amount of metal.

**Conventional Diagram of Limits and Fits:-**

In the system of limits and fits, we are simply interested in the tolerance on shafts and holes and not in their sizes. Therefore, in the conventional simplified diagram the shaft is shown resting on the hole to make it easy to understand.




Conventional Diagram of Limits

**Terminology for Limits and Fits:-**

**Basic or Nominal Size:** It is the standard size of a part with reference to which the limits of variation of a size are determined. It is referred to as a matter of convenience. The basic size is the same for the hole and its shaft. It is the designed size obtained by calculations for strength.

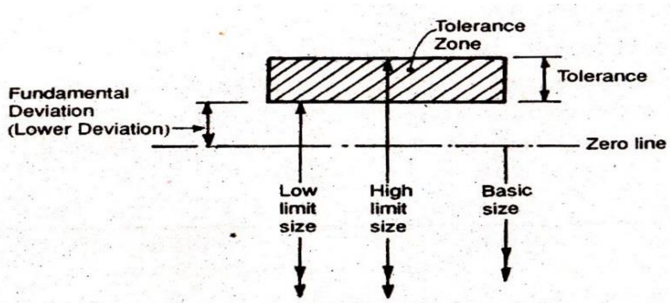
**Zero line:** It is a straight line drawn horizontally to represent the basic size. In the graphical representation of limits and fits, all the deviations are shown with respect to the zero line (datum line). The positive deviations are shown above the zero line and negative deviations below as shown in Fig (Conventional diagram of limits above).

**Deviation:** Deviation is the algebraic difference between the size (actual, maximum etc.) and the corresponding basic size.

**Upper Deviation:** It is the algebraic difference between the upper (maximum) limit of size and the corresponding basic size. It is a positive quantity when the maximum limit of size is greater than the basic size and a negative quantity when the upper limit of size is less than the basic size as shown in Fig. It is denoted by 'ES' for hole and 'es' for a shaft.

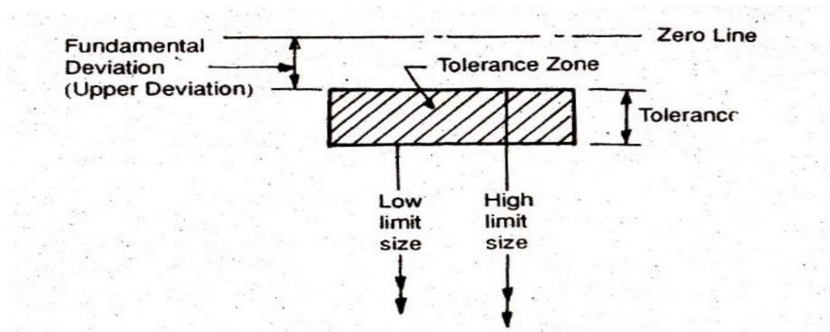
**Lower Deviation:** It is the algebraic difference between the lower limit of size and the corresponding basic size. It is a positive quantity when the maximum limit of size is greater than the basic size and a negative quantity when the lower limit of size is less than the basic size.

**Fundamental Deviation:** Fundamental deviation is that one of the two deviations (either the upper or the lower) which is the nearest to the zero line for either hole or a shaft. It fixes the position of the 'Tolerance Zone' in relation to the zero line as shown in Fig.




Lower deviation as fundamental deviation

The fundamental deviation for the hole is denoted by capital letters A, B, C, ..... 2 C and the same for shaft is denoted by small letters a, b, c   zc etc. as explained later.




**Upper deviation as fundamental deviation**

From Fig it is clear that when the tolerance zone is above the zero line, lower deviation is the fundamental deviation. While, when the tolerance zone is below the zero line, upper deviation is the fundamental deviation.

**FIT:-**

Fit may be defined as a degree of tightness or looseness, between two mating parts to perform a definite function when they are assembled together.

The fit given the relationship between two mating parts that is shaft and hole. A fit can either provide a fixed joint or movable joint. For example a shaft running in a bearing can move in relation to it and thus forms a movable joint, whereas, a pulley mounted on the shaft forms a fixed joint.

**Types of fits:-**

On the basis of positive, zero and negative values of Clearance, there are three basic types of fits:

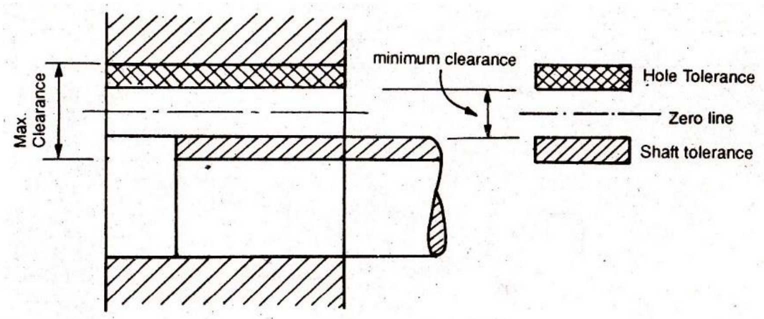
(1) Clearance Fit (2) Transition Fit and, (3) Interference Fit.

These are further classified in the following manner:

**Fits**

| *Clearance Fit* | *Transition Fit* | *Interference Fit* |
|---|---|---|
| (*a*) Slide Fit | (*a*) Push fit | (*a*) Force Fit |
| (*b*) Easy slide Fit | (*b*) Wringing Fit | (*b*) Tight Fit |
| (*c*) Running Fit | | (*c*) Shrink fit |
| (*d*) Slack running Fit | | |
| (*e*) Loose running Fit | | |

**(1) Clearance Fit:** In this type of fit aha& is always smaller than the hole i.e., the largest permissible aha& diameter is smaller than the diameter of the smallest hole. So that the shaft can rotate or slide through with different degrees of freedom according to the purpose of mating part.



Clearance Fit

Clearance fit exists when the shaft and the hole are at their maximum metal conditions. The tolerance zone of the hole is above that of the shaft as shown in Fig.

**Maximum Clearance:** It is the difference between the minimum size of shaft and maximum size of hole.

**Minimum Clearance:** It is the difference between the maximum size of shaft and minimum size of hole.

**i. Slide Fit:** This type of fit has a very small clearance, the minimum clearance being zero. Sliding fits are employed when the mating parts are required to move slowly in relation to each other e.g., tailstock spindle of lathe, feed movement of the spindle quill in a drilling machine, sliding change gears in quick change gear box of a centre lathe etc. .

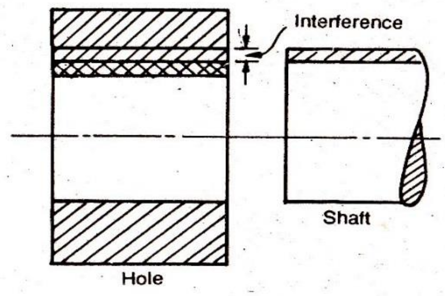
**ii. Easy Slide Fit:** This type of fit provides for a small guaranteed clearance. It serves to ensure alignment between the shaft and hole. It is applicable for slow and non-regular motion, for example, spindle of lathe and dividing heads, piston and slide valves, spigots etc.

**iii. Running Fit:** Running fit is obtained when there is an appreciable clearance between the ~mating parts. The clearance provides a sufficient space for a lubrication film between mating friction surfaces. It is employed for rotation at moderate speed, e.g., gear box bearings, shaft pulleys, crank shafts in their main bearings etc.

**iv. Slack running Fit:** It is obtained when there is a considerable clearance between the mating parts. This type of fit may be required as compensation for mounting errors e.g., arm shaft of I.C. engine, shaft of certifigual pump etc.

**v. Loose running Fit:** Loose running fit is employed for rotation at very high speed, eg., idle pulley on their shaft such as that used in quick return mechanism of a planer.

**(2) Interference Fit:** In this type of fit the minimum permissible diameter of the shaft is larger than the maximum allowable diameter of the hole. Thus the shaft and the hole members are intended to be attached permanently and used as a solid component.



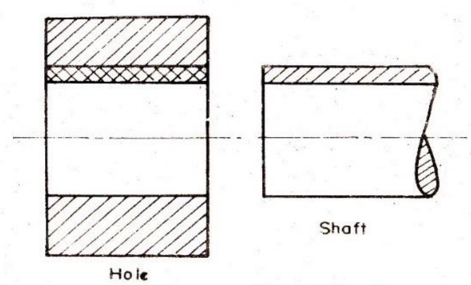

Interference fit

**i. Force Fit:** Force fits are employed when the mating parts are not required to be disassembled during their total service life. In this case the interference is quite appreciable and, therefore, assembly is obtained only when high pressure is applied. This fit, thus, offers a permanent type of assembly, e.g. , gears on the shaft of a concrete mixture, forging machine etc.

**ii. Tight Fit:** It provides less interference than force fit. Tight fits are employed for mating parts that may be replaced while overhauling of the machine, for example, stepped pulleys on the drive shaft of a conveyor, cylindrical grinding machine etc.

**iii. Heavy force and Shrink Fit:** It refers to maximum negative allowance. Hence considerable force is necessary for the assembly. The fitting of the frame on the rim can also be obtained first by heating the frame and then rapidly cooling it in its position.

**(3) Transition Fit:** Transition fit lies mid way between clearance and interference fit. In this type the size limits of mating parts (shaft and hole) are so selected that either clearance or indifference may occur depending upon the actual sizes of the parts. Push fit and wringing fit are the examples of this type of fit.



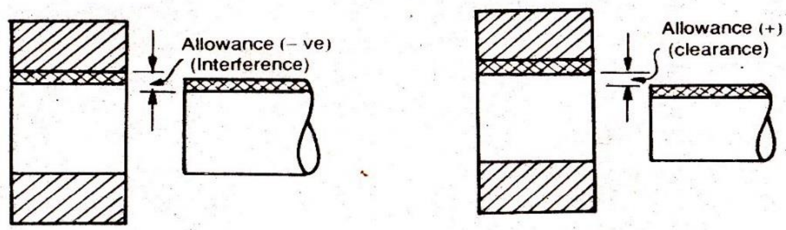

Transition fit

In this type of fit the tolerance zones of the hole and shaft overlap completely or in part.

**i. Wringing Fit:** A wringing fit provides either zero interference or a clearance. These are used where parts can be replaced without difficulty during minor repairs.

**ii. Push Fit:** The fit provides small clearance. It is employed for parts that must be disassembled during operation of a machine for example, change gears, slip bushing etc.

**ALLOWANCE:-**




Allowance is the prescribed difference between the dimensions of two mating parts for any type of fit.

It is the intentional difference between the lower limit of hole and higher limit of the shaft. The allowance may be positive or negative.

The positive allowance is called clearance and the negative allowance is called interference.

**Difference between Tolerance and Allowance:-**

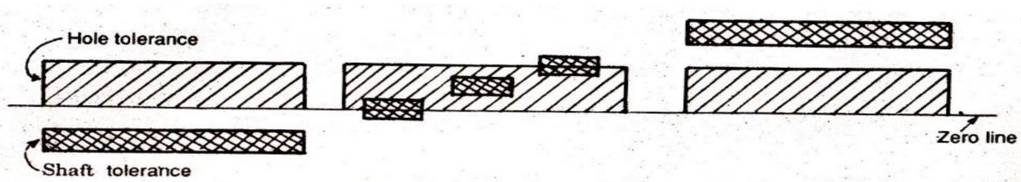
| *Tolerance* | *Allowance* |
|---|---|
| 1. It is the permissible variation in dimension of a part (either a hole or a shaft). | It is the prescribed difference between the dimensions of two mating parts (hole and shaft). |
| 2. It is the difference between higher and lower limits of a dimension of a part. | It is the intentional difference between the lower limit of hole and higher limit of shaft. |
| 3. The tolerance is provided on a dimension of a part as it is not possible to make a part to exact specified dimension. | Allowance is to be provided on the dimension of mating parts to obtain desired type of fit. |
| 4. It has absolute value without sign. | Allowance may be positive (clearance) or negative (interference). |

**Systems of Obtaining Different Types of Fits:-**

There are two systems of fit for obtaining clearance, interference or transition fit. These are:

(1) Hole basis system. (2) Shaft basis system.

**(1) Hole basis system:** In the hole basis system the hole is kept constant and the shaft sizes are varied to give the various types of fits. In this system lower deviation of the hole is zero i.e., the low limit of hole is the same as basic size. The high limit of hole and the two limits of size for the shaft are then varied to give the desired type of fit, as shown in Fig.

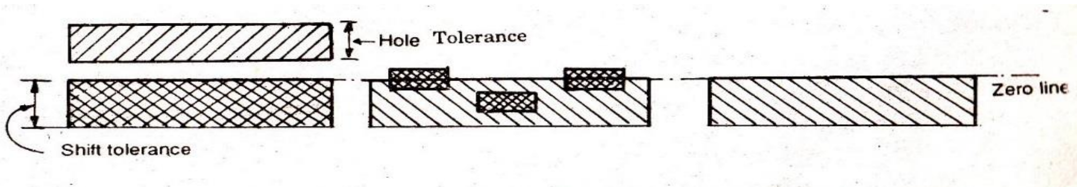



(*a*) Clearance Fit (*b*) Transition Fit (*c*) Interference Fit

Shaft basis System. In the shaft basis system the shaft is kept constant and the sizes of the hole are varied to give various types of fits.

In this system the upper deviation (fundamental deviation) of shaft is zero i.e., the high limit of shaft is the same as basic size and the various fits are obtained by varying the low limit of shaft and both the limits of hole.

**(2) Shaft basis system:**




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

The hole basis system is most commonly used because it is more convenient to make correct holes of fixed sizes, since the standard drills, taps, reamors and broaches etc. are available for producing holes and their sizes are not adjustable. On the other hand size of shaft produced by turning, grinding etc. can be very easily varied.

Shaft basis system is used when the ground bars or drawn bars are readily available. These bars do not require further machining and fit are obtained by varying the sizes of hole.

**<u>Difference between 'Hole Basis' and 'Shaft Basis' Systems:-</u>**

| | *Hole Basis System* | *Shaft Basis System* |
|---|---|---|
| 1. | Size of hole whose lower deviation is zero (H-hole) is assumed as the basic size. | Size of shaft whose upper deviation is zero ($h$-shaft) is assumed as basic size. |
| 2. | Limits on the hole are kept constant and those of shaft are varied to obtain desired type of fit. | Limits on the shaft are kept constant and those on the hole are varied to have necessary fit. |
| 3. | Hole basis system is preferred in mass production, because it is convenient and less costly to make a hole of correct size due to availability of standard drills and reamers. | This system is not suitable for mass production because it is convenient, time consuming and costly to make a shaft of correct size. |
| 4. | It is much more easy to vary the shaft sizes according to the fit required. | It is rather difficult to vary the hole sizes according to the fit required. |
| 5. | It requires less amount of capital and storage space for tools needed to produce shafts of different sizes. | It needs large amounts of capital and storage space for large number of tools required to produce holes of different sizes. |
| 6. | Gauging of shafts can be easily and conveniently done with adjustable gap gauges. | Being internal measurement, gauging of holes cannot be easily and conveniently done. |

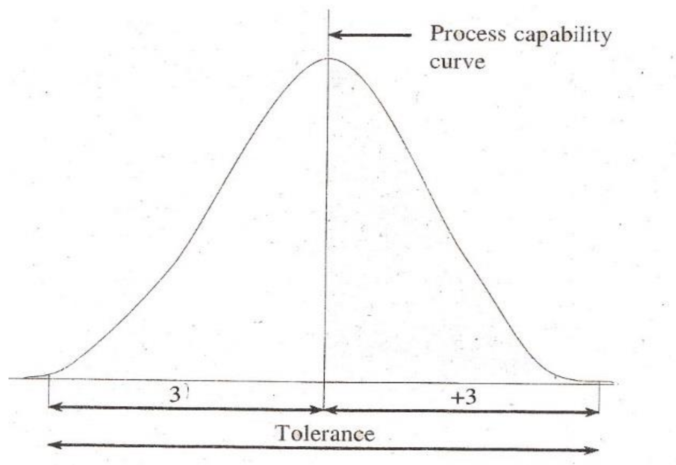
**Types of Assemblies:-**

There are three ways by which the mating parts can be made to fit together in the desired manner. These are:

(1) Trial and Error (2) Interchangeable Assembly (3) Selective Assembly

**(1) Trial and Error:** when a small number of similar assemblies are to be made by the same operator the necessary fit can be obtained by trial and error. This technique simply requires one part to be made to its nominal size as accurately as possible, the other part is then machined with a small amount at a time by trial and error until they fit in the required manner. This method may be used for "one off jobs", tool room work etc. where both parts will be replaced at once.

**(2) Interchangeable Assembly:**




It is a system of producing the mating parts in which large number of mating parts are produced. In earlier days, a single operator was confined with number of units and assemble it, which used to take long time and it was not economical. So to reduce the cost and time, mass production 'system was developed. In most production systems, the components are produced in one or more batches by different operations on different machines.

**Advantages of Interchangeability**

1. This system reduces the production cost and increases the output

2. The operator need not Waste time in assembling the parts by trial and error method.

3. Worn out parts and defective parts can be easily replaced.

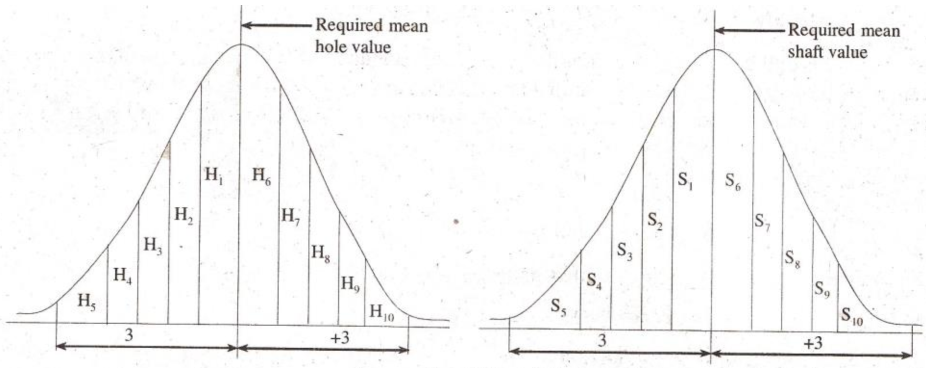
4. By this method, it is possible to produce mating parts at different places by different operators.

5. Maintenance cost and shut down period is reduced.

**(3) Selective Assembly:**

The need of the consumer is not only the quality, precision and trouble-free products but also the availability of products at economical prices. This is possible by automatic gauging for selective assembly. In this system, the parts are manufactured to rather wider tolerances and the products produced are classified into various groups according to their sizes by automatic gauging. Classification is made for formatting parts and only matched groups are assembled together.

If hole and shaft are to be produced with in a tolerance of 0.02 mm and both are in the curve of normal distribution, then automatic gauging divides 'them into parts with a 0.002 mm limit for selective assembly of individual pans. Consider an example of piston with cylinder. Let the size of the above be 60 mm and the clearance of 0. 12 mm is required for the assembly. Let the tolerance on bore and piston each be 0.04 mm. Then




Process Capability of Shaft and Hole

Dimension of bore diameter is $60^{\pm 0.12}$ mm and

Dimension of piston is $59.88^{\pm 0.12}$ mm

The pistons and bores may be selected to give the clearance of 0.12 as given below.

| | | | |
|---|---|---|---|
| Cylinder bore | 59.98 | 60.00 | 60.02 |
| Piston | 59.86 | 59.88 | 59.90 |

**What is the difference between international and British standards?**

There are a few different standards, British standards, European Standards, American standards, Canadian....

The International Standards (IEC) are worldwide, European ones cover European countries and country specific ones cover that country. Many countries have similar standards.

The ones that cover larger areas (International and European) are used by the countries when they write their standards. An example might be BS EN numbered standards which are British standards that cover the requirements of the European standard. Some are country specific only (BS) and some cover international standards (IEC). It can be confusing but there should be a standard in each country to cover most engineering things.

The main difference is the geographical area that they cover. If you are say working in Britain and follow the BS requirements (or BS EN, or IEC) that applies then you can say that you are working to best practices and can't be faulted for that.

There will be small differences between them based on custom and practices for the countries that have written them.

**Indian Standard System of Limits and Fits (IS-919 and 2709)**

The Indian standards are in line with the ISO (International Organizations for Standards) recommendations.

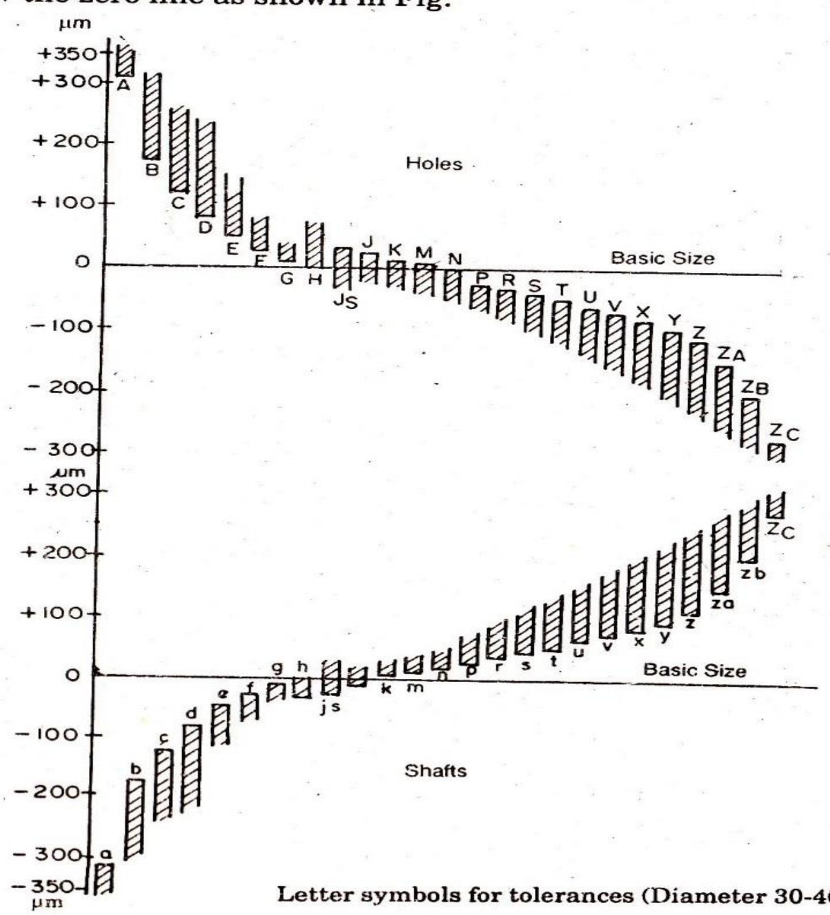
It consists of suitable combination of 18 grades of fundamental tolerances or in other words grades of accuracy for manufacture, and 25 types of fundamental deviations.

The 18 grades of fundamental tolerances are designated as IT01, IT0, IT1 to IT16. While, the fundamental deviations are indicated by letter symbols for both hole and shaft (capital letters 'A to Zc' for holes and small letters a to $z_c$ for shafts. These are : A, B, C, D, E, F, G, H, $J_S$, J, K, M, N, P, R, S, T, U, V, X, Y, Z , $Z_A$, $Z_B$, $Z_C$).

Innumerable fits ranging from extreme clearance to those of extreme interference can be obtained by a suitable combination of fundamental tolerances and fundamental deviations. Each of 25 holes has a choice of 18 tolerances.

For shafts '*a*' to '*h*' the upper deviation is below the zero line and for shafts '*j*' to '*Zi*' it is above the zero line.

For holes '*A*' to '*H*' lower deviation is above the zero line and for I to Zc it is below the zero line as shown in Fig.




Letter symbols for tolerances (Diameter 30-40 mm)

**Problems:-**

*EXAMPLE 1.* Find the values of allowance, and tolerances for hole and shaft assembly for the following dimensions of mating parts :

Hole : $25^{+0.05}_{+0.00}$ Shaft : $25^{-0.02}_{-0.05}$

*SOLUTION.*

(*i*) Hole : Tolerance = High limit − Low limit
= 25.05 − 25 = 0.05 mm

(*ii*) Shaft : Tolerance = High limit − Low limit

Now, High limit = 25 − 0.02 = 24.98 mm
Low limit = 25 − 0.05 = 24.95 mm
∴ Tolerance = 24.98 − 24.95 = 0.03 mm

(*iii*) Allowance = Low limit of hole − High limit of shaft
= Maximum metal condition of hole − Maximum metal condition of shaft
= 25.00 − 24.98 = 0.02 mm

*EXAMPLE 2.* A 50 mm diameter shaft is made to rotate in the bush. The tolerances for both shaft and bush are 0.050 mm. Determine the dimension of the shaft and the bush to give a maximum clearance of 0.075 mm with the hole basis system.

*SOLUTION.* In the hole basis system lower deviation of hole is zero therefore low limit of hole = 50 mm

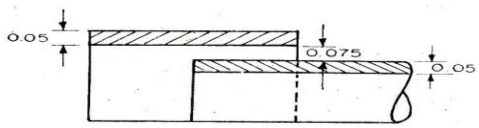



**Fig. 9.44.**

High limit of hole = Low limit + Tolerance
= 50.00 + 0.050 = 50.050 mm

High limit of shaft = Low limit of hole − Allowance
= 50.00 − 0.075 = 49.025 mm

Low limit of shaft = High limit − Tolerance
= 49.025 − 0.050 = 48.975 mm

**EXAMPLE 3.** For each of the following hole and shaft assembly, find shaft-tolerance, hole tolerance and state whether the type of fit is (*i*) clearance (*ii*) transition or (*iii*) interference.

(*a*) Hole : $50^{+0.25}_{+0.00}$ mm Shaft : $50^{+0.05}_{+0.005}$ mm

(*b*) Hole : $30^{+0.05}_{+0.00}$ mm Shaft : $30^{-0.02}_{+0.05}$ mm

(*c*) Hole : $25^{+0.04}_{+0.00}$ mm Shaft : $25^{+0.06}_{+0.04}$ mm

*SOLUTION.* (*a*) Hole : High limit of hole = 50.025 mm
Low limit of hole = 50.00 mm

∴ Hole tolerance = 50.025 − 50.00 = **0.025** mm ...(*i*)

Shaft : High limit of shaft = 50.05 mm
Low limit of shaft = 50.005 mm
Shaft tolerance = 50.05 − 50.005 = **0.045** mm ...(*ii*)

If we choose high limit of hole with high limit of shaft then
Allowance = 50.025 − 50.05 = − 0.025 (Interference)

If we choose high limit of hole and low limit of shaft then
Allowance = 50.025 − 50.005 = 0.020 mm (Clearance)

Similarly, if we choose low limit of hole and either high limit or low limit of shaft it is clear that there will be interference.

Thus, we conclude that the type of fit is **Transition Fit**.

(*b*) Hole : High limit = 30.05 mm
Low limit = 30.00 mm
∴ Tolerance = 0.05 mm

Shaft : High limit = 30 − 0.02 = 29.98 mm
Low limit = 30 − 0.05 = 29.95 mm
∴ Tolerance = 29.98 − 29.95 = 0.03 mm

If we select high limit of hole and high limit of shaft then
Allowance = 30.05 − 29.98 = 0.07 mm

If we select low limit of hole and high limit of shaft then
Allowance = 30.00 − 29.98 = 0.02 mm

Thus we conclude that the type of fit is **Clearance Fit**.

(*c*) Hole : High limit = 25.04 mm
Low limit = 25.00 mm
Tolerance = 25.04 − 25.00 = 0.04 mm

Shaft : High limit = 25.06 mm
Low limit = 25.04 mm
Tolerance = 25.06 − 25.04 = 0.02 mm

If we select, H.L. of shaft and L.L. of hole then
Allowance = 25.00 − 25.06 = − 0.06 mm

It is clear that for any combination of hole and shaft the allowance will be negative.

Thus we conclude that the type of fit is **Interference Fit**.

***Example 4.*** **In a limit system, the following limits are specified to give a clearance fit between a shaft and a hole.**

$$\text{Shaft } 50^{-0.006}_{-0.020} \text{ mm} \qquad \text{Hole } 50^{+0.030}_{-0.000} \text{ mm}$$

**Find : (*a*) Basic size (*b*) Shaft and hole tolerances (*c*) Maximum clearance (*d*) Minimum clearance.**

***Solution.*** (*a*) Basic size (same for hole and shaft) = 50 mm

(*b*) Shaft tolerance = H.L. of shaft – L.L. of shaft

= (50 – 0.006) – (50 – 0.02) = **0.014 mm**

Hole tolerance = H.L. – L.L. = 50.030 – 50.00 = 0.030 mm

(*c*) Maximum clearance = H.L. of hole – L.L. of shaft

= 50.030 – (50 – 0.02) = 50.030 – 49.98 = 0.05 mm

(*d*) Minimum clearance = L.L. of hole – H.L. of shaft

= 50.00 – (50 – 0.006) = + 0.006 mm.

***Example 5.*** **In a hole and shaft assembly of 30 mm nominal size, the tolerances for hole and shaft are as specified below :**

$$\text{Hole : } 30^{+0.02}_{-0.000} \text{ mm} \qquad \text{Shaft : } 30^{-0.040}_{-0.070} \text{ mm}$$

**Determine :**

(*i*) **Maximum and minimum clearance obtainable**

(*ii*) **Allowance**

(*iii*) **Hole and Shaft tolerance**

(*iv*) **MML shaft and hole**

(*v*) **The type of fit.**

***Solution.*** (*i*) Maximum clearance = H.L. of hole – L.L. of shaft

= 30.02 – (30 – 0.07) = + 0.09 mm

Minimum clearance = L.L. of hole – H.L. of shaft

= 30.00 – (30 – 0.04) = + 0.04 mm

(*ii*) Allowance = L.L. of hole – H.L. of shaft

= 0.04 mm as above

(*iii*) Hole tolerance = H.L. of hole – L.L. of hole

= 30.02 – 30.00 = 0.02 mm

Shaft tolerance = H.L. of shaft – L.L. of shaft

= 29.96 – 29.93 = 0.03 mm

(*iv*) MML for shaft *i.e.* maximum metal limit for shaft

= H.L. of shaft = 29.96 mm

MML for hole = L.L. of hole = 25.00 mm

(*v*) Since the allowance is positive, it gives a clearance fit.

***Example 6.*** **A hole and mating shaft are to have a nominal assembly size of 50 mm. The assembly is to have a maximum clearance of 0.15 mm and a minimum clearance of 0.05 mm. The hole tolerance is 1.5 times the shaft tolerance. Determine the limits for both hole and shaft :**

**By using (*i*) Hole basis system (*ii*) shaft basis system.**

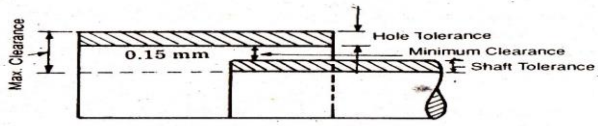



**Fig. 9.45.**

***Solution.*** (*i*) **Hole Basis system**

In hole basis system lower deviation of hole is zero *i.e.*, the low limit of hole is the same as basic size from Fig. 9.45.

Max. clearance = Hole tolerance + Minimum clearance + Shaft tolerance

Therefore 0.15 = 1.5 × shaft tol. + 0.05 + shaft tol.

∴ 0.15 – 0.05 = shaft tol. (1.5 + 1)

*i.e.*, Shaft tolerance = $\frac{0.1}{2.5}$ = 0.04 mm

Hole tolerance = 0.04 × 1.5 = 0.06 mm

Now, low limit of hole = 40 mm (basic size)

∴ High Limit of hole = 40 + 0.06 = 40.06 mm

Thus hole sizes are 40 and 40.06 mm.

We know that minimum clearance = Low limit of hole – High limit of shaft

Therefore, 0.05 = 40.00 – H.L. of shaft

∴ H.L. of shaft = 40 – 0.05 = 39.95 mm

L.L. of shaft = H.L. – Tolerance

= 39.95 – 0.04 = 39.91 mm

Thus, shaft limits are 39.95 mm, and 39.91 mm.

(*ii*) **Shaft Basis system**

In shaft basis system upper deviation of shaft is zero *i.e.*, H.L. of shaft is the same as basis size = 40.00 mm

L.L. of shaft = H.L. – Tolerance

= 40.00 – 0.05 = 39.95 mm

Max. clearance = H.L. of hole – Low limit of shaft

∴ 0.15 = H.L. of hole – 39.95

∴ H.L. of hole = 39.95 + 0.15 = 40.10 mm

L.L. of hole = H.L. – Tolerance

= 40.10 – 0.06 = 40.04 mm

***Example 7.*** In an assembly of two parts 50 mm nominal diameter, the lower deviation of the hole is zero and the higher is 5 microns ; while that of shaft is − 4 and − 8 microns respectively. Estimate the allowance and state the type of fit of the assembly.

***Solution.*** *Hole size :* H.L. of hole = 50.005 mm

L.L. of hole = 50.000 mm

*Shaft size* : H.L. of shaft = 50 − 0.004 = 49.996 mm

L.L. of shaft = 50 − 0.008 = 49.992 mm

Minimum allowance = Lower limit of hole − Higher limit of shaft

= 50.000 − 49.996 = 10.004 mm

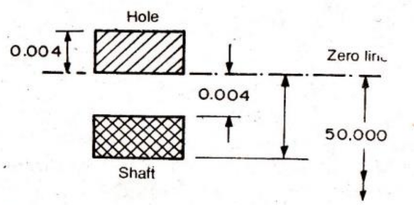



**Fig. 7.46.**

***Example 8.*** A 20 mm diameter shaft and bearing are to be assembled with a clearance fit. The tolerance and allowances are as under :

Allowance = 0.002 mm

Tolerance on hole = 0.005 mm

Tolerance on shaft = 0.003 mm

Find the limits of size for the hole and shaft if :

(*a*) the hole basis system is used (*b*) shaft basis system is used. The tolerances are disposed of unilaterally.

***Solution.*** *For Hole Basis System :*

*Hole size :*

Higher limit of hole = 20.005 mm

Lower limit of hole = 20.000 mm

Now, allowance given is + 0.002 mm

Therefore, Higher limit of shaft = Lower limit of hole − Allowance

= 20.000 − 0.002 = 19.998 mm

and, lower limit of shaft = Higher limit of shaft − Tolerance

= 19.998 − 0.003 mm = 19.995 mm

*For Shaft Basis System :*

Shaft size ; High limit = 20.000 mm and

Lower limit = 20.000 − 0.003 = 19.997 mm

Allowance = + 0.002 (given)

Therefore, Low limit of hole = High limit of size + Allowance

= 20.000 + 0.002 = 20.002 mm

and High limit of hole = 20.002 + 0.005 = 20.007 mm

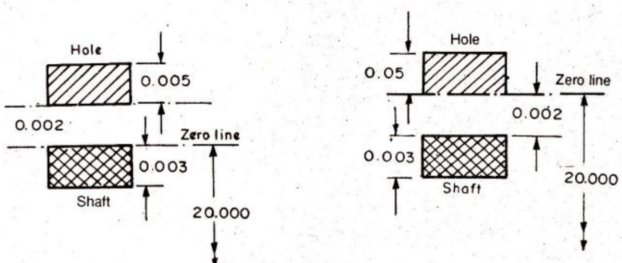



**Fig. 7.47.**



-----------------------THE END-----------------------

## Taylor's principle - Design of GO and NO GO Gauges:

### Taylor's principle of Gauge design:

This theory is the key to the design of limit gauges and defines the function and hence the form of most limit gauge. It states that,

1. The "Go" gauge should be designed to check the maximum material condition and should check as many dimensions as possible.
2. The "NOT Go" or "No Go" gauge should be designed to check the minimum materials limit and should only check one dimension at a time.

Thus a separate "No Go" gauge is required for each individual dimension. consider a system of limit gauge for a rectangular hole as shown in figure.

The "Go" gauge is used to ensure that the maximum metal condition is not exceeded and that metal does not encroach in to the minimum allowable hole space. It shoulc

Rectangular hole oversize in one Direction (31)

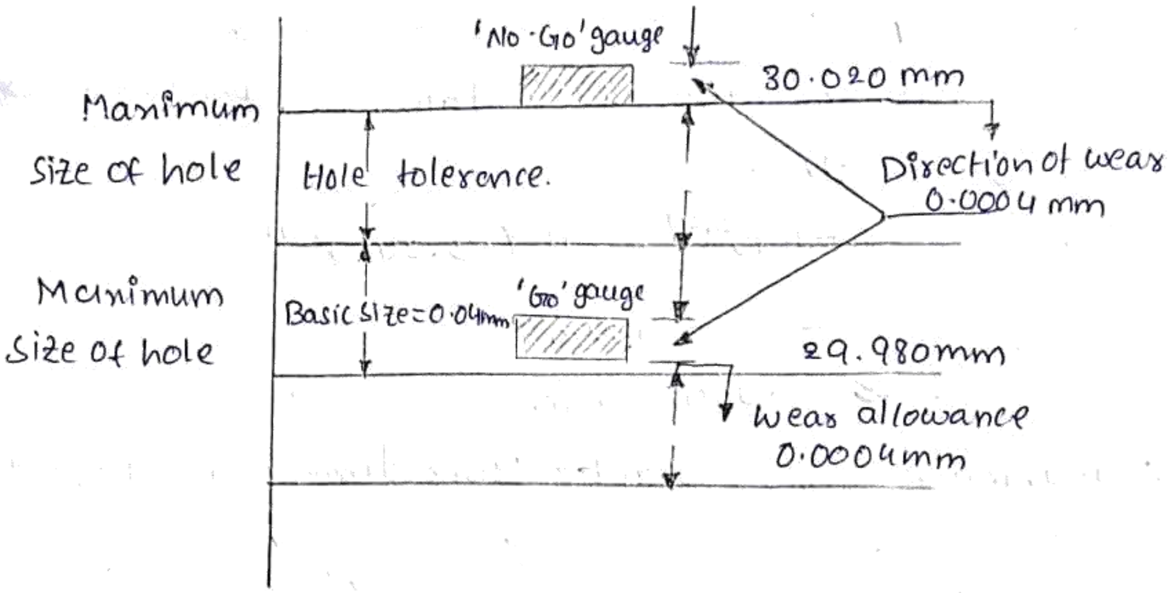
This system should be applied to all systems of limit gauges. The 'Go' gauge should be made equal in length to about three or four times of diameter, while the "No Go" gauge is always relatively short and approximately equal in length to the hole diameter, in case of circular hole.

In case of curved holes, if the length of the gauge is made shorter, then it will get pay through the obstruction in the hole and gives a wrong reading. But if the length of the gauge is made considerably long, it will not pass through the curved holes and error will be detected. A long gauges will thus check the surface not in one direction but in a number of sections simultaneously. The length of the "Go" gauge should not be less than 1.5 times the length of the hole to be checked.

Limitations of Taylor's principle:

1. Taylor's principle for 'Go' gauge is designed to have its length equal to the engagement length of fit. But in actual practice, it is not always possible. For instance, if Go gauge passes through a hole or shaft very easily so that it does not affect the required fit of assembly, then the length of 'Go' gauge (i.e., ring or cylindrical type gauge) might be less than engagement length of fit. — Similarly for big holes, the full form gauge will be much heavy and unsuitable to use. Hence, if 'Go' gauge does not gives roundness error to a affect the engagement fit than other gauges like spherical gauge, segmental cylindrical bar etc. should be used.

(6) 'NO - GO' gauge = $30.020^{+0.0004}_{+0.000}$ mm (39)




Q. Design a typical 'Go' and 'No Go' gauge for a shaft of 80 mm.

Answer:

Let us design the Go and NO Go gauge for 80 $H_8 e_9$ fit

Nominal diameter of shaft and hole is 80 mm

Since 80 mm diameter lies in the diameter steps of 50 and 80 mm.

$\therefore$ Value of D = $\sqrt{50 \times 80}$ = 63.246 mm

we know that, the fundamental tolerance factor,

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

$$\Rightarrow i = 0.45\sqrt[3]{63.246} + 0.001 \times 63.246$$

$$= 1.856 \mu m$$

$$\cong 0.00186 \text{ mm}$$

Hole type is $H_8$, and for H-hole, fundamental deviation = 0, $\therefore$ minimum size of hole = 80.000 mm

For $H_8$ i.e., $IT_8$, the value of tolerance

$$= 25i$$

$$= 25 \times 0.00186$$

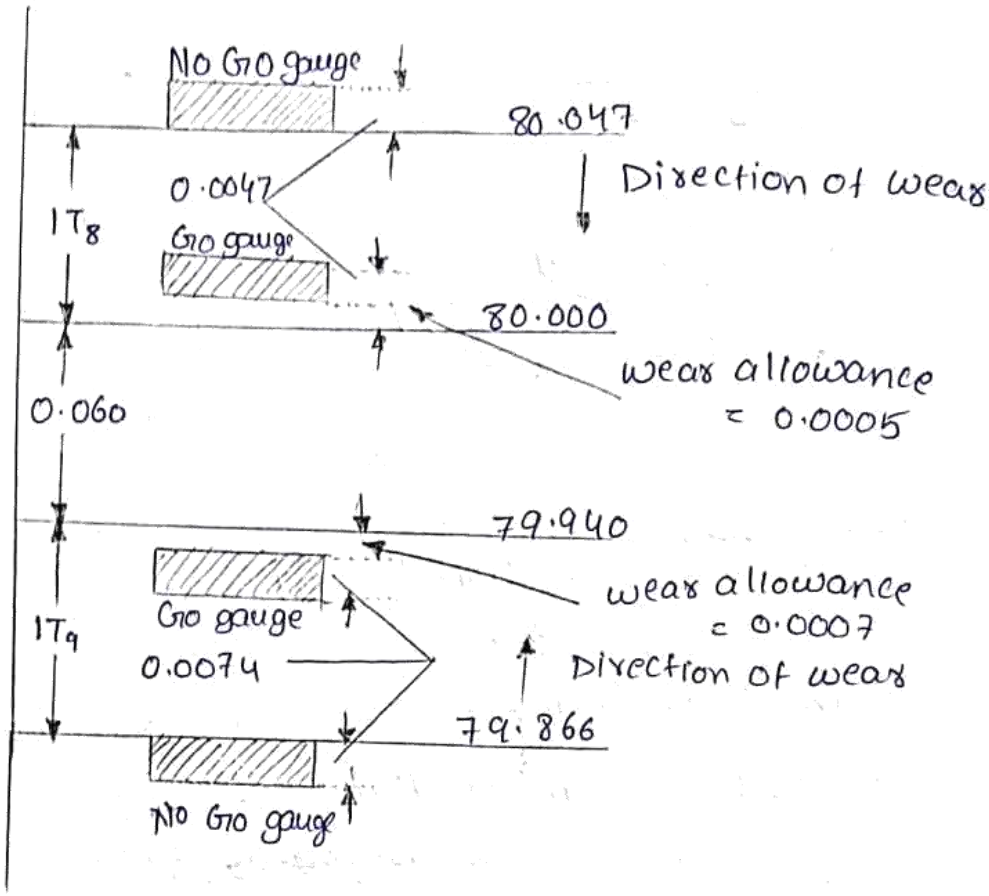
$$= 0.047 \text{ mm}$$

For shaft,



Go gauge $= 79.940^{-0.0007}_{-0.0007-0.0074} = 79.940^{-0.0007}_{-0.0081} = 80^{-0.0607}_{-0.0681}$ mm

No Go gauge $= 79.866^{-0.0000}_{-0.0074} = 80^{-0.1340}_{-0.1414}$ mm




## Snap gauges:

These gauges are used for gauging the shafts and male components. The 'Go' snap gauge is of a size corresponding to the high (maximum) limit of the shaft, while the 'NOT Go' gauge corresponds to the low (minimum limit). It is a plain gauge, category of form of tested surface with single ended and double ended gauge. Its ranges from 3mm to 100mm - with double end and 100 to 250 mm as single ended type. The gauging surfaces of the snap gauge is hardened and suitably grounded and lapped. Snap gauge have 'Go' and 'NO-Go' checking facility. The various snap, gap and ring gauges are shown in figure.

checked is parallel to the axis, as it normally is the gauge must be positioned parallel to the shaft axis also.

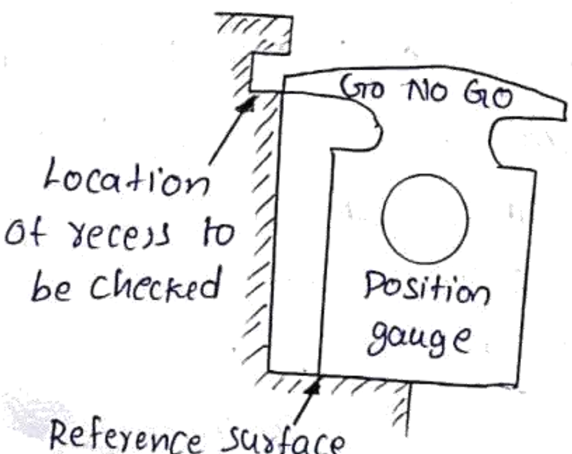
Profile gauges are used to check the form of the components. profiles are difficult to be checked by limit gauges and it is ~~used~~ practice to use fixed gauges mated to profile for checking profiles. There are two method of tolerance the form of profile (consisting of straight lines and curves).

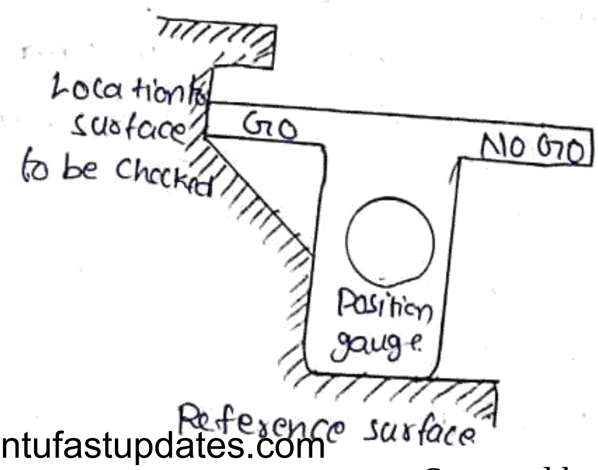
(i) It provide a tolerance zone within which the finished profile must lie. This method provides a uniform metal tolerance normal to the profile.

(ii) To use ordinates which are provided with individual tolerances. In this method the tolerance is normal to the surfaces will vary with the form of the profile.

## Position Gauge:-

The position gauges are employed for checking the position of some features as the work in relation to other surface or reference point. They are available to avoid variety and their design is based on the principle of sighting the gauge and work or on the method of feel. Practically, different position gauges are required for different works.

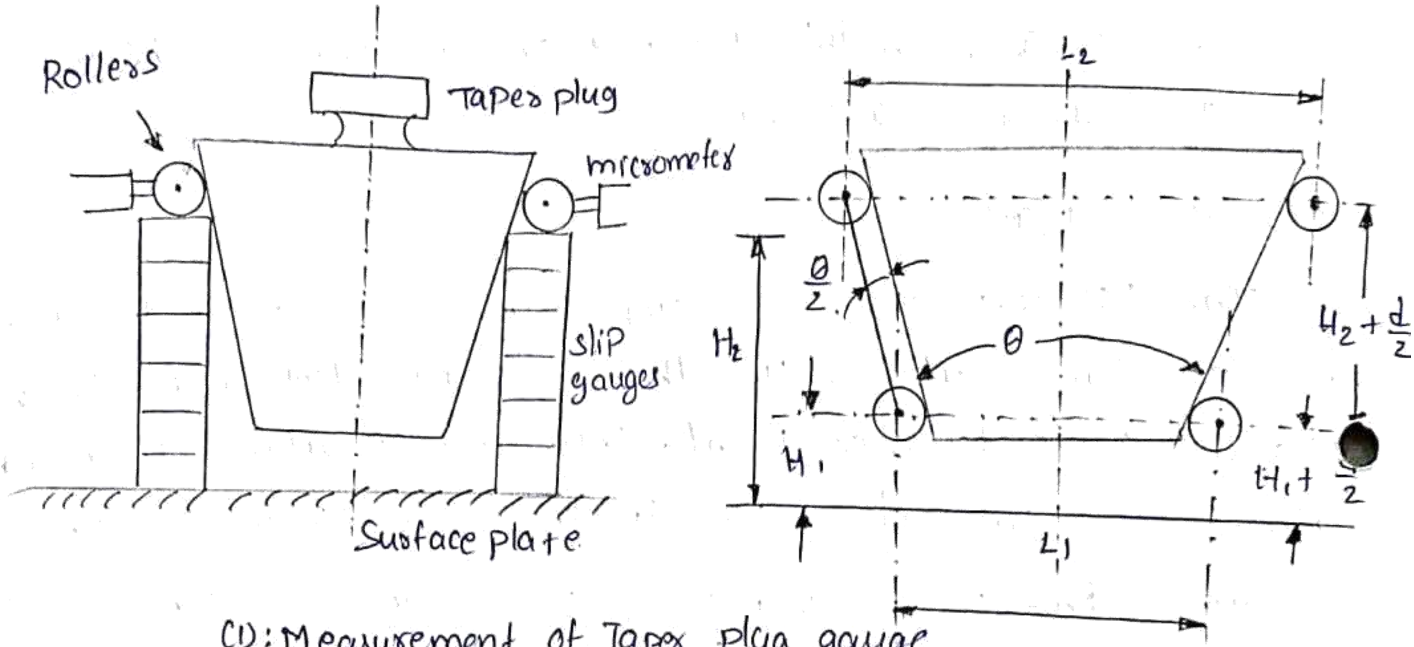


From the figure it may be noted that no light will pass between the reference surface and gauge surface in contact with "Go" side and light will pass "No Go" side. Figure shows checking to location of a recuse in relation to a flat surface and figure shows the surface parallel to the reference surface to be located.

## Checking the angle of taper using rollers, Micrometer and Slip gauges:

In this method, measurements are made over two equal rollers standing on slip gauges at each side of the taper plug gauge at two positions (one near the lower end and one near the upper end) are shown in figure (1).




(1): Measurement of Taper plug gauge.

At first the taper plug is placed on the surface plate. Two equal rollers are placed on the slip gauges on either sides of the taper plug at a height of $H_2$ and two equal rollers are placed on lower sides of the plug at a height of $H_1$. Now, the distance between the ends of the rollers are measured by a micrometer. Let '$L_1$' be the distance between the two upper position rollers and '$L_2$' be the distance between the two lower position rollers. Also "d" be the diameter of the roller then,

$$\tan\left(\frac{\theta}{2}\right)\left[\frac{\left[\frac{L_2-d}{2}\right]-\left[\frac{L_1-d}{2}\right]}{\left[H_2+\frac{d}{2}\right]-\left[H_1+\frac{d}{2}\right]}\right]$$

$$\therefore \tan\left(\frac{\theta}{2}\right)=\left[\frac{\left(\frac{L_2-d}{2}\right)-\left(\frac{L_1-d}{2}\right)}{\left[\frac{2H_2+d}{2}\right]-\left[\frac{2H_1+d}{2}\right]}\right]$$

$$=\frac{\left[\frac{L_2-d-L_1+d}{2}\right]}{\left(\frac{2H_2+d-2H_1-d}{2}\right)}$$

$$\tan\left(\frac{\theta}{2}\right)=\frac{L_2-L_1}{2(H_2-H_1)}$$

where, $\frac{\theta}{2}$ - Half the taper angle of the plug.

Q Calculate the angle of taper and minimum diameter of an internal taper from the following readings,

Diameter of bigger ball - 10.25 mm

Diameter of smaller ball - 6.07 mm

Height of top of bigger ball from datum - 30.13 mm

Height of top of smaller ball from datum - 10.08 mm.

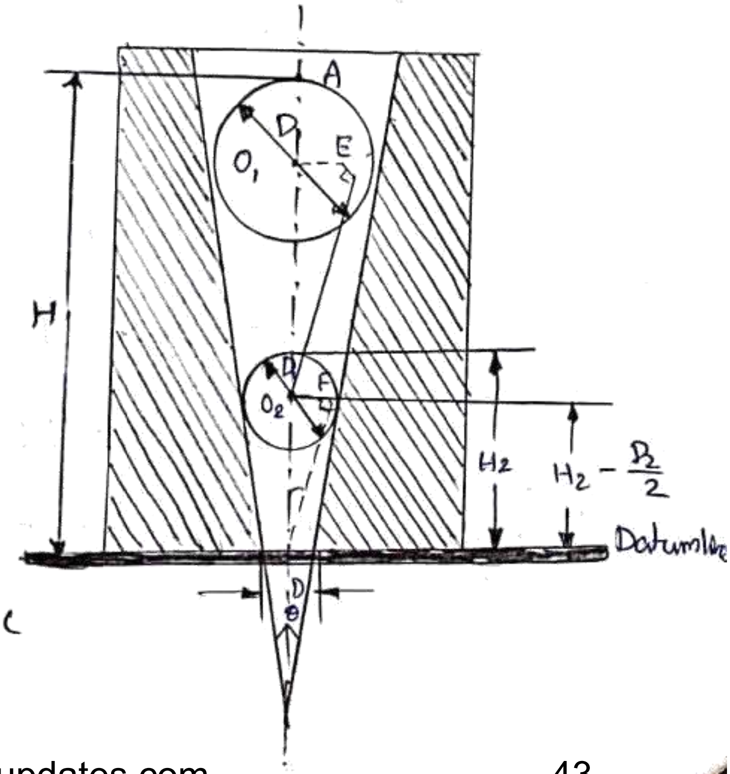
Answer: Given that

$D_1 = 10.25\text{mm}$

$D_2 = 6.07\text{mm}$

$H_1 = 30.13\text{ mm}$

$H_2 = 10.08\text{ mm}$




From triangle $O_1 O_2 D$, we have,

$$\sin\frac{\theta}{2}=\frac{O_1E}{O_1O_2}=\frac{O_1E}{AC-O_1A-O_2C}$$

$$\sin\frac{\theta}{2}=\frac{\frac{D_1}{2}-\frac{D_2}{2}}{H_1-\frac{D_1}{2}-\left(H_2-\frac{D_2}{2}\right)}$$

$$\sin\frac{\theta}{2} = \frac{D_1 - D_2}{2H_1 - D_1 - 2H_2 + D_2}$$

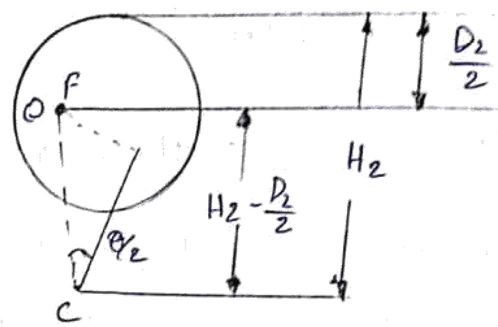
$$= \frac{10.25 - 6.07}{2(30.13) - 10.25 - 2(10.08) + 6.07}$$

$$\sin\frac{\theta}{2} = \frac{4.18}{35.92} = 0.11637$$

$$\frac{\theta}{2} = \sin^{-1}(0.11637) = 6.68265^{\circ}$$

∴ Taper angle, $\theta = 13.3653^{\circ}$

For finding minimum diameter (D) of an internal taper.




Let us consider the triangle $O_2CF$ i.e.,

$$\sin\frac{\theta}{2} = \frac{O_2F}{O_2C}$$

$$\sin\frac{\theta}{2} = \frac{\frac{D_2}{2} - \frac{D}{2}}{H_2 - \frac{D_2}{2}} = \frac{D_2 - D}{2H_2 - D_2}$$

$$0.11637 = \frac{6.07 - D}{2(10.08) - 6.07}$$

$$1.63965 = 6.07 - D$$

$$D = 6.07 - 1.63965 = 4.43\text{ mm}$$

∴ minimum diameter of taper = 4.43 mm.

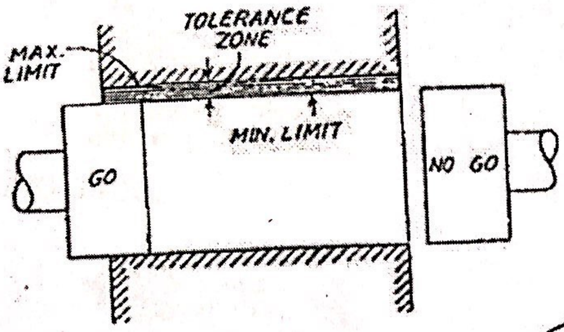
## 2.17 Gauges:

Before accepting any component that is manufactured, need to be inspected for high accuracy. In mass production several components will be manufactured checking each part requires high cost and time. Conformations for the parts can be done easily, by measuring the required tolerances of parts using gauges. Gauges are scale less rigid instruments, these gauges are made to specify the limits of the component. Unskilled persons can check the work piece. No need to do calculations for measurement. They give quick result.

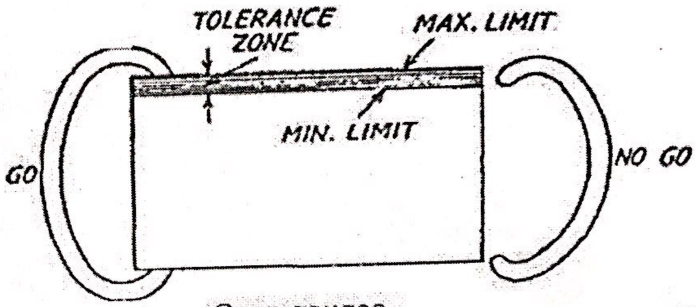
Gauges are of two types:

A **Go-No gauge** (or Go/no go) refers to an inspection tool used to check a workpiece against its allowed tolerances. Its name derives from its use: the gauge has two tests; the check involves the workpiece having to **pass** one test (*Go*) and **fail** the other (*No Go*).

It is an integral part of the quality process that is used in the manufacturing industry to ensure interchangeability of parts between processes, or even between different manufacturers.




Plug gauges

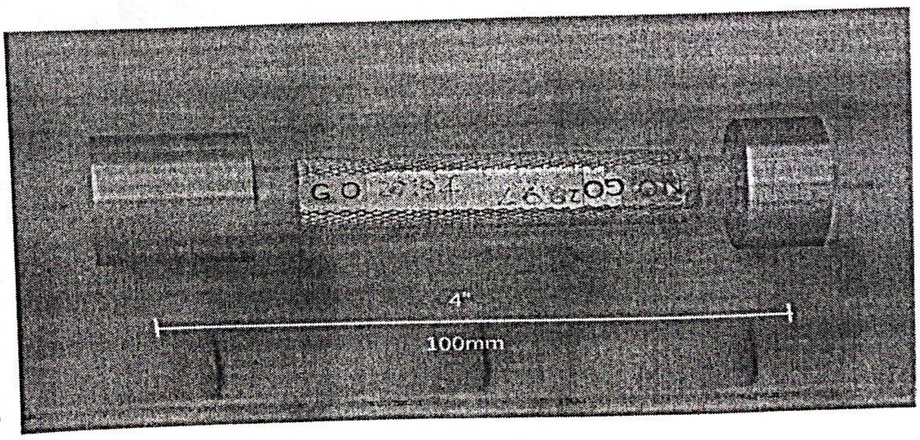



Snap gauges

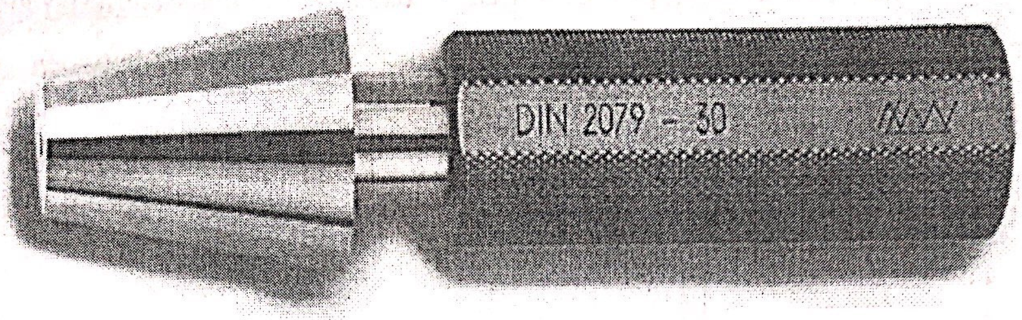
Types of gauges:

a.) PLUG GAUGE

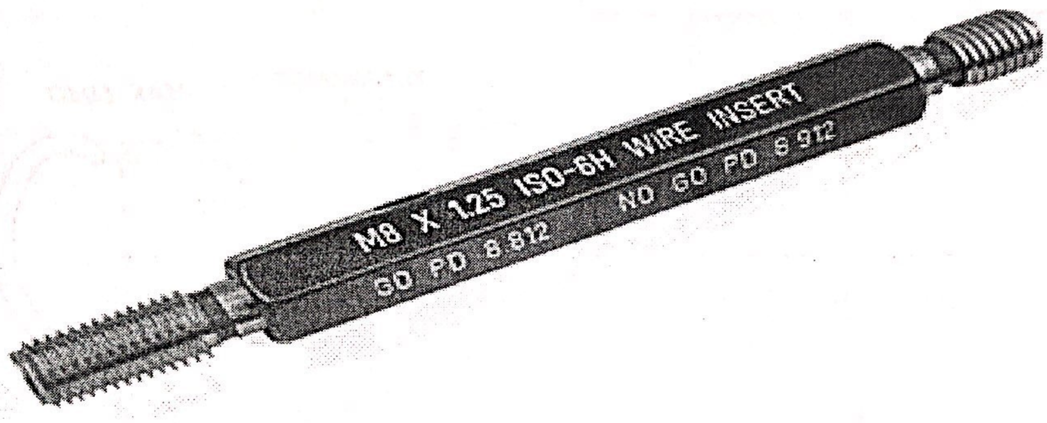
i. SOLID TYPE DOUBLE ENDED



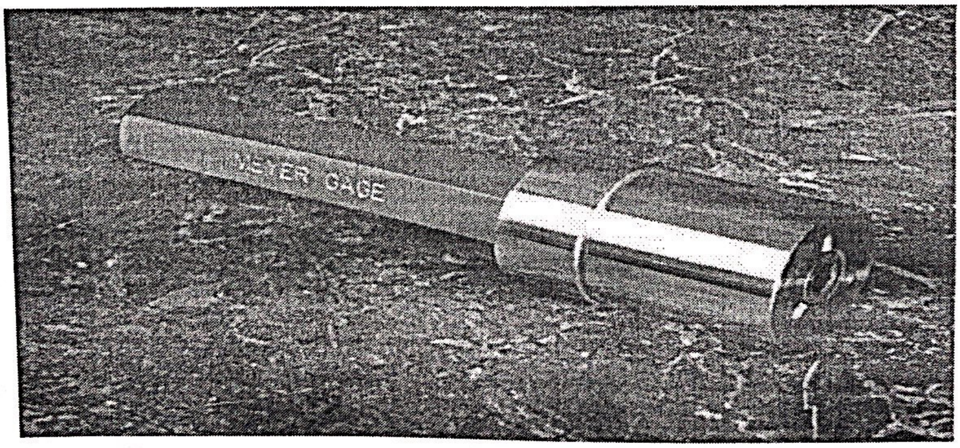

ii. TAPER INSERTED TYPE



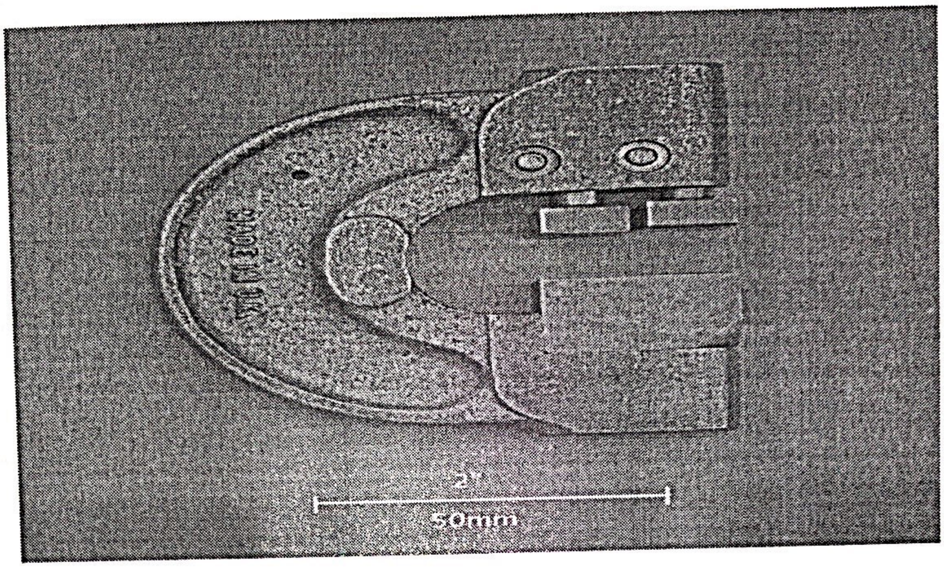

iii. FASTENED TYPE DOUBLE ENDED



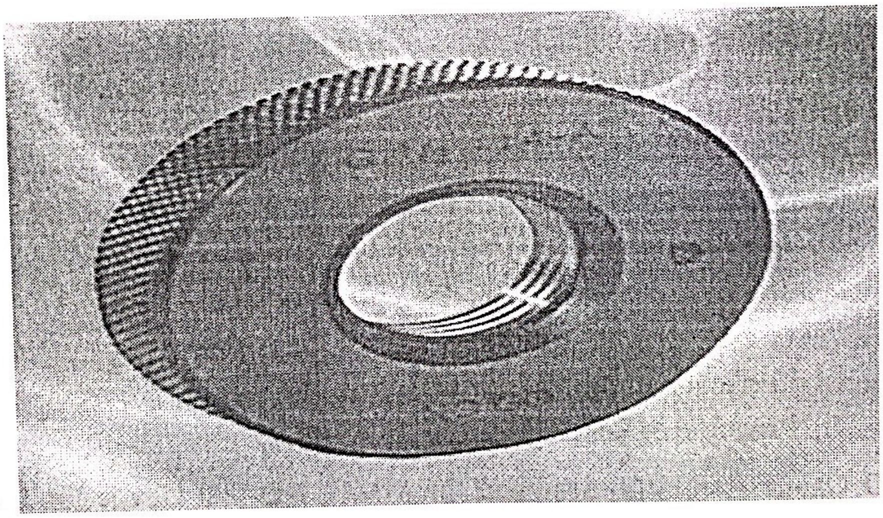

iv. PROGRESSIVE TYPE PLUG GAUGE



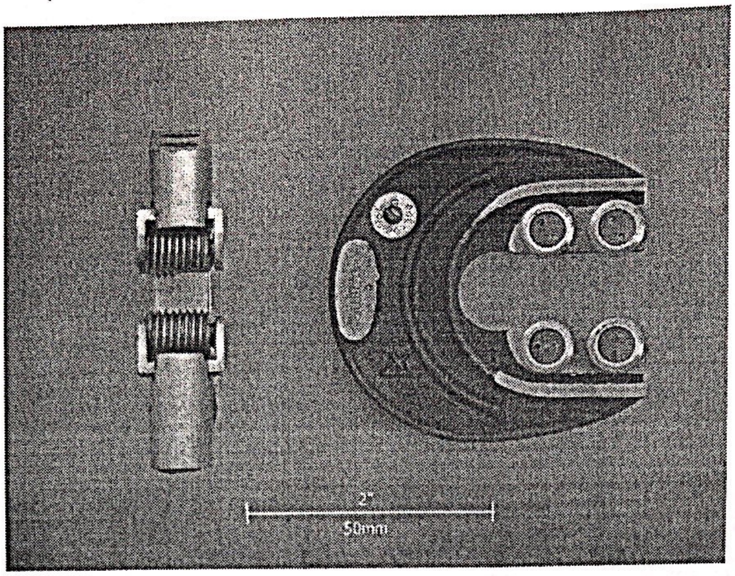
b.) SNAP GAUGE




c.) RING GAUGE



d.) THREAD SNAP GAUGE

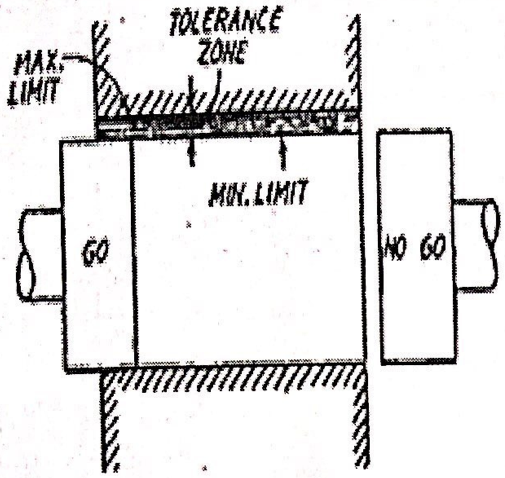


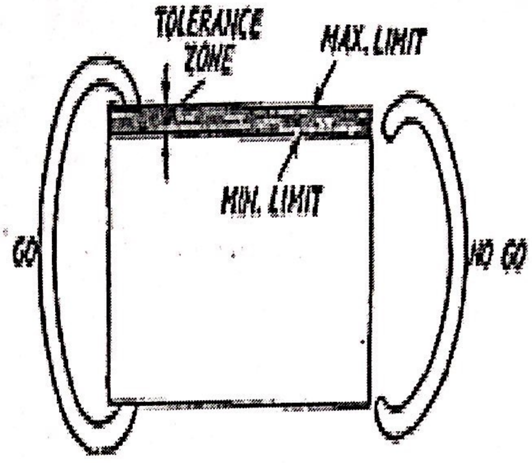

Material for gauge:

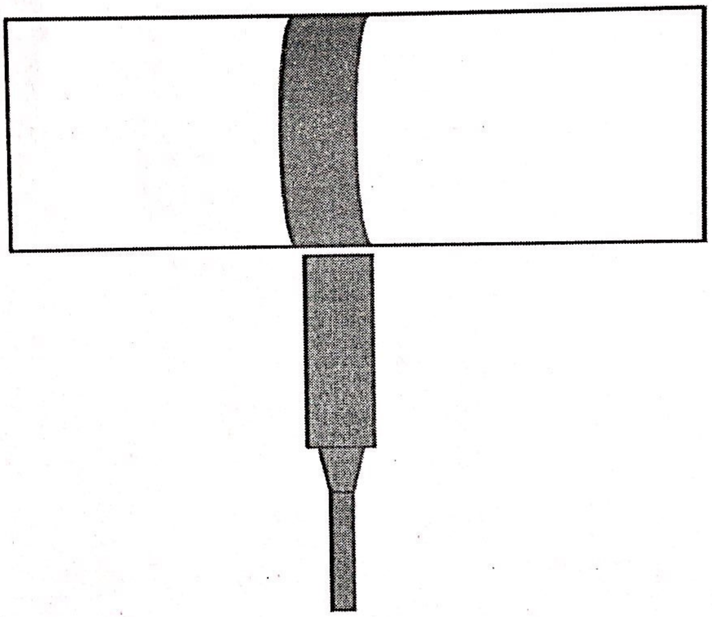
- Hardness to resist wear, Should be made with high carbon steel and heat treated to impart hardness
- Stability so that they won't change size and shape
- Corrosion resistant
- High degree of accuracy
- Low coefficient of thermal expansion
- Low thermal conductivity
- Coated products will be beneficiary

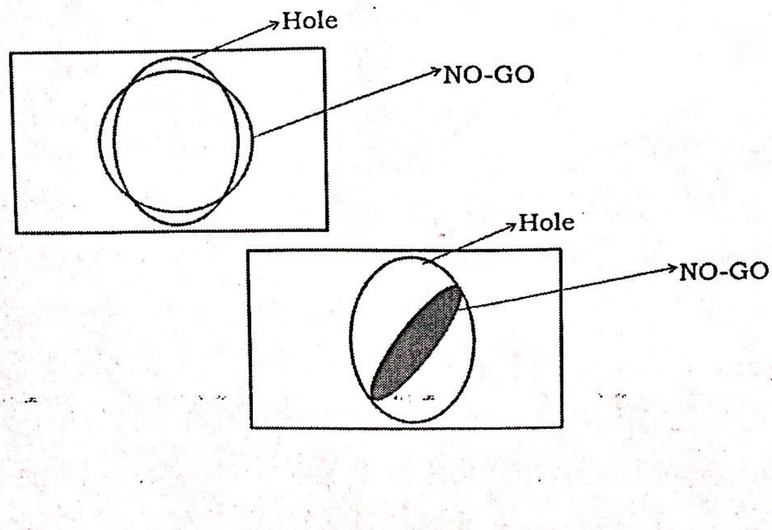
2.18 Taylors Principle of Gauge Design:

1. GO Gauge should be designed for MMC, NO-GO Gauge for LMC. If the plug gauge is check the hole, size of Go should be to lower limit and NO-GO to Upper limit. Similarly if snap gauge is used to check the shaft, size of GO should be to upper limit of shaft and NO-GO to lower limit.
2. Taylor's principle states that the "GO" gauge should check all the possible elements of dimensions at a time (Roundness, size, location, etc.) the no gauge should check only one element of the dimension at a time.
3. Holes that need to be inspected will in oval shape usually. So NO-GO will not enter and we wrongly prospect that NO-GO is not entering in hole so it's perfect.


TOLERANCE ZONE
MAX. LIMIT
MIN. LIMIT
GO
NO GO


TOLERANCE ZONE
MAX. LIMIT
MIN. LIMIT
GO
NO GO




Hole
NO-GO
Hole
NO-GO