Comparators

Introduction

A comparator works on relative measurements, *i.e.* to say, it gives only dimensional differences in relation to a basic dimension. So a comparator compares the unknown dimensions of a part with some standard or master setting which represents the basic size, and dimensional variations from the master setting are amplified and measured.

Advantages of comparators:

1. Not much skill is required on the part of operator in its use.
2. The calibration of instrument over full range is of no importance as comparison is done with a standard end length.
3. Zero error of instrument also does not lead to any problem.
4. Since range of indication is very small, being the deviation from set value, a high magnification resulting into great accuracy is possible.

The comparators are generally used for linear measurements, and various comparators available differ principally in the method used for amplifying and recording the variations measured. According to the principles used for obtaining suitable degrees of magnification of the indicating device relative to the change in the dimension being measured, the various comparators may be classified as follows:

Classification of comparators:

1. Mechanical comparators
2. Mechanical-optical comparators
3. Electrical and Electronic comparators
4. Pneumatic comparators
5. Fluid displacement comparators
6. Projection comparators
7. Multi-check comparators
8. Automatic gauging machines.

Characteristics of Comparators

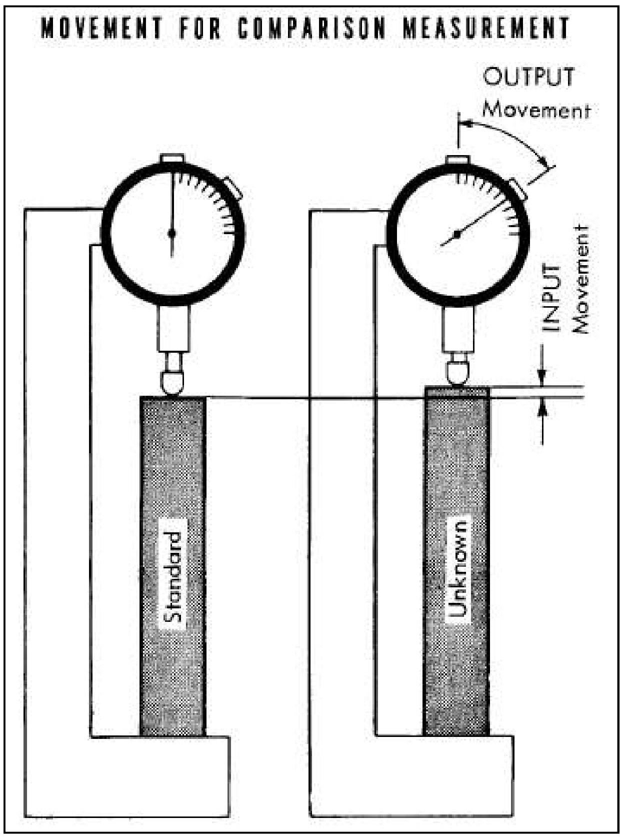
Before we discuss the various types of comparators, let us first look into various fundamental requirements which every comparator must fulfill. These are as follows:

1. The instrument must be of robust design and construction so as to withstand the effect of ordinary usage without impairing its measuring accuracy.
2. The indicating device must be such that readings are obtained in least possible time and for this, magnification system used should be such that the readings are dead beat. The system should be free from backlash, and wear effects and the inertia should be minimum possible.
3. Provision must be made for maximum compensation for temperature effects.
4. The scale must be linear and must have straight line characteristic.
5. Indicator should be constant in it return to zero.
6. Instrument, though very sensitive, must withstand a reasonable *ill usage* (معاملة قاسية) without permanent harm.
7. Instrument must have the maximum versatility, i.e., its design must be such that it can be used for a wide range of operations.
8. Measuring pressure should be low and constant.

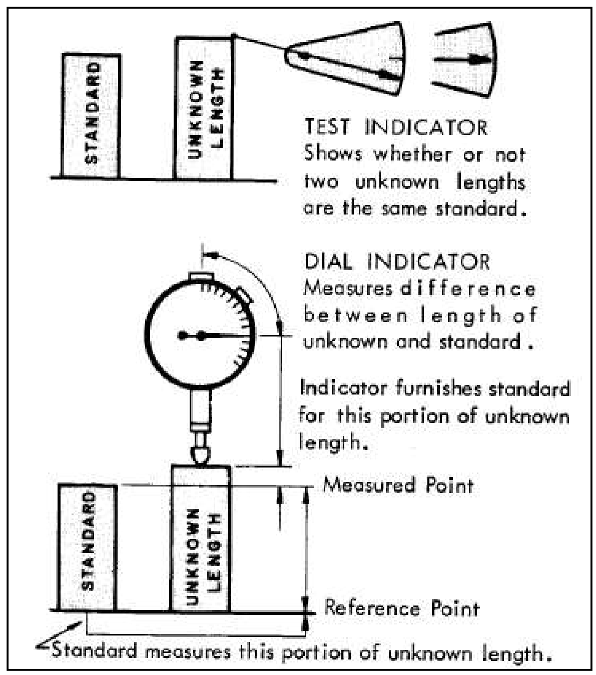
Uses of Comparators

The various ways in which the comparators can be used are as follows:

1. In mass production, where components are to be checked at a very fast rate.
2. As laboratory standards from which working or inspection gauges are set and correlated.
3. For inspecting newly purchased gauges.
4. Attached with some machines, comparators can be used as working gauges to prevent work spoilage (تلف) and to maintain required tolerances at all stages of manufacturing.
5. In selective assembly of parts, where parts are graded in three or more groups depending upon their tolerances.



Comparison measurement requires movement because it is change o f length that is desired.



The dial indicator measures change in length, not the length itself.

1. Mechanical Comparators

In these comparators, magnification is obtained by mechanical linkages and other mechanical devices.

- **<u>Systems of Displacement Amplification used in Mechanical Comparators:</u>**

a- Rack and Pinion: The measuring spindle integral with a rack, engages a pinion which amplifies the movement of plunger through a gear train. Fig (1-a).

b- Cam and gear train: In this case the measuring spindle acts on a cam which transmits the motion to the amplifying gear train. Fig (1-b).

c- Lever with toothed sector: In this case a lever with a toothed sector at its end engages a pinion in the hub of a crown gear sector which further meshes with a final pinion to produce indication. Fig (1-c).

d- Compound Levers: here levers forming a couple with compound action are connected through segments and pinion to produce final pointer movement. Fig (1-d).

e- Twisted Taut (مشدود) Strip: The movement of measuring spindle tilts the knee causing straining which further causes the twisted taut band to rotate proportionally. The motion of strip is displayed by the attached pointer.Fig (1-e).

f- Lever combined with band wound around drum: In this case, the movement of the measuring spindle tilts the hinged block, causing swing of the fork which induces rotation of the drum. Fig(1-f).

g- Reeds combined with optical display. In this case parallelogram reeds are used which transfer measuring spindle movement to a deflecting reed whose extension carries a target utilized in optical path.

i- Tilting mirror projecting light spots.

- **Dial Indicator:**

One of the most commonly used mechanical comparators is essentially of the same type as a dial indicator. It consists of a robust base whose surface is perfectly flat and a pillar carrying a bracket in which is incorporated a spindle and indicator. The linear movement of the spindle is magnified by means of a gear and pinion train into sizable rotation of the pointer on the dial scale. The indicator is set to zero by the use of slip gauges representing the basic size of the part. This is generally used for inspection of small precision-machined parts. This type of comparator can be used with various attachments so that it may be suitable for large number of works. With a V-block attachment it can be used for checking out-of-roundness of a cylindrical component.

- **The Johansson 'Mikrokator'**.
- **Reed Type Mechanical Comparator**.
- **The Sigma comparator**.

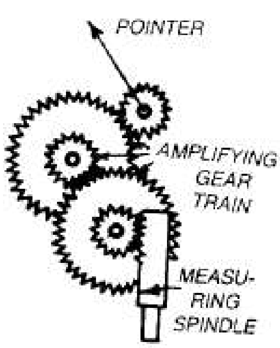


Fig1-a. rack and pinion

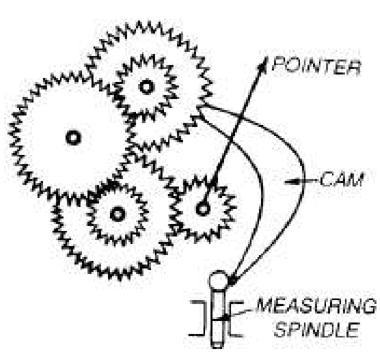


Fig 1-b. cam and gear train

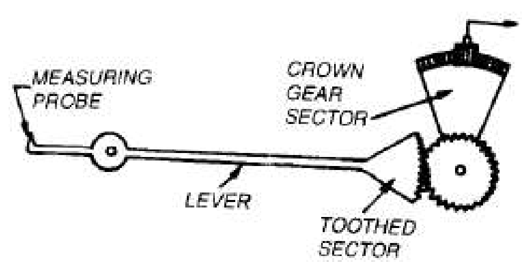


Fig1-c. lever with toothed gear.

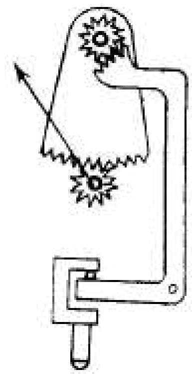


Fig1-d. compound levers.

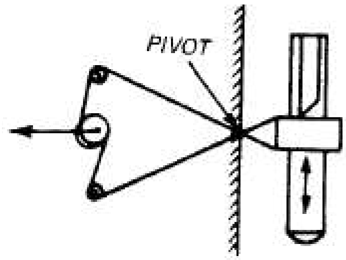


Fig1-f. lever combined with band wound around drum.

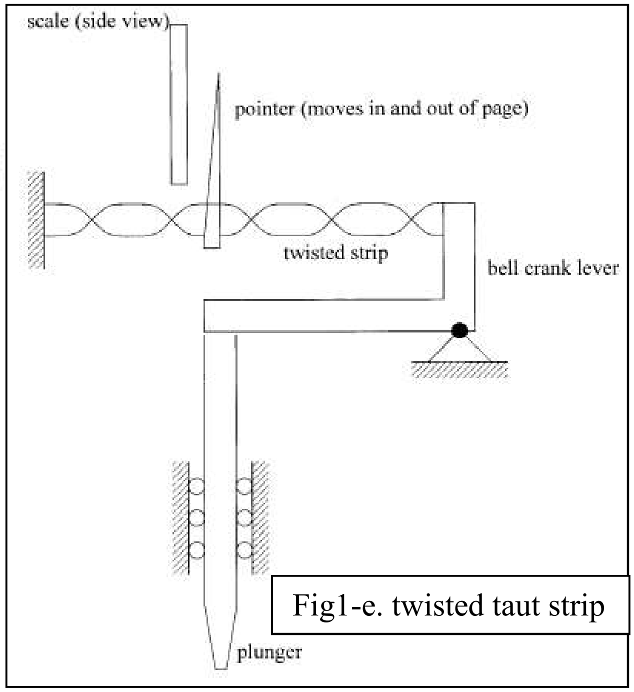


Fig1-e. twisted taut strip

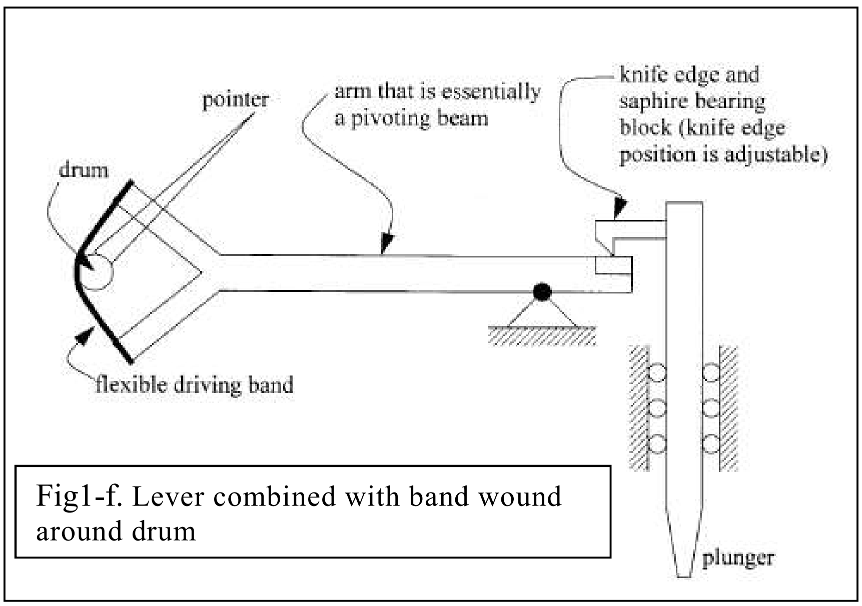


Fig1-f. Lever combined with band wound around drum

Advantages of Mechanical Comparators

i. These are usually cheaper in comparison to other devices of amplifying.
ii. These do not require any external supply such as electricity or air and as such the variations in outside supplies do not affect the accuracy.
iii. Usually the mechanical comparators have linear scale which is easily understood.
iv. These are usually robust and compact and easy to handle.
v. For ordinary workshop conditions, these are suitable and being portable can be issued from a store.

Disadvantages

i. The mechanical comparators have got more moving parts than other types. Due to more moving parts, the friction is more and ultimately the accuracy is less.
ii. Any slackness in moving parts reduces the accuracy considerably.
iii. The mechanism has more inertia and this may cause the instruments to be sensitive vibration.
iv. The range of the instrument is limited as the pointer moves over a fixed scale.
v. Error due to parallax is possible as the moving pointer moves over a fixed scale.

2-Mechanical Optical Comparators

In mechanical optical comparators small displacements of the measuring plunger are amplified first by a mechanical system consisting of pivoted levers. The amplified mechanical movement is further amplified by a simple optical system involving the projection of an image. The usual arrangement employed is such that the mechanical system causes a plane reflector to tilt about an axis and the image of an index is projected on a scale on the inner surface of a ground-glass screen. Optical magnifications provide high degree of measuring precision due to reduction of moving members and better wear resistance qualities. Optical magnification is also free from friction, bending, wear etc.

The whole system could be explained diagrammatically by (fig 2-a,b) which gives very simple arrangement and explains the principle of above comparator.

In this system, Mechanical amplification
= 20 /1 ,

And, Optical amplification

50 /1* x *2

It is multiplied by **2**, because if mirror is tilted by an angle **δθ**, then image will be tilted by **2 x δθ**. Thus overall magnification of this system
= 2* x *(20/1) (50/1 =2000 units)

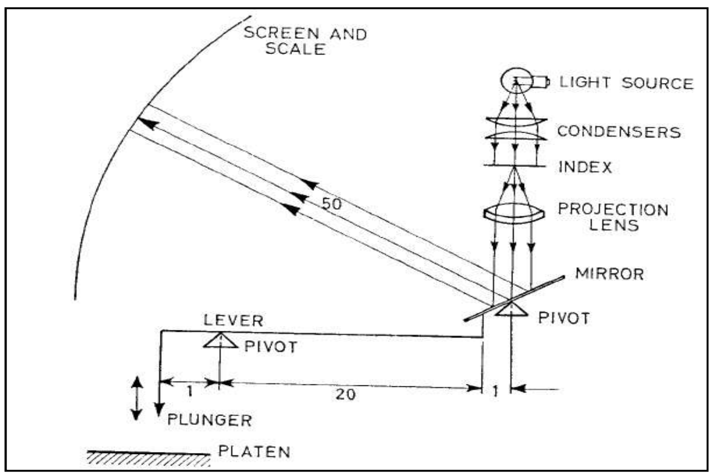


Fig 2-a. principles of Optical Comparator.

Thus it is obvious that optical comparators are capable of giving a high degree of measuring precision owing to high magnification and the reduction of moving members to minimum. Further these possess better wear resistance qualities as the only wearing members are the plunger and its guide and the mirror pivot bearing. Another advantage of the optical comparators is that provision of an illuminated scale enables readings to be taken without regard to the room lighting conditions. The point of importance in optical comparator is that mirror used must be of front reflection type and not normal back reflection type. In normal back reflection type there are two reflected images, one each from front and back. Thus the reflected image is not well defined one, as one bright and other blurred image are observed. If front reflection type of mirror is used, then it requires considerable care in its use to avoid damage to the reflecting surfaces.

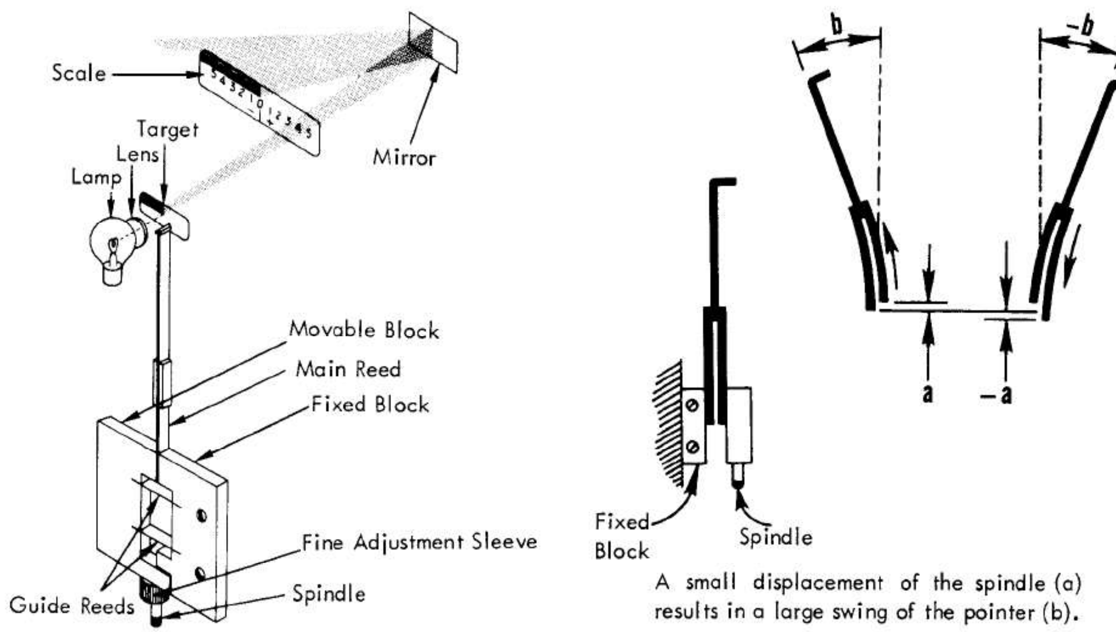


Fig 2-b. an optical lever is used to amplify the reed action. In the actual instrument, the optical path is longer than is shown here and a prism is used instead of a mirror.

Advantages of Optical Comparators:

i. It has small number of moving parts and hence a higher accuracy.
ii. In the optical comparators, the scale can be made to move past a datum line and thus have high range and no parallax errors.
iii. It has very high magnification.
iv. Optical lever is weightless.

Disadvantages:

i. As the instrument has high magnification, heat from the lamp, transformer etc. may cause the setting to drift.
ii. An electrical supply is necessary.
iii. The apparatus is usually large and expensive.
iv. When the scale is projected on a screen, then it is essential to use the instrument in a dark room in order to take the readings easily.
v. The instruments in which the scale is viewed through the eyepiece of a microscope are not convenient for continuous use.

3. Electrical and Electronic Comparators:

These comparators depend for their operation on Wheatstone bridge circuit. In d.c. circuit, a change of balance of the electrical resistance in each arm of the bridge is caused by the displacement of an armature relative to the arm under the action of the measuring plunger. Once out of balance is caused in the bridge, it is measured by a galvanometer graduated to road in units of linear movement of plunger. This circuit is operated by battery. For the bridge to balance, the ratios of the resistances in two arms must be equal.

If alternating current is applied to the bridge, the inductance and capacitance of the arms must also be accounted for along with resistance. In actual measuring instruments, one pair of inductances is formed by a pair of coils in the measuring head of the instrument. The movement of the plunger displaces an armature, thus causing a variation in the inductance of a pair of coils forming one arm of a.c. bridge. The arm carries the armature (Fig. 3-a) and the inductance in the coils is dependent upon the displacement of the armature relative to the coils. There are other refinements in actual instrument such as an electrical method of zero adjusting and a switch to change the magnification. The amount of unbalance caused by movement of measuring plunger is amplified and shown on a linear scale. Magnifications of the order of x 30,000 are possible with this system. Commonly used instruments are Electrichek, Electricator, Electrigage, Electrolimit and Electronic Measuring Equipment.

Electrical Comparators:

Electrical comparators are also known as electromechanical measuring systems as these employ an electro-mechanical device which converts a mechanical displacement into electrical signal.fig3-a.

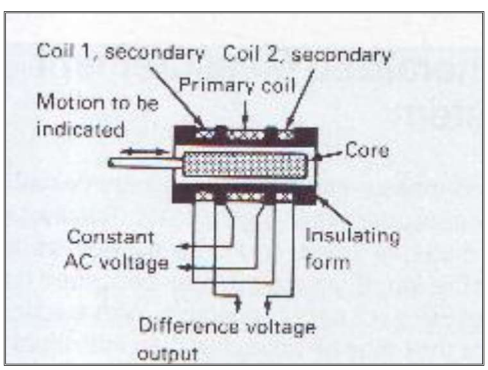


Fig3-a.

This is a LVDT (Linear- Variable-Differential Transformer). Linear movement of the core changes the Impedance. The electrical output changes in proportion to the core movement.

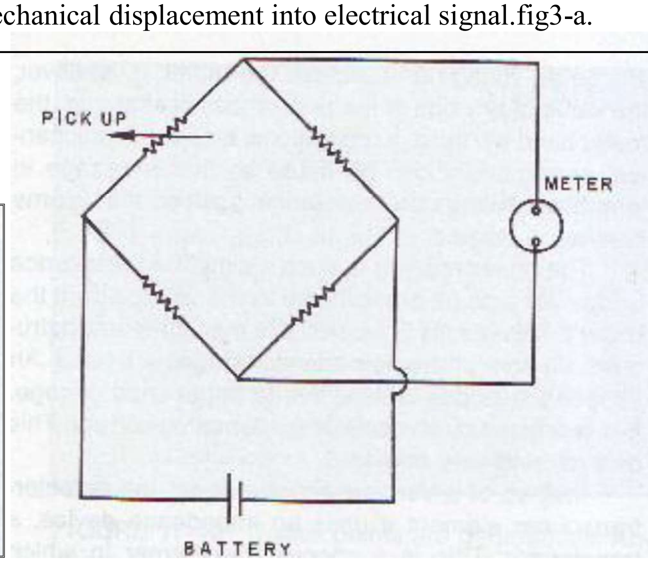


Fig.3-b.

This simplified bridge circuit is similar to those used in electronic comparators.

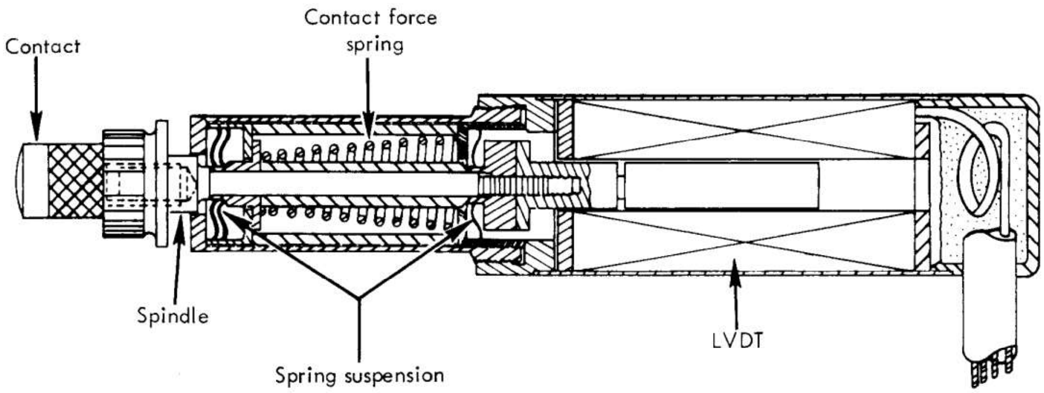


FIGURE 11–24 Frictionless gage heads use flexure springs to support the moving parts. They are used when the highest precision is required. The cylindrical type (bottom) has the same size mounting stem as dial indicators. This makes it interchangeable in indicator setups. However, these may not have the other features needed to utilize fully the capability of the frictionless heads.

Advantages of Electrical Comparators:

i. The electrical comparators have got small number of moving parts.
ii. It is possible to have a very high magnification and the same instrument may have two or more magnifications. Thus the same instrument can be used for various ranges.
iii. The mechanism carrying the pointer is very light and not sensitive to vibrations.
iv. As the instrument is usually operated on A.C. supply, the cyclic vibration substantially reduces errors due to sliding friction.
v. The measuring unit can be made very small and it is not necessary that the indicating instrument be close to the measuring unit, rather it can be remote also.

Disadvantages:

i. It requires an external agency to operate i.e., the A.C. electrical supply. Thus the variations in voltage or frequency of electric supply may affect the accuracy.
ii. Heating of coils in the measuring unit may cause zero drift and alter the calibration.
iii. If only a fixed scale is used with a moving pointer then with high magnifications a very small range is obtained.
iv. This is usually more expensive than mechanical instrument.

4- Pneumatic Comparators

Air gauging has rapidly increased during some past time due to the following important characteristics.

i. Very high amplifications are possible. It can be used to measure diameters, length, squareness, parallelism, and concentricity, taper, centre distance between holes and other geometric conditions.
ii. As no physical contact is made either with the setting gauge or the part being measured, there is no loss of accuracy because of gauge wear. For this reason, air spindle and air snap gauges last very long. Also very soft parts which are easily scratched can be gauged.
iii. Internal dimensions can be readily measured not only with respect to tolerance boundaries but also geometric form. In other words, while measuring a bore it can reveal complete story

of size, taper, straightness, camber and bell mouth etc.

iv. It is independent of operator skill.

v. High pressure air gauging can be done with cleansing of the parts which helps to eliminate errors due to dirt and foreign matter.

vi. Gauging pressures can be kept sufficiently low to prevent part deflection.
(In general, high pressure gauges are suitable for those parts in which tolerances are relatively large and low pressure air gauges are preferable for highly precise work.)

vii. Dimensional variations throughout the length of shaft or cylinder bore can be explored for out of roundness, taperness, concentricity, regularity and similar conditions.

viii. Not only it measures the actual size, but it can also be used to salvage oversized pieces for rework or to sort out for selective assembly, i.e., it is suitable both for variable inspection (measurement of size) and attribute inspection (GO and NO GO) gauging and limits.

ix. The total life cost of the gauging heads in much less.

x. It is accurate, flexible, reliable, universal and speedy device for inspecting parts in mass production.

xi. It is best suited for checking multiple dimensions and conditions on a part simultaneously in least possible time. It can be used for parts from 0.5 mm to 900 mm diameter having tolerance of 0.05 mm or less. It can be easily used for on line measurement of parts as they are being machined and take corrective actions.

Systems of Pneumatic Gauges:

Based on the physical phenomena on which the operation of pneumatic gauges is based, these may be classified as:

i. Flow or velocity type,

ii. Back pressure type.

Flow or velocity type pneumatic gauges operate ***by sensing and indicating the momentary rate of air flow***. Flow could be sensed by a glass tube with tapered bore, mounted over a graduated scale. Inside the bore a float is lifted by the air flow.

i. Free Flow Air Gauges:

(Flow or velocity type): In this case the compressed air after the filtering and pressure reducing unit flows through a tapered glass tube containing a small metal float and then through a plastic tube to the gauge head having two diametrically opposed orifices for air escapement into atmosphere .The position of the tube is dependent upon the amount of air flowing through the gauge head, which in turn is dependent upon the clearance between the bore to be measured and the gauge head.

The flow velocity type pneumatic comparator with zero adjustment and magnification adjustment is shown in **Fig. 4-a**. Magnification can be changed by passing some of the air supply, using a screw at the inlet to the tapered glass tube. The float can be zeroed by a bleed valve installed at the top of the tube. Size is measured by the velocity of air in a tapered glass tube which is measured by the height of the float in tube.

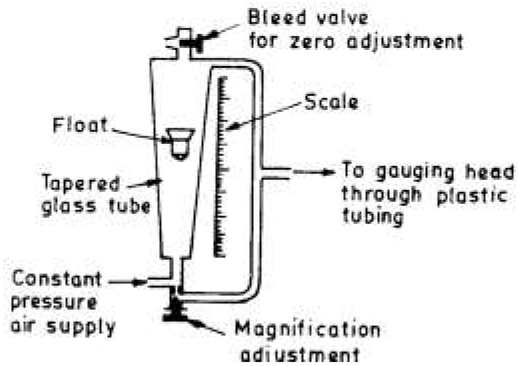


Fig 4-a. zero and magnification adjustment
in flow type of pneumatic comparator.

It is possible to read accurately up to microns depending upon scale length, or classify the sizes quickly and accurately. The amplification can be changed by quick change of tube, float and scale. Air gauge amplification and range are based on the tooling and instrument standards of manufacturer. The amplification and instrument are selected by considering the total tolerance spread and choosing the instrument that covers the range. About 50 to 100 mm of column is usually allowed for the actual tolerance spread.

In the gauging head, the air escapement orifices are recessed below its cylindrical surface so that the orifices never contact the part being gauged. Thus the surface wear will not affect the accuracy till it is worn down to orifice level. Also the orientation of gauge or the way operator holds the gauge is of no consequence and same readings will be obtained for given diameter. On the gauge, knobs are also provided for adjusting float position and calibration. Air gauge is set by placing masters for maximum and minimum tolerances on spindle alternatively and adjusting the float position for each master by turning the knurled knobs at the base of the instrument.

Free-flow column type gauges are usually assembled together side by side and thus multiple interrelated readings can be seen at a glance. This is the big ***advantage*** of air gauging that the multiple dimensions and conditions can be inspected with great ease, accuracy and speed.

Pneumatic circuits can be arranged to determine dimensional differences like taper (comprising the diameter of bore at different points along a part), bore centre distance and also to select parts to assemble to predetermined clearances or interference fits.

ii. Back Pressure Gauges: The air pressure variation system is based on the use of a two-orifice arrangement, as shown in **Fig. 4-b**. Air is passed at controlled pressure into the measuring head, and provides the source pressure, P_s. It passes through the control orifice O_1 into the intermediate chamber. Orifice O_1 is of constant size, but the effective size of O_2 may be varied by the distance ***d***. *As* ***d*** varies, pressure P_b also changes, and thus provides a measure of dimension ***d***. Thus the indicating device is a pressure gauge or manometer recording the pressure P_b between the orifices.

By suitably matching the diameters of O_1, and O_2 and controlling P_s, the pressure at P_b may be made to vary linearly with the effective size of O_2, over a limited portion of the curve obtained by plotting the relationship of the ratios A_2 / A_1, and P_b / P_s as shown in **Fig. 4-c**, where A_1 and A_2 are the areas of orifices O_1, and O_2 respectively.

For values of P_b / P_s between approximately ***0•6*** and ***0•8,*** the curve is linear within ***1 %,*** and it is these values that are used in the design of such comparators for the relative diameters of orifices.

If we consider the linear portion of the curve, i.e. between the values of ***0•6*** and ***0•8*** for P_b / P_s its law may be written as:

$$\frac{P_b}{P_s} = a - \frac{bA_2}{A_1}$$

The pneumatic magnification is proportional to the input pressure, and inversely proportional to the area, or the square of the diameter, of the control orifice.

It is clear that an essential operating requirement is that pressure P_s is constant. It is thus necessary to have a simple pressure regulator controlling the pressure of the air from the normal supply line, and if necessary reducing it from about ***55 N/cm²*** ***to 1 N/cm²***. **Fig. 4-c** shows the circuit diagram of the instrument produced by Solex Air Gauges Ltd., the instrument being arranged for internal measurement.

The air from its normal source of supply, say the factory air line, is filtered, and passes through a flow valve. Its pressure is then reduced and maintained at a constant value by a dip tube into a water chamber, the pressure value being determined by the head of the water displaced, excess air escaping to atmosphere.

The air at reduced pressure then passes through the control orifice, and escapes from the measuring orifice. The ***back pressure*** in the circuit is indicated by the head of water displaced in the monometer tube. The tube is graduated linearly to show changes of pressure resulting from changes in dimension ***d***, **Fig. 4-b**. Amplifications of up to **50 000** are obtainable with this system.

Another back-pressure comparator is produced by **Mercer Air Gauges Ltd**., but this operates at the much higher pressure of ***27•5 N/cm²*** gauge. The constant pressure input is produced from the line pressure by a diaphragm type regulator and passed to the control orifice and thence to the measuring orifice.

Interesting features are:

(a) ***Magnification adjustment***. It has been shown that the magnification can be varied by varying the diameter of the control orifice. This is achieved by means of a taper-needle valve in the control orifice and enables a single scale to be used for all work by adjusting the magnification and zero settings.

(b) ***Zero adjustment***. An air bleed, upstream of the measuring orifice and controlled by a taper-needle valve, provides a zero adjustment.

The pressure measuring device is a Bourdon tube type pressure gauge, the dial being graduated in linear units, i.e. ***0•01 mm, 0•001 mm***, or inch units.

As with all other comparators, initial setting is by means of reference gauges. In this case, it is important that the reference gauges, and the part being measured, are of the same geometric form. For example, slip gauges are applicable as setting gauges for flat work pieces, while circular section work requires the use of cylindrical setting gauges. For work of the type shown in ***Fig. 4-d***, a pair of reference ring gauges is necessary for setting purposes. If this precaution is not taken, the expansion characteristics of the air escaping from the measuring orifice, O_2, are changed and affect the accuracy of pressure readings on the manometer tube.

A possible disadvantage of the back-pressure type of instrument is its relatively slow speed of response under some conditions of use. It is clear that as the volume of air in the system increases, its response to changes of pressure will, due to its compressibility, be reduced. This characteristic is of no great concern when the total length of the circuit is short, but in applications to dimensional control in the operation of machine tools for example, this length may be considerable, and give rise to passivity.

The basic back- pressure system shows changes in the gauging pressure in respect to atmospheric pressure. There is no control over the later. In the balanced system ***Fig.4-e*** the changes in the measuring channel pressure are shown in respect to the reference channel pressure. Both channels are subject to careful control by the restrictors.

By these means some of the difficulties with back- pressure systems are eliminated and some desirable features obtained. Unlike the other systems, this one requires only one master and one adjustment, zero setting.

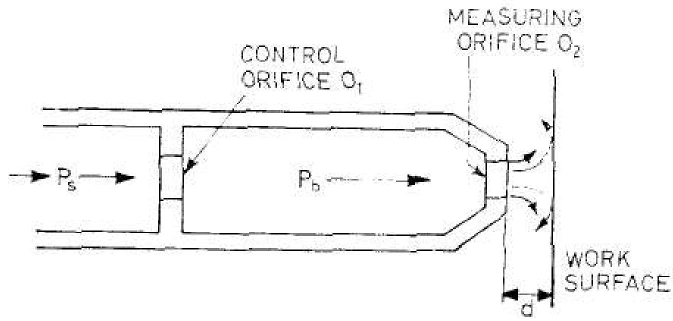


Fig.4-b. Essentials of a back- pressure pneumatic gauging system.

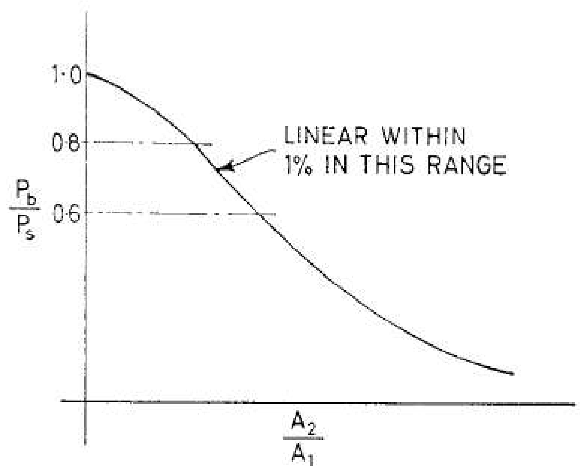


Fig.4-c. Characteristic curve of back- pressure

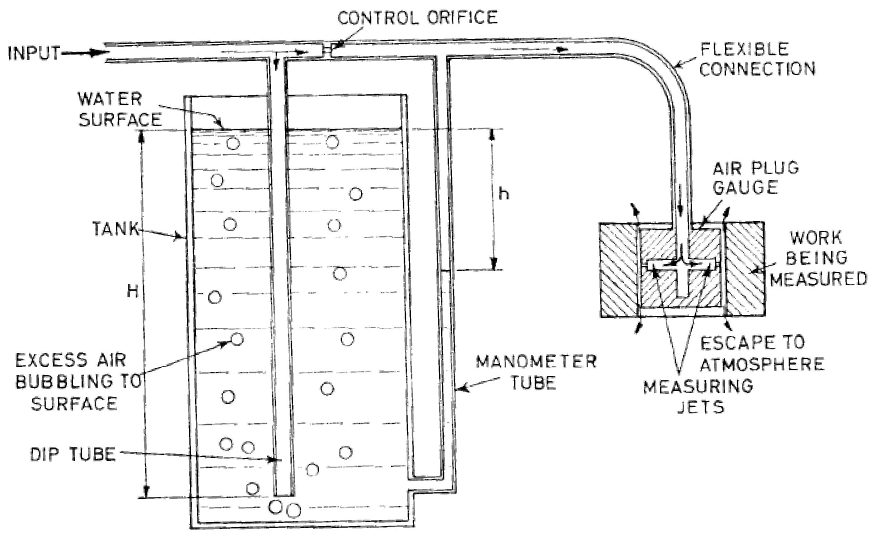


Fig.4-d. Application of back- pressure air gauging system used by Solex Air Gauging Ltd.

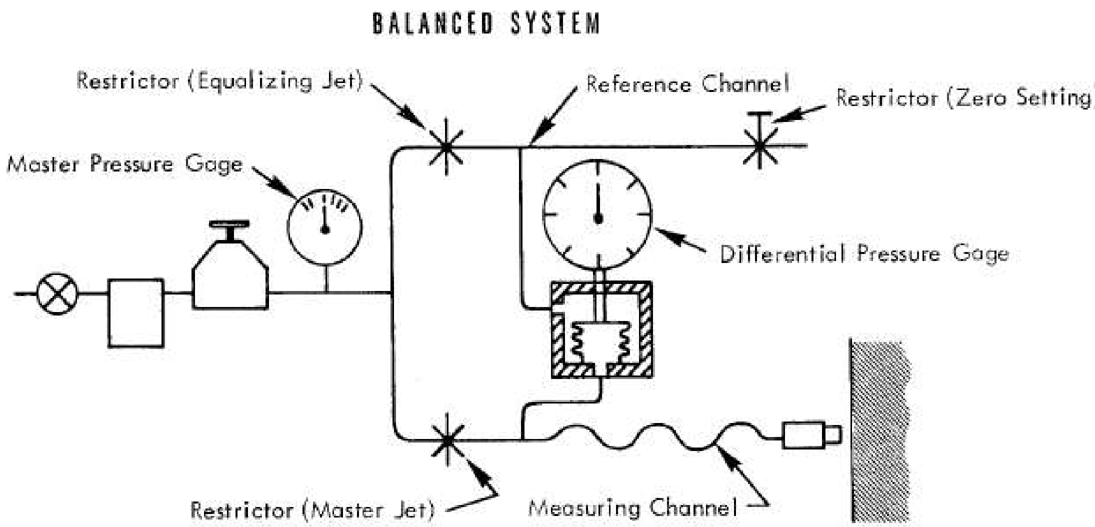


Fig.4-e. The balanced system has fixed amplification. The only adjustment is zero setting.

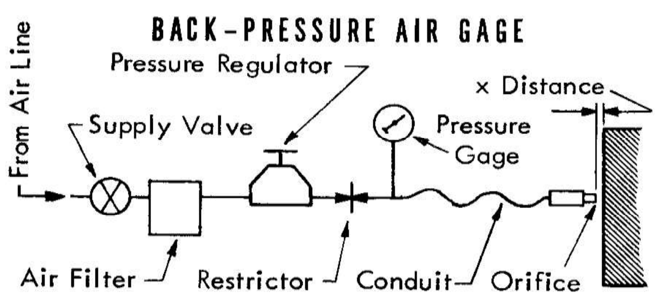


FIGURE 12–3 In the basic back-pressure air gage, a change in x alters the conduit pressure and is read on the pressure gage.

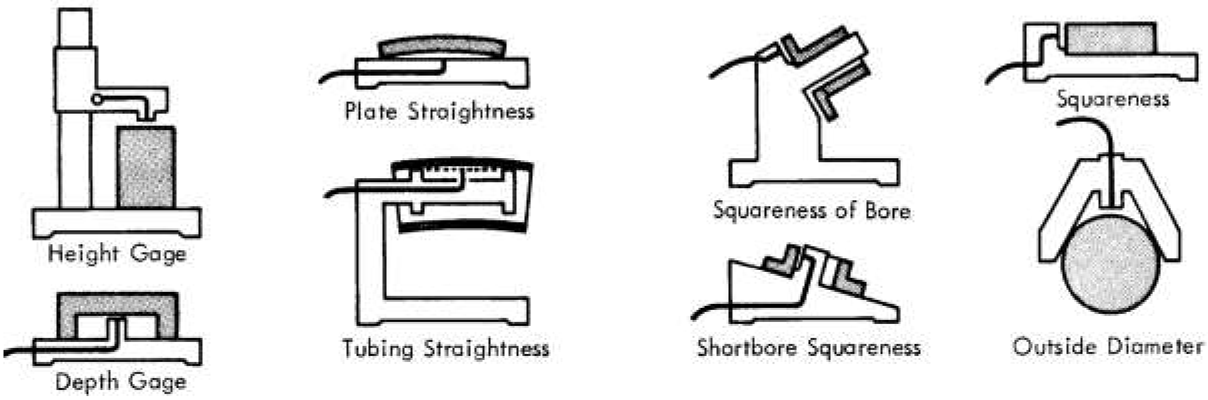


FIGURE 12–13 Single jet nozzles form the basic gaging element as in these examples.

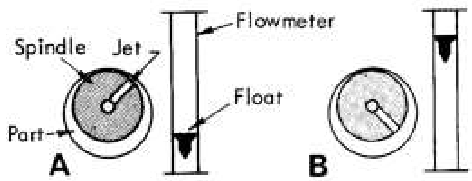


FIGURE 12–14 Rotation of the single jet spindle changes the height of the float.

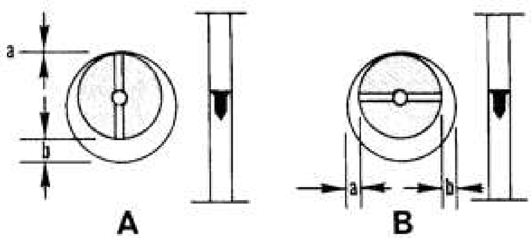


FIGURE 12–15 With opposite jets, rotation of spindle does not change float height because the sum a + b equals x for any position.

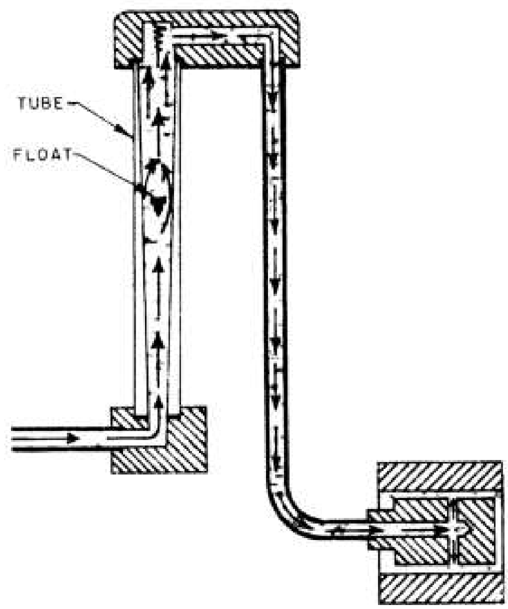


FIGURE 12–16 Cross section of typical spindle for the measurement of inside diameters.

Advantages of Pneumatic Comparators:

i. The gauging member does not come into contact with the part to be measured and hence practically no wear takes place on the gauging member.
ii. It has usually very small number of moving parts and in some cases none. Thus the accuracy is more due to less friction and less inertia.
iii. Measuring pressure is very small and the jet of air helps in cleaning the dust, if any, from the part to be measured.
iv. It is possible to have very high magnification.
v. The indicating instrument can be remote from the measuring unit.
vi. It is very suitable device for measuring diameter of holes where the diameter is small compared with the length.
vii. It is probably the best method for determining the ovality and taperness of the circular bores.

Disadvantages:

i. It requires elaborate auxiliary equipment such as accurate pressure regulator.
ii. The scale is generally not uniform.
iii. When indicating device is the glass tube, then high magnification is necessary in order to avoid the meniscus errors.
iv. The apparatus is not easily portable and is rather elaborate for many industrial applications.
v. Different gauging heads are required for different dimensions.