Module 1

STANDARDS OF MEASUREMENT

DEFINITION OF METROLOGY:

Metrology (from Ancient Greek metron (measure) and logos (study of)) is the science of measurement. Metrology includes all theoretical and practical aspects of measurement. Metrology is concerned with the establishment, reproduction, conservation and transfer of units of measurement & their standards. For engineering purposes, metrology is restricted to measurements of length and angle & quantities which are expressed in linear or angular terms. Measurement is a process of comparing quantitatively an unknown magnitude with a predefined standard.

OBJECTIVES OF METROLOGY:

The basic objectives of metrology are;

1. To provide accuracy at minimum cost.
2. Thorough evaluation of newly developed products, and to ensure that components are within the specified dimensions.
3. To determine the process capabilities.
4. To assess the measuring instrument capabilities and ensure that they are adequate for their specific measurements.
5. To reduce the cost of inspection & rejections and rework.
6. To standardize measuring methods.
7. To maintain the accuracy of measurements through periodical calibration of the instruments.
8. To prepare designs for gauges and special inspection fixtures.

NEED OF INSPECTION:

The need of inspection can be summarized as:

1. To ensure that the part, material or a component conforms to the established standard.
2. To meet the interchangeability of manufacture.
3. To maintain customer relation by ensuring that no faulty product reaches the customers.

4. Provide the means of finding out shortcomings in manufacture. The results of inspection are not only recorded but forwarded to the manufacturing department for taking necessary steps, so as to produce acceptable parts and reduce scrap.
5. It also helps to purchase good quality of raw materials, tools, equipment which governs the quality of the finished products.
6. It also helps to co-ordinate the functions of quality control, production, purchasing and other departments of the organization.

To take decision on the defective parts i.e., to judge the possibility of making some of these parts acceptable after minor repairs.

REQUIREMENTS OF MEASUREMENTS:

If the result of measurements has to be meaningful, then the following two important conditions must be satisfied:

1. The standard used for comparison must be accurately accepted known and commonly accepted.

   For example: a length cannot be simply said it is too long but it must be said it is comparatively longer than some standard.
2. The procedure and the apparatus used for comparison must be commonly accepted and must be provable.

METHODS OF MEASUREMENTS

These are the methods of comparison used in measurement process. In precision measurement various methods of measurement are adopted depending upon the accuracy required and the amount of permissible error.

The methods of measurement can be classified as:

l. Direct method

2. Indirect method

1. Direct method of measurement:

This is a simple method of measurement, in which the value of the quantity to be measured is obtained directly without any calculations. For example, measurements by using scales, vernier callipers, micrometers, bevel protector etc. This method is most widely used in production. This method is not very accurate because it depends on human insensitiveness in making judgment.

2. Indirect method of measurement:

In indirect method the value of quantity to be measured is obtained by measuring other quantities which are functionally related to the required value. E.g. Angle measurement by sine bar, measurement of screw pitch diameter by three wire method etc.

LEAST COUNT:

In Metrology the least count of an instrument is the smallest change in the value that can be measured with the measuring instrument.

A Vernier scale on caliper may have a **least count** of 0.02 mm while a **micrometer** may have a **least count** of 0.01 mm.

The least count error occurs with both systematic and random errors. Instruments of higher precision can reduce the least count error. By repeating the observations and taking the arithmetic mean of the result, the mean value would be very close to the true value of the measured quantity.

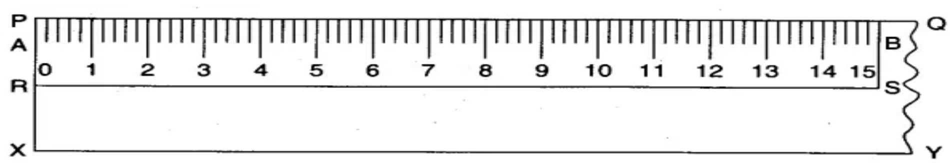


Fig. A. Scale of least count 0.2 cm.

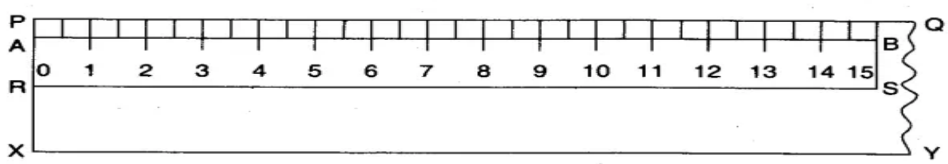
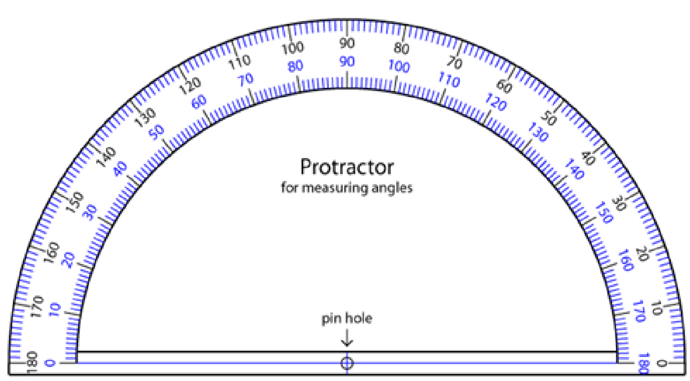


Fig. B. Scale of least count 0.5 cm.



ACCURACY

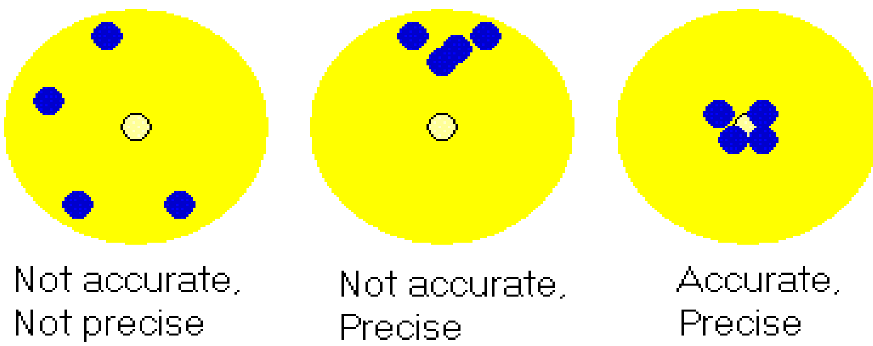
- The closeness of a measured value to the actual value of the object being measured is called as the accuracy of a substance. For instance, if in lab you obtain a weight measurement of 3.2 kg for a given substance, but the actual or known weight is 10 kg, then your measurement is not accurate.
- Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement.
- It is practically difficult to measure exactly the true value and therefore a set of observations is made whose mean value is taken as the true value of the quality measured.

PRECISION

- The closeness of two or more measurements to each other is known as the precision of a substance. From the above-given example, we can figure out that, if you weigh a given substance five times, and get 3.2 kg each time, then your measurement is very precise. Precision is independent of accuracy.
- The terms precision and accuracy are used in connection with the performance of the instrument.
- Precision is the repeatability of the measuring process.
- It refers to the group of measurements for the same characteristics taken under identical conditions.
- It indicates to what extent the identically performed measurements agree with each other. If the instrument is not precise it will give different (widely varying) results for the same dimension when measured again and again. The set of observations will scatter about the mean. The scatter of these measurements is designated as 0, the standard deviation. It is used as an index of precision. The less the scattering more precise is the instrument. Thus, lower, the value of 0, the more precise is the instrument.

DIFFERENCE BETWEEN ACCURACY AND PRECISION:

Sl No	Accuracy	Precision
1	Accuracy indicates how close a measurement is to be correct or accepted value	Precision indicates the closeness of two or more measurements to each other
2	the measurement will be close to the standard measurement	The measurement will be similar every time you measure.
3	Accuracy can be improved	Precise cannot be improved
4	Accuracy is not dependent on precision	Precision is not dependent on accuracy.



ERRORS IN MEASUREMENT

It is never possible to measure the true value of a dimension, there is always some error. The error in measurement is the difference between the measured value and the true value of the measured dimension.

Error in measurement =Measured value - True value.

TYPES OF ERRORS

1. Gross Errors

This category of errors includes all the human mistakes while reading, recording and the readings. Mistakes in calculating the errors also come under this category. For example while taking the reading from the meter of the instrument he may read 21 as 31. All these types of error are come under this category.

Gross errors can be avoided by using two suitable measures and they are written below:

- A proper care should be taken in reading, recording the data. Also calculation of error should be done accurately.

- By increasing the number of experimenters we can reduce the gross errors. If each experimenter takes different reading at different points, then by taking average of more readings we can reduce the gross errors.

2. Systematic Errors

Errors which occur due to changes in environment conditions, instrumental reasons or wrong observations. These errors are of three types

- Instrumental Errors
- Environmental Errors
- Observational Errors

Instrumental Errors:

These errors occur due to shortcomings in the instruments, improper use of instruments or loading effect of the instrument. Sometimes improper construction, calibration or operation of an instrument might result in some inherent errors. For example, weak spring in a Permanent Magnet Instrument might result in too high readings. These errors can be easily detected or reduced by applying correction factors, careful planning of measurement procedure or re-calibrating the instrument.

Environmental Errors

This type of error arises due to conditions external to the instrument. External condition includes temperature, pressure, humidity or it may include external magnetic field. Following are the steps that one must follow in order to minimize the environmental errors:

- Try to maintain the temperature and humidity of the laboratory constant by making some arrangements.
- Ensure that there should not be any external magnetic or electrostatic field around the instrument.

Observational Errors

- These errors occur due to a mismatch between a line of vision of the observer and the pointer above the instrument scale. This is also termed as Parallax error which occurs when the observer is unable to have a vision aligned with the pointer.
- These errors can be minimized by using highly accurate meters (having the pointer and scale on the same plane).

- Since they occur on Analog instruments, using digital display can eliminate these errors.

3. Random Errors

After calculating all systematic errors, it is found that there are still some errors in measurement are left. These errors are known as random errors. Some of the reasons of the appearance of these errors are known but still some reasons are unknown. Hence we cannot fully eliminate these **kinds of error**.

- Sources of these errors are not obvious and not easily figured.
- The error in measurement may be expressed or evaluated either as an absolute error or as a relative error.

DEFINITION OF STANDARDS:

A standard is defined as "something that is set up and established by an authority as rule of the measure of quantity, weight, extent, value or quality".

For example, a meter is a standard established by an international organization for measurement of length. Industry, commerce, international trade in modern civilization would be impossible without a good system of standards.

ROLE OF STANDARDS:

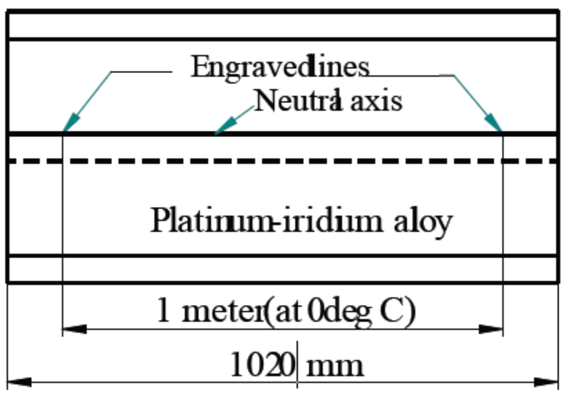
The role of standards is to achieve uniform, consistent and repeatable measurements throughout the world. Today our entire industrial economy is based on the interchangeability of parts the method of manufacture. To achieve this, a measuring system adequate to define the features to the accuracy required & the standards of sufficient accuracy to support the measuring system are necessary.

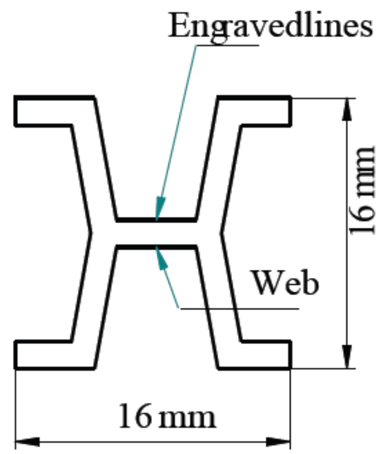
STANDARDS OF LENGTH

In practice, the accurate measurement must be made by comparison with a standard of known dimension and such a standard is called "Primary Standard". The first accurate standard was made in England and was known as "Imperial Standard yard" which was followed by International Prototype meter" made in France. Since these two standards of length were made of metal alloys they are called „material length standards".

INTERNATIONAL PROTOTYPE METER:

It is defined as the straight line distance, at 0oC, between the engraved lines of pure platinum-iridium alloy (90% platinum & 10% iridium) of 1020 mm total length and having a "tresca" cross section as shown in fig. The graduations are on the upper surface of the web which coincides with the neutral axis of the section.



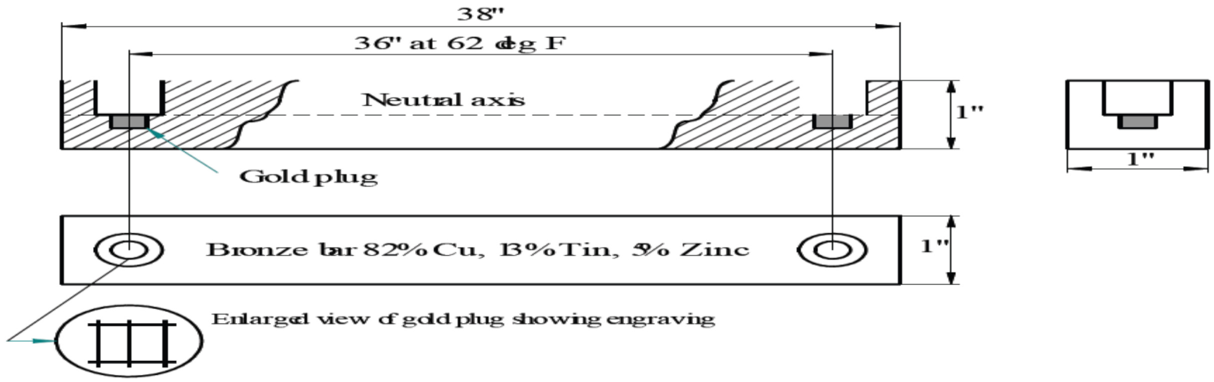


The tresca cross section gives greater rigidity for the amount of material involved and is therefore economic in the use of an expensive metal. The platinum-iridium alloy is used because it is non oxidizable and retains good polished surface required for engraving good quality lines.

IMPERIAL STANDARD YARD:

An imperial standard yard, shown in fig, is a bronze (82% Cu, 13% tin, 5% Zinc) bar of 1 inch square section and 38 inches long. A round recess, 1 inch away from the two ends is cut at both ends upto the central or „neutral plane" of the bar. Further, a small round recess of (1/10) inch in diameter is made below the center. Two gold plugs of (1/10) inch diameter having engravings are inserted into these holes so that the lines (engravings) are in neutral plane.

Yard is defined as the distance between the two central transverse lines of the gold plug at 620F. The purpose of keeping the gold plugs in line with the neutral axis is to ensure that the neutral axis remains unaffected due to bending, and to protect the gold plugs from accidental damage.



Bronze Yard was the official standard of length for the United States between 1855 and 1892, when the US went to metric standards. 1 yard = 0.9144 meter.

The yard is used as the standard unit of field-length measurement in American, Canadian and Association football, cricket pitch dimensions, swimming pools, and in some countries, golf fairway measurements.

DISADVANTAGES OF MATERIAL LENGTH STANDARDS:

1. Material length standards vary in length over the years owing to molecular changes in the alloy.
2. The exact replicas of material length standards were not available for use somewhere else.
3. If these standards are accidentally damaged or destroyed then exact copies could not be made.
4. Conversion factors have to be used for changing over to metric system.

LIGHT (OPTICAL) WAVE LENGTH STANDARD:

Because of the problems of variation in length of material length standards, the possibility of using light as a basic unit to define primary standard has been considered. The wavelength of a selected radiation of light and is used as the basic unit of length. Since the wavelength is not a physical one, it need not be preserved & can be easily reproducible without considerable error.

krypton-filled discharge tube in the shape of the element's atomic symbol. A colorless, odorless, tasteless noble gas, krypton occurs in trace amounts in the atmosphere, is isolated by fractionally distilling liquefied air. The high power and relative ease of operation of krypton discharge tubes caused (from 1960 to 1983) the official meter to be defined in terms of one orange-red spectral line of krypton-86.

METER AS ON TODAY:

In 1983, the 17th general conference on weights & measure proposed the use of speed of light as a technically feasible & practicable definition of meter.

“Meter is now defined as the length of path of travelled by light in vacuum in (1/ 299792458) second”. The light used is iodine stabilized helium-neon laser.

ADVANTAGES OF USING WAVE LENGTH STANDARDS:

1. Length does not change.
2. It can be easily reproduced easily if destroyed.
3. This primary unit is easily accessible to any physical laboratories.
4. It can be used for making measurements with much higher accuracy than material standards.
5. Wavelength standard can be reproduced consistently at any time and at any place.

SUBDIVISION OF STANDARDS:

The imperial standard yard and the international prototype meter are master standards & cannot be used for ordinary purposes. Thus based upon the accuracy required, the standards are subdivided into four grades namely;

1. Primary Standards
2. Secondary standards
3. Tertiary standards
4. Working standards

Primary standards: They are material standard preserved under most careful conditions. These are not used for directly for measurements but are used once in 10 or 20 years for calibrating secondary standards. Ex: International Prototype meter, Imperial Standard yard.

Secondary standards: These are close copies of primary standards w.r.t design, material & length. Any error existing in these standards is recorded by comparison with primary standards after long intervals. They are kept at a number of places under great supervision and serve as reference for tertiary standards. This also acts as safeguard against the loss or destruction of primary standards.

Tertiary standards: The primary or secondary standards exist as the ultimate controls for reference at rare intervals. Tertiary standards are the reference standards employed by National Physical laboratory (N.P.L) and are the first standards to be used for reference in laboratories & workshops. They are made as close copies of secondary standards & are kept as reference for comparison with working standards.

Working standards: These standards are similar in design to primary, secondary & tertiary standards. But being less in cost and are made of low grade materials, they are used for general applications in metrology laboratories.

Sometimes, standards are also classified as;

• Reference standards (used as reference purposes)
• Calibration standards (used for calibration of inspection & working standards)
• Inspection standards (used by inspectors)
• Working standards (used by operators).

LINE STANDARDS

When the length being measured is expressed as the distance between two lines, then it is called "Line Standard". Examples: Measuring scales, Imperial standard yard, International prototype meter, etc.

Characteristics of Line Standards:

1. Scales can be accurately engraved but it is difficult to take the full advantage of this accuracy. Ex: A steel rule can be read to about ± 0.2 mm of true dimension.
2. A scale is quick and easy to use over a wide range of measurements.
3. The wear on the leading ends results in „under sizing‟.
4. A scale does not possess a „built in‟ datum which would allow easy scale alignment with the axis of measurement, this again results in „under sizing‟.
5. Scales are subjected to parallax effect, which is a source of both positive & negative reading errors‟.
6. Scales are not convenient for close tolerance length measurements except in conjunction with microscopes.

END STANDARDS

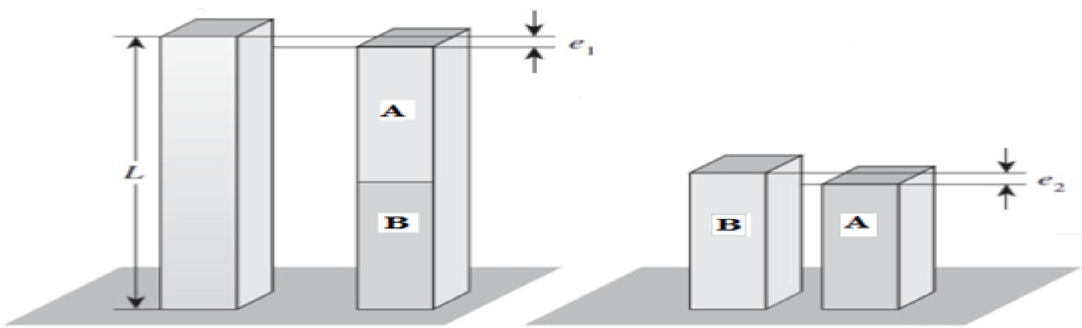
When the length being measured is expressed as the distance between two parallel faces, then it is called „End standard‟. End standards can be made to a very high degree of accuracy. Ex: Slip gauges, Gap gauges, Ends of micrometer anvils, etc.

Characteristics of End Standards:

1. End standards are highly accurate and are well suited for measurements of close tolerances as small as 0.0005 mm.
2. They are time consuming in use and prove only one dimension at a time.
3. End standards are subjected to wear on their measuring faces.
4. End standards have a „built in‟ datum, because their measuring faces are flat & parallel and can be positively located on a datum surface.
5. They are not subjected to the parallax effect since their use depends on "feel".
6. Groups of blocks may be "wrung" together to build up any length. But faulty wringing leads to damage.
7. The accuracy of both end & line standards are affected by temperature change.

CALIBRATION OF END BARS

The actual lengths of end bars can be found by wringing them together and comparing them with a calibrated standard using a level comparator and also individually comparing among themselves. This helps to set up a system of linear equations which can be solved to find the actual lengths of individual bars. The procedure is clearly explained in the forthcoming numerical problems.



b

The following procedure may be adopted for calibrating two end bars of each 500mm basic length.

A one meter (1000mm) calibrated bar is wrung to a surface plate and two 500mm bars (A & B) are wrung together to form a basic length of one meter, which is then wrung to a surface plate adjacent to a meter bar as shown in fig. the difference in height e1 or X1 is noted.

Then comparison is made between the two 500mm length bars A and B to determine the difference in length as shown in fig.

If $\mathbf{L_A}$=the length of 500mm length bar A

$\mathbf{L_B}$= the length of 500mm length bar B

$\mathbf{E_1/X_1}$ = difference between one meter length bar and the combined length of bars A & B.

$\mathbf{E_2/X_2}$ = difference in length between bar A & B.

L=Actual Length of one meter bar.

From fig a): $L \pm X1 = L_A + L_B$ ……… (1)

From fig b) : $L_B = L_A \pm X_2$ ……….(2)

Substituting eqn (2) in eqn (1),

$L \pm X1 = L_A + (L_A \pm X_2)$

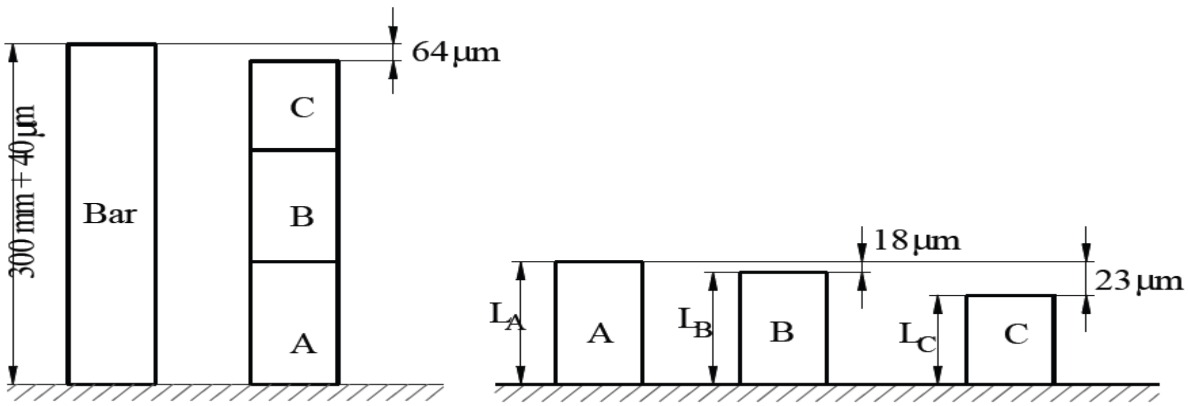
$= 2 L_A \pm X_2$

$$L_A = \frac{L \pm X1 \pm X2}{2} \quad \& \quad L_B = L_A \pm X_2$$

The above procedure can be used for calibrating any other number of length standards of the same basic size.

Numerical problem-1:

Three 100 mm end bars are measured on a level comparator by first wringing them together and comparing with a calibrated 300 mm bar which has a known error of +40µm. The three end bars together measure 64µm less than the 300 µm bar. Bar A is 18µm longer than bar B and 23µm longer than bar C. Find the actual length of each.



$L_A+L_B+L_C$ = 300mm + 40µm – 64µm

= 300mm -24 µm ………………….(1)

$L_A - L_B$ = 18 µm ………………... (2)

$L_A – L_C$ =23 µm ………………… (3)

Adding eqn (1), eqn (2) and eqn (3),

3 L_A = 300mm -24 µm+18 µm+23 µm

= 300mm + 17 µm

3 L_A = 300mm + 0.017 mm

L_A = 100.006 mm

From eqn (2), $L_A - L_B$ = 18 µm

100.006 - L_B = 0.018mm

L_B = 99.988 mm

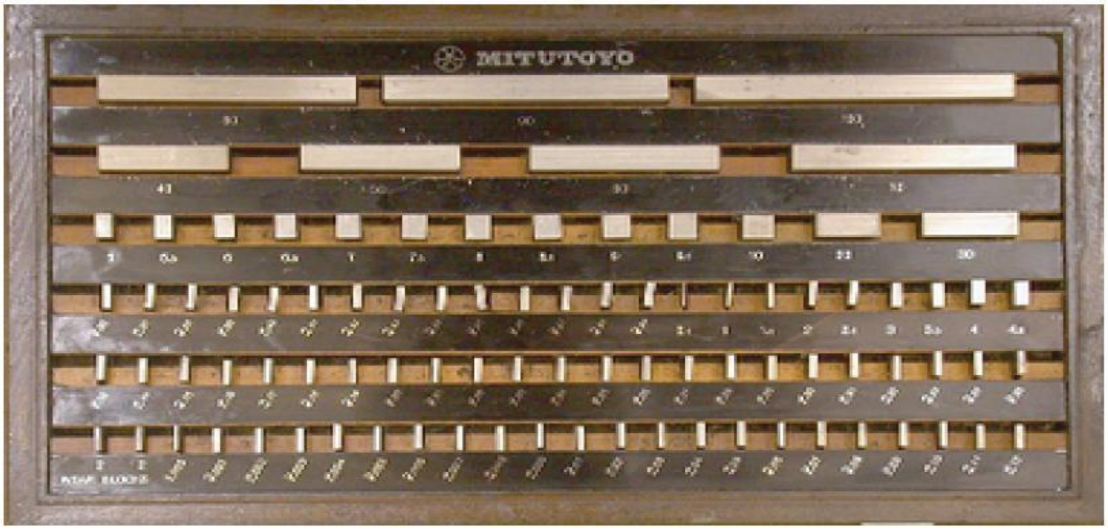
From eqn (3), $L_A – L_C$ =23 µm

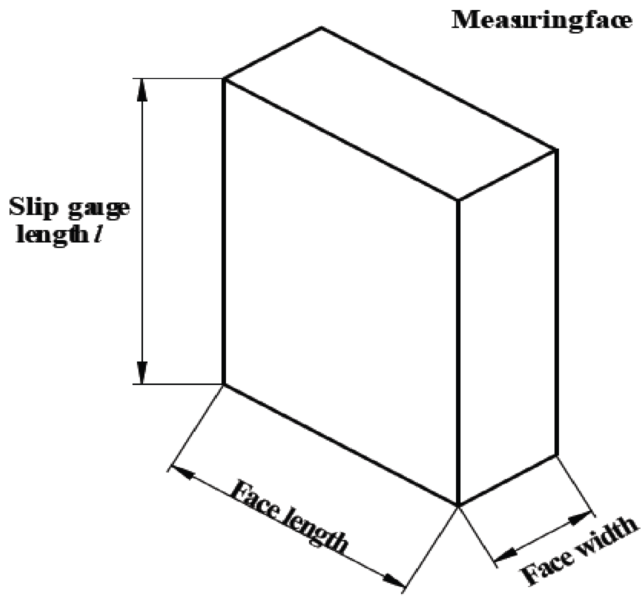
100.006 - L_C = 0.023 mm

L_C = 99.983 mm

SLIP GAUGES OR GAUGE BLOCKS (JOHANSSON GAUGES)

Slip gauges are rectangular blocks of steel having cross section of 30 mm face length & 10 mm face width as shown in fig.

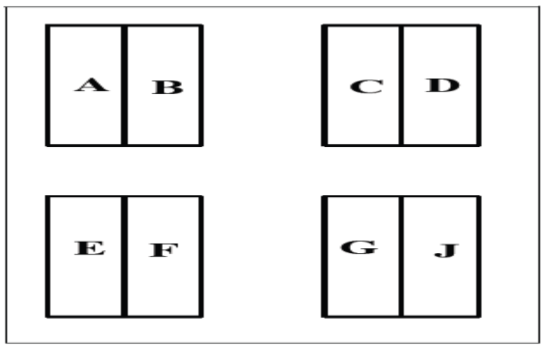


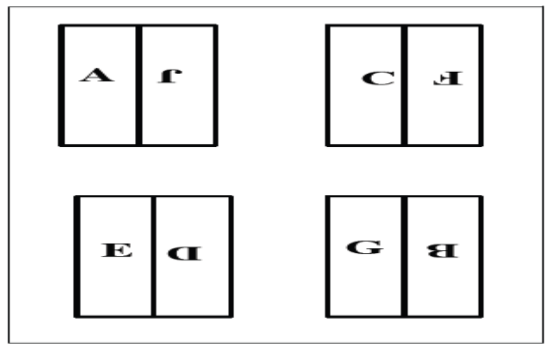


Slip gauges are blocks of steel that have been hardened and stabilized by heat treatment. They are ground and lapped to size to very high standards of accuracy and surface finish. A gauge block (also known Johansson gauge, slip gauge, or Jo block) is a precision length measuring standard consisting of a ground and lapped metal or ceramic block. Slip gauges were invented in 1896 by Swedish machinist Carl Edward Johansson.

Manufacture of Slip Gauges:

When correctly cleaned and wrung together, the individual slip gauges adhere to each other by molecular attraction and, if left like this for too long, a partial cold weld will take place. If this is allowed to occur, the gauging surface will be irreparable after use, hence the gauges should be separated carefully by sliding them apart. They should then be cleaned, smeared with petroleum jelly (Vaseline) and returned to their case.





Protector Slips:

In addition, some sets also contain protector slips that are 2.50mm thick and are made from a hard, wear resistant material such as tungsten carbide. These are added to the ends of the slip gauge stack to protect the other gauge blocks from wear. Allowance must be made of the thickness of the protector slips when they are used.

WRINGING OF SLIP GAUGES:

Slip gauges are wrung together to give a stack of the required dimension. In order to achieve the maximum accuracy the following precautions must be taken. • Use the minimum number of blocks. • Wipe the measuring faces clean using soft clean chamois leather. • Wring the individual blocks together by first pressing at right angles, sliding & then twisting.

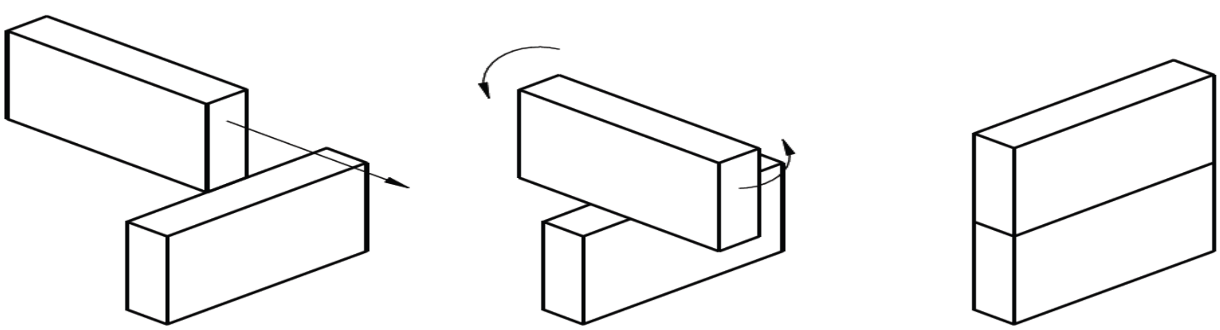


Fig: Wringing of Slip gauges

INDIAN STANDARD ON SLIP GAUGES (IS 2984-1966)

Slip gauges are graded according to their accuracy as Grade 0, Grade I & Grade II. Grade II is intended for use in workshops during actual production of components, tools & gauges. Grade I is of higher accuracy for use in inspection departments. Grade 0 is used in laboratories and standard rooms for periodic calibration of Grade I & Grade II gauges.

M-87 set of slip gauges:

Range (mm)	Steps (mm)	No. of pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9
1.0005	---	1
	Total	87

M-112 set of slip gauges:

Range (mm)	Steps (mm)	No. of pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 24.5	0.5	49
25,50,75,100	25	4
1.0005	---	1
	Total	112

Important notes on building of Slip Gauges:

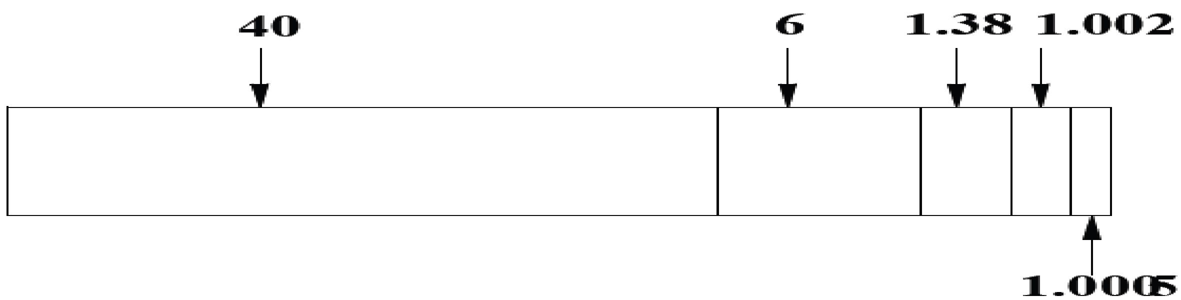
- Always start with the last decimal place.
- Then take the subsequent decimal places.
- Minimum number of slip gauges should be used by selecting the largest possible block in each step.
- If in case protector slips are used, first deduct their thickness from the required dimension then proceed as per above order.

Numerical problem-1

Build the following dimensions using M-87 set. (i) 49.3825 mm (ii) 87.3215 mm

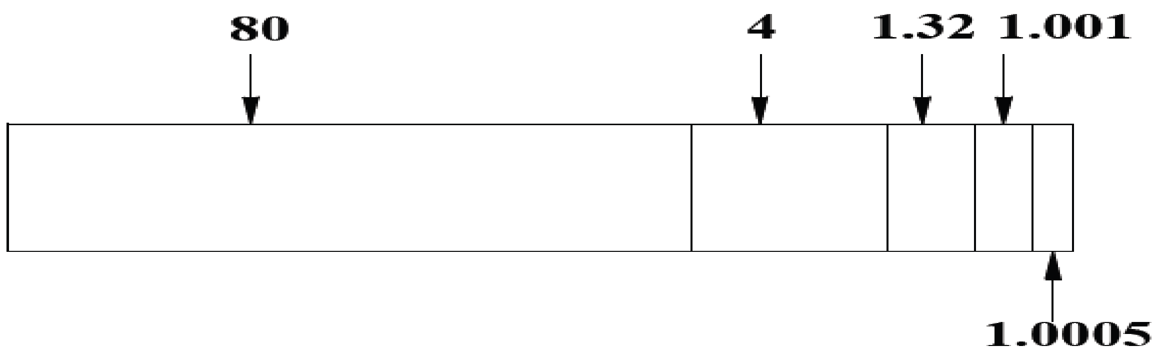
Solution:
(i) To build 49.3825 mm:

Combination of slips; 40+6+1.38+1.002+1.0005 = 49.3825 mm



(ii) To build 87.3215 mm:

Combination of slips; 80+4+1.32+1.001+1.0005 = 87.3215 mm



Numerical problem-2

Build up a length of 35.4875 mm using M112 set. Use two protector slips of 2.5 mm each

Solution: Combination of slips; 2.5+25+2+1.48+1.007+1.0005+2.5 = 35.4875 mm