INTRODUCTION TO DIMENSIONAL AND GEOMETRIC TOLERANCE

General Aspects

In the design and manufacture of engineering products a great deal of attention has to be paid to the mating, assembly and fitting of various comp onents. In the early days of mechanical engineering during the nineteenth century, the majority of such components were actually mated together, their dimensions being adjusted until the required type of fit was obtained. These methods demanded craftsmanship of a high order and a great deal of very fine work was produced. Present day standards of quantity production, interchangeability, and continuous assembly of many complex compounds, could not exist under such a system, neither could many of the exacting design requirements of modern machines be fulfilled without the knowledge that certain dimensions can be reproduced with precision on any number of components. Modern mechanical production engineering is based on a system of limits and fits, which while not only itself ensuring the necessary accuracies of manufacture, forms a schedule or specifications to which manufacturers can adhere.

In order that a system of limits and fits may be successful, following conditions must be fulfilled:

1. The range of sizes covered by the system must be sufficient for most purposes.
2. It must be based on some standards; so that everybody understands alike and a given dimension has the same meaning at all places.
3. For any basic size it must be possible to select from a careful ly designed range of fit the most suitable one for a given application.
4. Each basic size of hole and shaft must have a range of tolerance values for each of the different fits.
5. The system must provide for both unilateral and bilateral methods of applying th e tolerance.
6. It must be possible for a manufacturer to use the system to apply either a hole based or a shaft-based system as his manufacturing requirements may need.
7. The system should cover work from high class tool and gauge work where very wide limits of sizes are permissible.

Nominal Size and Basic Dimensions

— **Nominal size:** A 'nominal size' is the size which is used for purpose of general identification. Thus the nominal size of a hole and shaft assembly is 60 mm, even though the basic size of the hole may be60 mm and the basic size of the shaft 59.5 mm.

— **Basic dimension:** A 'basic dimension' is the dimension, as worked out by purely design considerations. Since the ideal conditions of producing basic dimension, do not exist, the basic dimensions c an be treated as the theoretical or nominal size, and it has only to be approximated. A study of function of machine part would reveal that it is unnecessary to attain perfection because some variations in dimension, however small, can be tolerated size of various parts. It is, thus, general practice to specify a basic dimension and indicate by tolerances as to how much variation in the basic dimension can be tolerated without affecting the functioning of the assembly into which this part will be used.

Definitions

The definitions given below are based on those given in IS: 919

— ***Shaft:*** The term shaft refers not only to diameter of a circular shaft to any external dimension on a component.

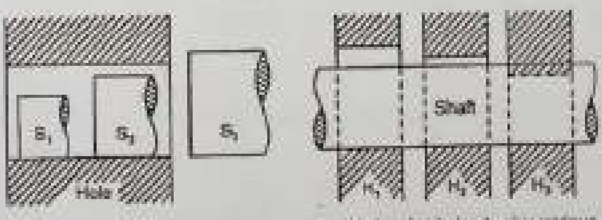
— ***Hole:*** This term refers not only to the diameter of a circular hole but to any internal dimension on a component.

— **Basics of Fit**

A fit or limit system consists of a series of tolerances arranged to suit a specific range of sizes and functions, so that limits of size may. Be selected and given to mating components to ensure specific classes of fit. This system may be arranged on the following basis:

1) Hole basis system

2) Shaft basis system.



'S' denotes shaft to give various fits with hole
Hole Basis System

'H' denotes holes to give various fits with shaft
Shaft Basis System

Nominal & Basic Dimension

— **Hole basis system:**

'Hole basis system' is one in which the limits on the hole are kept constant and the variations necessary to obtain the classes of fit are arranged by varying those on the shaft.

— **Shaft basis system:**

'Shaft basis system' is one in which the limits on the shaft are kept constant and the variations necessary to obtain the classes of fit are arranged by vary ing the limits on the holes. In present day industrial practice hole basis system is used because a great many holes are produced by standard tooling, for example, reamers drills, etc., whose size is not adjustable. Subsequently the shaft sizes are more re adily variable about the basic size by means of turning or grinding operations. Thus the hole basis system results in considerable reduction in reamers and other precision tools as compared to a shaft basis system because in shaft basis system due to non -adjustable nature of reamers, drills etc. great variety (of sizes) of these tools are required for producing different classes of holes for one class of shaft for obtaining different fits.

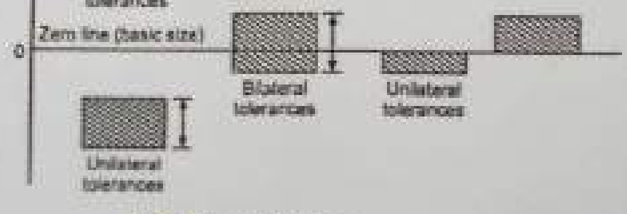
Systems of Specifying Tolerances

The tolerance or the error permitted in manufacturing a particular dimension may be allowed to vary either on one side of the basic size or on either side of the basic size. Accordingly two systems of specifying tolerances exit.

1) Unilateral system
2) Bilateral system.

In the unilateral system, tolerance is applied only in one direction.

Examples: $40.0^{+0.04}_{+0.02}$ or $40.0^{-0.02}_{-0.04}$



Types of Tolerances

In the bilateral system of writing tolerances, a dimension is permitted to vary in two directions.

Examples: $40.0^{+0.02}_{-0.04}$

LIMIT GAUGES

- A limit gauge is not a measuring gauge. Just they are used as inspecting gauges.
- The limit gauges are used in inspection by methods of attributes.
- This gives the information about the products which may be either within the prescribed limit or not.
- By using limit gauges report, the control charts of P and C charts are drawn to control invariance of the products.
- This procedure is mostly perform ed by the quality control department of each and every industry.
- Limit gauge are mainly used for checking for cylindrical holes of identical components with a large numbers in mass production.

Purpose of using limit gauges

- Components are manufact ured as per the specified tolerance limits, upper limit and lower limit. The dimension of each component should be within this upper and lower limit.
- If the dimensions are outside these limits, the components will be rejected.
- If we use any measuring instruments to check these dimensions, the process will consume more time. Still we are not interested in knowing the amount of error in dimensions.
- It is just enough whether the size of the component is within the prescribed limits or not. For this purpose, we can make use of gauges known as limit gauges.

Introduction

When we are producing components by various methods of manufacturing process it is not possible to produce perfectly smooth surface and some irregularities are formed. These irregularities are causes some serious difficulties in using the components. So it is very important to correct the surfaces before use. The factors which are affecting surface roughness are

1. Work piece material
2. Vibrations
3. Machining type
4. Tool and fixtures

The geometrical irregularities can be classified as

1. First order
2. Second order
3 Third order
4. Fourth order

1) **First order irregularities**

These are caused by lack of straightness of guide ways on which tool must move.

2) **Second order irregularities**

These are caused by vibrations

3) **Third order irregularities**

These are caused by machining.

4) **Fourth order irregularities**

These are caused by improper handling machines and equipments.

Elements of surface texture

1) **Profile**: - Contour of any section through a surface.

2) **Lay**: - Direction of the 'predominate surface pattern'

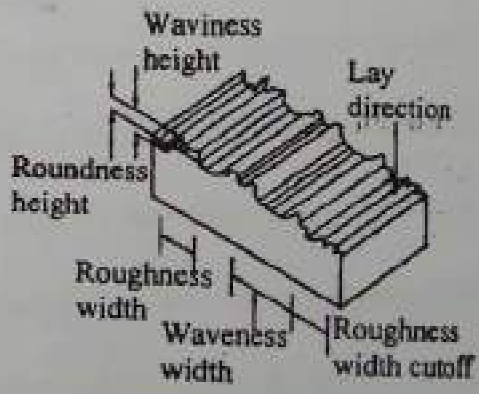
3) **Flaws**: - Surface irregularities or imperfection, which occur at infrequent intervals.

4) **Actual surface**: - Surface of a part which is actually obtained,

5) **Roughness**: - Finely spaced irregularities. It is also called primary texture.

6) **Sampling lengths**: - Length of profile necessary for the evaluation of the irregularities.

7) **Waviness**: - Surface irregularities which are of greater spacing than roughness.



Surface Texture

8) **Roughness height**: - Rated as the arithmetical average deviation.

9) **Roughness width**: - Distance parallel to the normal surface between successive peaks.

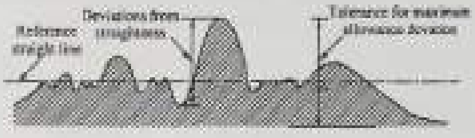
10) **Mean line of profile**: - Line dividing the effective profile such that within the sampling length.

11) **Centre line of profile** : - Line dividing the effectiveness profile such that the areas embraced b profile above and below the line are equal.

Scanned with CamScanner

STRAIGHTNESS MEASUREMENT

A line is said to be straight over a given length, if the variation of the distance of its from two planes perpendicular to each other and parallel to the general direction of the line remains within the specified tolerance limits. The tolerance on the straightness of a line is defined as the maximum deviation in relation to the reference straight line joining the two extremities of the line to be checked.



Straightness Measurement

Straight edge

A straight edge is a measuring tool which consists of a length of a length of a steel of narrow and deep section in order to provide resistance to bending in the plane of measurement without excessive weight. For checking the straightness of any surface, the straight edge is placed over the surface and two are viewed against the light, which clearly indicate the straightness. The gap between the straight edge and surface will be negligibly small for perfect surfaces. Straightness is measured by observing the colour of light by diffraction while passing through the small gap. If the colour of light be red, it indicates a gap of 0.0012 to 0.0075mm. A more accurate method of finding the straightness by straight edges is to place it in equal slip gauges at the correct point for minimum deflection and to measure the uniformity of space under the straight edge with slip gauges.

Test for straightness by using spirit level and Autocollimator

The straightness of any surface could be determined by either of these instruments by measuring the relative angular positions of number of adjacent sections of the surface to be tested. First straight line is drawn on the surface then it is divided into a number of sections the length of each sect ion being equal to the length of sprit level base or the plane reflector' s base in case of auto collimator. The bases of the spirit level block or reflector are fitted with two feet so that only feet have line contact with the surface and the surface of b ase does not touch the surface to he tested. The angular division obtained is between the specified two points. Length of each section must be equal to distance between the centerlines of two feet. The special level can be used only for the measurement of straightness of horizontal surfaces while auto -collimator can be used on surfaces are any plane. In case of spirit level, the block is moved along the line equal to the pitch distance between the centerline of the feet and the angular variation of the direction of block. Angular variation can be determined in terms of the difference of height between two points by knowing the least count of level and length of the base.

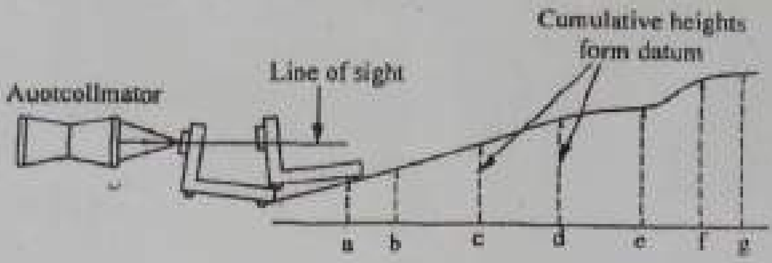


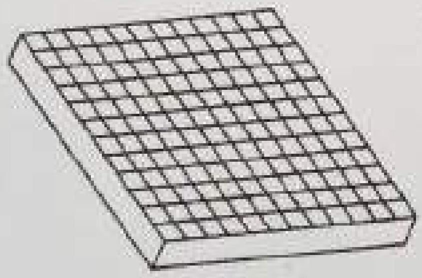
Fig.3.[illegible] Straightness using Auto-Collimator

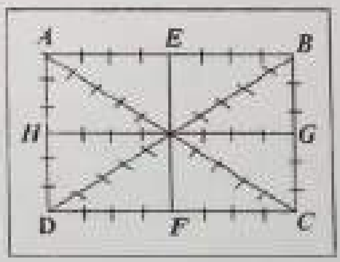
In case of autocollimator the instrument is placed at a distance of 0.5 to 0.75m from the surface to be tested. The parallel beam from the instrument is projected along the length of the surface to be tested. A block fixed on two feet and fitted with a plane vertical reflector is placed on the surface and the reflector face is facing the instrument. The image of the cross wires of the collimator appears nearer the center of the field and for the complete movement of reflector along the surface straight line the image of cross wires will appear in the field of eyepiece. The reflector is then moved to the other end of the surface in steps equal to. The center distance between the feet and the tilt of the reflector is noted down in second from the eyepiece.

FLATNESS TESTING

Flatness testing is possible by comparing the surface with an accurate surface. This method is suitable for small plates and not for large surfaces. Mathematically flatness error of a surface states that the departure from flatness is the minimum separation of a pair of parallel planes which will contain all points on the Surface. The figure which shows that a surface can be considered to be composed of an infinitely large number of lines. The surface will be flat only if all the lines are straight and they lie in the same plane. In the case of rectangular table arc the lines are straight and parallel to the sides of the rectangle in both the perpendicular direction. Even it is not plat, but concave and convex along two diagonals. For verification, it is essential to measure the straightness of diagonals in addition to the lines parallel to the sides.

Thus the whole of the surface is divided by straight line. The fig, shows the surface is divided by straight line. The end line AB and AD etc are drawn away from th e edges as the edges of the surface are not flat but get worn out by use and can fall off little in accuracy. The straightness of all these lines is determined and then those lines are related with each other in order to verify whether they lie in the same plane or not.



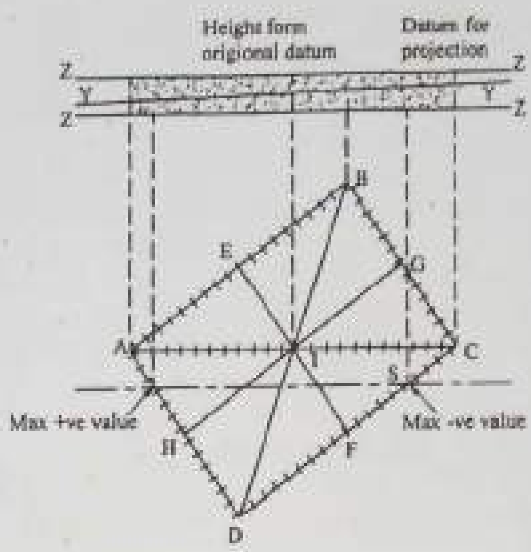


Procedure for determining flatness

The fig. shows the flatness testing procedure.

(i) Carry out the straightness test and tabulate the reading up to the cumulative error column.

(ii) Ends of lines AB, AD and BD are corrected to zero an d thus the height of the points A, B and D are zero.



Flatness Testing

The height of the point I is determined relative to the arbitrary plane ABD = 000. Point C is now fixed relative to the arbitrary plane and points B and D are set at zero, all intermediate points on BC and DC can be corrected accordingly. The positions of H and G, E and F are known, so it is now possible to fit in lines HG and EF. This also provides a check on previous evaluations since the mid -point of these lines should coincide with the position of mid-point I. In this way, the height of all the points on the surface relative to the arbitrary plane ABD is known.

ROUNDNESS MEASUREMENTS

Roundness is defined as a condition of a surface of revolution. Where all points of the surface intersected by any plane perpendicular to a common axis in case of cylinder and cone.

Devices used for measurement of roundness

1) Diametral gauge.

2) Circumferential conferring gauge => a shaft is confined in a ring gauge and rotated against a set indicator probe.

3) Rotating on center

4) Three-point probe.

5) Accurate spindle.

1) Diametral method

The measuring plungers are located 180° a part and the diameter is measured at several places. This method is suitable only when the specimen is elliptical or has an even number of lobes. Diametral check does not necessarily disclose effective size or roundness. This method is unreliable in determining roundness.

2) Circumferential confining gauge

Fig. shows the principle of this meth od. It is useful for inspection of roundness in production. This method requires highly accurate master for each size part to be measured. The clearance between part and gauge is critical to reliability. This technique does not allow for the measurement of other related geometric characteristics, such as concentricity, flatness of shoulders etc.

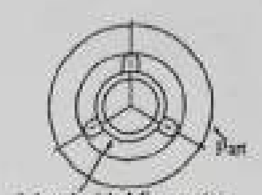
[illegible] Confining Gauge

3) Rotating on centers

The shaft is inspected for roundness while mounted on center. In this case, reliability is dependent on many factors like angle of centers, alignment of centres, roundness and surface condition of the centres and centre holes and run out of piece. Out of straightness of the part will cause a doubling run out effect and appear to be roundness error.

4) Three point probe

The fig. shows three probes with 120° spacing is very, useful for determining effective size they perform like a 60° V block. 60° V-block will show no error for 5 a 7 lobes magnify the error for 3-lobed parts show partial error for randomly spaced lobes.



Three Point Probe

Roundness measuring spindle

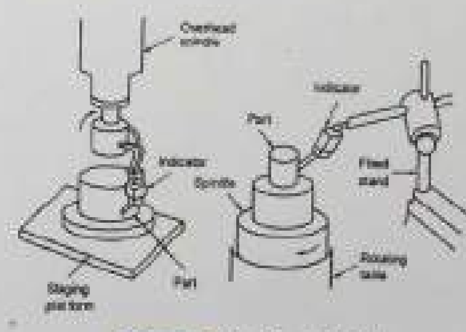
There are following two types of spindles used.

1) Overhead spindle

Part is fixed in a staging plat form and the overhead spindle carrying the comparator rotates separately from the part. It can determine roundness as well as camming (Circular flatness). Height of the work piece is limited by the location of overhead spindle. The concentricity can be checked by extending the indi cator from the spindle and thus the range of this check is limited.

2) Rotating table

Spindle is integral with the table and rotates along with it. The part is placed over the spindle and rotates past a fixed comparator



Rotating Table

Roundness measuring machine

Roundness is the property of a surface of revolution, where all points on the surface are equidistant from the axis. The roundness of any profile can be specified only when same center is found from which to make the measurements. The diameter and

(i) Least square circle

The sum of the squares of a sufficient no. of equally spaced radial ordinates measured from the circle to the profile has minimum value. The center of such circle is referred to as the least square center. Out of roundness is defined as the radial distance of the maximum peak from the circle (P) plus the distance of the maximum valley from this circle.

(ii) Minimum zone or Minimum radial separation circle

These are two concentric circles. The value of the out of roundness is the radial distance between the two circles. The center of such a circle is termed as the minimum zone center. These circles can be found by using a template.

(iii) Maximum inscribed circle

This is the largest circle. Its center and radius can be found by trial and error by compare or by template or computer. Since V = 0 there is no valleys inside the circle.

(iv)Minimum circumscribed circles

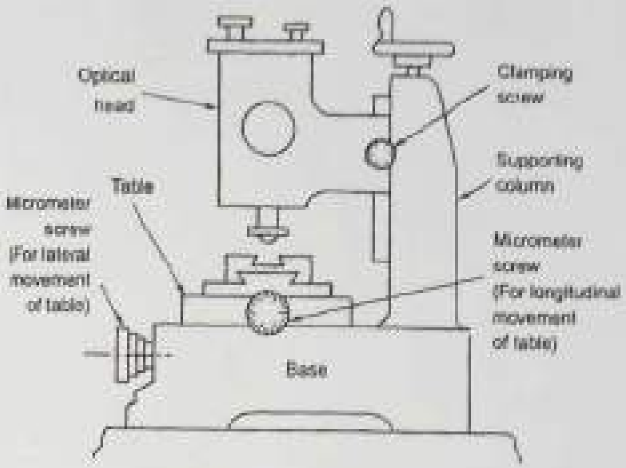
This is the smallest circle. Its center and radius can be found by the previous method since P = 0 there is no peak outside the circle. The radial distance between the minimum circumscribing circle and the maximum inscribing circle is the measure of the error circularity. The fig shows the trace produced by a recording instrument.

This trace to draw concentric circles on the polar graph which pass through the maximum and minimum points in such way that the radial distance be minimum circumscribing circle containing the trace or the n inscribing circle which can fitted into the trace is minimum. The radial distance between the outer and inner circle is minimum is considered for determining the circularity error. Assessment of roundness can be done by templates. The out off roundness is defined as the radial distance of the maximum peak (P) from the least square circle plus the distance of the maximum valley (V) from

Tool makers microscope

Working

Worktable is placed on the base of the base of the instrument. The optical head is mounted on a vertical column it can be moved up and down. Work piece is mounted on a glass plate. A light source provides horizontal beam of light which is reflected from a mirror by



[illegible] Tool Makers Microscope

900 upwards towards the table. Image of the outline contour of the work piece passes through the objective of the optical head. The image is projected by a system of three prisms to a ground glass screen. The measurements are made by means of cross lines engraved on the ground glass screen. The screen can be rotated through 360°. Different types of graduated screens and eyepieces are used.

Applications

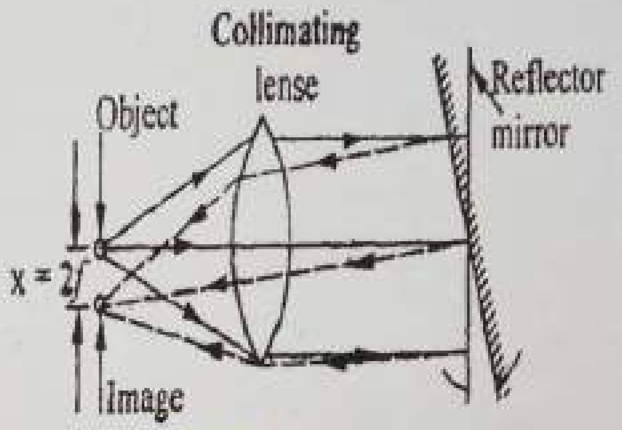
- Linear measurements.
- Measurement of pitch of the screw.
- Measurement of pitch diameter.
- Measurement of thread angle.
- Comparing thread forms.
- Centre to center distance measurement.
- Thread form and flank angle measurement

Thread form and flank angle measurement

The optical projections are used to check the thread form and angles in the thread. The projectors equipped with work holding fixtures, lamp, and lenses. The light rays from the lens are directed into the cabinet and prisons and mirrors. The enlarged image of thread is drawn. The ideal and actual forms are compared for the measurement.

AUTO- COLLIMATOR

Auto-collimator is an optical instrument used for the measurement of small angular differences, changes or deflection, plane surface inspection etc. For small angular measurements, autocollimator provides a very sensiti ve and accurate approach. An auto collimator is essentially an infinity telescope and a collimator combined into one instrument.



Auto-Collimator

Basic principle

If a light source is placed in the flows of a collimating lens, it is projected as a parallel beam of light . If this beam is made to strike a plane reflector, kept normal to the optical axis, it is reflected back along its own path and is brought to the same focus. The reflector is tilted through a small angle '0'. Then the parallel beam is deflected twice the angle and is brought to focus in the same plane as the light source.

The distance of focus from the object is given by

$$x = 2\theta . f$$

Where, f = Focal length of the lens

θ = Fitted angle of reflecting mirror.

WORKING OF AUTO-COLLIMATOR:

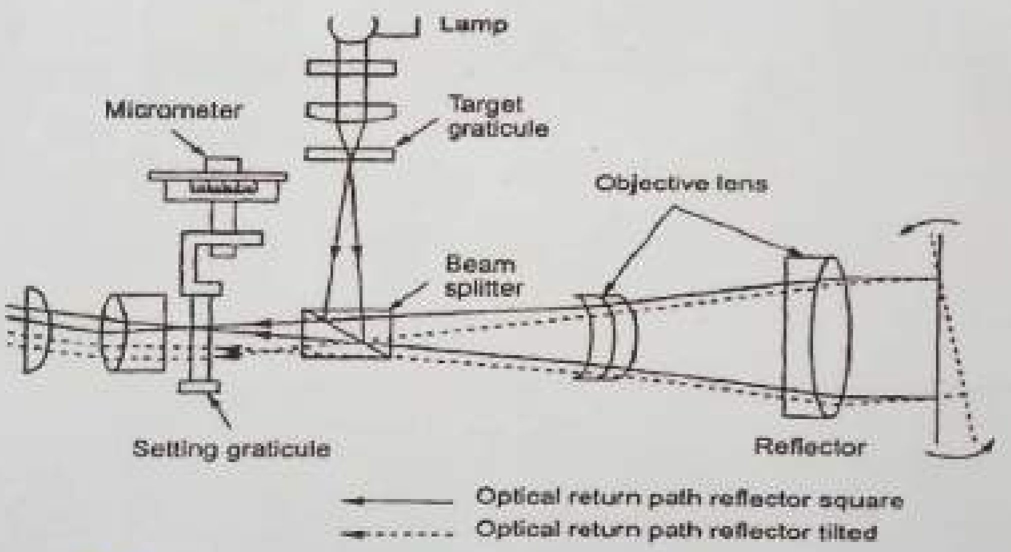
There are three main parts in auto-collimator.

1) Micrometer microscope.

2) Lighting unit and

3) Collimating lens.

Figure shows a line diagram of a modern auto -collimator. A target graticule is positioned perpendicular to the optical axis. When the target graticule is illuminated by a lamp, rays of light diverging from the intersection point reach the objective lens via beam splitter. From objective, the light rays are projected as a parallel rays to the reflector.



Line diagram of an injected graticule auto-collimator

A flat reflector placed in front of the objective and exactly normal to the optical axis reflects the parallel rays of light back along their original paths. They are then brought to the target graticule and exactly coincide with its intersection. A portion of the returned light passes through the beam splitter and is visible through the eyepiece. If the reflector is tilted through a small angle , the reflected beam will be changed its path at twice the angle. It can also be brought to target graticule but linearly displaced from the actual target by the amount $2\theta \times f$. linear displacement of the graticule image in the plane tilted angle of eyepiece is directly proportional to the reflector. This can be measured by optical micrometer. The photoelectric auto- collimator is particularly suitable for calibrating polygons, for checking angular indexing and for checking small linear displacements.

APPLICATIONS OF AUTO-COLLIMATOR

Auto-collimators are used for

1) Measuring the difference in height of length standards.
2) Checking the flatness and straightness of surfaces.
3) Checking square ness of two surfaces.
4) Precise angular indexing in conjunction with polygons.
5) Checking alignment or parallelism.
6) Comparative measurement using master angles.
7) Measurement of small linear dimensions.
8) For machine tool adjustment testing.