14.21 DRILL

A drill is a tool for making holes in a metal piece. It usually consists of two cutting edges set at an angle with the axis. There are three types of drills : (1) flat drill, (2) straight fluted drill, and (3) twist drill.

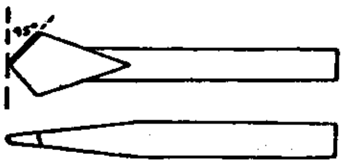


Figure 14.32 Flat drill

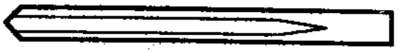


Figure 14.33 Straight fluted drill

The use of *flat drill* (Fig. 14.32) and *straight fluted drill* (Fig. 14.33) has many disadvantages and they are not generally used in a fitter's shop.

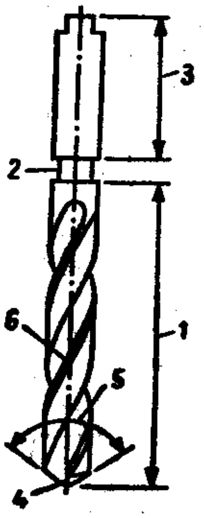


Figure 14.34 Twist drill
1. Length, 2. Neck, 3. Shank, 4. Lip
5. Lip angle, 6. Heel

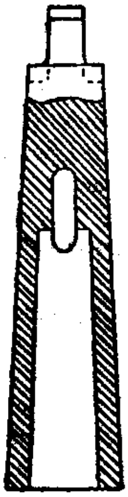


Figure 14.35 Drill socket

For rapid and accurate work twist drills are now universally adapted. A twist drill is illustrated Fig. 14.34. The best cutting angle is 118° and to obtain the correct diameter of the hole, the drill should be ground with both lips at 59° to the axis of the drill, with the lengths of the cutting edges exactly equal. A drill having unequal cutting edges and the point angles not symmetrical will probably result in a large hole running out of line.

There are two types of twist drill : (1) parallel shank, and (2) tapered shank.

Parallel shank drill can be held in an ordinary self-centering drill chuck which have parallel jaws to hold these straight shank drills. They are made from 0.200 mm to 40 mm size and used on most portable drilling machine such as the electric drill and hand drill.

In a *tapered shank drill* the shank is tapered and the drill spindle is bored out with a corresponding taper. By this means the drill can be fitted directly into place, the taper effectually centering it and providing the principle driving grip. The tapered shank on a drill enables it to be quickly and accurately inserted into the spindle of the machine. Drills are taken out of the spindle hole by a taper cotter called *drift*. When it is necessary to use a drill with a smaller shank than the bore in the spindle a *drill socket* or *sleeve* is generally used (Fig . 14.35). The drills are made from 3.0 mm to 100 mm size.

The smaller sizes of drills are not usually marked and the size is found by the use of a drill gauge. The taper used in a drill is Morse Standard Taper.

14.22 DRILLING

It is the operation of producing circular holes in a metal piece. This is done with the help of a drilling machine. Of the many types of drilling machine and drilling tools, the pillar drilling machine as shown in Fig. 14.36 is frequently used in a fitting shop.

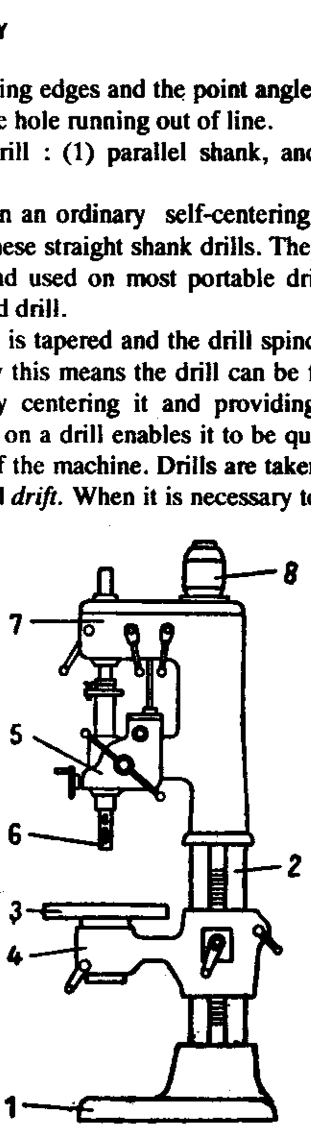


Figure 14.36 Piller drilling Machine
1. Base plate, 2. Pillar, 3. Table, 4. racket, 5. Drill head, 6. Drill spindle, 7. Gear case, 8. Motor

In drilling, the job is firmly held in a vice, or any other clamping device, over the table of the machine. Cylindrical workpieces are mounted by means of a gripping plate and a V-block. The gripping plate must be long enough to be fastened by two fixing screws at both ends with the V-block and the workpiece placed between them.

The socket containing the drill is fitted in the machine spindle and the spindle is lowered by the hand lever to lightly tough the centre-mark of the job already marked out for drilling (Fig. 14.31). Be sure that the point of the drill is exactly over the centre-punch mark. The machine is now started and the rotating drill gradually pressed into the metal to produce the hole. As the nose of the drill enters the metal see whether the drill is running central. If not, cut a groove with a round-nosed chisel towards the direction in which the correction must be applied. This will help to bring the drill into the correct position. The pressure on a drill should be relieved frequently, otherwise the cutting edges will be strained and the drill will be damaged. Oil or soap water in the form of coolant should be used to prevent the cutting edges of the drill from being spoiled. Brass and cast iron, of course, do not require any coolant. On a very hard steel, paraffin or turpentine is used. They not only act as coolant but also help make the cutting smooth.

Different types of drill and drilling machine and also drilling operations are described and illustrated in Vol. II of this book.

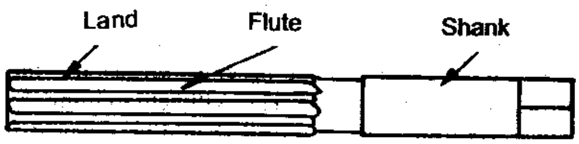
14.23 REAMER

When an accurate hole with a smoother finish is required a reamer is used to remove a little metal from the hole and to bring it to the correct size. The reamers are supposed to remove minimum amount of metal from 0.1 to 0.15 mm for rough reaming and 0.05 to 0.02 mm for finish reaming. Holes with a diameter less than 25 mm should be first rough reamed and then finished reamed. Holes over 25 mm in diameter are first enlarged with a counterbore. They are then rough reamed and finally brought to size with a finishing reamer.

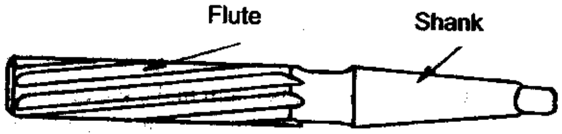
There are two kinds of reamers namely those which are turned by hand, called hand reamers, and those which are used on the machine called *machine reamers.* There are also reamers which can be expanded which means that they can be made larger to cut a little oversize. These are called *expanding reamers.* An expanding reamer is specially made so that its size can be changed by 1.6 mm.

They are obtainable in cast steel or in high speed, with *parallel* or *tapered cutters,* with *straight* or *spiral flutes.* The standard tapered reamers are 1 in 50 and then there is a range of reamers for morse tapers.

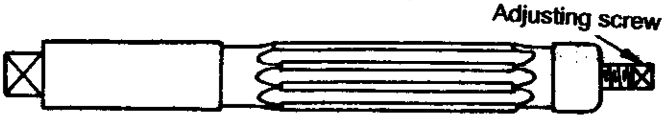
The hand reamer in Fig. 14.37 has a square shank for holding in a tap wrench or similar tool. This is a parallel reamer, and it has a series of straight flutes cut along its length. The number of cutting edges varies according to the make and size of the reamer. The cutting edges of reamers have a small amount of *land* along their top edges. When the reamer is sharpened it is ground in the flute, and, top of the land must *not* be touched.



Hand reamer



Machine reamer



Expanding reamer

Figure 14.37 Types of reamer

Some hand reamers are slightly tapered at the end so that a gradual 'lead in' to the hole may be obtained. The taper extends for approximately a quarter of the total length. This type of reamer is useful for starting the reaming operation. Hand reamers are also obtainable with spiral flutes. The spiral is *left handed.* If the reamer had a right-hand spiral it would tend to screw itself into the hole too quickly as the reamer was turned and produce an irregular hole.

Machine reamers are made parallel along their length with a slight taper in the same way as hand reamers, but they are mostly made with a taper shank. These, too, have left-handed spiral flutes.

14.24 REAMING

Hand reaming is done when exactness is required. The reamer is placed into the hole and turned with a tap wrench, as in tapping. When starting the reaming, care must be taken to ensure that the reamer is require with the axis of the hole being reamed. A slow, steady, screw-like motion by the reamer gives the best result. Lubrication may be used and the reamer is turned only in the *clockwise* direction even when removing it from the hole.

If a blind hole is being reamed, the reamer with the slightly tapered end should be followed by the parallel one so that a parallel hole to the bottom may be obtained.

14.25 TAPS

A tap is a screw-like tool which has threads like a bolt and three or four flutes cut across the thread. It is used to cut threads on the inside of a hole, as in a nut. The edges of the thread formed by the flutes are the cutting edges. The lower part of the tap is somewhat tapered so that it can well attack the walls of the drill hole. The upper part of the tap consists of a shank ending in a square for holding the tap by a tap wrench. This is a two-handled wrench, and it may be either fixed or adjustable. The adjustable wrenches may be used for taps of various sizes. A tap wrench is shown in Fig. 14.38.

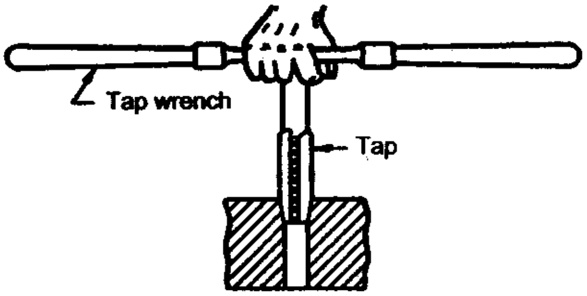


Figure 14.38 Tap wrench

Taps are made from carbon steel or high speed steel and are hardened and tempered. Hand taps are usually made in sets of three : (1) taper tap, (2) second tap, called plug tap, and (3) bottoming tap. They are illustrated in Fig. 14.39. According to the IS specification they are called Rougher, Intermediate, and Finisher respectively.

The end of the of the *Rougher* has about six threads tapered. This is used to start the thread so that the threads are formed gradually as the tap is turned into the hole.

The *Intermediate* is tapered back from the edge about three or four threads. This is used after the taper tap has been used to cut the thread as far as possible.

The *Finisher* has full threads for the whole of its length. This is used to finish the work prepared by the other two taps.

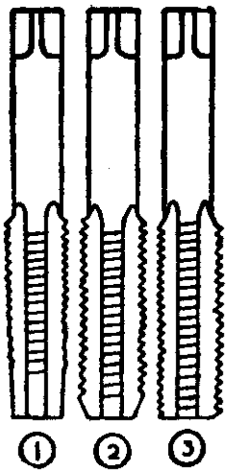


Figure 14.39 Types of hand taps

14.26 TAP DRILL SIZE

The size of the tap being the outside diameter of its threads, it is evident that the drill-hole must be smaller than the tap by twice the depth of the thread. The amount to be subtracted from the tap diameter depends on the shape of the threads, e.g., B.S.W., B.S.F., Indian Standard Thread (IS), etc. Tap drill size may thus be derived from the following formula :

$$D = T - 2d$$

where D is the diameter of the tap drill size, T diameter of the tap or bolt to be used and d depth of thread.

Example : In a tap or bolt of Indian Standard Specification, if :

Outside diameter (T) = 10 mm
Pitch of the thread (p) = 1.5 mm
Depth of the thread (d) = $0.61\,p$ (Approx.)
then, Tap drill size (D) = $10 - 2 \times 0.61 \times 1.5$
= $10 - 1.83$
= 8.17 mm
Nearest drill size = 8.20 mm

Tap drill size can also be worked out when applying the following "rule of thumb" which is sufficiently accurate for most cases.

Tap drill size = Outside diameter × O.8.

14.27 TAPPING

Cutting inside threads is called tapping. After the hole has been drilled with the tap drill, it is ready for tapping.

The work is clamped in a vice with the hole in the upright position. A *Rougher* is first to be used. The square end of the tap is clamped by a tap wrench which is then grasped with the right hand directly over the tap and tap is placed into the hole (Fig. 14.38). A steady downward pressure on the wrench is needed to get the thread started and a square is used to check the correct position of the tap in relation to the hole. The tap is turned in one hand until the thread has a good start. It is then no longer necessary to press down because the tap will draw itself into the work when turned. Tap is now turned by holding the tap wrench by two hands giving a downward pressure. Once the tap is cutting well, it is turned back half a rotation after every two or three rotations so that the chips are being broken and can thus be easily discharged through the chip flutes. The operation is continued until the length of the tap enters the hole, and finally this Rougher is withdrawn.

After rough cutting by means of the Rougher, cutting is continued in the same way as before with the Intermediate tap and, eventually, with the Finisher tap.

In the case of a hole, which goes through – and – through the tap is made to pass through the hole so much that it projects a little beyond the surface of the work. If the hole does not go through the work, the Rougher tap should be followed by an Intermediate tap to finish the threads right up to the bottom of the hole. But if full threads to the bottom of the hole are wanted a Finisher tap must be used. If the tap is forced round after touching the bottom of the hole, the thread may be damaged. A good safeguard is to sprinkle a little chalk, dust into the bottom of the hole, and when the work is nearing completion, the tap should be withdrawn occasionally and examined for traces of the tell-tale chalk.

Taps are extremely hard and of slender construction, so that they break easily if unnecessary force is used. A broken tap is extremely difficult to remove. If part of the tap projects above the surface it may be removed with pliers. If the tap is broken below the surface it may have to be heated to draw the temper, drilled down the centre and split with a narrow chisel. Sometimes a two-finger tool is used to hole the broken tap over the two flutes for unscrewing it. It may also be removed by a screw extractor which acts like a cork screw.

Oil should be used during the tapping so as to ensure smooth cutting and to prevent teeth from being damaged. Lard oil is generally used for threading steel, but no lubricant is necessary for threading cast iron.

14.28 DIES AND STOCKS

Dies are used to cut threads on a round bar of metal, such as the threads on a bolt. It is a round or square block of hardened steel with a hole containing threads and flutes which from cutting edges. There are mainly two types of dies in common use : (1) solid die, and (2) adjustable die.

A solid die (Fig. 14.40) is one which has fixed dimension and cannot be adjusted for larger or smaller diameter.

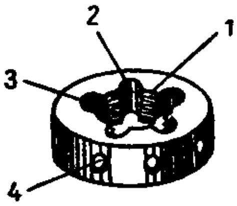


Figure 14.40 Solid die
1. Throat of threading die
2. Chip breaking flutes
3. Thread profile
4. Drill holes for stock

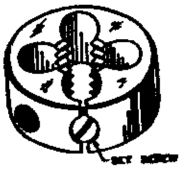


Figure 14.41 Adjustable split die

Adjustable means that it can be set to cut larger or smaller diameter. A *circular adjustable split die* as shown in Fig. 14.41 is very common. The die is split through one side and a slight adjustment is made by means of the set-screw shown. If this screw is tightened up the die is opened up slightly, whilst unscrewing will cause the die to spring in. Another common type is the *two-piece rectangular die* (Fig. 14.42). In this type the dies are fitted into a special stock and they are closed by means of the adjusting screw.

The size of a die is specified by the outside diameter of the thread to be cut and pitch of the thread.

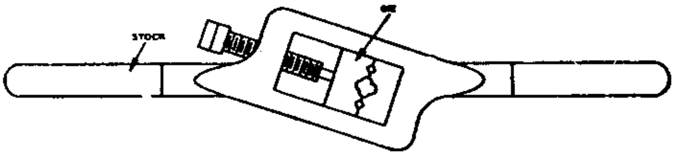


Figure 14.42 Die stock and dieing

Stock. The tool for holding and turning the threading die is called a *die-stock* (Fig. 14.42). It is often just called a stock. Die-stocks are provided with threaded pins. When the threading die has been inserted into the stock, the thread pins are tightened so that they engage in the drill holes of the die to hold it.

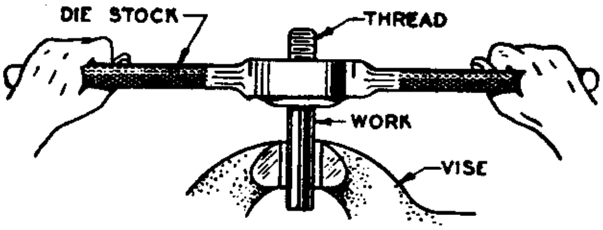


Figure 14.43 Two-piece rectangular die

14.29 DIEING

Cutting external threads on a round rod or bolt with a die and stock is called dieing or external threading.

When using a die the blank should be filed clean of hard scale and the end slightly pointed for easy entrance into the die. The die is held in a two-handed stock. When starting the thread, care must be taken to ensure that the die is square with the axis of the bar being threaded, otherwise it would bear more heavily on one side, resulting in a "drunken" thread. The stock is then turned and the die will begin to cut the thread. When cutting has actually started the die should be turned backward and forward in a similar fashion to the method used for tapping, using plenty of lubricant. When sufficient length of thread has been made the stock is screwed back and the adjusting screw tightened up farther and the process repeated. By this process it is possible to gradually cut the thread deeper and deeper until the correct depth has been reached. If, however, a solid die is used the cutting will be over in one operation only. Cutting with a solid die does not give satisfactory work, particularly in a reasonably accurate job.

REVIEW QUESTIONS

1. State the different processes done in bench work and fitting.
2. (i) With the help of neat sketches explain the construction and working of : (a) Fitters' parallel jaw bench vice, (b) hand vice, (c) pipe vice, and (d) pin vice. (ii) State the care taken in vices, (iii) How a vice is specified ?
3. Level the different parts of a hand hammer and state its classification. How a hammer is specified ? What is the main difference between the hand hammer used in a smithy shop and a fitting shop ?
4. Name and explain the use of different types of chisels used in a fitting work giving their specification.
5. Name and explain various types of files. How are files classified ? With a neat sketch, name the different parts of a rectangular file.

6. Write short notes on : (a) Single cut and double cut files. (b) Safe edge file. (c) Grading of files according to pitch.
7. State the difference between a file and a scraper in regard to their use. State the different types of scraper used in a fitting shop and give their specification.
8. Sketch and describe a hacksaw. Where are the all hard and flexible blades used ? How the use of hacksaw blades differ according to pitch of their teeth ?
9. Sketch and describe : (a) surface plate, (b) scriber, (c) V-block, (d) angle plate, and (e) try-square, giving their uses in a bench work. State how they are specified. How you will test the trueness of a try-square with the help of a surface plate.
10. How many types of punches are used in a bench work ? Describe a centre punch with the help of a neat sketch.
11. How do you classify drills ? Sketch a twist drill and name the different parts. What is the advantage of a twist drill over a flat drill ? Why flutes are provided in a twist drill ?
12. State the different types of reamers and give their uses.
13. Describe taps and dies giving their uses in a fitting shop. How a tap drill size is derived ?
14. Write short notes on the following operations :
    (a) Chipping
    (b) Sawing
    (c) Draw filing
    (d) Scraping
    (e) Grinding
    (f) Drilling
    (g) Tapping
    (h) Dieing.

15

LIMITS, FITS AND SURFACE QUALITY

15.1 INTRODUCTION

In the metal working processes, it has been found that design criteria, material properties and manufacturing technology are inextricably interwoven.

The crucial is the one : it is not enough that a process should be capable of producing parts that satisfy service requirements and other constraints ; it must of so at *minimum* cost. What this minimum is depends of course on the state of technology.

The functional aspect of a component in the present-day production system, can be achieved even without going for its *exact* dimension. This increases the rate of production and reduces the unit cost of the product. That mean, a *predetermined* variation in the basic dimension will bring down the unit cost of the product. A design of great consequence for both manufacturing process and economy, therefore, rests on the use of *standard parts* which will meet the required accuracy and surface finish. The standard part may or may not confirm to the exact dimension. It will appropriate, therefore, because, of its manufacturing implications to give a brief dimension of the subject here.

15.2 INTERCHANGEABLILITY

The object of all modern methods of manufacturing is to produce parts of absolute accuracy. But it is not always possible, particularly in mass production, to keep the exact measurement. Given sufficient time, any operator could work to and maintain the sizes to within a close degree of accuracy, but there would still be small variations. It is known if the deviations are within certain limits, all parts of equivalent size will equally fit for operation in machines and mechanisms. Certain deviations are, therefore, recognised and allowed to ensure interchangeability of mating parts, coupled with the desired degree of tightness or looseness on assembly. When a system of this kind has been worked out, so that one component will assemble *correctly* with any mating component, both being chosen at random, the system is called an *interchangeable system*, sometimes called a *limit system* or a *system of limits and fits.*

If interchangeability is not achieved, *selective assembly* will be required; that is each part must be selected to fit its mating part. Selective assembly is costly and should be avoided wherever possible.

Interchangeability of their parts is, therefore, a major pre-requisite for economic production, operation and maintenance of machinery, mechanism and instruments. It is by interchangeable spare parts that various machines, machines tools, tractors, motor cars, airplanes and many others can be dismantled for replacement of work parts in service conditions in the field, and also in many local workshops with least possible loss of time.

15.3 ELEMENTS OF INTERCHANGEABLE SYSTEMS

Specification of dimensions is a designer function. The size of one of the mating parts is first determined.

SIZE AND LIMITS OF SIZE

The *size* is a number expressing the numerical value of a length in a particular unit.

The *basic size* of a dimension or part is the size in relation to which all limits of variation are determined. This is fixed up by the designer from its functional considerations. The other term used with respect to a component is the nominal size.

The *nominal size* is the size specified in the drawing as a matter of convenience. It is usually given in the drawing as a rounded-off whole millimeters/meters, but sometimes fractions are used. The nominal size is used primarily for the purpose of identification of a component and is never used in the precision measurement of parts.

As said earlier, a rigid attitude towards the maintenance of a basic size shall increase the cost of production and a little variation in dimension is accepted resulting in a size which is different from the basic size. This is called the actual size.

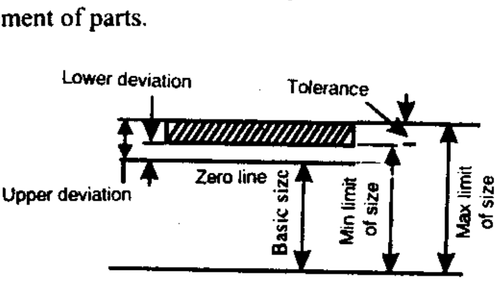


Figure 15.1 Basic size and its deviation

The *actual size* of a dimension or part is its measured size. An actual size of a ready part will, therefore, always deviate from one specified in the drawing, i.e., from the nominal or basic size. But the different between the basic size and actual size must not exceed a certain limit, as otherwise it will interfere with the interchangeability of mating components.

Limits of size are two extreme permissible sizes between which the actual size is contained. The *high limit* or *max. limit* H for a dimension is the largest size, while the *low limit* L for a dimension is the smallest size, permissible. they are depicted in Fig. 15.1.

TABLE 15.1 DEVIATIONS FOR LINEAR DIMENSIONS

All dimensions in millimeters

Range of nominal deviation		Class of deviation			
Above	Upto including	Fine	Medium	Coarse	Extra coarse
0.5	3	± 0.05	± 0.1	--	-
3	6	± 0.05	± 0.1	± 0.2	± 0.5
6	30	± 0.10	± 0.2	± 0.5	± 1.0
30	125	± 0.15	± 0.3	± 0.8	± 1.5
125	315	± 0.20	± 0.3	± 1.2	± 2.0
315	1000	± 0.30	± 0.8	± 2.0	± 3.0
1000	2000	± 0.50	± 1.2	± 3.0	± 4.0
2000	4000	± 0.80	± 2.0	± 4.0	± 6.0

DEVIATION AND ZERO LINE

The algebraic difference between size (actual, maximum, etc.) and the corresponding the basic size is called *deviation*. The deviations for the linear dimensions (*IS : 2102-1966*) are given in Table 15.1.

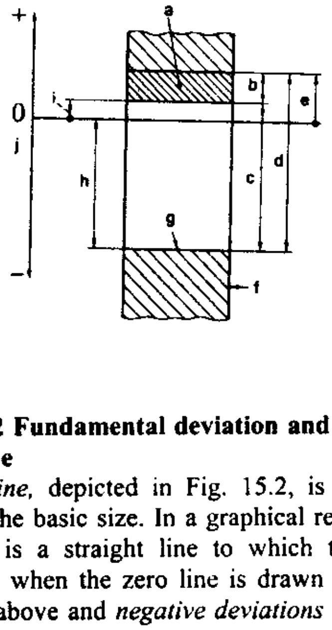
The deviations from the basic dimensions at the boundaries of the tolerance zone are called upper and lower deviations as shown in Fig. 15.1.

The *upper deviation* is the algebraic difference between the two maximum limit of size and the corresponding basic size.

The *lower deviation* is the algebraic difference between the minimum limit of size and the corresponding basic size.

The *mean deviation* is the arithmetical mean between the upper and lower deviations.

The *fundamental deviation* is the one of the deviations which is conventionally chosen to define the position of tolerance zone in relation to the zero line. In other words, the deviation of the tolerance band (on shaft or hole) away from the basic size is called the fundamental deviation (FD). This is shown in Fig. 15.2.



Key

a	tolerance zone
b	tolerance
c	lower limit of size
d	upper limit of size
e	upper limit of deviation
i	lower limit of deviation
f	nominal integral feature
g	nominal integral feature of size
h	nominal size
j	deviations µ

Figure 15.2 Fundamental deviation and tolerance zone with respect to the zero line

The *zero line,* depicted in Fig. 15.2, is the line of zero deviation and represents the basic size. In a graphical representation of limits and fits, a zero line is a straight line to which the deviations are referred. By convention, when the zero line is drawn horizontally, *positive deviations* are shown above and *negative deviations* below it. They are preceded by the symbol (+) and (–) respectively.

TOLERANCES OF PARTS

Tolerance on a dimension is the difference between the maximum limit of size and minimum limit of size. It is, in fact, the variation in size tolerated to cover reasonable imperfections in workmanship and varies with different grades of work.

The tolerance, however, is equal to the algebraic difference between the upper and lower deviations and has an absolute value without sign. The value of tolerance is a function of the basic size and is designated by a number symbol, called the *grade.*

There are two basic ways of specifying tolerance : (1) bilateral and (2) unilateral, tolerances.

Bilateral tolerances are used where the parts may vary in either direction from the desired or nominal size. That is, if the tolerance is divided, some being allowed on either side of the nominal size, the system is said to be bilateral (*bi*=two). The dimension $25^{+0.05}_{-0.05}$ is an example of bilateral tolerance. It is not necessary that the variation should be equal.

Unilateral tolerances are used where it is important for the dimension to vary in only one direction. Parts manufactured will fall close to the desired dimension but can vary in only one direction. An example is the drilled hole. Since the drill is made close to the normal hole size, it is seldom possible to drill a hole undersize. All drilled holes should carry only a plus tolerance. Since the tolerance is allowed on one side of the nominal size, the system is said to be unilateral (uni=one). The dimension $25^{+0.00}_{-0.10}$ is an example of unilateral tolerance. Unilateral tolerance is used in most industries as it permits changing the tolerance value without altering the characteristic mating of respective parts.

In an example, $40^{+0.03}_{-0.02}$ the basic size is 40 mm, the upper deviation is 0.03 mm, the lower 0.02 mm. Hence, the maximum limit size is (40 + 0.03) = 40.03 mm, the minimum limit size being (40–0.02) = 39.98 mm. Therefore, the tolerance in this case is (40.033 – 39.98) = 0.05 mm.

In a graphical representation of tolerance, the zone bounded by the two limits of size of the part and defined by its magnitude (that is, tolerance) and by its position in relation to the zero line is the *tolerance zone*. This is illustrated in Fig. 15.2 and 15.3.

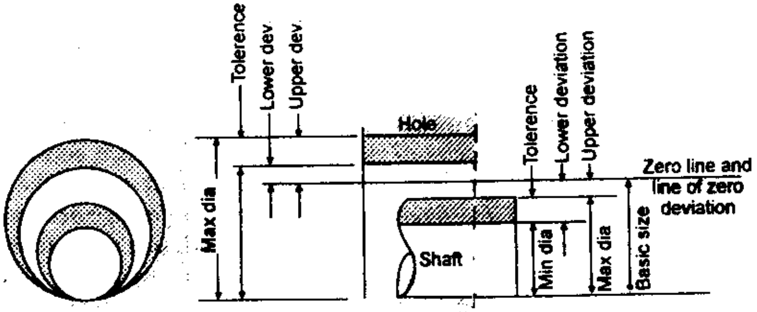


Figure 15.3 Diagram illustrating basic size deviations and tolerances

15.4 FITS, ALLOWANCES, CLEARANCES & INTERFERENCES

In dealing with two mating surfaces or parts, one which enters into the other is known as the *enveloped surface* or *male part*, and the other in which one enters is the *enveloping surface* or *female part*. The enveloped surface of a cylindrical part is considered as a shaft while the enveloping surface as a hole. The dimensions corresponding to them are called a shaft diameter and a hole diameter. In the case of a key and its key way, the key represents a shaft, while the key way represents a hole.

Fits. The relationship between two parts where one is inserted into the other with a certain degree of tightness or looseness is known as a *fit*.

Depending on how the parts mate, fits can provide for different degree of freedom of movement.

Allowances. An intentional difference between the hole dimension and shaft dimension for any type of fit is called the allowance (Fig. 15.4)

If we subtract the minimum shaft size from the largest hole size we obtain the *maximum allowance*, while the *minimum allowance* is the difference between the largest shaft and the smallest hole size.

An allowance may be either a positive (+) or a negative (-) amount according to the type of fit required. If the conditions are such that the shaft is smaller than the hole it is said that there is *positive allowance*, but if the shaft is larger than the hole it is said that there is *negative allowance*.

Clearances. A positive difference between the diameters of the hole and the shaft, the hole diameter being larger than the shaft diameter, allowing relative movement between the parts, is called a clearance as shown in Fig. 15.4.

The positive difference between the maximum limit size of a hole and the minimum limit size of a shaft is known as the *maximum clearance*. Similarly, the *minimum clearance* is the positive difference between the minimum limit size of the hole and the maximum size of the shaft.

The *mean clearance* is the arithmetical mean of the maximum and minimum clearances.

Interferences. A negative difference between the diameters of the hole and the shaft, the shaft diameter being larger than the hole diameter, is called an interference as shown in Fig. 15.4.

The *maximum interference* is the negative difference between the maximum limit size of the shaft and the minimum limit size of the hole. Similarly, the *minimum interference* is the negative difference between the minimum limit size of the shaft and the maximum limit size of the hole. The *mean interference* is the arithmetical mean of the maximum and the minimum interference.

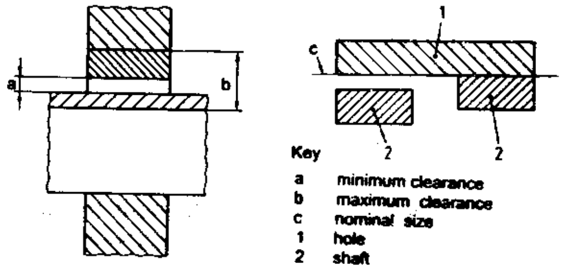
15.5 TYPES OF FIT

Depending upon the actual limits of the hole or shaft, the fits in the ISO 286-1 & 2 1988 and also in Indian Standard have been divided into three main classes as follows (Fig. 15.4).

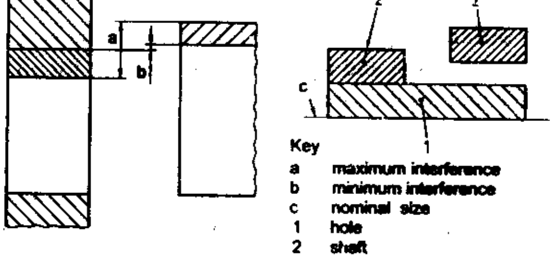
Clearance fits. In a *clearance fit* (Fig. 15.4a) there is a positive allowance between the largest possible shaft and the smallest possible hole. With such fits the minimum clearance is greater than zero. Such fits give loose joints, i.e., there must be some degree of freedom between a shaft and a hole.

Clearance fits may be subdivided as:

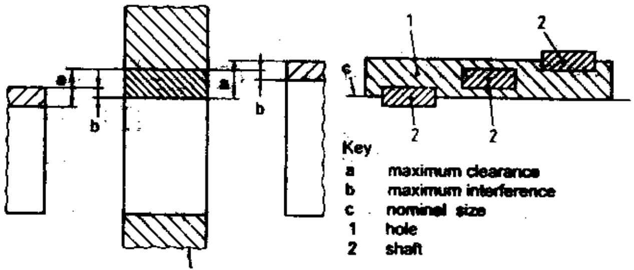
1. Slide fit. 2. Easy slide fit. 3. Running fit.
4. Slack running fit. 5. Loose running fit.



a Clearance fit



b Interference fit



c Transition fit

Figure 15.4 Diagrammatic representation of different types of fits

Interference Fits. In an *interference fit* there is a negative allowance or interference between the largest hole and the smallest shaft, the shaft being larger than hole. Refer Fig.15.4b for the details.

Interference fits may be classified as: (1) shrink fit, (2) heavy drive fit and (3) light drive fit

Transition Fits. They cover cases between the first two classes (Fig. 15.4c). The use of *transition fits* does not guarantee either an interference or a clearance, i.e., any pair of parts of mating with a transition fit may fit with interference, while another pair with the same fit may have a clearance fit. Transition fits may be classified as : (1) force fit, (2) tight fit, (3) wringing fit, and (4) push fit.

Newall system classifies fits as : (1) running fit, (2) push fit, (3) driving or press fit ,and (4)force fit or shrink fit

15.6 HOLE BASIS AND SHAFT BASIS

In a general limit system it is necessary to decide on what basis the limits are to be found to give the desired fit. There are two distinct systems for varying the sizes of parts known as : hole basis and shaft basis.

A limit system is said to be on a *hole basis* when the hole is constant member and different fit are obtained by varying the size of the shaft. In this hole system the high and low limits are constant for all fits of the same accuracy grade and for the same basic size.

A limit system is said to be on a *shaft basis* when the shaft is the constant member and different fits are obtained by varying the size of the hole. In this shaft system the high and low limits are constant for all fits of the same accuracy and grade and for the same basic size. Both hole and shaft basis are illustrated in Fig. 15.5.

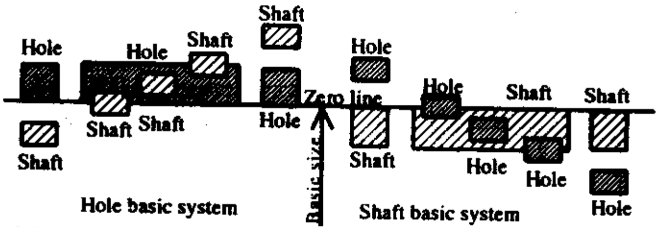


Figure 15.5 Examples illustrating the 'hole basis' and 'shaft basis' system

All modern limit systems employ the hole basis, the chief reason being that it is easier to vary the size of the shaft than that of the hole. The majority of holes in engineering work is produced with drill and reamer or some similar tool and to vary the size of holes would necessitate the use of a very large number of tools of varying sizes. By employing hole basis one size reamer suffices for all the holes to any particular diameter. However, in some instances the shaft basis system proves to be more advantageous to use than the hole basis system.

15.7 GEOMETRIC DIMENSIONING AND TOLERANCES

So far we have concerned with linear dimensions with no mention of the variation in the geometry of the part. Geometric dimensioning establishes the amount of variation in *form* which will be acceptable. Typical requirements are that certain surfaces must be square with each other, or that certain diameters must be concentric. Among the important geometric features are : straightness, flatness, squareness, parallelism and concentricity. specific angles between intersecting lines or planes may also be considered geometric dimensions.

Geometric tolerances are concerned with the accuracy of the relationship of one feature to another, and now, where necessary, it is accepted that separate tolerances should be specified for geometric features, in addition to linear tolerances. The principles of geometric tolerancing have shown the importance of the maximum metal condition (MMC) which refers to the condition of a hole or shaft when the maximum amount of material is left on, i.e., high limit shaft and low limit hole. It is always these limits which critically affect interchangeability of parts.

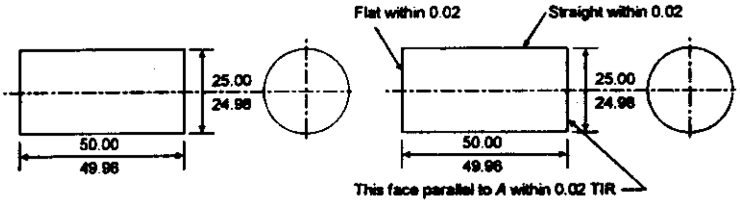


Figure 15.6 Diagram showing geometric dimensions and tolerances

To illustrate the principle of geometric tolerance, consider the cylinder shown at Fig. 15.6. The linear limit dimensions of the simple cylindrical piece on the left of Fig. 15.6 define the maximum and minimum limits of profile of work. The form or shape of the part may vary as long as no portions of the part exceed the maximum profile limit or are within the maximum profile. But to provide great control of the form than is imposed by the limit dimensions, certain tolerances appear in the form of notations on the drawing as are illustrated on the right of Fig. 15.6.

Geometric dimensions must have tolerances, the same as linear dimensions. For instance, an angle of 50° between two planes may be designated as $50^{\pm 0}$, $50^{\pm 2}$, $50^{\pm 4^\circ}$, $50^{+5^\circ}_{-0^\circ}$ or whatever the requirements.

15.8 LIMIT SYSTEMS

Besides the Indian Standard Systems, two other representative and well-known limit systems used are the Newall and the British Standard.

THE NEWALL SYSTEM

This is a bilateral, hole basis system for sizes upto 150 mm. It provides two classes of hole (A and B) to accommodate two grades of workmanship. Class A is for extremely accurate work and class B for general engineering work. It gives six classes of shaft (F, D, P,X,Y,Z) suitable for the following classes of fits: (1) force fit, (2) driving fit, (3) push fit and (4) running fit. The running fit is again sub-divided into three grades as follows :

Class X, for work where easy fits are wanted.
Class Y, for high speeds and average machine work.
Class Z, for fine tool and instrument work.

THE ISO SYSTEM

This system, set out in *BS 4500: 1969*. allows for 27 types of fits and 18 grades of tolerance, covering a size range of 0 to 3150 mm. In this system, the 27 possible holes are designated by capital letters A B C D E .... etc., and the shaft by letters a b c d e .... etc. The eighteen grades of accuracy are covered by the numerals 01, 0, 1, ... 16, these being designated IT 01, IT 0, IT 1, etc., upto IT 16. For specifying any particular hole or shaft the rule is to write, the letter followed by the numeral denoting the tolerance grade, e.g. H7 for a hole or f7 for a shaft. A fit involving these elements is written H7-f7 or H7/f7. For ordinary engineering practice the H holes and particularly H7, H8, H9 and H11 are recommended as being satisfactory for most purposes.

The system is on a hole basis and although a unilateral system is recommended, bilateral tolerance is included in the specification for the benefit of concerns who prefer to work to this system.

15.9 THE INDIAN STANDARD SYSTEM

The system of limits and fits recommended in *IS : 919-1963* comprises 18 grades of fundamental tolerances or, in other words, grades of accuracy of manufacture, with designations IT 01, IT 0 and IT 1 to IT 16; and 25 types of fundamental deviations indicated by letter symbols for both holes and shafts (capital letters A to ZC for holes and small letters a to zc for shafts) in diameter steps ranging from 1 to 500 mm. The 25 deviation are represented by A, B, C, D, E, F, G, H, I, J, K, M, N, O, P, R, S, T, U, V, X, Y, Z , ZA, ZB and ZC.

Innumerable fits ranging from extreme interference to those of extreme clearance can be obtained by suitable combination of fundamental tolerances and fundamental deviations mentioned above. All but very exceptional engineering requirements are covered, from very coarse work to fine gauge manufacture. A unilateral hole basis system is recommended, but a full range of holes suitable for use on shaft basis system, unilateral or bilateral, is also included in *IS : 919-1963*. Two Indian Standards have already been published, namely, *IS : 2101-1962* for sizes above 500 mm and upto 3150 mm and *IS : 2709-1964*.

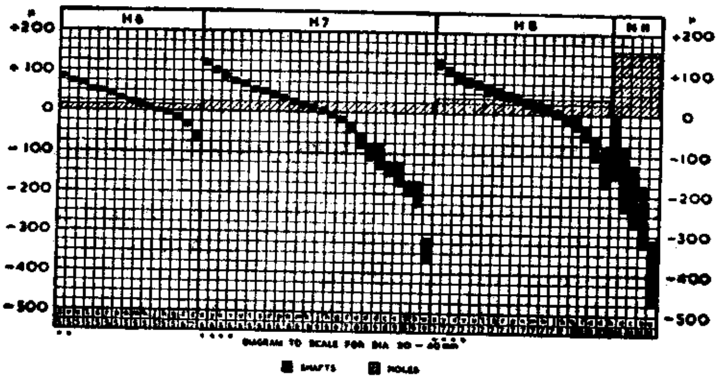


Figure 15.7 Recommended selection of fits for general engineering requirements – Hole–basis system

For the sake of convenience, a *basis size* is ascribed to the part and each of the two limits is defined by its *deviation* from this size (the magnitude and sign of the deviation is obtained by subtracting the basic size from the limit in question).

The following symbols (Fig. 15.3) are used in this standard :

Upper deviation of a hole ES - "High"
Lower deviation of a hole EI - "Low"
Upper deviation of a shaft es - "High"
Lower deviation of shaft ei - "Low"

This system gives the following classes of fits : (1) clearance fit, (2) interference fit and (3) transition fit. A selection of fits for general use is given in Fig. 15.7.

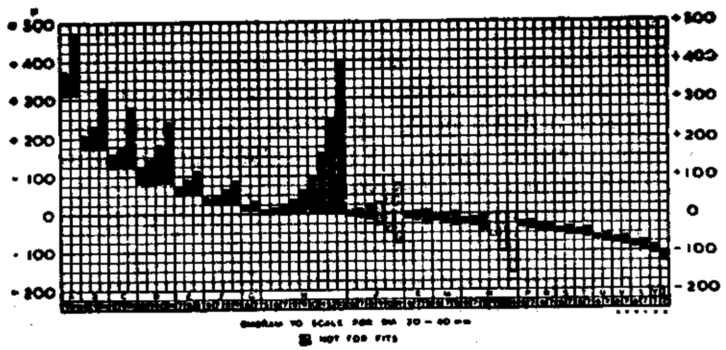


Figure 15.8 Tolerance zones for holes arranged according to symbol

A fit is indicated by its basic size common to both components, followed by symbols representing the limits of each of its two components, the hole being quoted first, for example:

For ordinary engineering practice the H holes and particularly H6, H7, H8 and H11 are recommended as being satisfactory for most purposes. Likewise, a selection of shafts is recommended which, when associated with H holes, will provide for most of the fits required. The chief of these is set out in Table 15.2.

Tolerances and deviations for sizes upto 500 mm. The 18 grades of tolerances that are provided with designations IT 01, IT 0 and IT 1 to IT 16 are known as *standard tolerances*. For grades 5 to 16, the values have been determined in terms of the standard tolerance unit i, where

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

$$i = 0.004\,D + 2.1 \text{ for sizes above 500 mm.}$$

D = the *geometrical mean* of the above diameter limits. The term 0.001 D has been introduced out of consideration for the uncertainties in measuring, which increase as the diameter increases. The relative magnitude of each grade is given in Table 15.3.

TABLE 15.2 QUALITY OF FITS

Combination of hole & shaft	*Quality of fit*	*Typical uses*
	RUNNING AND SLIDING FITS	
H6 g5 Fine H7 g6 Normal H8 g7 Coarse	Precision	Small clearance used in precision equipment under very light load-bearings for accurate link work and for piston and slide valves. Also used for spigot or location fits.
H6 f6 Fine H7 f7 Normal H8 f8 Coarse	Close running	Widely used as grease or oil lubricated bearings having low temperature differences ; bearings for gear shafts, small electric motor shafts, and pump shafts.
H7 e7 Fine H8 e8 Normal H9 e9 Coarse	Normal running	Used for properly lubricated bearings with appreciable clearance. Finer grades for high speed and heavy loads-turbo generator and large electric motor bearings.
H8 d8 Fine H8 d8 Normal H9 d9 Coarse	Loose running	For plummer block bearinggs and loose pulleys.
	TRANSITION AND INTERFERENCE FITS	
H6 j5 Fine H7 j6 Normal H8 j7 Coarse	Clearance transition	Very small clearance is obtained–used for fits where a slight interference is permissible-coupling spigots and recesses, gear rings clamped to steel hubs,
H6 k5 Fine H7 k6 Normal H8 k7 Coarse	True transition	Fits averaging no clearance where slight interference can be tolerated, with the object of eleminating vibration-ball bearing races of light duty.
H6 m5 Fine H7 m6 Normal H8 m7 Coarse	Interferance transition	Fits averaging slight interference-used for ball bearing races of medium duty.
H6 p5 Fine H7 p6 Normal	Press fit	Light press fit for nonferrous parts whic can be dismantled when required - bearing bushes - press fit for steel, cast iron or brass to steel assemblies - bush in a gear.
H6 r5 Fine H7 r6 Normal	Drive fit	Medium drive fit for ferrous parts and light drive fir for nonferrous parts that can be dismantled.
H6 s5 Fine H7 s6 Normal	Drive fit	Permanent or semi-permanent assemblies of steel and cast iron members with considerable gripping force - collars pressed on the shafts, valve seatings, etc. For light alloys this gives a press fit.
H6 u5 Fine H7 u6 Normal	Force or shrink fit	High interference fit. A thorough investigation into the degree of grip and the stresses in the part must be made.

TABLE 15.3 TOLERANCE GRADES AND THEIR VALUES

Grades	IT5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT1
values (in microns)	7i	10i	16i	25i	40i	64i	100i	160i	250i	400i	640i	1000i

The values of standard tolerances corresponding to Grades 01, 0 and 1 are given in Table 15.4.

TABLE 15.4

	IT 01	*IT 0*	*IT 1*
Values in microns for D in mm	0.3+0.008 D	0.5+0.012 D	0.8+0.020 D

The value of IT 2 to IT 4 have been regularly scaled approximately geometrically between the values of IT 1 and 5.

The fundamental deviation for *shafts* (upper deviation es, or lower deviation ei) are calculated by means of formulae provided in (Table 15.5) (IS : 919-1963). The other deviation may be derived directly using the absolute value of the standard tolerance IT by means of the following algebraic relationship :

ei = es - IT. or es = ei + IT

The deviation given in the Standard is that corresponding, in principle, to the limit closest to the zero line; in other words, the upper deviation es for shafts a to h and the lower deviation ei for shafts j to zc.

Deviations for *holes* are identical with shaft deviations of the same symbol but disposed on the other side of the zero line.

The various diameter steps specified by IS : 919-1963 are 1-3, 3-6, 6-10, 10-14, 14-18, 18-24, 24-30, 30-40, 40-50, 50-65, 65-80, 80-100, 100-120, 120-140, 140-160, 160-180, 180-200, 200-225, 225-25, 250-280, 280-315, 315-355, 355-400, 400-450 and 450-500 mm.

Problem 15.1 : Calculate the limits, tolerances and allowances for a 20 mm shaft and hole pair designated H8 d8.

It is seen that 20 mm lies in the diameter steps of 18 and 24 mm. Therefore, the value of *D* (geometrical mean) = $(18 \times 24)^{1/2}$ = 20.80 mm.

The standard tolerance unit

$$i = 0.45\sqrt[3]{D} + 0.001D$$
$$= 0.45\sqrt[3]{20.80} + 0.021$$
$$= 1.28 \text{ microns.}$$

For hole of quality 8, from Table 15.3, the standard tolerance, 25 i = 25x1.28 = 32 microns = 0.032 mm.

For the 'H' hole the FD = 0

Hence, the hole limits are 20 mm and (20+0.032) = 20.032 mm.

Therefore, hole tolerance = (20.032 - 20) = 0.032 mm.

For shaft of quality 8, the standard tolerance

= 25i = 25x1.28 = 0.032 mm

For 'd' shaft the FD from Table 15.5

= - 16 $D^{0.44}$ = - 16 x $(20.80)^{0.44}$

= - 61 microns = - 0.061 mm

The shaft limits are (20.000 - 0.061) = 19.939 mm and 20.00 – (0.061 + 0.032) = 19.907 mm.

Therefore, shaft tolerance = 19,939 - 19.907

= 0.032 mm

Minimum allowance = 0.061 mm

Problem 15.2 : A hole and shafting system has the following dimensions :

60 H7/m6

The standard tolerance is given by

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

where, D = diameter (mm) of the geometric mean step of 50 mm to 80 mm.

i = standard tolerance, microns.

The multipliers for grade 7 is 16 and for grade 6 is 10

The fundamental deviation for fit m is given by

FD = + (IT 7 - IT 6)

The diameter range lies between 50 mm and 80 mm.

1. What is the class of fit ?
2. State the actual dimension of the holes and the shaft.

$$D = \sqrt{50 \times 80} = 63.25$$
$$i = 0.45\sqrt[3]{63.25} + 0.001 \times 63.25$$
$$i = 1.85325\mu = 0.00185mm$$

For hole of quality 7, the multiplier being 16, the standard tolerance,

$16i = 16 \times 1.85 = 29.60$ microns

For 'H' hole, the FD = 0

Therefore, the hole dimensions are 60.000mm and (60+0.0296)

= 60.0296 mm

Hence, tolerance = (60.0296 - 60.000) = 0.0296 mm

For shaft of quality 6, the multiplier being 10, the standard tolerance,

$10i = 10 \times 0.00185 = 0.0185$ mm

FD for 'm' fit = + (IT 7 - IT 6)

$= +(16i - 10i)$

$= +(6 \times 0.00185)$

= + 0.01110 mm

Therefore, the shaft dimensions are (60 + 0.01110) = 60.01110 mm and 60 + (0.0110 + 0.0185) = 60.0295 mm.

Hence, this is the case of the *transition fit.*

Problem 15.3 : A gear ring is fitted on a hub having H7-j6 fit. The bore of the gear ring is 90 mm in diameter. Calculate the (i) hub dimensions and (ii) gear bore sizes.

The fundamental deviations are

H=0; j = – 9 microns.

The multipliers for standard tolerances are 10 for IT 6 and 16 for IT 7. Standard tolerance is given by:

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

where D is the diameter of the geometric mean step sizes ranging between 80 and 120 mm.

$$D = \sqrt{80 \times 120} = 97.98 \approx 98\text{mm}$$

$$i = 0.45\sqrt[3]{98} + 0.001 \times 98$$

= 2.173 microns = 0.002173 mm

For 'bore' of quality 7, the multiplier being 16, the tolerance,

$16i = 16 \times 0.002173 = 0.0348$ mm

For 'H' hole, the FD = 0

Therefore, the hole dimensions are **90.000** mm, and (90.000+0.0348)

= **90.0348 mm.**

For 'hub' FD for j-fit = - 9 micron = - 0.009 mm.

Therefore the hub dimensions are (90 - 0.009)

$= \mathbf{89.991}$ mm and 90 - (0.009 + 0.02173)
$= \mathbf{89.969}$ **mm.**

This is a case of *clearance fit.*

IS : 919 – 1963

TABLE 15.5 FORMULEA FOR FUNDAMENTAL SHAFT DEVIATION

Upper deviation (es)		*Lower deviation (ei)*	
Shaft designation	*In microns (for D in mm)*	*Shaft designation*	*In microns (for D in mm)*
a =	$-(265 + 1.3\,D)$_ for D≤120	j5 to j8	No formula
		k4 to k7	$= +0.6\sqrt[3]{D}$
a =	$-3.5\,D$ for D>120	k for grades ≤ 3 and ≥ 8	= 0
a ≈	$-(140+0.85\,D)$ for D > 160	m =	+(IT 7 – IT 6)
	for D ≤ 160	n =	$+5\,D^{0.34}$
a ≈	$-1.8\,D$ for D > 160	p =	+ IT 7 + 0 to 5
		r =	+ geometric mean of values ei for p and s
c =	$-52\,D^{0.2}$ for D ≤ 40	s =	+ IT 8 + 1 to 4 for D ≤ 50
c =	$-(95 + 0.8\,D)$ for D > 40	s =	+ IT 7 + 0.4 D for D > 50
d =	$-16\,D^{0.44}$	t =	+IT 7 + 0.63 D
e =	$-16\,D^{0.41}$	u =	+IT 7 + D
f =	$-16\,D^{0.41}$	v =	+IT 7 + 1.25 D
g =	$-16\,D^{0.34}$	x =	+IT 7 + 1.6 D
		y =	+IT 7 + 2 D
		z =	+IT 7 + 2.5 D
		za =	+IT 7 + 3.15 D
h =	0	zb =	+IT 7 + 4 D
		zc =	+IT 7 + 5 D

For js : The two deviations are equal to ± IT/2

15.10 SELECTIVE ASSEMBLY

In the foregoing discussion it has been explained that interchangeability means assembly of two mating parts. In other words, any part selected at random will fit properly with any randomly selected mating components. In some cases this random assembly or full interchangeability is *not* found to be achieved. For example, if a part at its low limit is assembled with a mating part at its high limit, the fit so obtained may not fully satisfy the functional requirements of the assembly. Also machine capabilities are sometimes not sufficient to satisfy the needs of random assembly. Complete interchangeability in those cases, however, is obtained by selective assembly.

Normally in selective assembly, the components are put into groups according to size and then assembled with mating components also classified according to size in the same number of groups. Corresponding groups are then expected to assemble and function properly.

Take the example of a shaft and pulley where a constant interference of 0.20 mm is desired. The shaft and pulley hole sizes are $80.20^{+0.10}_{-0.10}$ and $80.20^{+0.10}_{-0.10}$ mm respectively.

The maximum and minimum interference, on the calculation, being 0.00 and 0.40 mm respectively, the interference between parts assembled at random may be *anywhere* from 0.00 to 0.40 mm. Now by assembling from proper groups as shown below, interference can be held to the desired value of 0.20 mm.

Pulley	80.00	80.05	80.10
Shaft	80.20	80.25	80.30

This method is called *selectively assembly*. This is specially useful in case of interference and where the tolerances are small. Selective assembly, however, is costly in inspection and quality control in mass production.

SURFACE QUALITY

The proper functioning and service life of a machine part depend to a considerable extent on the quality of its surfaces.

The action of a cutting tool in machining never results in absolutely smooth and even surface of the parts, the later invariably bear some traces of unevenness, roughness, notches, scores, lines, etc., both in the direction of primary motion, in which the cutting is performed and in the direction of feed. Even these surfaces which seem perfectly smooth after scrapping, lapping, etc. have a minor unevenness.

15.11 SURFACE CHARACTERISTICS

The standard terms which are used to explain surface characteristics are defined below and illustrated in Fig. 15.9.

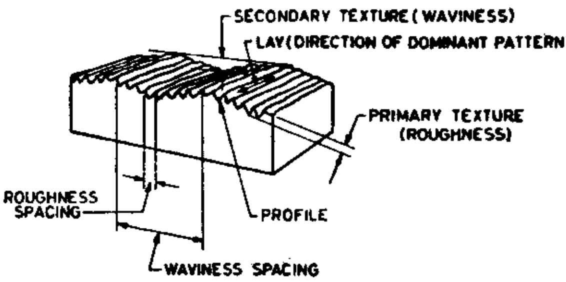


Table 15.9 Surface characteristics

Profile : Profile is defined as the contour of any section through a surface.

Primary texture (Roughness) : This refers to relatively finely spaced surface irregularities which result from the inherent action of the production process. These are deemed to include transverse feed marks and the irregularities in them. In Russian literature this is called 'micro-geometrical deviation'.

Secondary texture (Waviness) : Waviness consists of those surface irregularities which are of greater waves more or less of the same size. Waviness may be caused by vibrations, machine or work deflection, chatter, wrapping, etc. The most clear defined waviness appears in turning, milling, planing, broaching and grinding. In Russian literature this is called 'micro-geometrical deviation'.

Lay : Lay is defined as the direction of the predominant surface markings. This is ordinarily determined by the production method used.

Flaws : Flaws are surface imperfections such as blow holes, cracks, porosity, etc. which appear at frequent intervals and at random locations. The flaws, unless otherwise specified, shall not be included in the surface characteristics.

15.12 EVALUATION OF SURFACE FINISH

Some of the well known methods for evaluating the roughness of a surface are given below.

1. Centre line average method : The 'M-system', also known as Center Line Average Method (CLA) or Mean Line System, expresses the arithmetical average (AA) departure of the actual surface both above and below a mean line, within a specified sampling length. According to Indian Standard, the surface roughness is specified in terms of CLA values denoted by R_a, meaning average roughness height, in microns (μm).

The central line is defined as the line parallel to the general direction of the profile for which the areas embraced by the profile above and below the line are equal. The center line and the mean line may be considered to be equivalent for practical purposes.

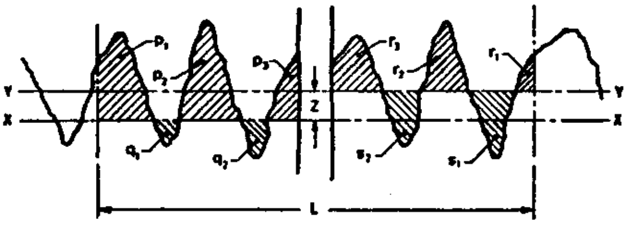


Figure15.10 To determine R_a values by central line average method (M-system)

(a) To determine the R_a values, it is necessary to first determine the mean line for a given profile. Any straight line *XX* is drawn [parallel to the general direction of the surface profile over the sampling the length *L* in Fig. 15.10. The sum of all the areas p1, p2, etc. and q1, q2, etc. are then determined either by measuring ordinates or by the use of a planimeter. the line *XX* is then shifted by a distance *Z* such that

$$Z = \frac{\text{sum of areas } p - \text{sum of the area } q}{L}$$

Now the line *yy* being the *required center line*, sum of the areas r_1, r_2, etc. will be equal to sum of the areas s_1, s_2, etc. The arithmetic average is given by :

$$R_a = \frac{\text{sum of areas } r + \text{sum of the area } s}{L} \times 1000/M$$

where areas are expressed in sq. mm, *L* in mm and *M*, the vertical magnification of the record.

(b) If in a given profile of sampling length *L*, a center line, say *AB* is located such that the sum of the areas A_1, A_3, etc. above the line is equal to the areas A_2, A_4, etc. below this line, then

$$R_a = \frac{A_1 + A_2 + A_3}{L} = \Sigma A/L$$

(c) If n measurement are made vertically without considering plus or minus from the center line on the profile in the Fig. 15.12(b) and are called y_i, then

$$R_a = \frac{y_1 + y_2 + y_3 + \dots\dots + y_n}{n} = \frac{\sum_1^n |y_i|}{n}$$

$$\text{Or,} \quad R_a = \frac{1}{l}\int_0^l |y| dx$$

(d) The 'E-system' expresses the arithmetical average departure of a surface both above and below a *mean curve* . this is developed from what is known as a 'contacting envelope' by displacing it to a position where the areas enclosed by the profile above and below the mean curve are equal. This envelop or curve is obtained by rolling a circle of radius 'r'. which is normally 25 mm, across the surface. It touches the peaks of the surfaces and is parallel to the locus by the centre of this circle as it rolls over the surface as illustrated in Fig. 15.11.

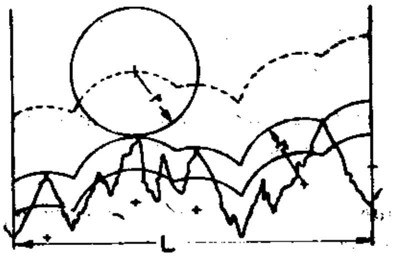


Figure 15.11 To determine R_a values by 'Contacting envelope' method (E-system)

1. Root mean square method : In this method, the rms average value is obtained by setting many equidistant ordinates on the mean line as in Fig. 15.12(b) and taking the root of the mean of the squared ordinates as:

$$\text{rms} = \sqrt{\frac{y_1^2 + y_2^2 + \ldots\ldots y_n^2}{n}} = \left[\frac{\sum |y_i^2|}{n}\right]^{1/2}$$

For a given profile of the same sampling length, the rms values are about 11% greater than R_a values.

3. Peak-to-valley average method : The PVA value is obtained as the average difference between (say) five highest peaks and equal number of deepest valleys over the sampling length measured parallel to the mean line and not crossing the profile as shown in Fig. 15.12(a). This is denoted by R_z

$$R_z = \frac{(h_1 + h_3 + \ldots\ldots\ldots\ldots + h_9) - (h_2 + h_4 + \ldots\ldots\ldots\ldots + h_{10})}{5} \mu m$$

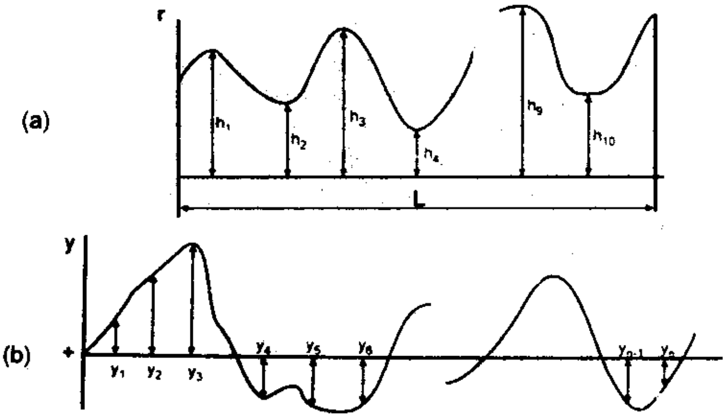


Figure 15.12 To determine R$_a$ values by
(a) PVA method, (b) RMS. method

Roughness values : The preferred values for R_a and R_z shall be selected from the following :

R_a 0.025, 0.05, 0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.3, 12.5, 25
R_z 0.05, 0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.3, 12.5, 25, 50, 100

The readers may see Appendix-II for tolerance grade and surface roughness of various manufacturing processes.

Surface roughness statements : If a single R_a value is stated it means that R_a value is from zero to that is stated. When both minimum and maximum R_a values needed to specify these shall be expressed as :

$R_a \, {}^{8.0}_{16.0}$ or alternatively R_a 8.0 - 16.0

The sampling length shall be indicated in parenthesis following the roughness value as : R_a 8.0 (2.5).

Sampling length : This is also called the 'Instrument cut-off' in regard to measuring instruments. The value of sampling length L shall be selected from the following series :

0.80, 0.25, 0.8, 2.5, 8, 10 and 25 mm.

For machining process 0.25, 0.8 and 2.5 mm and for non-machined surfaces 0.8 and 2.5 mm lengths are suitable.

15.13 SYMBOLS ON DRAWINGS

The symbols to be used for lay are :

= Parallel to the line representing the surface.
⊥ Perpendicular to the line representing the surface.
X Angular in both directions to the line representing the surface.
M Multidirectional.
C Approximately circular relative to the centre.
R Approximately radial relative to the centre of the surface.

The surface roughness on drawing is represented by *triangles*. They are classified into four groups with their R_a values as shown below (Fig. 15.13) :

Figure 15.13

The fully specify the surface texture on drawings, the symbols as shown in Fig. 15.14, are recommended.

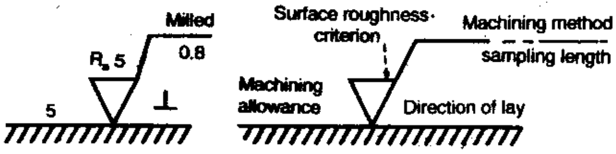


Figure 15.14 Symbols to specify surface texture on drawings

REVIEW QUESTIONS

1. What is interchangeability ? How does it influence production ?
2. What is meant by 'selective assembly', and what are its advantages and disadvantages ?
3. Explain the terms: tolerance, allowance, basic size, standard size, nominal size and limits.
4. Explain the difference between the allowance and clearance. Explain also unilateral and bilateral tolerances. State their advantages and disadvantages.
5. Describe geometric dimensioning and tolerance. List the important geometric features which are covered by geometric dimensioning.
6. What is fit ? Name the three main types of fits with their uses and suitable sketches.
7. State the importance of limits and fits in large-scale production. Describe any system of setting limits and fits you know.
8. State what is meant by 'hole basis' and 'shaft basis'. Which one is preferred and why ?
9. What do you mean by 'surface quality' ? State the geometric characteristics of the forms of surfaces.
10. Explain the difference between roughness and waviness.
11. State different methods of surface evaluation.
12. Calculate the fundamental deviation and tolerances and obtain the limits of hole and shaft size in the fit: 25 $H8$-$d9$. The diameter steps are 18 mm and 30 mm. The FD for d shaft is given as- $16D^{044}$. The tolerance unit is $i = 0.45\sqrt[3]{D} + 0.001D$.

16

MEASUREMENT AND INSPECTION

16.1 INTRODUCTION

Measurement has played an important role in man's scientific and technological advancement. Measuring instruments, tools, and various gauges are used for measurement and inspection to establish the manufacturing accuracy of parts. They help to timely detect inaccurately machined parts and to avoid rejects and defects which is the job of the inspection department. They are also helpful in other ways. They are used to layout the positions of surfaces to be machined, to set and adjust tools, and to align machines for effective utilisation of all parameters of production.

A *measuring instrument* is any device that may be used to obtain a dimensional or surface measurement while a *gauge* is intended for quickly checking parts in production, that is to determine whether or not a dimension is within its specified limits. A gauge usually does not reveal the actual size of dimension. Unfortunately many measuring instruments have well established names which include the term gauges.

16.2 STANDARDS OF MEASUREMENT

The basis of measurement is the provision of a system of fundamental unit together with primary standards from which working standards can be derived. The earliest method used for measuring the dimension of a part consisted in comparing its dimension with a known standard. This concept of measurement has not changed ever since, and a progress has been made at the International level towards adapting a uniform standard of measurement. Standards are material representations of the fundamental units as the legal and scientific bases to which all measurements must be referred. However, two widely used length standards are :

1. International standard metre
2. Imperial standard yard

In 1960 the 11th General Conference on Weights and Measures (CGPM) adopted the International System of units (SI). By international agreement, the metre has been defined as the length of path travelled by light in a vacuum during the time interval of 1/299 792 458 of a second (17th CPGM, 1983) ; originally 1/10 000 000 of the distance from the North Pole to the Equator through Paris, France. Previously, and for practical purposes, the International prototype Metre was defined as the distance, at 0°C, between the centre portions of two lines graduated on the polished surface of a bar of pure platinum-iridium alloy (10% iridium) of 1020 mm total length and having a cross-section of 16 mm x 16mm with a web at its middle as shown in Fig. 16.1. The web has two lines engraved over it ; the distance of which is accepted as 1 metre.

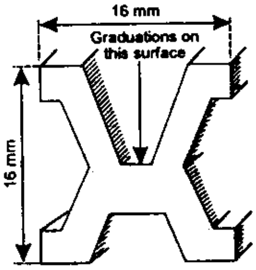


Figure 16.1 Cross-section of the Standard Metre

The *yard* in its current form was set up in the year 1845. It is made of a solid square bronze bar 38 inch long and 1 inch^2 cross section. At 1 inch from each end (36 inch centres) there is a round recess cut to the centre of the bar and at the bottom of this hole a gold plug 1/10 inch diameter is inserted in a smaller hole. The surface of each plug is scribed with three fine transverse lines about 1/100 inch apart and two lines at right angles also about 7/100 inch apart. This is illustrated in Fig. 16.2. The measure of the yard is that between the middle transverse lines at each end, the distance being taken at the point midway between two longitudinal lines at 62 °F.

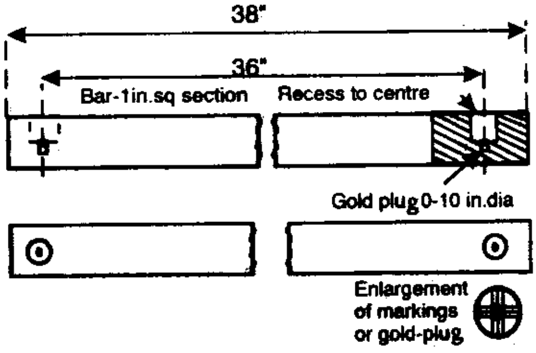


Figure 16.2 The Imperial Standard Yard

LINE AND END STANDARDS

The length standard can be classified as the line standard and end standard. In the length standard, the unit of length is defined as the distance between the centres of engraved lines as in a steel rule. Whereas in the end standards it is the distance between the end faces of the standard as in a micrometer.

The International prototype Metre and the Imperial standard yard are line standards, since the measure of length is determined as between two lines. This form of measurement is not very convenient to use. Commercial line standards have the disadvantages that there is a limit to the accuracy with which the lines can be produced, and their employment involves the use of microscopes and other special equipment.

For all the important works in the shop, therefore, the users prefer end standards e.g. slip gauges, length bars, the ends of micrometer anvils, gap gauges, and so on. The distance between the end faces directly determines the length of the standard. The end faces are hardened, lapped flat and parallel to a very high degree of accuracy.

A modern end standard consists fundamentally of a block or bar of steel, generally hardened, whose end faces are lapped flat and parallel to within a few tenths of a micrometer. By the process of lapping, its size too can be controlled very accurately. Although, from time to time, various types of end bars have been constructed, some having flat and some spherical faces, the flat, parallel-faced bar is firmly established as the most practical method of end measurement.

16.3 CLASSIFICATION OF MEASURING INSTRUMENTS

Measuring instruments may be classified according to the accuracy they are capable of maintaining in measuring the parts to be inspected. These are precision and non-precision instruments. Precision instruments are those which have the ability to measure parts within an accuracy of 0.01 mm or more. The modern level of measuring technique enables us to measure dimensions accurately to a few microns (0.001 mm), and in some cases to fractions of a micron. *Non-precision* instruments are limited to the measurement of parts to a visible line graduation on the instrument used, such as a graduated rule or scale.

Measuring instruments may be *direct reading* or of the *transfer type*. A direct measuring instrument is used to determine the actual dimension and size of a workpiece. An indirect, measuring instrument, in effect, transfers the measurement from the workpiece to a direct-measuring instrument, then a comparison is made. Indirect measuring is a comparison measuring.

There are again *line measuring devices* and *end measuring devices.* In a line measuring device, the ends of a dimension being measured are aligned with the graduations of the scale from which the length is read directly, as for example, steel rules. In an end measuring device, the measurement is taken between two ends as in a micrometer, caliper, gauge block, etc. End measuring devices are more important and useful and they are used for precision measurement.

Most measuring instruments have specific and limited uses, although some can be used for more than one purpose. Some are suitable for measuring linear dimensions, others for angular or geometric dimensions, and specialized ones are devoted to measuring surface finish. Some measuring instruments are reserved for reference purposes, as standards of comparison. The principal measuring instruments are listed in Table 16.1.

TABLE 16.1 PRINCIPAL MEASURING INSTRUMENTS

1. Linear measurements
    - A. Nonprecision instruments
        - (a) Steel rule
        - (b) Calipers
        - (c) Dividers
        - (d) Telescopic gauge
        - (e) Depth gauge
    - B. Precision instruments
        - (a) Micrometers
        - (b) Vernier calipers
        - (c) Height gauges
        - (d) Slip gauges
    - C. Comparators
    - D. Measuring machines
2. Angular measurements
    - A. Nonprecision instruments
        - (a) Protractors
        - (b) Adjustable bevel
        - (c) Engineers' square
        - (d) Combination set
    - B. Precision instruments
        - (a) Bevel protractors
        - (b) Dividing head
        - (c) Sine bar
        - (d) Angle gauges
        - (e) Spirit levels
        - (f) Clinometers
        - (g) Autocollimators
3. Taper measurement
4. Surface measurement
    - (a) Straight edge
    - (b) Surface table
    - (c) Surface gauge
    - (d) Optical flat
    - (e) Profilometer
    - (f) Use of laser

16.4 LINEAR MEASUREMENT (NONPRECISON)

The linear measurement includes the measurement of lengths, diameters, heights, and thickness. The basic principle of linear measurement is that of comparison with standard dimensions on a suitably engraved instrument or device.

Under nonprecision group are included the simpler tools which are used to measure to the line graduations of a rule.

STEEL RULE

The steel rule is one of the most useful tool in the shop for taking linear measurements of blanks and articles to an accuracy of from 1.0 to 0.5 mm. It consists of a strip of hardened steel having line graduations etched or engraved at interval of fraction of a standard unit of length. Depending upon the interval at which the graduations are made the scales can be manufactured in different sizes and styles. This is usually marked in both inches and centimetres, the inches being subdivided into 1/8, 1/16, 1/32, 1/64 inch, and the metric rule into millimeters. Metric rules with only millimeter and centimeter graduations as shown in 16.3 are now used in this country. The scale divisions are spaced 1 mm from one another. Some rules are graduated into divisions of 0.5 mm.

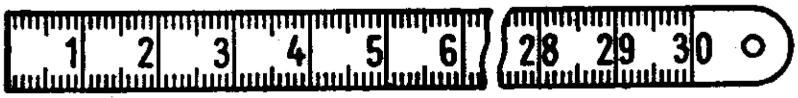


Figure 16.3 Steel rule

Steel rules are made 150, 300, 500 and 1000 mm long. The width of lengths unto 500 mm is 18 to 22 mm and the thichness 0.4 to 0.6 mm. Rules longer than 500 mm are made 40 to 76 mm wide and 0.8 to 1.0 mm thick. There are scales which have got some attachments and special features with them to make their use more versatile. They may be made in folded form so that they can be kept in pocket also. Certain scales, called shrink or contraction rule, are virtually steel rules, and they are used in foundry and pattern making shops.

CALIPERS

A caliper is used to transfer and compare a dimension from one object to another or from a part to a scale or micrometer where the measurement can not be made directly. Four types of calipers are generally used. They are as follows :

Outside caliper. An outside caliper is a two legged steel instrument with its legs bent inwards as shown in Fig. 16.4. It is used for measuring or comparing thickness, diameters, and other outside dimensions. A steel rule must be used in conjunction with them if a direct reading is desired. The side of a caliper is specified by the greatest distance it can be opened at the tips of the legs.

Inside calipers. An inside caliper is exactly similar to an outside caliper in appearance with its legs bent outward as shown in Fig. 16.5. This is used for comparing or measuring hole diameters, distances between shoulders, or other parallel surfaces of any inside dimension. To obtain a specific reading steel scale must be used, as with the outside calipers.

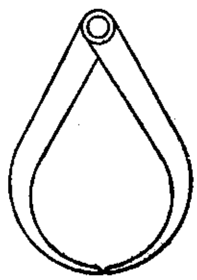


Figure 16.4
Outside caliper

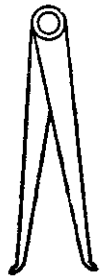
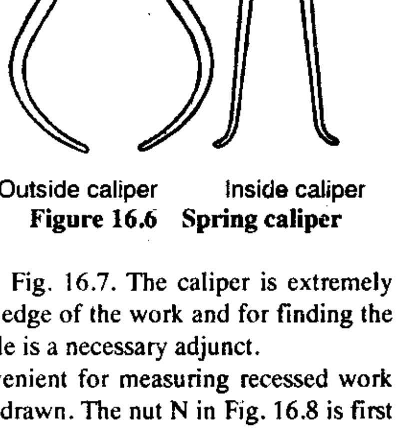


Figure 16.5
Inside caliper

Spring caliper. For finer work the use of spring caliper (Fig. 16.6)–both outside and inside advocated. A loop spring on top of the joint between the two legs applies force tending to separate the legs at the bottom. An adjusting screw and nut keep the legs in position. An *inside spring caliper* has legs turned outward to make contact with the inside of holes and grooves. A steel rule must be used in conjunction with them, as with ordinary calipers. When a spring caliper is applied to an object, it must make sure contact but not be forced. A sense of "fell" or "touch" is necessary to use a caliper successfully.



Outside caliper Inside caliper
Figure 16.6 Spring caliper

Hermaphrodite caliper. This is sometimes called *odd-leg caliper*. It has one pointed leg like a divider and one bent leg as shown in Fig. 16.7. The caliper is extremely useful for scribing lines parallel to the edge of the work and for finding the centre of a cylindrical work. A steel rule is a necessary adjunct.

Transfer caliper. This is convenient for measuring recessed work where ordinary calipers cannot be withdrawn. The nut N in Fig. 16.8 is first locked and the caliper opened or closed against the work. The nut is then loosened and the leg swung clear of the obstruction leaving the auxiliary arm in position. The leg can now be moved back against the stop, where it will show the size previously measured. There may be both outside and inside transfer calipers.

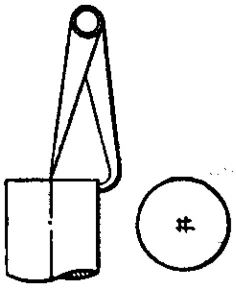


Figure 16.7 Hermaphrodite caliper

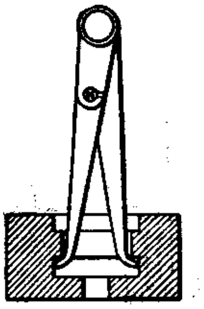


Figure 16.8 Transfer caliper

DIVIDERS

A divider is similar in construction to a caliper except that both legs are straight with sharp hardened points at the end as shown in Fig. 16.9. The tool is used for transferring dimensions, scribing circles, and doing general layout work. In practice, one point is placed in the centre pop making the exact centre, and the circle or arc may then be scribed on the job with the other point. The size is measured by the greatest distance it can be opened between the legs. Thus a 100 mm divider open 100 mm between the points. A steel scale must also be used with this instrument.

A large circle or an arc having a large radius may be made with a tool called a *trammel*. It is sometimes called a *beam compass*.

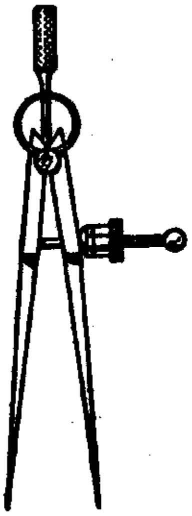


Figure 16.9 Divider

TELESCOPIC GAUGE

The telescopic gauge, shown in Fig. 16.10 is used for measuring the inside size of slots or holes. The gauge consists of a handle and two plungers, one telescopic into the other and both under spring tension. The plungers can be locked in position by turning a knurled screw at the end of the handle. To measure the diameter of a hole, the plungers are first compressed and locked in position. Next, the plunger end is inserted in the hole and allowed to expand to touch opposite edges. Finally, the plungers are locked in place, taken out of the hole, and measured by an outside micrometer since it has no graduations of its own.

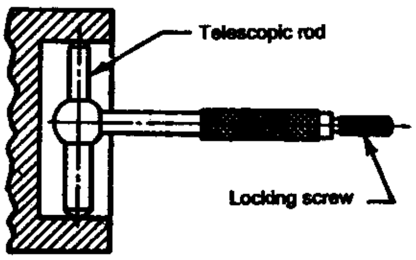


Figure 16.10 Telescopic gauge

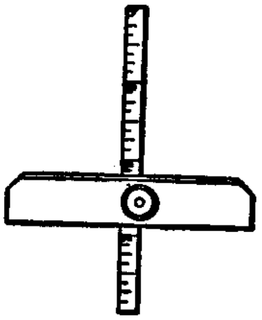


Figure 16.11 Depth gauge

DEPTH GAUGE

This tool is used to measure the depth of blind holes, grooves, slots, the heights of shoulders in holes and dimensions of similar character. This is essentially a narrow steel rule to which a sliding head is clamped at right angles to the rule as shown in Fig. 16.11. The head forms a convenient marker in places where the rule must be held at a distance from the point being measured.

16.5 LINEAR MEASUREMENT (PRECISION)

Since modern production is concerned with interchangeable products, a great precision dimensional control is required in industry. For this to be chivvied, importance of precision measuring instruments can be well visualized.

EXTERNAL MICROMETER

The external micrometer is primarily used to measure external dimensions like diameters of shafts, thickness of parts, etc. to an accuracy of 0.01 mm. The essential parts of the instrument as shown in Fig. 16.12 are as follows:

1. Frame. The frame is made of steel, cast steel, malleable cast iron or light alloy.

2. Hardened anvil. The anvil shall protrude from the frame for a distance of at least 3 mm in order to permit of the attachment of a measuring wire support.
3. Screwed spindle. This spindle does the actual measuring and possesses thread of 0.5 mm pitch.
4. Graduated sleeve or barrel. It has datum or fiducial line and fixed graduations.
5. Thimble. This is tubular cover fastened with the apindle and moves with the spindle. The bevelled edge of the thimble is divided into 50 equal parts, every fifth being numbered.
6. Ratchet or friction stop. This is a small extension to the thimble. The rachet slips when the pressure on the screw exceeds a certain amount. This produces uniform reading and prevents any damage or distortion of the instrument.
7. Spindle clamp or clamp ring. This is used to lock the instrument at any desired setting.

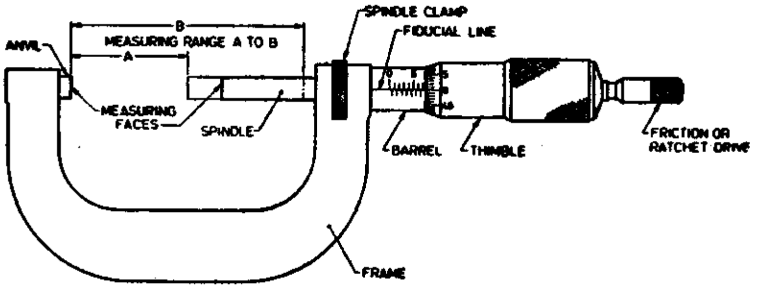


Figure 16.12 Different parts of an external micrometer (metric)

Reading : The graduation on the barrel is in two parts, namely one above the reference line and the other below. The graduation above the reference line is graduated in 1 mm intervals. The first and every fifth are long and numbered 0, 5, 10, 15, 20 and 25. The lower graduations are graduated in 1 mm intervals but each graduation shall be placed at the middle of the two successive upper graduations to be read 0.5 mm.

The micrometer screw has a pitch of 0.5 mm, while the thimble has a scale of 50 divisions round its circumference. Thus, on going through one complete turn, the thimble moves forward or backward by one thread pitch of 0.5 mm, and one division of its scale is, therefore, equivalent to a longitudinal movement of $0.5 \times 1/50$ mm = 0.01 mm. It is the value of one division on the thimble which is the least that can be correctly read with the help of a micrometer and is called the *least count.*

The job is measured between the end of the spindle and the anvil which is fitted to the frame. When the micrometer is closed, the line marked "0" on the thimble coincides with the line marked "0" on the barrel. If he "0" graduation does not concide then the micrometer requires adjustment.

to take the reading from the micrometer note : (1) the number of main divisions in millimeters above the reference line, (2) the number of subdivisions below the reference line exceeding only the upper graduation, and (3) the number of divisions in the thimble. As for example, if a micrometer shows a reading of 7.5 mm as in Fig. 16.12 then

7 divisions above reference line = 7.00 mm
1 division below reference line = 0.50 mm
0 thimble division = 0.00 mm

7.50 mm

If the bevelled edge of the thimble is passed along the micrometer barrel from the zero to a point somewhat beyand division 18.5, while division 5 on the thimble scale coincides with the longitudinal line, the reading will be 18.5+0.05 = 18.55 mm.

The external micrometers have a range of 25 mm and are available with the following ranges of measurement : 0 to 25, 25 to 50, 50 to 75, 75 to 100, 100 to 125, and so on, with 575 to 600 mm as the largest one. The measuring range of micrometers greater than 300 mm in size can be extended by means of interchangeable and adjustable anvils. In using a micrometer over 0 to 25 mm, the initial gap beteen the measuring faces must be added with the reading obtained from the micrometer.

English micrometer. An English micrometer has an accuracy of 0.001 in.

The spindle screw has 40 threads per inch. One turn of the thimble, therefore, opens the jaw 1/40 of an inch. The barrel is graduated for a length of one indch. This length is divided into ten equal parts and each 1/10 is again sub-divided into four equal parts, each part being equal to

1/4 of 1/10 = 1/10 = 0.025 in.

The bevelled edge of the thimble is divided into 25 equal parts, every fifth being numbered. If then we rotate the thimble 1/25 of a revolution, or the distance between any two adjacent marks on the bevelled edge, the thimble and the spindle have moved in or out of the barrel.

$$1/25 \text{ of } 1/40 = 1/1000 = 0.001 \text{ in.}$$

Similarly, if the thimble is rotated through five spaces, the spindle will move 0.005 in and so on.

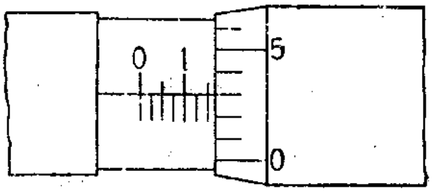


Figure 16.13 English micrometer showing a reading of 0.153 in.

A very quick method of using a micrometer is to read (1) the number of main divisions, (2) the number of sub-divisions, and (3) the number of divisions on the thimble. As for example, if a micrometer shows a reading of 0.153 in as illustrated in Fig. 16.13, then

1. main division = 0.100 in
2. sub-divisions = 0.050 in
3. divisions on the thimble = 0.003 in

0.153 in

Outside micrometers have a range of 1 in, from 0 to 1 in, from 1 to 2 in, and so on, with 5 to 6 in, as the largest one. Therefore, when we use a 2 to 3 in micrometer we must not forget that the size is over 2 in, and that 2 in has to be added to the reading obtained from the barrel and the thimble.

Vernier micrometer. Some micrometers measure 1/10000 in by means of additional graduations on the barrel. This is called Vernier micrometer. The Vernier scale is used in reading a micrometer whenever

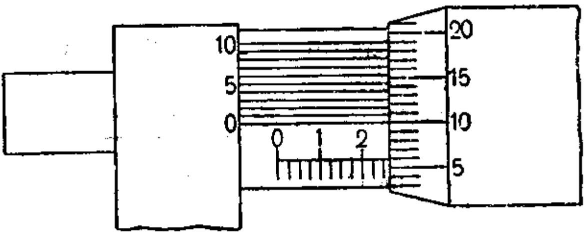


Figure 16.14 English vernier micrometer

the longitudinal line on the spindle does not coincide, that is, it is not in alignment with a line on the thimble.

The Vernier scale consisting of 10 spaces running parallel to the longitudinal lines on the barrel (as shown in Fig. 1614), covers exactly 9 of the spaces of the thimble. Since the 10 spaces of the Vernier equal the overall spaces of the 9 divisions of the thimble, then 1 division of the Vernier equals

1/10 of 9/1000 = 9/10000 in.

Graduations on the thimble equal to 1/1000 or 10/10000 in. The difference between one division on the thimble and one division on the barrel is, therefore, 10/10000 – 9/10000 = 1/10000 = 0.0001 in.

Micrometer correction. *When the zero on the thimble is below the index line, then the zero error must be deducted from the reading.*

Example 16.1 : When the micrometer is closed let the reading on the thimble be 2.

(Zero error = + 0.002 in).

Let the micrometer reading with an object between the anvil and the spindle = 0.502 in

Deduct the zero error = 0.002 in

∴ Actual thickness = 0.500 in

When the zero on the thimble is above the index line, then the zero error must be added to the reading.

Example 16.2 : When the micrometer is closed let the reading on the thimble be 23.

(Zero error = 25 – 23 = – 0.002 in)

Let the micrometer reading = 0.498 in

Add the zero error = 0.002 in

∴ Actual thickness of the object = 0.500 in

SCREW THREAD MICROMETER

The screw thread micrometer is an instrument used for measuring pitch diameter of screw threads to an accuracy of 0.01 mm and 0.001 in.

It consists of the same parts as that of outside micrometer with the only difference that the movable spindle is pointed and the end of the anvil is of the same form as the screw thread to be measured (see Fig. 16.15). In measuring screw threads, the angle of the spindle point and sides of the anvil vee contact the surfaces of the thread so that the reading of the instrument indicates the pitch diameter of the thread. The zero on the thimble represents a line drawn through the AB as shown in Fig. 16.15.

The graduations on the sleeve and the thimble are similar to that of an external micrometer.

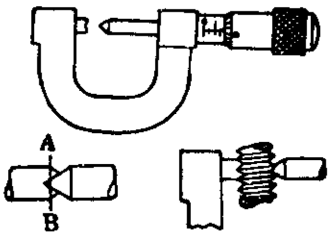


Figure 16.15 Screwed threaded micrometer

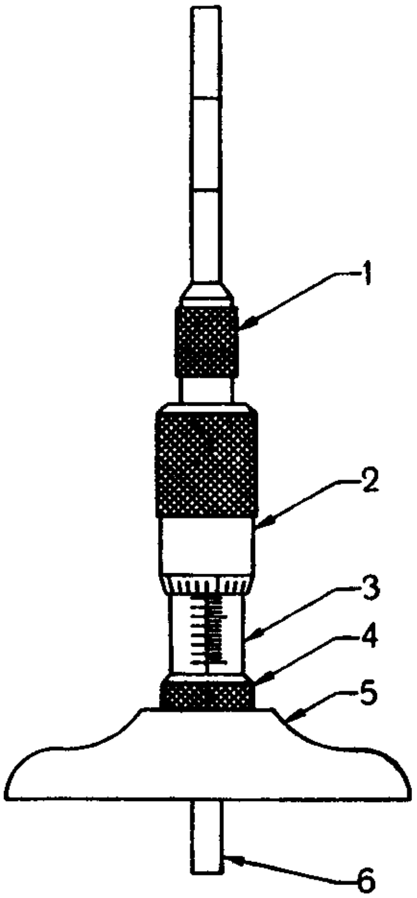


Figure 16.16 Depth micrometer
1. Ratchet stop, 2. Thimble, 3. Sleeve, 4. Locking ring, 5. Head, 6. Spindle

DEPTH MICROMETER

It is an instrument used for measuring depth of holes to an accuracy of 0.01 mm and 0.001 in. Depth micrometer can only be used in places where there is a satisfactory seating for the instrument head, and the bottom of the hole being measured is parallel with the seating.

It consists of the following parts as shown in Fig. 16.16.

1. Micrometer head.
2. Screwed spindle. This spindle does the actual measuring.
3. Graduated sleeve. This has the datum line and fixed graduations which are

numbered 0,9,8,7, etc. reading from left to right.

4. A tubular cover., This is known as the thimble fastened with the spindle at its outer end and moves with the spindle.
5. Ratchet stop. A small extension to the thimble.
6. Locking ring. This is to lock the instrument at any desired setting.

In use, the spindle is screwed back to a point where it will clear the bottom of the hole being gauged. The instrument head is then placed across the top of the hole and held there whilst the spindle is screwed down until it just contacts the work.

The principle of measurement is similar to that of an external micrometer. Each depth micrometer is supplied with three interchangeable spindles and thus has the measuring ranges 0 to 25 mm, 25 to 50 mm, 50 to 75 mm and 75 to 100 mm.

Depth micrometers are available with measuring ranges of 50 to 75, 75 to 175, 175 to 600, 650 to 1,250, 800 to 2,500, 1,250 to 4,000, 2,500 to 6,000, 4,000 to 10,000 mm.

INSIDE MICROMETER

The inside micrometer is intended for internal measurement to an accuracy of 0.01 mm. In principle, it is similar to an external micrometer and is used for measuring holes with a diameter over 50 mm.

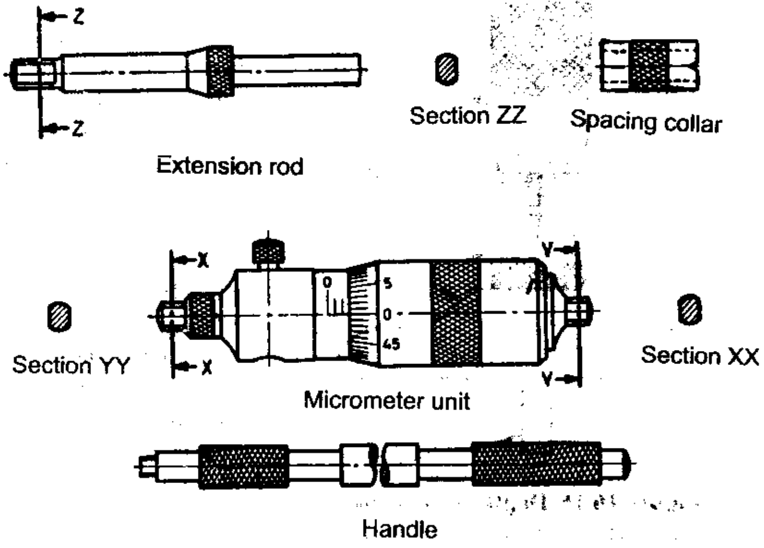


Figure 16.17(a) Different parts of an inside micrometer

The instrument shown in Fig. 16.17(a) comprises a measuring unit, extension rod with or without spacing collar, and a handle. When the micrometer screw is turned in the barrel, the distance between the measuring faces of the micrometer can vary from 50 to 63 mm. To measure the holes with a diameter over 63 mm, the micrometer is fitted with extension rods. Extension rods of the following sizes are in common use: 13, 25, 50, 100, 150, 200 and 600 mm.

Reading : The micrometer screw has a pitch of 0.5 mm. The barrel or sleeve is provided with a scale of 13 mm long and graduated into half-millimeter and millimeter divisions as in the external micrometer. A second scale is engraved on the bevelled edge of the thimble. The bevelled edge of the thimble is divided into 50 scale divisions round the circumference. Thus on going through one complete turn, the thimble moves forward or backward by one thread pitch of 0.5 mm, and one division of its scale is, therefore, equivalent to a longitudinal movement of 0.5 × 1/50 = 0.01 mm.

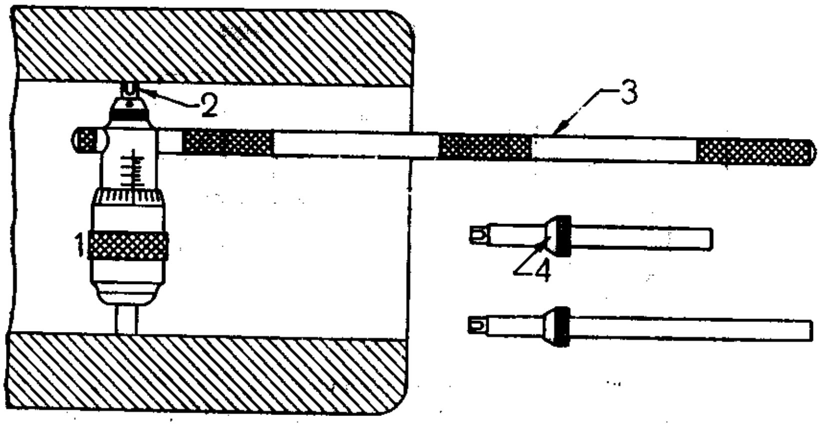


Figure 16.17(b) Measuring the internal diameter of a hole by means of an inside micrometer
1. Micrometer, 2. Anvil, 3. Handle, 4. Extension rod

VERNIER CALIPER

The vernier caliper is primarily intended for measuring both inside and outside diameters of shafts, thickness of parts, etc. to an accuracy of 0.02 mm by a vernier scale attached to the caliper. A vernier scale is the name given to any scale making use of the difference between two scales which are nearly, but not quite alike, for obtaining small differences.

The instrument illustrated in Fig. 16.18 comprises a beam or main scale which carries the fixed graduations, two measuring jaws, a vernier head having a vernier scale engraved on it, and an auxiliary head of a vernier clamp which is used for a specified dimension by a micrometer screw. The vernier head and the auxiliary head can be locked to the main scale by the knurled screw attached to each head.

Reading : An enlarged diagram of the metric vernier scale is shown in Fig. 16.19. On the main scale, I cm is divided into 10 parts, each being 1 mm. This is again divided into two giving 0.5 mm. The vernier scale has 25 divisions which are numbered from 0 to 25. Every fifth division is numbered. The length of 25 divisions on the vernier is equal to the length of 12 divisions or 12 mm on the main scale. Therefore, each vernier division = 12/25 = 0.48 mm. Each small division on the main scale being 0.5 mm, the difference between one division on the main scale and one division on the vernier is equal to 0.5 – 0.48 = 0.02 mm = 1/50 mm.

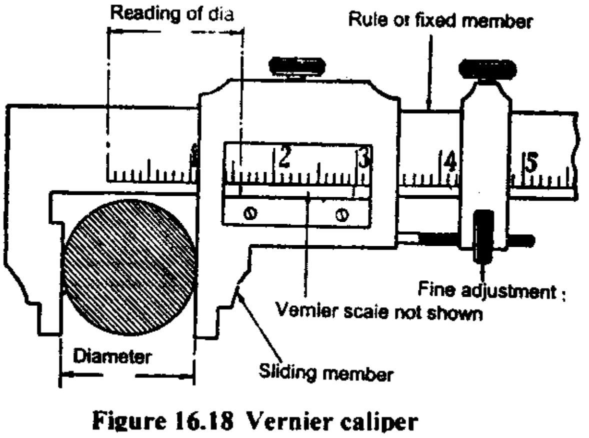


Figure 16.18 Vernier caliper

To read the vernier, first note the centimetres, millimeters, and half millimeter that the zero of the vernier has moved from the zero of the main scale. Then count the number of divisions on the vernier scale from zero line to the line which coincides with a line on the main scale. As for example, if a vernier shows a reading of 21,36 mm, as illustrated in Fig. 16.19 then

2 main divisions = 20 mm
1 sub-division = 1 mm
18 Vernier divisions = 0.36 mm

21.36 mm

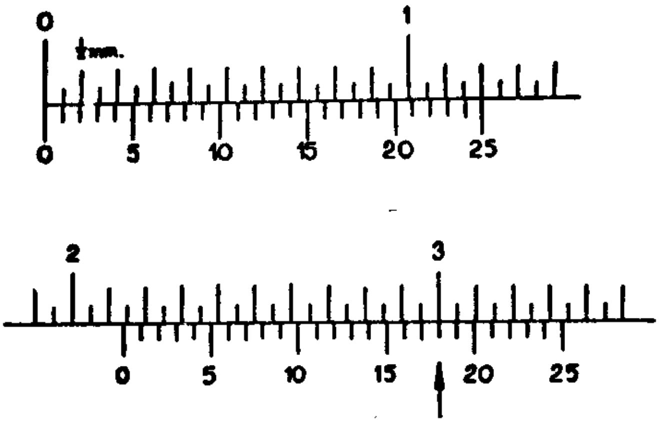


Figure 16.19 Metric vernier reading

Another form of metric vernier is obtained in which 50 divisions on the vernier scale coincide with 49 divisions on the main scale. One main scale division is 1 mm and there is no 1/2 mm division. The vernier scale division in this case, is, therefore, 49/50 mm, the difference being 1– 49/50 = 1/50 = 0.02 mm.

The measuring ranges of the caliper can be 0 to 25, 0 to 150, 0 to 200 mm, etc.

English vernier caliper. An English vernier caliper has an accuracy of 0.001 in.

On the main scale, 1 in is divided into 10 equal parts (numbered 1,2,3,4, etc. as shown in Fig. 16.20) and each 1/10th is divided into 4 giving 1/4 of 1/10th = 1/40 in = 0.025 in. The vernier scale has 25 divisions, which are numbered from 0 to 25. Every fifth division is numbered. The length of 25 divisions on the Vernier is equal to length of 24 divisions on the main scale of the caliper. These 24 divisions being equal to 24 x 0.025 = 0.600 in.

One division on the vernier equals 1/25 of 0.600 or 0.024 in. The difference, therefore, between one division on the main scale and one division on the Vernier is equal to

$$0.025 - 0.024 = 0.001 = 1/1000 \text{ in.}$$

A reading of 1,436 in is shown in Fig. 16.20

VERNIER HEIGHT GAUGE

The vernier height gauge is used to measure the height of parts to an accuracy of 0.02 mm in metric measurement and 0.001 in English measurement. This is also used for precision layout work. The essential parts of the instrument shown in Fig. 16.21 are as follows :

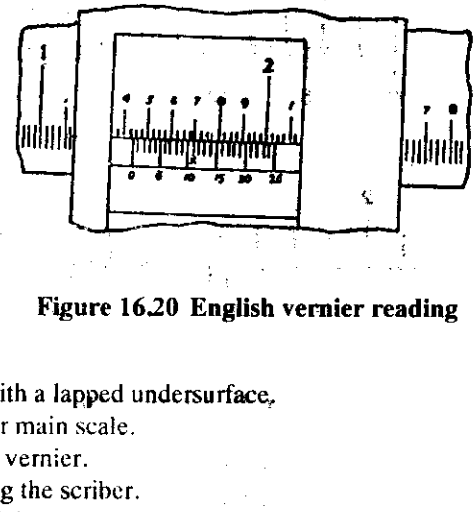


Figure 16.20 English vernier reading

1. Instrument base with a lapped undersurface.
2. Graduated beam or main scale.
3. Sliding head with vernier.
4. Sliding jaw holding the scriber.
5. Vernier clamp which moves with the sliding head.
6. Fine adjustment screw in the vernier clamp.
7. Two knurled screws which lock the vernier head and clamp to the rule at any desired setting.

The vernier height gauges are available for the following lower and upper limits of measurement : 0 to 200, 20 to 250, 30 to 300, 40 to 500, 60 to 800 and 60 to 1,000 mm.

Before using a vernier height gauge it is advisable to check it. To adjust the zero reading, place the gauge on a surface plate and move the head down until the measuring face of the jaw meets the plate surface. The zero line of the vernier should coincide with that of the scale. If, however, the vernier height gauge has the lower measuring limits of 20, 30, 40 or 60 mm, its zero adjustment is carried out by placing the corresponding size of the gauge block on the surface and underneath the jaw. To find the height of the workpiece the height of the jaw from the surface plate, i.e. the lower measuring limit is to be added to the reading obtained in the scale.

For marking out , the scriber is set for the specified height and then the lines are scribed by moving the scriber along the workpiece.

It sometimes happens that the depth of a hole has to be measured with a height gauge for this job a special fitting is obtainable.

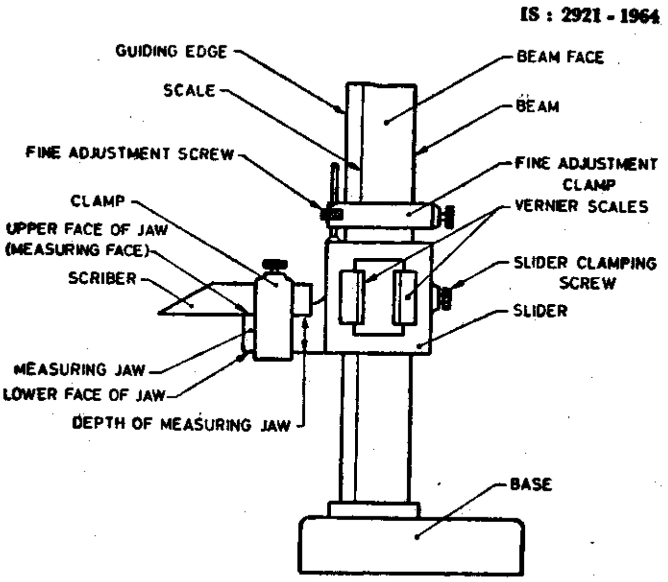


Fig. 15.21 Vernier height gauge

Figure 16.21 Vernier height gauge

The graduation of a height gauge is exactly similar to that of a vernier caliper both in metric and English measurements. Two forms of metric graduations are illustrated in Fig. 16.22.

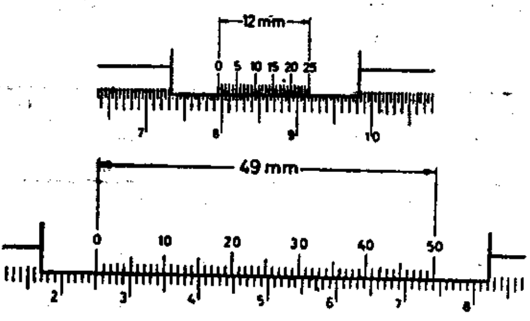


Figure 16.22 Graduation of a height gauge

SLIP GAUGES

Slip gauges or *precision gauges blocks*, as they are sometimes called, are used for precise measurement of parts and for verifying measuring tools such as micrometers, comparators, and various limit gauges. Slip gauges often called Johannsen gauges after their originator, are rectangular blocks made of alloy steel having a cross-section of about 32 mm by 9 mm which, before being finished to size, are hardened and finished to a high degree of accuracy. They are also carefully matured so that they are independent of any variation in shape or size. The diatance between two opposite faces determines the size of the gauge.

Slip gauges are made in five grades of accuracy : Grade I, Grade II, Grade 0, Grade 00 and calibration grade. The grade most commonly used in the production of components, tools, and gauges is Grade I, for rough work Grade II and for checking other gauges and standards Grades 00 and calibration grade. The permissible departures from absolute accuracy for the first three grades is given in Table 16.2.

Slip gauges are supplied in sets, the size of which varies from a set of about 112 pieces down to one containing 32 pieces. The grade and the size of set desirable depend on the class of work for which they are required and the number of combinations that they should be available. An M 88 Grade I set which meets the requirement of the average workshop contains the gauges listed in Table 16.3.

In English measurement there are five sets containing 81, 49, 41, 35 and 28 pieces. A 81-set has a wide range of combination but for general purpose a 49-set is usually employed.

***TABLE 16.2** PERMISSIBLE ERRORS IN SLIP GAUGES
(Unit 1/1,00,000 mm)

Size of gauge (mm)		*Grade I*			*Grade II*			*Grade O*		
Over	*Upto & incl.*	*F*	*P*	*Gauge length*	*F*	*P*	*Gauge length*	*F*	*P*	*Gaug length*
–	20	25	35	+50 –25	15	20	+20 –15	10	10	±10
20	60	25	35	+80 –50	15	20	+30 –20	10	10	±15
60	80	25	35	+120 –25	15	25	+50 –20	10	15	±20
80	100	25	35	+140 –100	15	20	+60 –30	10	15	±25

F = Flatness P = Parallelism

***TABLE 16.3** GAUGES IN AN M 88 SET OF SLIPS
(Sizes in millimeters)

Size of range	*Increment*	*No. of pieces*
1.0005	–	1
1.001–1.009	0.001	9
1.01 – 1.49	0.01	49
0.5 – 9.5	0.5	19
10 – 100	10	10
	Total	88

*Courtesy : Workshop Technology (4Th. Ed.), W.A.J. Chapman, ELBS and Edward Arnold (Publishers) Ltd.

During use, the required number of gauge blocks are 'wrung' together to form the required dimension taking extreme care in handling the gauge blocks. The cleanliness of the surface of the slips and a standard temperature of 20°C during measurement is essential for accurate and reliable inspection. A number of slip gauge holders are sold by the manufacturer of slip gauges to enable efficient handling.

16.6 COMPARATORS

Comparators are instruments which derive their name from the fact that they are used for simple and accurate comparison of parts as well as working gauges and instruments with standard precision gauge blocks. Sometimes they act as gauge themselves. Comparators are designed in several types to meet various conditions, but comparators of every type incorporate some kind of magnifying device to magnify how much a dimension deviates, plus or minus, from an ideal. Most comparators indicate actual units of measurement, but some only indicate whether a dimension deviates within a given tolerance range. They also provide rapid means of inspecting very small articles made in large quantities.

The comparators are classified according to the principles used for obtaining suitable degrees of magnification of the indicating device. The common types are :

1. Mechanical Comparators
2. Electrical comparators
3. Optical comparators
4. Pneumatic comparators

MECHANICAL COMPARATORS

A mechanical comparator employs mechanical means for magnifying the small movement of the measuring stylus brought about due to the difference between the standard and the actual dimension being checked.

Mechanical comparators operating essentially on the same principle are available in different designs. They are : Sigma, Venwick, John Bull, Mercer, Mikrokator, etc. The method of magnifying small movement of the stylus in all mechanical comparators is effected by means of levers, gear-trains or a combination of these elements. Mechanical comparators are available having magnifications from 300 to 5000 to 1, and used mostly for inspection of small parts machined to close limits.

Dial indicators may be classified as mechanical comparators as they have multiplying mechanism which greatly magnifies on the dial any movement of the indicator.

Dial indicators. The essential parts of the instrument is like a small clock with a plunger projecting at the bottom as illustrated in Fig. 16.23. Very slight upward pressure on the plunger moves it upward and the movement is indicated by the dial pointer. The dial is graduated into 100 divisions. A full revolution of the pointer about this scale corresponds to 1 mm travel of the plunger. Thus, a turn of the hand by one scale division represents a spindle travel of 0.01 mm. A revolution counter or a small dial to indicate the travel of the plunger through whole millimeters is sometimes incorporated in the gauge on the big dial.

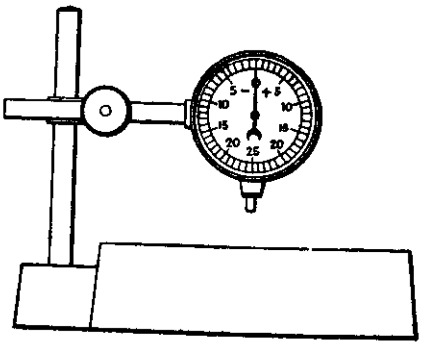


Figure 16.23 Dial gauge and surface plate

The mechanism of such an instrument is illustrated in Fig. 16.24. Movement of stem *1* is transmitted by means of an toothed rack through a compound gear train *2* and *3* to a pointer *4*, which moves around a dial face. The required measuring pressure is provided by small spring incorporated in the mechanism.

The indicator is adjusted to zero by either turning the rim of the dial, or turning the head of the plunger while holding the dial stationary.

Dial indicators are available for ranges of measurement of 0 to 3, 0 to 5, and 0 to 10 mm. These measurements indicate total movement "lift" of the plunger.

Dial gauges or dial indicators are used to true and align machine tools, fixtures and work, to test and inspect the size and trueness of a finished work to an accuracy of 0.01 mm. In English measurement dials are graduated in 0.001 in and some in 0.0001 in. They are also used in conjunction with other measuring instruments, e.g. inside calipers, depth gauges, etc, to measure inside and outside dimensions, errors in parallelism, flatness, etc.

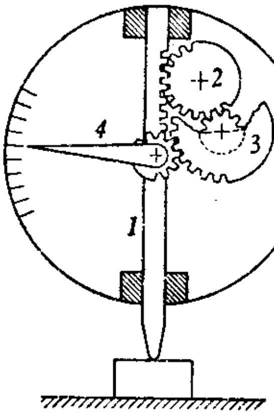


Figure 16.24 Dial indicator mechanism
1. Stem. 2 & 3. Gear train 4. Pointer

ELECTRICAL COMPARATORS

Electrical Comparators are used as a means of detecting and amplifying small movements of a work contacting elements.

An electrical comparator consists essentially of a pick-up head or transducer for converting a displacement into a corresponding change in current and a meter or recorder connected in the circuit to indicate the electrical change, calibrated to show in terms of displacement. Generally, an amplifier is needed to provide the requisite sensitivity and to match the characteristics of different parts of the circuit. Electrical comparators can be classified according to the electrical principle used in the pick-up head. Most of the comparators use either a differential transformer, an inductance bridge, a strain gauge or a capacitor as a means of detecting movement of the gauging element.

There are different types of electrical comparators. One kind called an *electrolimit gauge* is used to check or measure the outside diameter of a roll. The object to be checked is placed on the anvil on the base under the overhanging gauging spindle. Movement of the spindle for its deviation from a standard dimension unbalances an electric circuit. The displacement is magnified electrically and shown on the dial or meter.

Electrical comparators offer a number of advantages over the mechanical type. They have little or no moving parts and, therefore, they can maintain their accuracy over long periods. Also sensitivity of these comparators can be adjusted at will to suit the type of measurement being done. In general, a higher magnification is possible with these comparators as compared to that of mechanical comparators. Electrical comparators are available having magnifications from 600 to 10,000 to 1 according to the meter used.

OPTICAL COMPARATORS

Optical Comparators have a high degree of precision and the magnification is obtained with the help of light beams which have the advantage of being straight and weightless. Optical comparators, therefore, suffer less wear during usage than the mechanical type.

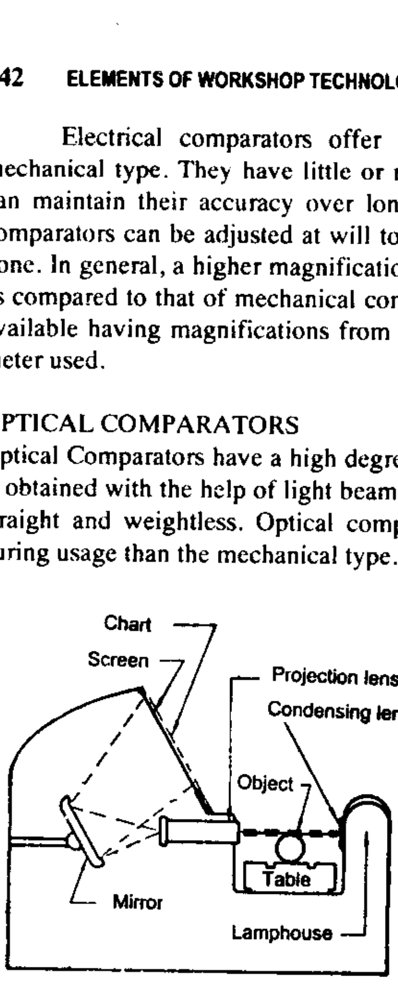


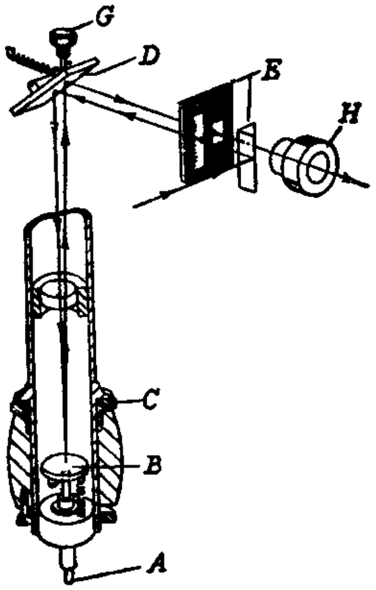
Figure 16.25 Diagram showing the principle of an optical comparator

Optical comparators are used to magnify parts of very small size and of complex configuration that require accurate and enlarged profile. So they are widely employed in the inspection of many small parts such as needles, saw teeth, gear teeth, screw threads, etc. Since they check work to definite tolerances, they can be used to study wear on tools or distortion caused by heat treatment.

In an *optical* or *projection comparator* which is designed on the same principle as the ordinary projection lantern, an object is placed before a light source, and the shadow of the profile is projected at some enlarged scale on a screen where it is compared to a master chart or drawing. This is illustrated in Fig. 16.25. Interchangeable projection lenses which serve to magnify the image give accurate magnifications from 5 to 100 times.

The optical system of a typical optical comparator is illustrated in Fig. 16.26. Light is collected from a suitable source by a circular swivelling mirror placed at the left-hand side near the eyepiece. This light which is directed onto the 90 prism shown between *H* and *E* illuminates the scale incorporated in *E* and its image is reflected downwards by the mirror *D* through the lens onto mirror *B*. This mirror, which is carried on a pivot and rests on the top of the measuring finger *A*, reflects the image of the scale back the way it came. The mirror is so arranged that the return path offset slightly to enable it to be observed through the eye-piece *H*. In the diagram *C* represents a fine adjustment ring for vertical position and *G* a final adjustment for zero setting.

In setting the comparator, the centre zero on the scale is level with the zero mark in the eyepiece. Any variation of the work causes the measuring finger *A* to tilt the mirror *B* and displaces the reflection of the scale from its midposition. The accuracy of measurement of this type of instrument is usually limited to 0.001 mm, and one of such division appears to occupy a space of about 2 mm. The scale movement provided for (+) or (–) variation on each side of the zero is about 0.02 mm.



[Precision Grinding Ltd.]

Figure 16.26 Optical system of a comparator

1. measuring finger, 2. mirror, 3. fine adjusment ring for vertical position, 4. mirror, 5. prism, 6. final adjusment for zero setting, 7. eye-piece

PNEUMATIC COMPARATORS

In recent years, pneumatic comparators have been extensively used specially in automatic size control. They are cheap, independent of the contact pressure, and simple to operate. Besides, this form of comparator is free from mechanical wear. However, pneumatic comparators are sensitive to temperature and humidity changes and their accuracy may be influenced by the surface roughness of the parts being checked. The magnification of this type of comparator is as high as 10,000.

A typical air comparator is illustrated in Fig. 16.27. The operation is based on the fact that if air under constant pressure escapes by passing through two orifices the air pressure in the space between them is dependent on the cross-sectional area of the orifices. If one of them is kept uniform, the pressure will vary according to the size, of the other.

In the diagram, the pipe *1* is connected to an air supply and through restriction jets *2* to tube *11* which dips into water in a deep container open to the atmosphere. Air entering at pipe *1* expands in tube *11* and maintains a constant head of water *H*, excess air escaping as bubbles. Air from *11* passes through control jet *3*, and finally escapes through the measuring jet at *6*. The pressure in the pipe between control jet 3 and measuring jet *6* will depend on the size of the orifice at *6*, i.e. upon the gap 'd' which is controlled by the distance between the measuring face and table, and is reflected by the height of a column of liquid in the manometer tube *8* on the face of the gauge. The scale *9* is so calibrated that a head difference 'h' indicates differences in the gap 'd' magnified several hundred times.

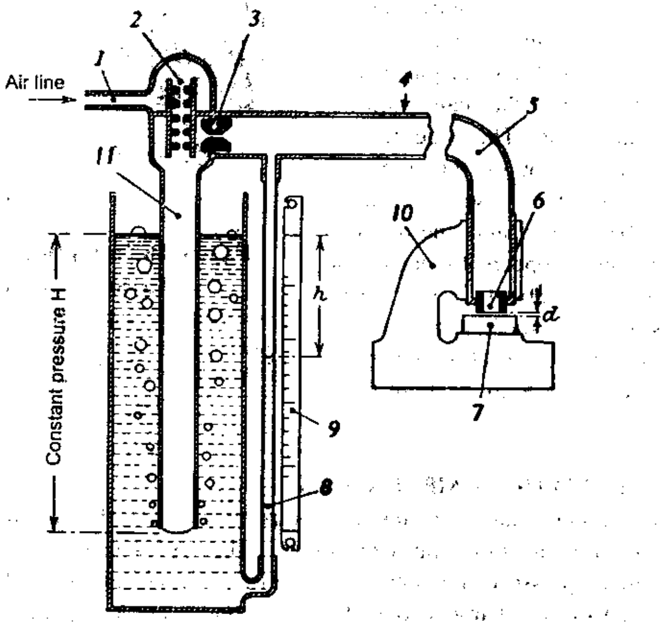


Figure 16.27 Diagram showing the principle of a pneumatic comparator
1. Pipe, 2. Restriction jets, 3. Control jet, 4. Flexible connector, 5. Intermediate chamber, 6. Measuring jet, 7. Part to be measured, 8. Manometer tube, 9. Scale, 10. Stand, 11. Dip tube

16.7 MEASURING MACHINES

Measuring machines are now finding wide applications in industry to attain proficiency in taking measurements of very great accuracy. These are more than comparators. They contain their own standards of measurement in the form of scale or scales, micrometer or other devices. These are used for high degree tool and precision work. The difference in length may be read off directly. The time taken in building up combination of slip gauges is eliminated. It can be vertical or horizontal. The measuring standard is a glass scale which is observed through a microscope.

In machines for metric measurement, the readings are given to 1/1000 of a millimeter (0.001 mm) and the scale carrying the vernier is graduated in millimeters. The measuring wheel of the machine is so designed and arranged that the indicated size can be read in decimals of a millimeter, the digits appearing in their proper rotation of the wheel.

Machines for English measurements are made to give readings to 1/100000 of an inch (0.00001 in). The indicated size can be read in decimals of an inch and it appears in correct rotation of the graduated wheel as described for metric readings.

16.8 ANGULAR MEASUREMENT

Under the heading of angular measurement various angle measuring devices are dealt with. The accuracy of these tools and instruments varies considerably according to particular application from that of the angle gauge or protractor to high precision optical and spirit level instruments.

As in linear measurement where two kinds of standards (e.g. end standard and line standard) are used, so also in angular measurement two types of angle measuring devices are used. They are angle gauges corresponding to slip gauges, and divided scales corresponding to line standards. The difference in the linear and angular measurement is that no absolute standard is required for angular measurement. However the commonly used instruments are described and explained below.

PROTRACTORS

One of the simplest ways of measuring the angle between two faces of a component is to use a protractor. The instrument consists of two arms which can be set along the faces and a circular scale which indicates the angle between them. The body of the instrument is extended to form one of the arms, and this is known as the *stock*. The other arm is in the form of a blade which rotates in a turret mounted on the body. Either the body of the turret carries the divided scale, the other member carrying a vernier or index. The ordinary protractor measures angles only in degrees and used for nonprecision work. Universal bevel protractor, on the other hand, measures angles in degrees and 5 minutes and is used as a standard workshop tool.

BEVEL GAUGE

An instrument known as an adjustable bevel gauge is widely used for checking, comparing or transferring angles and laying out work. This tool, illustrated in Fig. 16.28, consists of two adjustable blades which may be moved into almost any position to give any desired angle. But no direct reading is obtained, and the angle must be set or checked from some other angular measuring device.

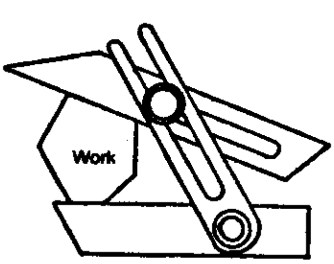


Figure 16.28 Adjustable bevel

ENGINEERS' SQUARE

With either plain or bevel square, it is possible to finish a surface and measure angles to extreme accuracy. The square should be held firmly against the true side and then lowered on to the face which is to be checked, the observation then being made against a good light and viewed along the plane of the surface and not at an angle to it.

COMBINATION SET

This is a very useful instrument frequently used in the fitting and machine shop. It combines in one instrument a *square head*, a *centre head*, and a *bevel protractor* as shown in Fig. 16.29. The three heads are used separately being held in at any desired position by nuts which engage in a slot machined on the whole length of the beam at its back.

The beam of the instrument which acts as a rule is marked either in inches or centimetres or in both for measuring the length and height as and when required. Length of the rule varies from 200 to 6,000 mm.

The square head has one edge square to the rule, giving a right angle (90°), whilst the other edge form a mitre (45°). It is also provided with a spirit level. Both 90°and 45° can be tested by this head in conjunction with the rule.

The centre head with the rule fastened to it is called a *centre square*. It has two arms at right angles to one another and is so set on the rule that this angle is exactly divided in two by the edge of the rule. This may be used to find the centre of a round bar or shaft.

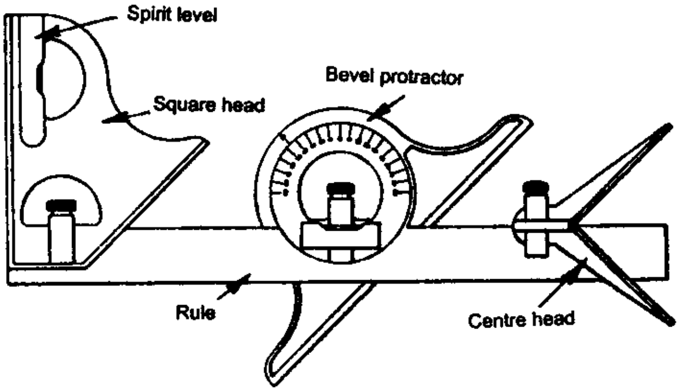


Figure 16.29 A combination set

The protractor head can be used with the rule to measure angles or to measure the slope of a surface. The scale on the protractor may be divided into degrees or a vernier attached, whereby the angle can be measured in degrees and minutes. It is also fitted with a spirit level to help in leveling the work of setting it at an angle.

BEVEL PROTRACTOR

The universal bevel protractor shown in Fig. 16.30 is an instrument used for measuring and testing angles. It is well adapted for all classes of work where angles are to be laid out or measured to within the limits of five minutes. It consists of the following parts :

The bass or stock *A* is integral with a disc *B* which is fitted with a pivot at the centre and carries a datum line *D*. On this pivot the dial *C* is allowed to rotate when the clamping nut *E* is released. A second unit *F* clamps the blade *G* rigidly to the dial *C*. The blade can be moved lengthwise or replaced by one of a different length when *F* is released. A Vernier scale is fitted on the disc to take vernier reading for accurate measurement. To set the instrument it is only necessary to release *E*, turn *B* until the line *D* is opposite the required angle and then tighten E.

Reading. The dial is graduated in degrees over an arc of 180° reading 0° to 90° from each extremity of the arc. The vernier scale is divided up so that 12 of its divisions occupy the same space as 23° on the main scale. Therefore, one division of the vernier is equal to 23/12 = 1 11/12 i.e. 1/12 or 5 min. shorter than two spaces on the true scale. The instrument, therefore, allows settings to 5 minutes of angles to be obtained.

In order to take a reading from the protractor, first read off directly from the true scale the number of whole degrees between 0 and 0 of the vernier scale, then count in the same direction the number of spaces from zero of the vernier scale to a line which coincides with a line on the true scale. Multiply this number by 5, and the product will be the number of minutes to be added to the whole number of degrees.

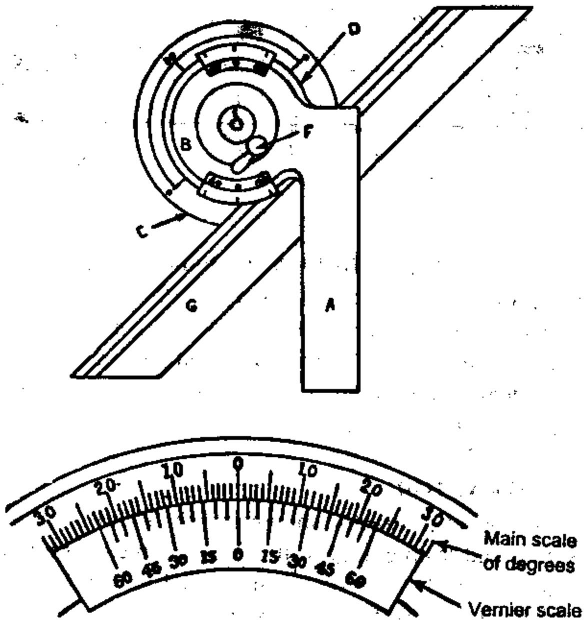


Figure 16.30 Universal bevel protractor

DIVIDING HEAD

Although the index or dividing head, shown in Fig. 16.31, was originally developed for use on milling machine, it is used in inspection work for checking angles about a common centre. The head consists of a worm and worm–gear set having a ratio of 40 to 1. So, one turn of the crank will turn the spindle one–fortieth of a revolution or 9 degrees. By using index plates with the head, a desired angle can be obtained with close accuracy. The operation of this device has been described and explained in the chapter on "Gear Cutting" in Vol. II of this title.

SINE BAR

Measurement of angles using bevel protractor is direct, whereas sine bars make indirect measurements. Sine bars are frequently used in conjunction with slip gauges for setting of angles and of tapers from a horizontal surface, preferably a clean surface plate. The accuracy attainable with this instrument is quite high and the errors in angular measurement are less than 2 seconds for angles unto 45 degree.

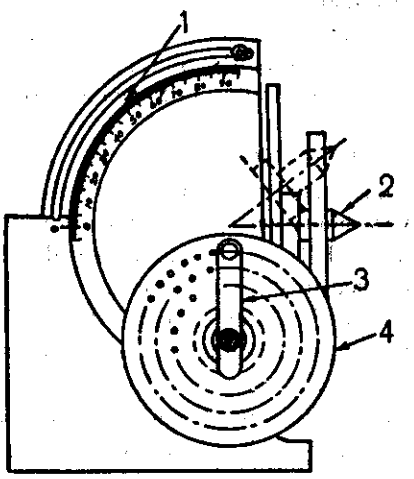


Figure 16.31 Universal dividing head
1. Swivelling block, 2. Live centre,
3. Index crank, 4. Index plate.

The most common type of sine bar consists of an accurately lapped steel bar which is stepped at the ends, with a roller secured in to each step by a screw which holds it in contact with both faces of the step. This is shown in Fig. 16.32. A sine bar is specified by the distance between the centres of two rollers, i.e. 100 mm or 250 mm. A 100 mm bar is very common. For accurate measurements, the following points in its construction are important :

1. The rollers must be of the same diameter.
2. The distance between their centres, i.e. 100 mm or 250 mm must be absolutely correct.

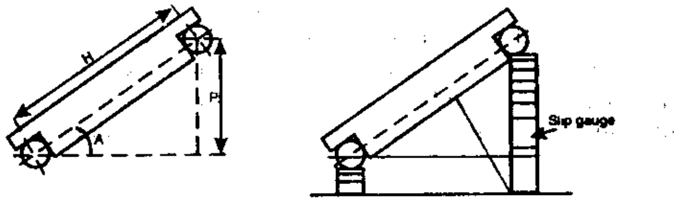


Figure 16.32 The sine bar

3. The centre line of roller centres must be absolutely parallel with bottom and top edges of the bar.

In Fig. 16.32, $\sin A = P/H$ or $H \sin A = P$

If H (the distance between the centre) is 100 mm then the Sine of A multiplied by 100 gives P, i.e. the total height of slip gauges in millimeters. The Sine for any angle can be obtained from trigonometrical tables.

Problem 16.1 : How high must one roller be above the other to check an angle of 10°, using a 100 mm sine bar.

From tables, Sine 10° = 0.1737. Therefore, the difference between the height of rollers (100 mm bar used) = 100×0.1737 = 17.37.

ANGLE GAUGES

Angle gauges are used for measuring and setting out angles in the workshops where precision work in the measurement of angles are required. These are wedge shaped steel blocks and their working faces are finished in the same manner as slip gauges, enabling them to be wrung together in combinations. A full set comprises twelve pieces divided into three series : degrees, minutes and fractions of a minute as follows : 1, 3, 9, 27 and 41 degrees ; 1, 3, 9 and 27 minutes ; 0.1, 0.3 and 0.5 minute. With twelve separate gauges used in conjunction with a precision square, it is possible to set up any angle between 0 and 360° to be built up in steps of 6 seconds by wringing blocks together in additive or subtractive manner. Thus, taking the 1°, 3°, 9 ° blocks.

$$3^\circ + 1^\circ = 4^\circ,\ 9^\circ - (3+1)^\circ = 5^\circ,\ 9^\circ - 1^\circ = 8^\circ \text{ and so on.}$$

There are two sets of gauges available, designated as A and B. The standard B contains all the 12 gauges, while standard A contains one additional gauge of $0.05'$ $(3'')$ which enables combinations to be built up to $3''$.

The block formed by a combination of a number of these gauges is rather bulky, and can not always be conveniently used directly to the work, but it is usually possible to use the gauges as a reference in conjunction with angle measuring device such as a bevel or autocollimator.

SPIRIT LEVELS

Spirit levels enable the position of a surface to be determined with respect to horizontal. They are widely used for the static leveling of machinery and other equipment. A calibrated spirit level can, however, be used for the measurement of small angles only with a wide variety of applications.

The level consists essentially of a glass vial containing spirit and filled except for a bubble. The inside surface of the glass container is convex and is ground to a large radius. The vial is carried in a metallic body with a flat base and is adjusted so that when the base is horizontal the bubble rests at the centre of a scale which is engraved on the glass. When the base of the level is tilted through a small angle, the bubble, in rising to the top point of the vial radius, moves through a certain distance along the scale depending upon the angle of the tilt.

The sensitivity of a level is the angle of tilt that will move the bubble through one division and is expressed as so many seconds per division. Each division is approximately 2.5 mm in length. The most useful sensitivity for general precision work is 10 seconds. The sensitivity of the level depends upon the curvature of the vial, length of the bubble and internal diameter of the vial. More the radius of curvature more sensitive is the spirit level. It will be of interest, therefore, to determine the radius of curvature of the vial.

In Fig. 16.33, when the base is tilted through an angle α with the horizontal, the bubble moves a distance d in the top of the vial from the midposition. If R is the radius of the vial and the computation is carried out in radians, the

α (radian) = d/R

Also, if L is the length of the base of the level and h the difference in height between its ends, then for small values of h,

α (radian) = h/L

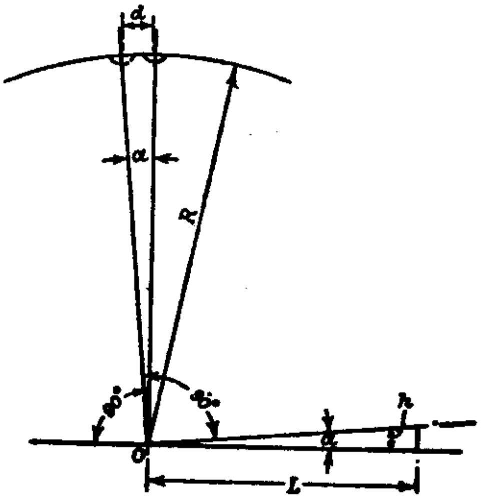


Figure 16.33 Diagram of spirit level

Hence $h/L = d/R$ and $d = R\,\alpha\,h/L$

i.e. the sensitivity of the level increases as R increases.

Ten seconds represent 0.0000485 radians, and the length of the arc for 1 division movement is 2.5 mm. The radians R is therefore given by :

$$R = d/\alpha = 2.5/0.0000485 = 51.5 \text{ m (approx.)}$$

The radians of the vial, for the above sensitivity (i.e. 10 seconds) must be 51.5 m.

CLINOMETERS

This instrument is really a spirit level mounted on a rotating member whose angle of inclination relative to its base can be measured by a circular scale. The scale may cover the whole circle or only part of it. The clinometer is mainly used to determine the included angle of two adjacent faces of a workpiece. The base of the instrument is placed on one face and the rotating body adjusted till zero reading of the bubble is obtained. The angle of rotation is then noted on the circular scale against an index. A second reading is then taken in the similar manner on the second face of the workpiece. The difference between the two readings gives the included angle between the faces.

Clinometers are generally used for checking angular faces, and relief angles on large cutting tools and milling cutter inserts. They can also be used for setting rotating tables on jig boring machines, angular work on grinding machines, and similar works.

Average clinometers read to one or two minutes, while instruments of the precision type may be obtained which read to 0.1 minute.

AUTOCOLLIMATOR

The autocollimator or autocollimating telescope is an optical instrument used for the measurement of small angular differences, changes or deflections. It is also used to determine straightness, flatness, alignment, etc. It incorporates two optical principles the projection and reception of a parallel beam of light by a lens, and the change in direction of a beam reflected from a plane surface with change of angle of the surface.

Imagine, first of all, a converging lens with a point source of light O at its principal focus, as in Fig. 16.34 (a). When a beam of light strikes a flat reflecting surface it is reflected, and if the surface is perpendicular to the ray it is turned back along its original path as in Fig. 16.34 (a). When the surface is tilted at any other angle, the total angle through which the light is deflected is *twice* the angle through which the mirror is tilted, and is brought to a focus in the same plane as the light source but to one side of it, as in Fig. 16.34 (b). Obviously,

$$OO' = 2\theta f = x \text{ (say)},$$ where f is the focal length of the lens.

Thus, by measuring the linear distance OO'(x), the inclination of the reflecting surface θ can be determined.

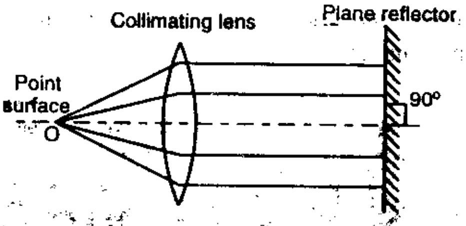


Figure 16.34(a) Principle of auto-collimator
(Reflector is at 90° with the horizontal)

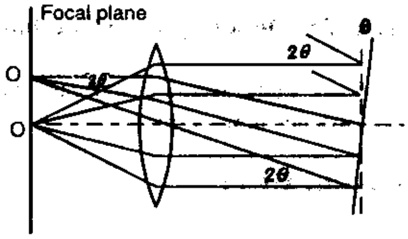
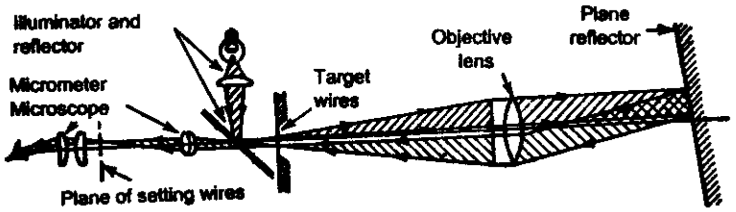


Figure 16.34(b) Principle of auto-collimator
(Reflector is not at 90° with the horizontal)

The position of the final image does not depend upon the distance of the reflector from the lens. That is, the separation x is independent of the position of the reflector from the lens. If, however, the reflector is moved too long, the reflected ray will then completely miss the lens and no image will be formed.

In actual working, the work surface whose inclination is to be obtained forms the reflecting surface and the displacement OO'(x) is measured by a precision microscope which is calibrated directly to the values of inclination (θ).

The optical system of a autocollimator is shown in Fig. 16.35 with the principal parts leveled in the diagram. The target wires are illuminated by the electric bulb and act as a source of light since it is not convenient to visualize the reflected image of a point and then to measure the displacement x precisely. The image of the illuminated wire after being reflected from the surface being measured is formed in the same plane as the wire itself. The eyepiece system containing the micrometer microscope mechanism has a pair of setting lines which may be used to measure the displacement of the image by setting to the original cross lines and then moving over to those of the image. Generally, a calibration is supplied with the instrument, giving the angle of inclination of the reflecting surface per division of the micrometer scale.



Hilger & Watts, Ltd.

Figure 16.35 Optical system of a collimator

Autocollimators are quite accurate and can read upto 0.1 second, and may be used for a distance upto 30 metres.

16.9 TAPER MEASUREMENT

The taper angle is measured by the following measuring instruments :

1. Bevel protractor
2. Tool room microscope
3. Autocollimator
4. Sine bar and dial gauge
5. Rollers, slip gauges and micrometers

Taper micrometer. This measuring instrument makes it possible to check both internal and external tapers ten times faster than with older conventional methods, and does not require sine bars or more elaborate equipment. The instrument has within itself the sine bar principle, and it gives the actual value of the taper of small angles. Larger tapers can be directly obtained from micrometer reading.

16.10 SURFACE MEASUREMENT

It is now well established that all machined surface, irrespective of the machining process, contain minute hills and valleys, the occurrence of which may be periodic or nonperiodic tending to form a kind of pattern or texture. The surface is generally irregular and results due to various causes which are inseparable to each other. Thus, it is seen that different workplaces possess different types of surfaces. It is, therefore, necessary to measure the surface texture quantitatively, and many types of instruments are in use for checking the accuracy of a surface or the condition of a finish.

STRAIGHTEDGE

Straightedges are commonly used for testing the straightness and flatness of plane surfaces. The ordinary shape is rectangular but for accurate work one edge is bevelled or formed into a thin knife edge as shown in Fig. 16.36. The narrow edge is the working surface, while the wide edge adds to the rigidity of the tool and serves as its base when not in use. Placing the straight-edge on its edge protects the working surface from damage and from getting dirty.

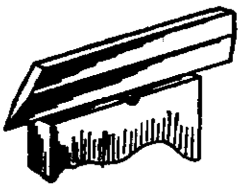


Figure 16.36 Straightedge

Flatness is checked by a light test. The narrow edge of the tool is applied to the surface to be tested and kept horizontally at eye level, watching for light between the straightedge and the surface along the straightedge. Light seen at one place or another indicates deviation from straightness. This method proves very accurate and within 3 to 5 microns.

SURFACE PLATE AND SURFACE GAUGE

The *surface plate* is as essential for position accuracy as the length standard is for linear accuracy. It establishes the reference plane from which all precision measurement starts, is transferred, or is interpolated. Used in conjunction with other gauges, the plate becomes a functional gauge in itself. A surface plate has been described under the Chapter "Bench Work and Fitting".

The *surface gauge* or as it is sometimes called, the *scribing block*, as shown in Fig. 16.37, is very largely used in the laying lout of parts that have to be fitted or machined. It is often used in conjunction with a surface plate to scribe lines at a given vertical height from the face of the work or test the parallelism of the work. When used with the scriber, it is a line measuring or locating instrument. If the scriber, is replaced by a dial indicator, it then becomes a precision instrument for checking surface. The tool has a V-shaped groove at the bottom of the base for resting the block on a round bar, so that dimensions may be set off from the bar to some other part of the work.

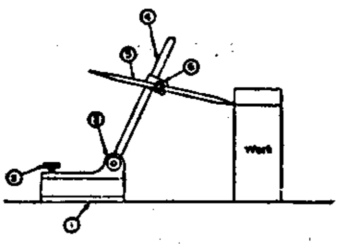


Figure 16.37 The surface gauge
1. Base, 2. Pin, 3. Clamping nut,
4. Spindle, 5. Scriber, 6. Scriber clamp

OPTICAL FLAT

Optical flats are used for testing the flatness of workpieces, gauge blocks, micrometer anvils, etc. Such measurements are based on *interferometry* ; the science of measuring with light waves.

The optical flat is made from natural quartz and consists of a flat piece, circular in section and manufactured in a variety of diameters and thicknesses. A typical size is 50 mm in diameter and 15.875 mm thick. The faces of an optical flat are accurately polished to nearly true planes. Some manufactured optical flats are true on one side only.

In use the flat is placed upon the object to be tested and a light having a single color (monochromatic light) is thrown upon it. Helium is most commonly used in industry as a source of monochromatic or single wave-length light because of its convenience.

The principle of light wave interference and the operation of the optical flat are illustrated in Fig. 16.38 wherein an optical flat is shown resting at a slight angle on a workpiece surface. The ray of light penetrates the flat, and as it reaches the bottom surface it is divided into two rays. One ray is reflected back to the eye from the bottom surface of the flat, while the other is reflected back from the top surface of the object being tested. If the rays are *in phase* when they reform, their energies reinforce each other, and they appear *bright*. If they are *out of phase*, their energies cancel and they are *dark*. The rays have the same wave-length, but the second ray will lag behind the first ray by an amount equal to twice the space between the flat and the work. If this space is equal to half a wave-length, the second ray will be in step with the first one when it join it again in air. If it is a full wave-length, the second will also join the first one. But, if the distance is equal to one-fourth or three fourths of a wave-length, the second ray will be a half wave-length out of step with the first one and will neutralize it when they join and create a dark band.

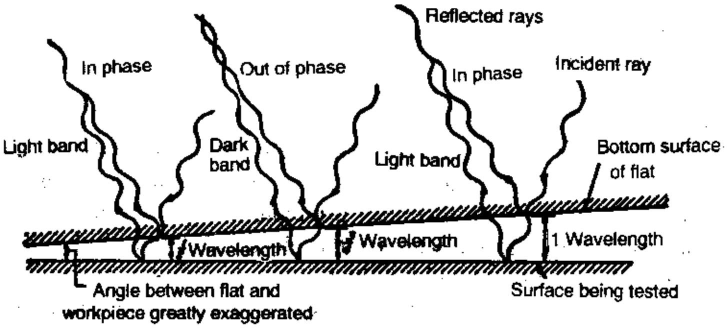


Figure 16.38 Diagram showing the principle of an optical flat

Since each dark band indicates a change of one-half wave length in distance separating the work surface and flat, measurements are made very simply by counting the number of these bands or interference lines and multiplying that number by one half wave-length of the light source. This procedure may be illustrated by the use of Fig. 16.39, which shows an optical flat, being used in connection with a gauge block of known size to check the height of a steel ball. The gauge block is placed on to a toolmakers' flat and the optical flat is placed on top with the ball in position. If the parts are not of the same size, the optical flat will be tilted slightly, and parallel interference lines will appear on the top

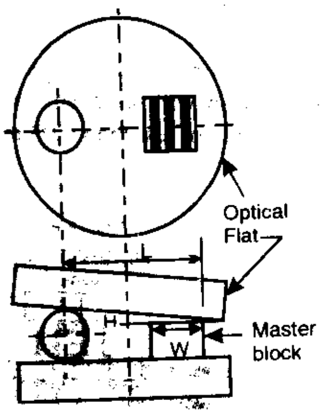


Figure 16.39 Method of measuring a ball using an optical flat and gauge block

surface of the gauge block. The difference in height can be determined from the number of bands that appear and may be calculated by the following formula :

H = 1/2 – wave-length × N × (L/W)

where,
N = number of bands appearing on width of the block.
L = distance between contact points.
W = width of the precision block.

PROFILOMETER

The Profilometer is an instrument used to determine directly the height of surface micro-irregularities, i.e., surface roughness. This direct measurement is based on a contact principle and the surface irregularities are determined by the readings on the electrical meter of the instrument using a tracer point moved across the inspected surface.

In Fig. 16.40, a sharp diamond stylus or pointer in a head is moved at a constant rate across the surface being measured. As the stylus is moved over the surface it rises and falls at a rate depending upon the surface roughness. These movements of the stylus set up electrical impulses that are amplified and energize a meter which is graduated in microns. In English measurement, the meter gives directly the root-mean-square (rms.) average in microinches of the surface irregularities. One microinch equals 1/40 micron.

Profilometers are employed in shops and laboratories for evaluating surface finish with an *Hrms* of the micro-irregularities not more than 12 microns and not less than 0.03 micron.

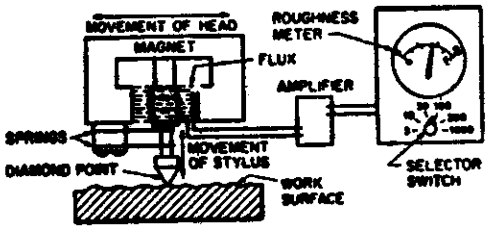


Figure 16.40 Profilometer to measure surface roughness

Profilograph. The other type of instruments for evaluating surface finish by the tracer method is the profilograph. This is illustrated in Fig. 16.41.

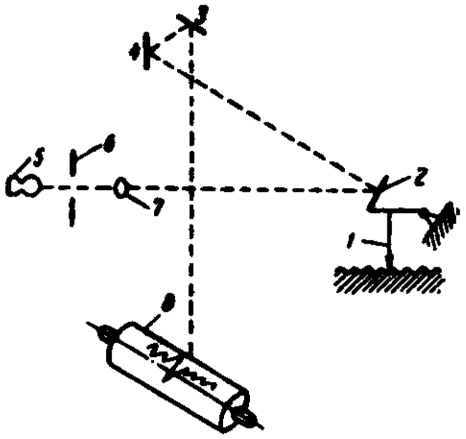


Figure 16.41 Optical diagram of the profilograph
1. Stylus, 2, 3 & 4. Mirrors, 5. Lamp, 6. Split, 7. Lens,
8. Revolving drum with light-sensitisd paper

The diamond stylus *1*, pivoted together with the mirror *2*, passes over the inspected surface. A beam of light from lamp *5*, passing through the precision slit *6* and lens *7*, falls on the mirror. Upon oscillations of stylus *1* in passing over the tested surface, the direction of the light beam, reflected from the mirror *2*, is changed. This beam is directed through a system of mirrors *3* and *4* to the revolving drum *8* with light-sensitized paper. A record of the light beam, reflected by the mirrors, remains on the paper. After developing, the paper will show a graph of the microprofile of the inspected surface magnified from 400 to 2,000 times in the vertical direction and from 10 to 50 times in the horizontal direction.

16.10 USE OF LASER

The laser (*L*ight *A*mplification by *S*timulated *E*mission of *R*adiation) is finding an expanding use in precise measurement to-day. It is simple to operate, requires no contact and is accurate, even over distances of 30,000 mm or more.

A laser-beam interferometer combination can be mounted conveniently on the machine frame, and one portion of the beam is aimed at the specially shaped target prism mounted on the machine carriage. The laser interferometer is connected to a computerized control and read-out console which will visibly display the measured dimension to 0.00008, 0.00025, or 0.0025 mm least count.

In use as a measuring instrument, the movement of the reflector target causes interference bands to move across a reference point in the interferometer. A count of the number of bands provides a measure of the target movement.

16.11 GAUGES

Gauges are tools which are used for checking the size, shape and relative positions of various parts but not provided with graduated adjustable members. Gauges are, therefore, understood to be single-size fixed-type measuring tools.

A clear distinction between measuring instruments and gauges is not always observed. Some tools that are called gauges are used largely for measuring or layout work. Even some that are used principally for gauging give definite measurement.

Classification of gauges. Gauges are classified as standard and limit.

Standard gauges are made to the nominal size of the part to be tested and have the measuring member equal in size to the mean permissible dimension of the part to be checked. A standard gauge should mate with the part with some snugness.

Limit gauges or "go" and "no go" *gauges* are made to the limit sizes of the work to be measured. One of the sides or ends of the gauge is made to correspond to the maximum and the other to the minimum permissible size. The function of limit gauges is to determine whether the actual dimensions of the work are within or outside the specified limits. A limit gauge may be either *double end* or *progressive*. A double end gauge has the "go" member at one end and the "no go" member at the other end. The "go" member must pass into or over an acceptable piece but the "no go" member should not. The progressive gauge has "no go" members next to each other and is applied to a workpiece with one movement. Some gauges are fixed for only one set of limits and are said to be *solid gauges*. Others are *adjustable* for various ranges.

To promote consistency in manufacturing and inspection, gauges may be classified as working, inspection, and reference or master gauges.

Working gauges are those used at the bench or machine in gauging the work as it is being made. *Inspection gauges* are used by the inspection personnel to inspect manufactured parts when finished. *Reference* or *master gauges* are used only for checking the size or condition of other gauges, and represent as exactly as possible the physical dimensions of the product.

Depending on the elements to be checked, gauges are also classified into :

1. gauges for checking holes ;
2. gauges for checking shafts ;
3. gauges for checking tapers ;
4. gauges for checking threads ;
5. gauges for checking forms.

The following gauges represent those most commonly used in production work. The classification is principally according to the shape or purpose for which each is used.

1. Plug
2. Ring
3. Snap
4. Thread
5. Form
    (a) Template (b) Screw pitch
    (c) Radius and fillet
6. Thickness
    (a) Precision gauges blocks
    (b) Feeler
    (c) Plate
    (d) Wire, etc.
7. Indicating
8. Air-operated

Gauge materials. High carbon and alloy steels have been the principal materials used for many years. Objections to steel gauges are that they are subjected to some distortion because of the heat-treating operation and that their surface hardness is limited. These objections are largely overcome by the use of chrome plating or cemented carbides as the surface material. Some gauges are made entirely of cemented carbides or they have cemented carbide inserts at certain wear points.

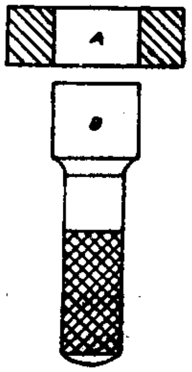


Figure 16.42 Standard ring and plug gauge
1. Ring gauge, 2. Plug gauge

PLUG GAUGES

Plug gauges are used for checking holes of many different shapes and sizes. There are plug gauges for straight cylindrical holes, tapered, threaded square and splined holes.

Fig. 16.42 shows a *standard plug gauge* used to test the nominal size of a cylindrical hole.

Fig. 16.43 shows a *double ended limit plug gauge* used to test the limits of size. At one end it has a plug of minimum limit size, the "go" end and ; at the other end a plug of maximum limit, the "no go" end. These ends are detachable from the handle so that they may be renewed separately when worn. In a *progressive limit plug gauge* (Fig. 16.43) the "go" and "no go" sections of the gauge are on the same end of the handle.

Larger holes are gauged with *annular plug gauges*, which are shell-constructed for light weight, and *flat plug gauges*, made in the form of diametrical sections of cylinders.

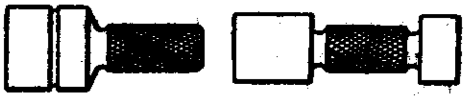


Figure 16.43 Progressive and double-ended limit plug gauges

RING GAUGES

Ring gauges are used to test external diameters. They allow shafts to be checked more accurately since they embrace the whole of their surface. Ring gauges, however, are expensive to manufacture and therefore find limited use. Moreover, ring gauges are not suitable for measuring journals in the middle sections of shafts.

A common type standard ring gauge is shown in Fig. 16.42. In a limit ring gauge, the "go" and "no go" ends are identified by an annular groove on the periphery. Above about 35 mm all gauges are flanged to reduce weight and facilitate handling.

TAPER GAUGES

The most satisfactory method of testing a taper is to use taper gauges. They are also used to gauge the diameter of taper at some point. Taper gauges are made in both the plug and ring styles and, in general, follow the same standard construction as plug and ring gauges. A taper plug and ring gauge is shown in Fig. 16.44.

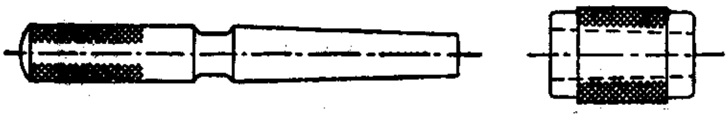


Figure 16.44 Taper plug and ring gauge

When checking a taper hole, the taper plug gauge is inserted into the hole and a slight pressure is exerted against it. If it does not rock in the hole, it indicates that the taper angle is correct. The same procedure is followed in a ring gauge for testing tapered spindle.

The taper diameter is tested for size by noting how far the gauge enters the tapered hole or the tapered spindle enters the gauge. A mark on the gauge shows the correct diameter for the large end of the taper.

To test the correctness of the taper, two or three chalk or pencil lines are drawn on the gauge about equidistant along the length or in the hole along a generatrix of the cone. Then the gauge is inserted into the hole and slightly turned. If the lines do not rub off evenly, the taper is incorrect and the setting in the machine must be adjusted until the lines are rubbed equally all along its length. Instead of making lines on the gauge, a thin coat of paint (red lead, carbon black, prussian blue, etc.) can be applied.

The accuracy of a taper hole is tested by a *taper limit gauge* illustrated in Fig. 16.45. This has two check lines "go" and "no go" each at a certain distance from the end face. The "go" portion corresponds to the minimum and the "no go" to the maximum dimension.

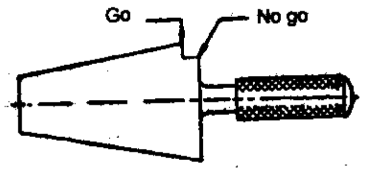
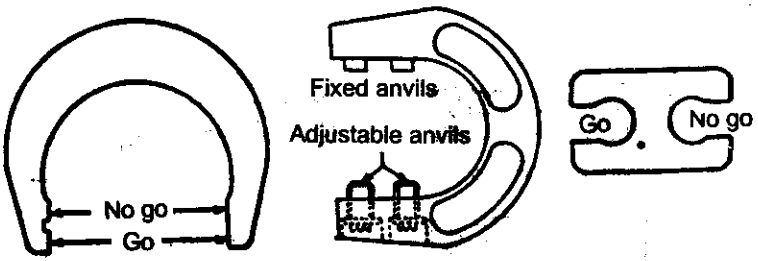


Figure 16.45 Limit taper plug gauge

SNAP GAUGES

Snap gauges are used for checking external dimensions. Shafts are mainly checked by snap gauges. They may be solid and progressive or adjustable or double ended. The most usual types illustrated in Fig. 16.46, are as follows :



Caliper gauge
Adjustable gauge
Double ended solid gauge

Figure 16.46 Snap gauges

1. *Solid* or *non-adjustable caliper* or *snap gauge* with "go" and "no go" ends is used for large sizes.
2. *Adjustable caliper* or *snap gauge* is used for larger sizes.

This is made with two fixed anvils and two adjustable anvils, one for the "go" and the other for the "no go". The housing of these gauges has two recesses to receive the measuring anvils secured with two screws. The anvils are set for a specified size within an available range of adjustment of 3 to 8 mm. The adjustable gauges can be used for measuring series of shafts of different sizes provided the diameters are within the available range of the gauge.

3. *Double ended solid snap gauge* with "go" and "no go" ends is used for smaller sizes.

THREAD GAUGES

Threads (pitch diameter of thread) are checked with *threads gauges*. For checking internal threads (nuts, bushes, etc.) *plug thread gauges* are used, while for checking external threads (screws, bolts) *ring thread gauges* or *snap gauges* are used. Single-piece thread gauges serve for measuring small diameters. For large diameters the gauges are made with removable plugs machined with a tang. *Standard gauges* are made single-piece. Common types of thread gauges are illustrated in Fig. 16.47.

Standard plug gauges may be made of various kinds : (i) plug gauge with only threaded portion ; (ii) threaded portion on one end and plain cylindrical plug on the opposite end to give correct "core" diameter ; (iii) thread gauge with core and full diameters.

Limit plug gauges have a long-thread section on the "go" end and a short-thread section on the "no go" end to correspond to the minimum and maximum limits respectively.

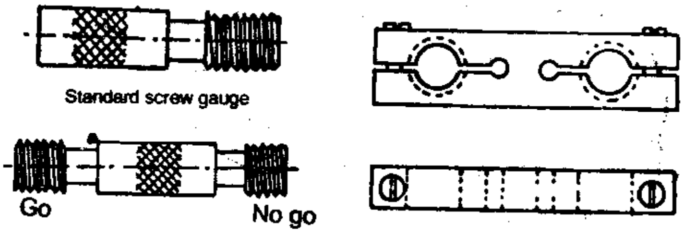


Figure 16.47 Thread gauge

Roller ring gauges similarly have "go" and "no go" ends. They may also be solid and adjustable.

Roller snap gauges are often used in production practice for measuring external threads. They comprise a body, two paired "go" rollers and two paired "no go" rollers.

Taper thread gauges are used for checking taper threads. The ring thread gauges (taper) are made in two varieties– rigid (non-adjustable) and adjustable. The "go" non-adjustable ring gauges are full threaded while the "no go" have truncated thread profile.

FORM GAUGES

Form gauges may be used to check the contour of a profile of a workpiece for conformance to certain shape or form specifications.

Template gauge. Form gauges made from sheet steel are called profile or template gauge. A profile gauges may contain two outlines that represent the limits within which a profile must lie as shown in Fig. 16.48.

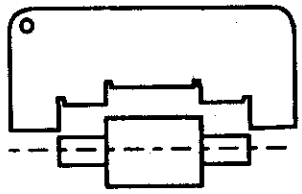


Figure 16.48 A profile gauge

SCREW PITCH GAUGES

Screw pitch gauges serve as an everyday tool used in picking out a required screw and for checking the pitch of screw threads. They consist of a number of flat blades which are cut out to a given pitch and pivoted in a holder as given in Fig. 16.49. Each blade is stamped with the pitch or number of threads per inch and the holder bears an identifying number designating the thread it is intended for. The sets are made for metric threads with an angle of 60°, for English threads with an angle of 55°.

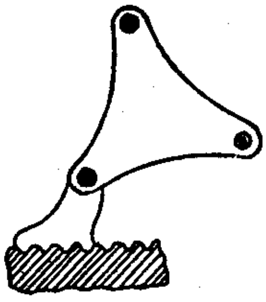


Figure 16.49 Screw pitch gauge

A set for measuring metric threads with 20 blades has pitches form 0.4 to 6 mm and for English threads with 16 blades has 4 to 28 threads per inch.

In checking a thread for its pitch the closest corresponding gauge blade is selected and applied upon the thread to be tested. Several blades may have to be tried until the correct is found.

RADIUS AND FILLET GAUGES

The function of these gauges is to check the radii of curvature of convex and concave surfaces over a range from 1 to 25 mm. The gauges are made in sets of thin plates curved to different radii at the ends as shown in Fig. 16.50. Each set consists of 16 convex and 16 concave blades.

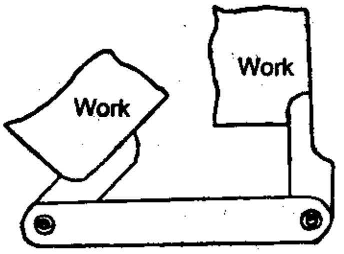


Figure 16.50 Radius and fillet gauge

FEELER GAUGES

Feeler gauges are used for checking clearances between mating surfaces. They are made in the form of a set of steel, precision machined blade 0.03 to 1.0 mm thick and 100 mm long. The blades are pivoted in a holder as shown in Fig. 16.51. Each blade has an indication of its thickness.

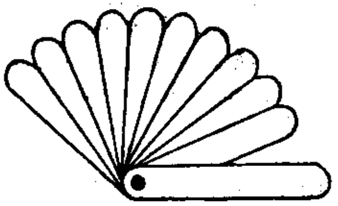


Figure 16.51 Feeler gauge

The Indian standard establishes seven sets of feeler gauges : Nos. 1,2,3,4,5,6,7, which differ by the number of blades in them and by the range of thickness. Thin blades differ in thickness by 0.01 mm in the 0.03 to 1 mm set, and by 0.05 mm in the 0.1 to 1.0 mm set.

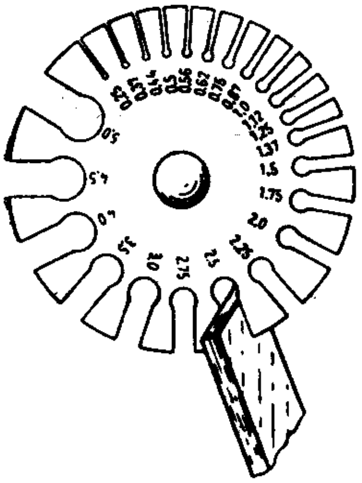


Figure 16.52 A plate gauge

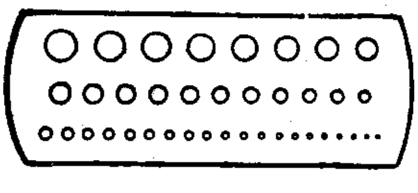


Figure 16.53 A wire gauge

To find the size of the clearance, one or two blades are inserted and tried for a fit between the contacting surfaces until blades of suitable thickness are found.

PLATE GAUGE AND WIRE GAUGE

The thickness of sheet metal is checked by means of plate gauges, and wire diameters by means of wire gauges. The plate gauge shown in Fig. 16.52 is used to check the thickness of plates from 0.25 to 5.0 mm, and the wire gauge in Fig. 16.33 from 0.1 to 10 mm.

INDICATING GAUGES

Indicating gauges employ a means to magnify how much a dimension deviates, plus or minus, from a given standard to which the gauge has been set. They are intended for measuring errors in geometrical form and size, and for testing surfaces for their true position with respect to one another. Besides this, indicating gauges can be adapted for checking the run out of toothed wheels, pulleys, spindles and various other revolving parts of machines.

Indicating gauges can be of a dial or lever type, the former being the most widely used.

AIR GAUGES

Pneumatic or air gauges are used primarily to determine the inside characteristics of a hole by means of compressed air. There are two types of air gauges according to operation : a flow-type and a pressure-type gauge. The flow-type operates on the principle of varying air velocities at constant pressure, and the pressure type operates on the principle of air escaping through an orifice.

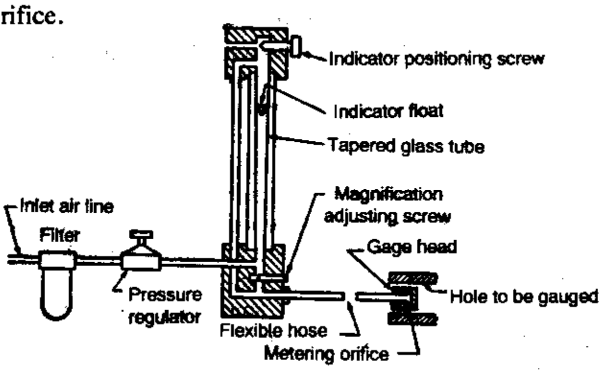


Figure 16.54 A flow-type air gauge

Fig. 16.54 illustrates the principle of flow-type gauge which is more widely used at present. Compressed air cleaned and dried through a filter passes through a vertical tapered glass tube containing an indicator float at constant pressure. The air then passes out through a flexible hose into a gauging head where it escapes through one or more orifices. The amount of the flow is controlled by the size of the space between the gauging head and the work and different rates of flow of air in the glass tube cause the indicator float to assume different vertical positions. This is registered in a dial which is calibrated in fractions of a millimeter.

REVIEW QUESTIONS

1. What do you understand by 'line standards' and 'end standards' ? How are 'end standards' derived from 'line standards'? Give examples of these two types of standards.
2. What are measuring, precision measuring, and gauging ?
3. Describe the following : (1) spring caliper ; (2) hermaphrodite caliper ; (3) transfer caliper ; (4) telescopic gauge, giving their uses.
4. Sketch and describe the working principles and uses of the following : (1) outside micrometer, (2) inside micrometer, and (3) depth micrometer. What is the limitation of a micrometer ?
5. Explain the theory of a vernier scale. What is the principal advantage of a vernier caliper.
6. What is meant by measurement by comparison. Outline briefly the principles of working of : (1) a mechanical, (2) an optical and (3) a pneumatic, comparator ; and discuss briefly their relative merits.
7. Describe the use of : (1) slip gauges, and (2) angle gauges, for measuring and comparing lengths and angles.
8. Write notes on: (1) combination set, (2) dividing head, (3) bevel gauge, (4) bevel protractor and (5) sine bar.
9. Explain how a spirit level can be used for angular measurement.
10. Write brief explanatory notes on 'autocollimator'.
11. Sketch and explain the optical path of a 'profile projector' and discuss the uses of such projectors.
12. Describe the principle and application of interferometry.
13. How would you measure the surface roughness of fine finished surfaces ? State and explain the working of an optical flat.
14. Discuss how would you proceed to check; (1) flatness, (2) squares, (3) roundness, and (4) concentricity.
15. What do you understand by limit gauging? Distinguish between workshop and inspection gauges.
16. Describe the use of limit gauges with suitable sketches.
17. Describe the ways air gauges operate. What are their advantages ?

17

SURFACE COATING OF METALS

17.1 INTRODUCTION

A metal form may have been produced by machining, casting, forging, and other methods. These processes produce different surfaces, and one (or more) subsequent operation is generally required to produce a desired surface. This is what is called 'surface coating of metals'. Coatings are used on most metal products today, either for protective or for both protective and decorative purposes. In general, coatings or finishes are used for the purpose of decoration, surface protection, corrosion resistance, and the providing of a hard surface. The covering should be uniform and free from runs, checks or peelings. In some instances, coatings are applied prior to completion of fabrication. Most often, however, coatings are applied to finished components to form the final product.

The key to successful finishes is a clean surface to assure good adhesion. There is a considerable difference in cost of finishing materials and processes for applying the various finish types as there are competitive means of cleaning, competitive means of drying, and competitive means of applying the coating. However, the various processes involved in preparing work for coating and applying the coatings are closely interrelated and they are briefly described in this chapter.

CLEANING OF METALS

Cleaning operations are performed both preparatory to finishing operations and after finishing operations. They are primarily used to remove dirt, oil, oxides, scale, and other harmful ingredients that ultimately affect the life of the product. The unwanted surface contaminants that generally exist may broadly be classified into six groups :

1. Pigmented drawing compounds.
2. Unpigmented oil and grease.

3. Chips and cutting fluids.
4. Rust and scale.
5. Polishing and buffing compounds.
6. Miscellaneous surface contaminants

Selection of cleaning process is mainly influenced by :

1. Type of contaminants.
2. Degree of cleanliness required.
3. Composition of metal.
4. Condition of metal.
5. Thickness of rust and scale.
6. Allowable metal loss.
7. Surface finish tolerances.
8. Shape and size of workpieces.
9. Production requirement.
10. Available equipment.
11. Cost involved.

Depending on them, cleaning processes may be classified as :

1. Chemical cleaning.
2. Mechanical cleaning.

17.2 CHEMICAL CLEANING

Chemical cleaning, such as (1) alkaline pickling, (2) acid pickling, (3) emulsified solvent cleaning. (4) electrolytic cleaning, (5) vapour degreasing and (6) ultrasonic cleaning, are generally used to ensure clean parts and surfaces before the finish is applied. They may be used individually or in combination, depending upon the material to be cleaned and the effects desired.

ALKALINE CLEANING

The most common type of cleaning is with alkali. It is efficient and economical in removing oil and grease by saponification or emulsification or both. Mineral, lard and unpigmented drawing compounds are easily removed by alkaline cleaners. Silicones, parafin, and sulphurised, oxidized or carbonized, oils are difficult, but can be removed by alkaline cleaners.

In this process, a bath is prepared from cleaning agents, such as caustic soda or sodium metasilicate. These materials are added to some type of soap to aid in emulsification. The mixture produces an alkali which serves as the cleaning agents. This process is used on all metals except zinc, lead, tin, brass, and aluminium. On assemblies comprised of dissimilar metals, the presence of alkaline solution in crevices may result in galvanic corrosion, and even a trace of alkali will contaminate paint and phosphate coating. Parts are therefore thoroughly rinsed after cleaning.

ACID PICKLING

The most common method of removing unwanted pigmented compounds which are mostly oxides of metal is by acid pickling. Either diluted sulphuric, hydrochloric or phosphoric acid is sprayed on the part, or the part ; is dipped into a tank, agitated, and then washed and rinsed thoroughly. Muriatic acid can also be used either hot or cold as a pickling solution. Alkaline cleaning of the part should be used first to remove all dirts and oils in order to obtain an even removal of the oxides during the pickling process. Sometimes it is necessary to add pickling inhibitors such as detergents, liquid glycol, ether, etc. to decrease the action of acid upon the metal particularly aluminium and other non-ferrous metals.

Acid pickling is also used in the removal of oil and grease. In some applications, acid pickling is used to remove light rust. Acid cleaners, on the other hand, are chemically limited in their ability to remove polishing and buffing compound. Soaps and other acid-hydrolyzable materials present in these compounds are decomposed by acid cleaners into insoluble materials. This prevents the use of acid picking in most instances.

Acid cleaning of steel parts creates hydrogen, which is absorbed by the steel and causes "hydrogen embrittlement". The hydrogen in the steel, of course, can be reduced by heating the parts after pickling. Since splash and vapours from the acid solution corrode equipment and tanks, the maintenance cost is high and working conditions are disagreeable.

EMULSIFIED SOLVENT CLEANING

Solvent cleaning is used on such metals as zinc, lead, and aluminium since their surfaces might be attacked by alkaline cleaners. This is primarily designed to remove oil and grease.

In this process, an organic solvent is mixed with a hydrocarbon-soluble emulsifying agent. The agent may be a soap and kerosene mixture with a small amount of water or mixture of sulfonated castor oil and water. Cleaning is performed by dipping the part in the solutions and then rinsing. Workpieces with heavy deposits of oil and grease are soaked in this solution or the solution is swabbed into heavily contaminated areas. They are then rinsed in hot water, preferably by means of pressure spray permitting them to be flushed away. Parts to be electroplated should afterwards be treated with alkaline cleaner to remove any organic material.

ELECTROLYTIC CLEANING

This is effective as a final cleaning process for removing oil and grease from machined surfaces when extreme cleanliness is required. It is almost always used for final cleaning of steel parts prior to electro-plating.

In electrolytic cleaning, an alkaline cleaning solution is used with electric current passing through the bath in which the part to be cleaned is one electrode. This causes the emission of oxygen at the positive pole and hydrogen at the negative pole. The material from which the part is made and the cleaning action desired determine whether the part should be made the anode or cathode. Parts from soft metals, such as lead, zinc, and tin must necessarily be cleaned cathodically because they would be badly etched if cleaned anodically. Steel may be cleaned either anodically or cathodically. Anodic cleaning of steel is receiving favour because of absence of embrittlement and smut deposition. At the cathode, a greater amount of gas is liberated than at the anode, and the hydrogen has some reducing action on oxides present. The electrolytic action, however, breaks up the oil film adhering to the metal surface and results in chemically clean surface suitable for plating.

Chlorides should be carefully avoided and the soap content should be low or excessive foaming with danger of an explosion may result.

VAPOUR DEGREASING

Vapour degreasing is an effective and widely used method of removing a wide variety of oils and greases. It develops a high degree of cleanliness. Vapour degreasing has proved especially effective for removing soluble material from crevices, such as rolled or welded seams, where other cleaners may be permanently entrapped. Vapour degreasing is particularly well adapted to cleaning oil impregnated parts, such as bearings and for removing solvent, soluble oils from the interior of storage tanks.

In this process, a solution known as trichloroethylene is heated to its boiling point. A vapour is produced, and the parts to be cleaned are suspended in this vapour. The condensation of the vapour on the work removes all the grease and oil.

Vapour degreasing has found particular value for cleaning of metal previous to lacquering, japanning, enamelling, and general organic finishing, but must be followed in cleaning previous to plating by an alkaline cleaner to remove traces of organic matter that may remain on the surface after degreasing.

ULTRASONIC CLEANING

When ultrasonic vibrations of sufficient power level are transmitted in a liquid, cavitation takes place. This action in liquids has two effects : *bulk*, which refers to those effects within the liquid and *surface*, which occurs between the liquid and the solid. Many organic compounds are broken down by cavitation. Thus the dirt and grease clinging to solid articles in an ultrasonic cleaning tank are ripped apart and emulsified.

Frequencies of approximately 30,000 Hz are characteristic of ultrasonic cleaning. Typical fluids used are water to which has been added a detergent or solvent such as cyclohexane and trichloroethylene.

Ultrasonic cleaning is, however, more expensive than other methods because of initial cost of equipment, and higher maintenance cost. Consequently, the use of this process is largely restricted to applications in which other methods have proved inadequate or unsuitable.

Typical areas of application in which ultrasonic methods have proved advantageous are as follows :

1. Removal of tightly adhering or embeded particles from solid surfaces.
2. Removal of fine particles from powder metallurgy parts.
3. Cleaning of small precision parts, such as those for cameras, watches, or microscope components.
4. Cleaning of parts made of precious metals.
5. Cleaning of parts with complex configurations.

A typical ultrasonic cleaning facility is composed of a generator for producing a electric energy, a transducer for converting the electric inpulses into high-frequency sound waves, and a tank for holding the cleaning fluid into which the transducer transmits its sound energy.

17.3 MECHANICAL CLEANING

Mechanical cleaning is performed by mechanical means with and without the use of any chemical cleaner primarily for the purpose of removing all classes of rust and scale from mill products, forgings, castings, weldments and heat treated parts. Scale is usually produced on a part when the metal is heated to elevated temperatures. Mechanical cleaning may also be used for decorative purposes as in polishing. The method includes :

1. abrasive blast cleaning.
2. tumbling.

3. barrel rolling.
4. power brushing. and
5. mechanical polishing and buffing.

ABRASIVE BLAST CLEANING

This method is widely used for removing all classes of scale and rust from forgings, castings, weldments, and heat treated parts. Depending on the finish requirements, blasting may be the sole means of scale removel or it may be used to remove the major portion of scale, with pickling employed to remove the remainder.

In this process the parts are generally cleaned by the use of abrasive particles such as sand, steel grit, or shot, impelled against the surfaces to be cleaned.

Some cleaning is performed by means of a high-velocity air blast, with the blast directed by hand. In many cases, an air less blast machine that cleans by impact is also used. The abrasive is fed from an overhead storage hopper to the centre of a radially rotating wheel, whereupon the metallic shot or grit is hurled in a controlled stream upon the work to be cleaned. All traces of sand, scale, oxides, and other material are removed right down to the virgin metal, providing an excellent surface for bonding final finishes.

The airless blast machine is used for cleaning engine blocks, crankshafts, castings of different shape and size, railroad cars, car wheels, oil and gas pipes, steel strip, and many other purposes.

TUMBLING

Tumbling, often, is the least expensive process for removing rust and scale from metal parts. Parts configuration and size are the primary limitations of the process. Tumbling in dry abrasives (deburring compounds) is effective for removing rust and scale from small parts of simple shape. However, parts of complex shape, with deep recess and other irregularities, cannot be descaled uniformly by tumbling. It may require several hours of tumbling, if the method is used. The addition of descaling compounds instead of deburring compounds will often decrease the tumbling time by 75 per cent.

The operation is accomplished by placing workpieces in a drum or barrel, together with stars, jacks, slugs, or abrasive materials. The abrasive materials can be sand, granite chips, slag, or aluminium oxide pellets. In operation, the barrel is rotated, and the movement of the workpieces and the accompanying slugs or abrasive material against each other produces by friction a fine cutting action which remove the fins, flashes, and scale from the products.

BARREL ROLLING

Barrel rolling and tumbling are quite similar operations, except that the barrel is loaded only to 40 to 60 per cent capacity, while in tumbling a drum is generally packed nearly full.

Abrasives, such as cinders, slag, granite chips, sharp sand, alundum, or carborundum are placed in the barrel with the work pieces, along with water or a dilute acid solution. Sometimes, mineral matter or scrap punchings are added to the wet rolling. Hard wood dust or leather scraps are used in dry rolling to keep the work pieces separated. As the barrel turns, the mass rolls over and falls to the bottom of the barrel. This motion cuts down the surface of the parts.

POWER BRUSHING

Brushing is the least used of descaling parts, although it is satisfactory for removing light rust or loosely adhering scale. It is better suited for work pieces formed from tubing than for castings and forgings. Power brushing methods are finding additional use as production tools for metal finishing operations. A major advantage of the power brush is that it can be used in manual, semiautomatic, or integrated methods.

Various types of brushes are used for removing unwanted materials. These include wire, fiber cord, etc. Wire wheel brushes are best for general purpose jobs and such metals as steel, stainless steels, nickel alloys, brass, bronze and copper. Cord brushes are used with abrasive compounds for polishing, finishing, and burring metal parts.

MACHINE POLISHING AND BUFFING

Polishing is usually undertaken to make metal smoother or to produce a more uniform surface. The function of the buffing operation, on the other hand, is to produce a smooth, uniform surface with a high, brilliant lusture.

Semi-automatic machines are mostly used for doing this jobs. These machines carry a series of polishing and buffing wheels which can be adjusted to different positions so that all surfaces of the part can either be polished or buffed as required. The compounds and wheels selected are governed by the shape of the part, the material of which it is fabricated, and the appearance of the product. For ordinary polishing and buffing operations, polishing and buffing wheels are mounted on floor polishing lathes.

Commonly used polishing wheels are constructed of canvas, muslin, felt, and leather, while buffs are flexible wheels made of cotton cloth, canvas, linen, flannel or wool discs.

Polishing and buffing compounds, like wheels, are usually divided in two broad categories :

1. cutting down, the removing of scratches and grain lines from previous operations, and
2. colouring, which gives the product the final, bright, deep lusture.

Buffing compounds can either be greaseless or have a grease base. A mixture of glue base, a softening agent, and a mineral make up a greaseless compound. Grease buffing compounds use oil, tallow, and other bonds. Many abrasive elements are used for the colouring compounds, such as red rouge, green rouse, crocus, and white colouring compounds.

Besides polishing and buffing wheels, coated abrasive belts and brushes are now widely used in modern metal industry today. The belts used for polishing are coated with resins and hide glues, followed by either emery, flint, crocus, garnet, aluminium oxide, or silicon carbide. The advantage of using abrasive belt is the quick change that is possible from a used belt to a new one, or from one grade to another.

The ability of the belt to remove stock rapidly and to produce fine finishes, plus its ability to produce a very fast and extremely cool cut, has led to the rapid development of coated abrasive machines.

FINISHES OF METALS

The principal types of finishes applied to metal products are :

1. Metallic coatings.
2. Plastic coatings.
3. Organic finishes.
4. Inorganic finishes.

17.4 METALLIC COATINGS

Metallic coatings may generally be applied by electroplating, hot dipping such as galvanizing, calorizing, phosphate coating or anodising and spraying of molten metal (metallizing). They are used to provide a decorative finish, protection against corrosion, and resistance to wear. They also serve as base for painting to provide reflectant surface, and to provide a thermally or electrically conductive surface.

ELECTROPLATING

Electroplating may be described as a process of covering a surface or object usually metallic with a thin adherent coating of the same or other metal by electrolysis. The form and details of the original part are retained.

Essential elements of plating process are the cathode, anode, electrolyte, and direct current at low voltage. The articles (work pieces) are connected electrically to the cathode bar, and on the anode bars are suspended plates of metal being deposited. The solution itself contains dissolved salts of the metal to be plated, i.e. of the coating metal. In order to increase its conductivity, other chemicals that will ionize highly are added (such as sulphuric acid to an acid copper-plating bath). As the current is passed through the circuit metallic ions migrate to the cathode and, upon losing their charge, are deposited as metal upon it. The current density largely determines the rate at which the metal is deposited. Plating metals are chromium, nickel, copper, zinc, cadmium, and tin. The precious metals, such as silver, gold, platinum and rhodium are also applied for plating. Chromium plating is widely used because of its pleasing appearance and its resistance to corrosion and wear. Aqueous solutions, called electrolytes, used in electroplating are designated as acid, neutral and alkaline baths. The acid bath is used extensively for low cost plating; the neutral bath primarily in the plating of nickel; and the alkaline bath transmits a dense, fine-grain deposit that may be made highly reflective and smooth.

The technique of electroplating is basically the same for all metals, although there are certain variations in some of the details. Since electrodeposited metal will adhere firmly only to clean surface, the need for thorough cleaning of the parts to be plated is of fundamental importance. The cleaning or polishing operations may, therefore, require any one of the following steps :

1. removal of all oil, grease or organic materials by immersing the parts in hot alkaline solution, and lastly by rinsing in clean water ; and
2. removal of surface irregularities, scale, and oxides by picking or by use of a file, abrasive wheel, or wire brush. The work piece must then be polished and buffed to ensure adhesion or to obtain the desired appearance.

HOT-DIPPING

Hot dipping is a rapid, inexpensive process which allows to form coating of corrosion-resistant metals into base metals by dipping in molten bath at less cost than by electroplating. The process is widely used for zinc coating on iron and steel. Tin, lead, and aluminium coatings are applied to the base metals in addition to zinc. Base metals are restricted to the materials with higher melting temperatures such as cast iron, steel, and copper. The coating of sheet, strip, wire, and pipe is done on continuous basis whereas other shapes have to be immersed in the bath in batches.

The hot dipped coating consists of an alloy layer covered with a layer of pure metal. The alloy layer forms as atoms of molten metal diffuse into and combine with the base metal. The thickness of alloy layer increases with increased diffusion. This is made by higher bath temperatures and longer immersion times. For a durable and protective coating, alloying provides the necessary uniformity and adherence. The outer layer of pure coating metal is formed from the metal adhering to the surface as the article is withdrawn from the bath. Rapid withdrawal increases the rate of cooling and reduces the drainage period, giving a thicker outer layer. Uniform and adherent coating can be formed only if the surface of the work is clean and free from any undesirable material. Hot-dip coating process, therefore, requires a series of cleaning operations which include degreasing, rinsing, scale removal (pickling), fluxing, dipping and final surface treatment.

Galvanizing, tin coating, calorizing, perkerizing, etc., are good examples of hot dipping process.

Galvanizing. Galvanizing is a commercial term used to designate a process by which a zinc coating is produced on iron or low-carbon steel by immersion in molten bath of zinc. The word galvanizing had its origin in the concept of the galvanic (electro-chemical) protection from corrosion afforded by zinc in contact with iron or steel.

The galvanization of zinc to the surface of metal may be accomplished by four different processes : sherardizing, electrolytic plating (or electroplating), schoop (or spraying) and the hot dipping process.

The hot dipping process is probably the most economical of all the galvanizing process for mass production. In this process, first the surface of the work is properly cleaned and usually fluxed by dipping the material in a solution of zinc choloride and hydrochloric acid. The fluxing treatment cleans the base metal and prevents its oxidation as its enters the molten metal bath. The molten metal bath is covered with a molten flux layer which is usually of zinc ammonium chloride. Coatings and small objects may be immersed in an aqueous flux solution and heated in an oven to form a dried flux which protects the work from oxidation as it enters the bath. The metal is then ready to be dipped in the zinc bath. The temperature of the bath varies somewhat with the type of work being processed, but the average is about 450°C. The length of time of immersion in the molten zinc bath depends on the mass of the articles being coated. Large pieces must, therefore, remain in the zinc considerably larger than small ones. The final step in the galvanizing process is to allow the work to cool and dry after withdrawing from the bath. As the hot zinc dries, or solidifies, the spangles appear. Spangles or large crystals of zinc form if the rate is low enough to give a longer time for growth. When smooth paint finish is required, spangles should be avoided. However, in galvanizing, adhesion results form the tendency of the molten zinc to diffuse into the base metal. The zinc coated material is rendered corrosion resistant by this process.

It is used for all forms of outdoor hardware, structural parts, pipes, sheetings for roofs and walls of building, washtubs, ash cans, all sorts of containers, telegraph wire, fencing materials, transformer parts, etc.

Tin coating. Tin coating is usually applied to sheet steel by hot dipping or by electrotinning.

In the first process, the tin coating is applied after proper cleaning by dipping the material into molten tin at a temperature of approximately 315°C. This gives a coating about 0.0025 mm thick.

With electrotinning, the metal is immersed in an electrolyte and a current is passed from the electrode to the metal part.

The various applications of tin coating include tin cans for food, biscuit-tins, kitchen utensils, copper wire, copper tubes used in refrigerators, etc. The porosity being great in tin coating, lacquer seal is necessary for containers used for food packaging.

Calorising. Calorising is the commercial name for the cementation of a metal surface with aluminium. The process is intended primarily as means of protecting iron from oxidation at elevated temperatures rather than from corrosion.

Calorising may be done by different processes. In the hot dipping process, however, the parts are thoroughly cleaned, fluxed in calcium chloride, and dipped in molten aluminium for about 20 minutes. They are then baked in hydrogen atmosphere at 900°C for 24 hr. Upon heating, the aluminium diffuses deeper into the metal and the coating becomes thicker, but of a lower average aluminium content because of diffusion. The temperature at which calorised metals may be used to best advantage is of great importance.

Calorised coatings have proved to be quite resistant to attack by sulphurous gases, and such materials have an important application in the oil-refining industry. Other applications include furnace parts, carburising and heat treatment boxes, and pyrometric equipment where oxidation occurs at high rate.

Phosphate coating or parkerizing. Parkerizing is a process for placing a thin phosphate coating which serves as a base or primer, for enamels and paints on iron and steel.

The parts to be processed are first degreased and cleaned free from oil, grease, rust, scale, etc. and then immersed or dipped in a solution of manganese dihydrogen phosphate which has a temperature of 90°C, and is held there for about 45 min. During the dipping period, the phosphate from manganese dihydrogen phosphate decomposes and phosphate separates out and forms a reasonably thick coating on steel parts.

Parkerizing, being a heavier coating, provides reasonable corrosion protection for indoor use. Therefore, it is necessary to apply oil or paint to such surfaces after parkerizing to insure a long life and good finish otherwise rusting and corrosion will ultimately occur.

This process is widely used in the automotive and electrical appliance industries to prepare automobiles, washing machines, refrigerators, outdoor fittings and similar products to receive an organic finish.

ANODIZING

The surface of aluminium in the normal condition is usually covered by an oxide film of very small thickness. This oxide film imparts certain degree of passivity (i.e. markedly reduced corroding tendency) to the metal. However, due to its relatively small thickness, high porosity and low mechanical strength, it does not provide a reliable protection against corrosion. Protection of aluminium by electrode position of other metals on its surface is quite difficult, cumbersome and expensive. Paints and varnishes do not adhere very well to the aluminium surface.

The most reliable method of protecting aluminium is by means of artificially produced oxide film. The thickness of natural oxygen film on aluminium can be increased by heating the metal in air or oxygen, by treating it with oxidizing agents or by anodic polarization of the metal. Films obtained by heating are thin and mechanically weak. Films obtained by chemical treatment do not increase the corrosion resistance of aluminium to any appreciable extent although they provide a useful base for paint and varnish coatings. Electrolytic treatment produces films of *sufficient thickness* to provide good protection against corrosion. These films introduce favourable changes also in certain mechanical, electrical and physico-chemical properties of aluminium. As a result, anodizing protects and beautifies aluminium surfaces, and converts the aluminium surface into a nonconductor.

Anodizing requires the presence of an electrolyte that allows the flow of electrons between the two electrodes. The electrolytes are usually aqueous solution of sulphuric acid, oxalic acid, and chromic acid. The cathode is made of either lead or graphite. The anode is aluminium workpiece to be coated or anodized. Anodizing in sulphuric acid and in oxalic acid can be carried out with either ac or dc. However, a thin anodizing layer is usually generated by ac, whereas dc generates a coating that has a deeper penetration. Direct current is therefore usually recommended.

The coating, or oxile film, formed on the surface of aluminium is caused by the reaction of the anode and electrolyte. When the current is applied through the electrolyte, oxygen is liberated at the surface of the anode and bubbles rise up to the surface of the electrolyte. During this release of oxygen, oxygen impinges on the aluminium and causes an oxide formation. During the time of oxidation process, the oxide coating thickens or grows, into the metal. The growth can be identified as a cellular structure created as a direct result of the oxidation process. The process is somewhat reverse of electroplating. Instead of simply adding the material to the surface as with electroplating, the reaction progresses inward from the surface of the piece. This makes it a permanent part of the original base material.

The second procedure used after anodizing in sulphuric acid is the sealing process. The oxide film becomes highly porous. The anodized parts must therefore be sealed after the treatment. The film is sealed in hot water or an aqueous solution such as potassium chromate solution at 85 to 100°C for about 1/2 hour.

The sulphuric acid process is the most extensively used process. It produces film having a high absorptive capacity and resistance to corrosion. The process can be used for almost all aluminium alloys also. The consumption of electric power and the time of treatment are less than those in other two processes. But the process is less suited to parts having narrow gap, recesses or cavities and crevices such as riveted joints because the acid retained in these recesses is difficult to remove and ultimately give rise to corrosion. Chromic acid is somewhat less harmful in this respect. Films obtained in chromic acid solution constitute and excellent base for paint and varnish coatings. Anodic oxidation in chromic acid is not recommended for alloys having high copper content. Oxalic acid has the lowest solvent action on the oxide film. Hence it is possible to obtain very thick film by this process. However, frequent occurrence of pitting (i.e. localised corrosion) on the surface renders this impracticable.

The thickness of oxide films and their properties depend on the anodizing conditions and on the conditions of the metal being anodized. The film thickness increases with the current density, the anodizing time (upto a certain limiting value), and with a lowering of the temperature of the solution. A high temperature results in the formation of more porous and elastic films having improved absorptive properties and adhesion. Increase in current density also increases the porosity of the film.

The article to be anodized is first cleaned with an aluminium decreasing agent or a hot household detergent solution and rinsed in cold water. It is possible to impart excellent coloured coatings for decorative finish by immersing the parts in warm dye solutions, and then sealing the dye in the porous oxide coatings by dipping in dilute nickel acetate. Modern aluminium glasses and pitchers are examples of this process.

METAL SPRAYING OR METALLIZING

Metal spraying or metallizing literally means "to treat with, especially to coat with a metal to impregnate with a metal or metallic compound". Although this includes electroplating and other processes, it is customary to limit the use of the term to designate only the process of metal spraying. Metallizing, normally includes the preparation of the base metal, the spraying on the metal, and the finishing of the surface by grinding or by some other method.

Two common methods are used in metal spraying, the variation being in the initial form in which the metal is used.

One uses spray gun which feeds the base metal in wire form. The gun consists of a gas torch with hole in the centre of the tip for the wire to come out, a small turbine powered by compressed air and gears to feed the wire through the tip into the oxyacetylene flame of the gun torch as fast as it melts, and an "air cap" around the torch tip or nozzle, which supplies a blast of air to atomize the molten metal and deposit it on the prepared surface. When metal is melted in a flame of burning gas, the metal is oxidized to a certain extent, regardless of any surrounding atmosphere. This oxide in molten form, is trapped in the deposit along with the molten metal.

In other method, metallizing equipment uses metal in *powdered form*. The powdered metal is fed from a container through a rubber hose to the spray gun, and out through the centre of the flame, similar to the "wire gun". Since the metal is already finely divided or atomized, the blast of air needed is just sufficient only to deposit the molten metal on the surface being coated.

The 'wire gun' is more popular because the wire is generally less costly, more readily available, and more easily handled. Moreover, any tough metal that is available in wire form can be sprayed with a wire gun. The feed to the gun is more trouble free, and the deposit generally denser and more desirable, when used in the as-sprayed condition. On the other hand, the 'power gun' having no turbine or gears, costs less, is lighter to handle, and without the blast of atomising air, can be used more effectively to heat the base metal when such heat is needed. Oxy-acetylene flame is used when spraying the high melting point metals such as molybdenum, but hydrogen, city gas and such other fuel gases may be used in combination with oxygen for spraying the metals of low melting point.

However, the surface on which the metal is deposited should be rough like that obtained from a very rough turn on a lathe and it must be clean and free from moisture or oil. This provides a mechanical lock for a deposited metal. A metallized coating adheres to steels, stainless steels, monel, nickel, iron and most aluminium alloys. It saves machining and can be used as a base for other less expensive material. The surface acts as an oil reservoir similar to powdered metal materials and forms an excellent bearing material. The properties of porosity and ability to hold oil have led to spraying babbit in bearing sleeves. This sprayed-babbit material is superior to cast-babbit bearings because of its oil absorption ability.

Metal spraying is extensively used for building up worn parts, for protection from corrosion, and for improving wearing surfaces. Cloth and paper are coated for use in electrical condensers. Thus metal spraying is a production tool as well as a repair tool.

17.5 PLASTIC COATING

Metal surfaces that need protection from corrosion can be coated with plastics because of their excellent anti-corrosive characteristics for a wide variety of corrosive environments. Chemical plant equipments, tanks, pipelines, valve bodies are the common places where protection from corrosive environment is achieved by plastic coating the metal parts. Plastic coated metals also find wide application in cans for food-stuffs, water-treatment plants, decorative metal furnitures, etc. In general, the coatings have good resistance to corrosion coupled with good adhesion, high resistance to abrasion, and attractive appearance. The composite character of plastics coating on metals combine the mechanical properties of metal and protective and other properties of plastics.

Commercially satisfactory coatings are possible with the following plastics that are basically thermoplastics, i.e. having ability to set and harden at high temperature by way of crosslinking.

1. Plasticized poly vinyl chloride – P.V.C.
2. Penton.
3. Nylon.
4. Cellolose acetate butyrate – c.a.b.
5. Polythene.
6. Polytetrafluoro ethylene – p.t.f.e.
7. Polytrifluoro monochloro ethylene – p.t.f.c.e.

METHODS OF COATING PLASTICS

The methods employed for coating the plastics on metals are as follows :

1. Dipping : (a) Liquid plastisol method.
   (b) Fine powder method.
2. Spraying : (a) Electrostatic spraying.
   (b) Flame spraying.
3. Depositing : (a) Vacuum coating.

Liquid plastisol method. It is based on forming a coat on P.V.C. by cross-linking. The article to be coated is heated and is then dipped into a tank of cold liquid P.V.C. The action of heat cause the plasticizer and polymer to cross link and form a gelatinous deposit. Coating thickness upto 12 mm can be achieved by this method.

Fine powder dipping. It is based on dipping the heated article into a gas agitated bed of fine powder. The article is further heated to fuse the coated particles so that a smooth layer is obtained. This method is employed for coating a large variety of plastics, e.g., polythene, nylon, c.a.b., penton, and some selected grades of P.V.C.

Electrostatic spraying. Powder spray gun employed in this method is applied with a high voltage source so that particles impelled at high velocity acquire strong charge. The part to be coated is earthed so that it attracts the charged particles. The powder produce an envelope on the entire part as soon as it is earthed and this thickens the deposit. The coated object is then heated into a continuous film.