COLLEGE VISION & MISSION STATEMENT

VISION
Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

MISSION
- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torch bearers of tomorrow’s society.
- To strive to attain ever-higher benchmarks of educational excellence.

DEPARTMENTAL VISION & MISSION STATEMENTS

VISION
To impart excellent technical education in mechanical engineering to develop technically competent, morally upright and socially responsible mechanical engineering professionals.

MISSION:
- To provide an ambience to impart excellent technical education in mechanical engineering.
- To ensure state-of-the-art facility for learning, skill development and research in mechanical engineering.
- To engage students in co-curricular and extra-curricular activities to impart social & ethical values and imbibe leadership quality.
PROGRAM EDUCATIONAL OBJECTIVES (PEO’S)

After successful completion of program, the graduates will be

PEO 1: Graduates will be able to have successful professional career in the allied areas and be proficient to perceive higher education.

PEO 2: Graduates will attain the technical ability to understand the need analysis, design, manufacturing, quality changing and analysis of the product.

PEO 3: Work effectively, ethically and socially responsible in allied fields of mechanical engineering.

PEO 4: Work in a team to meet personal and organizational objectives and to contribute to the development of the society in large.

PROGRAM OUTCOMES (PO’S)

The Mechanical engineering program students will attain:

PO1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems

PO2. Problem analysis: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences

PO3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations

PO4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions

PO5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations

PO6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice
PO7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development

PO8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice

PO9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings

PO10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions

PO11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments

PO12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

**PROGRAM SPECIFIC OUTCOMES (PSO’S)**

After successful completion of program, the graduates will be

**PSO 1:** To comprehend the knowledge of mechanical engineering and apply them to identify, formulate and address the mechanical engineering problems using latest technology in a effective manner.

**PSO 2:** To work successfully as a mechanical engineer in team, exhibit leadership quality and provide viable solution to industrial and societal problems.

**PSO 3:** To apply modern management techniques and manufacturing techniques to produce products of high quality at optimal cost.

**PSO 4:** To exhibit honesty, integrity, and conduct oneself responsibly, ethically and legally, holding the safety and welfare of the society paramount.
Contents

Module 1: Introduction to Metrology, Linear Measurement and angular measurements

Module 2: System of Limits, Fits, Tolerance and Gauging, Comparators

Module 3: Measurement of screw thread and gear, Advances in metrology

Module 4: Measurement systems and basic concepts of measurement methods, Intermediate modifying and terminating devices

Module 5: Force, Torque and Pressure Measurement, Measurement of strain and temperature
MODULE 1

1.1 Introduction to Metrology:
   1.1.1 Definition,
   1.1.2 objectives and concept of metrology,
   1.1.3 Need of inspection, Principles, process,
   1.1.4 methods of measurement,

1.2 Classification and selection of measuring instruments and systems.
   1.2.1 Accuracy,
   1.2.2 precision
   1.2.3 errors in measurement.

1.3 System of measurement,
   1.3.1 Material Standard,
   1.3.2 Wavelength Standards,
   1.3.3 Subdivision of standards
   1.3.4 Line and End standards
   1.3.5 Classification of standards and Traceability,
   1.3.6 calibration of End bars(Numericals), standardization.

1.4 Linear Measurement and angular measurements:
   1.4.1 Slip gauges- Indian standards on slip gauge,
   1.4.2 method of selection of slip gauge, stack of slip gauge,
   1.4.3 adjustable slip gauge, wringing of slip gauge, care of slip gauge, slip gauge accessories,

1.5 problems on building of slip gauges (M87, M112).

1.6 Measurement of angles- sine bar, sine center, angle gauges,

1.7 optical instruments for angular measurements,

1.8 Auto collimator-applications for measuring straightness and squarenes
1.1 **Introduction to Metrology:**

1.1.1 **Definition,**

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.

1.1.2 **objectives and concept 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.

1.1.3 **Need of inspection, Principles, process,**

In order to determine the fitness of anything made, man has always used inspection. But industrial inspection is of recent origin and has scientific approach behind it. It came into being because of mass production which involved interchangeability of parts. In old craft, same craftsman used to be producer as well as assembler. Separate inspections were not required. If any component part did not fit properly at the time of assembly, the craftsman would make the necessary adjustments in either of the mating parts so that each assembly functioned properly. So actually speaking, no two parts will be alike/and there was practically no reason why they should be. Now new production techniques have been developed and parts are being manufactured in
large scale due to low-cost methods of mass production. So hand-fit methods cannot serve the purpose any more. When large number of components of same part is being produced, then any part would be required to fit properly into any other mating component part. This required specialisation of men and machines for the performance of certain operations. It has, therefore, been considered necessary to divorce the worker from all round crafts work and to supplant hand-fit methods with interchangeable manufacture. The modern production techniques require that production of complete article be broken up into various component parts so that the production of each component part becomes an independent process. The various parts to be assembled together in assembly shop come from various shops. Rather some parts are manufactured in other factories also and then assembled at one place. So it is very essential that parts must be so fabricated that the satisfactory mating of any pair chosen at random is possible. In order that this may be possible, the dimensions of the component part must be confined within the prescribed limits which are such as to permit the assembly with a predetermined fit. Thus industrial inspection assumed its importance due to necessity of suitable mating of various components manufactured separately. It may be appreciated that when large quantities of work-pieces are manufactured on the basis of interchangeability, it is not necessary to actually measure the important features and much time could be saved by using gauges which determine whether or not a particular feature is within the prescribed limits. The methods of gauging, therefore, determine the dimensional accuracy of a feature, without reference to its actual size. The purpose of dimensional control is however not to strive for the exact size as it is impossible to produce all the parts of exactly same size due to so many inherent and random sources of errors in machines and men. The principal aim is to control and restrict the variations within the prescribed limits. Since we are interested in producing the parts such that assembly meets the prescribed work standard, we must not aim at accuracy beyond the set limits which, otherwise is likely to lead to wastage of time and uneconomical results. Lastly, inspection led to development of precision inspection instruments which caused the transition from crude machines to better designed and precision machines. It had also led to improvements in metallurgy and raw material manufacturing due to demands of high accuracy and precision. Inspection has also introduced a spirit of competition and led to production of quality products in volume by eliminating tooling bottle-necks and better processing techniques.
1.1.4 methods of measurement,

Two basic methods are commonly employed for measurement.

(a) Direct comparison with primary or secondary standard.

(b) Indirect comparison through the use of calibrated system.

**Direct comparison**

In this method, measurement is made directly by comparing the unknown magnitude with a standard & the result is expressed by a number. The simplest example for this would be, length measurement using a meter scale. Here we compare the bar’s length (unknown quantity/measure and) with a scale (Standard/predefined one). We say that the bar measures so many mms, cms or inches in length.

• Direct comparison methods are quite common for measurement of physical quantities like length, mass, etc.

• It is easy and quick.

**Drawbacks of Direct comparison methods**

• The main drawback of this method is, the method is not always accurate and reliable.

• Also, human senses are not equipped to make direct comparison of all quantities with equal facility all the times.

• Also measurements by direct methods are not always possible, feasible and practicable.


**Indirect comparison**

• Most of the measurement systems use indirect method of measurement.

• In this method a chain of devices which is together called as measuring system is employed.

• The chain of devices transform the sensed signal into a more convenient form & indicate this transformed signal either on an indicator or a recorder or fed to a controller.

• i.e. it makes use of a transducing device/element which convert the basic form of input into an analogous form, which it then processes and presents as a known function of input.

• For example, to measure strain in a machine member, a component senses the strain, another component transforms the sensed signal into an electrical quantity which is then processed suitably before being fed to a meter or recorder.

• Further, human senses are not equipped to detect quantities like pressure, force or strain.

• But can feel or sense and cannot predict the exact magnitude of such quantities.
Mechanical measurements and Metrology - 15ME46B

• Hence, we require a system that detects/sense, converts and finally presents the output in the form of a displacement of a pointer over a scale, a change in resistance or raise in liquid level with respect to a graduated stem.

<table>
<thead>
<tr>
<th>DIRECT COMPARISON</th>
<th>INDIRECT COMPARISON</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Unknown quantity is measured comparing directly with primary or secondary standards</td>
<td>1) Unknown magnitude is measured by comparing with a standard indirectly through the use of a calibrated system</td>
</tr>
<tr>
<td>2) Human senses are very much necessary for measurement</td>
<td>2) Consists of a chain of devices which form a measuring system</td>
</tr>
<tr>
<td>3) Results obtained from direct comparison are not that dependable</td>
<td>3) This consists of a detector element to detect, a transducer to transducer and a unit to indicate or record the processed signal</td>
</tr>
<tr>
<td>4) Not always accurate</td>
<td>4) Fairly accurate</td>
</tr>
</tbody>
</table>

1.2 Classification and selection of measuring instruments and systems.

Measurements are generally made by indirect comparison method through calibration. They usually make use of one or more transducing device. Based upon the complexity of measurement system, three basic categories of measurements have been developed. They are:

1. Primary measurement
2. Secondary measurement
3. Tertiary measurement

**Primary measurement**

In primary mode, the sought value of a physical parameter is determined by comparing it directly with reference standards. The requisite information is obtainable through senses of sight and touch.

Example: matching of two lengths when determining the length of an object with a ruler.

**Secondary measurement**

The indirect measurements involving one translation are called secondary measurements. Example: the conversion of pressure into displacement by bellows.
Tertiary measurement

The indirect measurements involving two conversions are called tertiary measurements. Example: the measurement of the speed of a rotating shaft by means of an electric tachometer.

1.2.1 Accuracy,

The accuracy of an instrument indicates the deviation of the reading from a known input. In other words, accuracy is the closeness with which the readings of an instrument approaches the true values of the quantity measured. It is the maximum amount by which the result differs from the true value.

Accuracy is expressed as a percentage based on the actual scale reading / full scale reading.

\[
\text{Percentage accuracy based on reading} = \frac{V_r \text{ (max or min)} - V_a}{V_a} \times 100
\]

\[
\text{Percentage accuracy (based on full scale reading)} = \frac{(V_r \text{ (max or min)} - V_a) \times 100}{V_{fs}}
\]

\(V_a = \) Actual value
\(V_r = \) max or min result value.
\(V_{fs} = \) full scale reading

Example: 100 bar pressure gauge having an accuracy of 1% would be accurate within +/-1 bar over the entire range of gauge.

1.2.2 precision

The precision of an instrument indicates its ability to reproduce a certain reading with a given accuracy. In other words, it is the degree of agreement between repeated results.

<table>
<thead>
<tr>
<th>Sl no</th>
<th>Accuracy</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>It is the closeness with the true value of the quantity being measured</td>
<td>It is a measure of reproducibility of the measurements</td>
</tr>
<tr>
<td>2</td>
<td>The accuracy of measurement means conformity to truth</td>
<td>The term precise means clearly or sharply defined</td>
</tr>
<tr>
<td>3</td>
<td>Accuracy can be improved</td>
<td>Precision cannot be improved</td>
</tr>
<tr>
<td>4</td>
<td>Accuracy depends upon simple techniques of analysis</td>
<td>Precision depends upon many factors and requires many sophisticated techniques of analysis</td>
</tr>
</tbody>
</table>
1.2.3 errors in measurement.

Error may be defined as the difference between the measured value and the true value.

Error classification

Classified in different ways

- Systematic error
- Random errors
- Illegitimate errors

Systematic errors

- Generally the will be constant / similar form /recur consistently every time measurement is measured.
- May result from improper condition or procedures employed.

Calibration errors

Calibration procedure-is employed in a number of instruments-act of checking or adjusting the accuracy of a measuring instrument.

Human errors

- The term “human error” is often used very loosely.
- We assume that when we use it, everyone will understand what it means.
- But that understanding may not be same as what the person meant in using the term.
- For this reason, without a universally accepted definition, use of such terms is subject to misinterpretation.

1) Systematic or fixed errors:

(a) Calibration errors
(b) Certain types of consistently recurring human errors
(c) Errors of technique
(d) Uncorrected loading errors
(e) Limits of system resolution Systematic errors are repetitive & of fixed value. They have a definite magnitude & direction

2) Random or Accidental errors:

(a) Errors stemming from environmental variations
(b) Certain types of human errors
(c) Due to Variations in definition
(d) Due to Insufficient sensitivity of measuring system.

Random errors are distinguishable by their lack of consistency. An observer may not be consistent in taking readings. Also the process involved may include certain poorly controlled variables causing changing conditions. The variations in temperature, vibrations of external medium, etc. cause errors in the instrument. Errors of this type are normally of limited duration & are inherent to specific environment.

(3) Illegitimate errors:
(a) Blunders or Mistakes
(b) Computational errors
(c) Chaotic errors

1.3 System of measurement,

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.

1.3.1 Material Standard,

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 0°C, 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.

**1.3.2 Wavelength Standards,**
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.

A 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.

**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. Teritiary 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)

### 1.3.3 Subdivision of 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.

1.3.4 Line and End standards

**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.
1.3.5 calibration of End bars (Numericals), standardization.

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.

**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 +40mm. The three end bars together measure 64 mm less than the 300 mm bar. Bar A is 18 mm longer than bar B and 23 mm longer than bar C. Find the actual length of each bar.
Numerical problem-2

Four end bars of basic length 100 mm are to be calibrated using a standard bar of 400 mm whose actual length is 399.9992 mm. It was also found that lengths of bars B, C & D in comparison with A are +0.0002 mm, +0.0004 mm and -0.0001 mm respectively and the length of all the four bars put together in comparison with the standard bar is +0.0003 mm longer. Determine the actual lengths of each end bars.

1.4 Linear Measurement and angular measurements:

1.4.1 Slip gauges- Indian standards on slip gauge,

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.
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**
### M-112 set of slip gauges

<table>
<thead>
<tr>
<th>Range (mm)</th>
<th>Steps (mm)</th>
<th>No. of pieces</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.001 to 1.009</td>
<td>0.001</td>
<td>9</td>
</tr>
<tr>
<td>1.01 to 1.49</td>
<td>0.01</td>
<td>49</td>
</tr>
<tr>
<td>0.5 to 9.5</td>
<td>0.5</td>
<td>19</td>
</tr>
<tr>
<td>10 to 90</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>1.0005</td>
<td>---</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>87</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Range (mm)</th>
<th>Steps (mm)</th>
<th>No. of pieces</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.001 to 1.009</td>
<td>0.001</td>
<td>9</td>
</tr>
<tr>
<td>1.01 to 1.49</td>
<td>0.01</td>
<td>49</td>
</tr>
<tr>
<td>0.5 to 24.5</td>
<td>0.5</td>
<td>49</td>
</tr>
<tr>
<td>25, 50, 75, 100</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>1.0005</td>
<td>---</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>112</strong></td>
</tr>
</tbody>
</table>

1.4.2 method of selection of slip gauge, stack of slip gauge,

### 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.

1.5 problems on building of slip gauges (M87, M112).

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
1.5.1 adjustable slip gauge, wringing of slip gauge, care of slip gauge, slip gauge accessories,

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
1.6 Measurement of angles- sine bar, sine center, angle gauges,

Angular Measurements

Introduction

Definition of Angle

• Angle is defined as the opening between two lines which meet at a point.
• If a circle is divided into 360 parts, then each part is called a degree (°).
• Each degree is subdivided into 60 parts called minutes ('), and each minute is further subdivided into 60 parts called seconds ("").

The unit ‘Radian’ is defined as the angle subtended by an arc of a circle of length equal to radius. If arc AB = radius OA, then the angle \( \theta \) = 1 radian.

\[ \theta = \sin^{-1}\left(\frac{H}{L}\right) \]

Sine bar

Sine bars are made from high carbon, high chromium, corrosion resistant steel which can be hardened, ground & stabilized. Two cylinders of equal diameters are attached at the ends as shown in fig. The distance between the axes can be 100, 200 & 300 mm. The Sine bar is designated basically for the precise setting out of angles and is generally used in conjunction with slip gauges & surface plate. The principle of operation relies upon the application of Trigonometry.

In the below fig, the standard length AB (L) can be used & by varying the slip gauge stack (H), any desired angle \( \theta \) can be obtained as, \( \theta = \sin^{-1}\left(\frac{H}{L}\right) \).
(1) For checking unknown angles of a component

A dial indicator is moved along the surface of work and any deviation is noted. The slip gauges are then adjusted such that the dial reads zero as it moves from one end to the other.

(2) Checking of unknown angles of heavy component
In such cases where components are heavy and can’t be mounted on the sine bar, then sine bar is mounted on the component as shown in Fig. The height over the rollers can then be measured by a vernier height gauge; using a dial test gauge mounted on the anvil of height gauge as the fiducial indicator to ensure constant measuring pressure. The anvil on height gauge is adjusted with probe of dial test gauge showing same reading for the topmost position of rollers of sine bar. Fig. 8.18 shows the use of height gauge for obtaining two readings for either of the roller of sine bar. The difference of the two readings of height gauge divided by the centre distance of sine bar gives the sine of the angle of the component to be measured. Where greater accuracy is required, the position of dial test gauge probe can be sensed by adjusting a pile of slip gauges till dial indicator indicates same reading over roller of sine bar and the slip gauges.

**Advantages of sine bar**

1. It is used for accurate and precise angular measurement.
2. It is available easily.
3. It is cheap.

**Disadvantages**

1. The application is limited for a fixed center distance between two plugs or rollers.
2. It is difficult to handle and position the slip gauges.
3. If the angle exceeds 45°, sine bars are impracticable and inaccurate.
4. Large angular error may results due to slight error in sine bar.

**Sine Centers**
It is the extension of sine bars where two ends are provided on which centers can be clamped, as shown in Figure. These are useful for testing of conical work centered at each end, up to 60°. The centers ensure correct alignment of the work piece. The procedure of setting is the same as for sine bar. The dial indicator is moved on to the job till the reading is same at the extreme position. The necessary arrangement is made in the slip gauge height and the angle is calculated as $\theta = \sin^{-1} \left( \frac{h}{L} \right)$.

**Vernier Bevel Protractor (Universal Bevel Protractor)**

It is a simplest instrument for measuring the angle between two faces of a component. It consists of a base plate attached to a main body and an adjustable blade which is attached to a circular plate containing vernier scale.
The adjustable blade is capable of sliding freely along the groove provided on it and can be clamped at any convenient length. The adjustable blade along with the circular plate containing the vernier can rotate freely about the center of the main scale engraved on the body of the instrument and can be locked in any position with the help of a clamping knob.

The adjustable blade along with the circular plate containing the vernier can rotate freely about the center of the main scale engraved on the body of the instrument and can be locked in any position with the help of a clamping knob.

The main scale is graduated in degrees. The vernier scale has 12 divisions on either side of the center zero. They are marked 0-60 minutes of arc, so that each division is $\frac{1}{12}$ of 60 minutes, i.e. 5 minutes. These 12 divisions occupy same arc space as 23 degrees on the main scale, such that each division of the vernier $= (\frac{1}{12}) \times 23 = 1\frac{11}{12}$ degrees.

**Angle Gauges**

These were developed by Dr. Tomlinson in 1939. The angle gauges are hardened steel blocks of 75 mm length and 16 mm wide which has lapped surfaces lying at a very precise angle.

In this method, the auto collimator used in conjunction with the angle gauges. It compares the angle to be measured of the given component with the angle gauges. Angles gauges are wedge shaped block and can be used as standard for angle measurement. They reduce the set uptime and minimize the error. These are 13 pieces, divided into three types such as degrees, minutes and seconds. The first series angle are $1^\circ$, $3^\circ$, $9^\circ$, $27^\circ$ and $41^\circ$ and the second series angle are $1'$, $3'$, $9'$ and $27'$ And the third series angle are $3''$, $6''$, $18''$ and $30''$. These gauges can be used for large number of combinations by adding or subtracting these gauges, from each other.
The engraved symbol ‘<’ indicates the direction of the included angle. Angle gauges are available in a 13 piece set.

Nominal angles of combination angle gauges

<table>
<thead>
<tr>
<th>Degrees</th>
<th>1</th>
<th>3</th>
<th>9</th>
<th>27</th>
<th>41</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minutes</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>27</td>
<td>-</td>
</tr>
<tr>
<td>Fraction of minute (or seconds)</td>
<td>0.05</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
<td>-</td>
</tr>
</tbody>
</table>

These gauges together with a square block enable any angle between 0° & 360° to be built within an accuracy of 1.5 seconds of the nominal value. The wringing is similar to that of slip gauges.

**Numericals on building of angles**

The required angle may be built by wringing suitable combination of angle gauges similar to that of slip gauges. Each angle is a wedge and thus two gauges with narrow ends together provide an angle which is equal to the sum of angles of individual gauges. Two gauges when wrung together with opposing narrow ends give subtraction of the two angles.

**Numerical 1:**

Build an angle of 57°34’9”

**Solution:**

Degree = 41° +27° -9°+1°-3°=57°
Minutes = 27°+9’-3’+1’ = 34’
Seconds = 6”+ 3” =9”
Numerical 2:

Give the combination of angle gauges required to build 102°8’ 42”

Solution:

Degree: 90°+9°+3° =102°
Minutes: 9’-1’ = 8’
Seconds 30”+ 18”- 6” =42”

Clinometer

A clinometer is a special case of the application of spirit level. In clinometer, the spirit level is mounted on a rotary member carried in housing. One face of the housing forms the base of the instrument. On the housing, there is a circular scale. The angle of inclination of the rotary member carrying the level relative to its base can be measured by this circular scale. The clinometer mainly used to determine the included angle of two adjacent faces of workpiece. Thus for this purpose, the instrument base is placed on one face and the rotary body adjusted till zero reading of the bubble is obtained. The angle of rotation is then noted on the circular scale against the index. A second reading is then taken in the similar manner on the second face of workpiece. The included angle between the faces is then the difference between the two readings.

Clinometers are also used for checking angular faces, and relief angles on large cutting tools and milling cutter inserts.
These can also be used for setting inclinable table on jig boring; machines and angular work on grinding machines etc.

The most commonly used clinometer is of the Hilger and Watts type. The circular glass scale is totally enclosed and is divided from 0° to 360° at 10′ intervals. Sub-division of 10′ is possible by the use of an optical micrometer. A coarse scale figured every 10 degrees is provided outside the body for coarse work and approximate angular reading. In some instruments worm and quadrant arrangement is provided so that reading upto 1′ is possible.

In some clinometers, there is no bubble but a graduated circle is supported on accurate ball bearings and it is so designed that when released, it always takes up the position relative to the true vertical. The reading is taken against the circle to an accuracy of 1 second with the aid of vernier.

**Autocollimators**

This is an optical instrument used for the measurement of small angular differences. For small angular measurements, autocollimator provides a very sensitive and accurate approach. Auto-collimator is essentially an infinity telescope and a collimator combined into one instrument. The principle on which this instrument works is given below. O is a point source of light placed at the principal focus of a collimating lens in Fig. 8.30. The rays of light from O incident on the lens will now travel as a parallel beam of light. If this beam now strikes a plane reflector which is normal to the optical axis, it will be reflected back along its own path and refocused at the same point O. If the plane reflector be now tilted through a small angle θ, then parallel beam will be deflected through twice this angle and will be brought to focus at O’ in the same plane at a distance x from O. Obviously OO’=x=2θ.f, where f is the focal length of the lens.
There are certain important points to appreciate here:

The position of the final image does not depend upon the distance of reflector from the lens, i.e. separation $x$ is independent of the position of reflector from the lens. But if reflector is moved too much back then reflected rays will completely miss the lens and no image will be formed. Thus for full range of readings of instrument to be used, the maximum remoteness of the reflector is limited.

For high sensitivity, i.e., for large value of $x$ for a small angular deviation $\theta$, a long focal length is required.

**Principle of the Autocollimator**

A crossline “target” graticule is positioned at the focal plane of a telescope objective system with the intersection of the crossline on the optical axis, i.e. at the principal focus. When the target graticule is illuminated, rays of light diverging from the intersection point reach the objective via a beam splitter and are projected from the objective as parallel pencils of light. In this mode, the optical system is operating as a “collimator”

A flat reflector placed in front of the objective and exactly normal to the optical axis reflects the parallel pencils of light back along their original paths. They are then brought to focus in the plane of the target graticule and exactor coincident with its intersection. A proportion of the returned light passes straight through the beam splitter and the return image of the target crossline is therefore visible through the eyepiece. In this mode, the optical system is operating as a telescope focused at infinity.

If the reflector is tilted through a small angle the reflected pencils of light will be deflected by twice the angle of tilt (principle of reflection) and will be brought to focus in the plane of the target graticule but linearly displaced from the actual target crosslines by an amount $2\theta \times f$. 
Linear displacement of the graticule image in the plane of the eyepiece is therefore directly proportional to reflector tilt and can be measured by an eyepiece graticule, optical micrometer no electronic detector system, scaled directly in angular units. The autocollimator is set permanently at infinity focus and no device for focusing adjustment for distance is provided or desirable. It responds only to reflector tilt (not lateral displacement of the reflector).

This is independent of separation between the reflector and the autocollimator, assuming no atmospheric disturbance and the use of a perfectly flat reflector. Many factors govern the specification of an autocollimator, in particular its focal length and its effective aperture. The focal length determines basic sensitivity and angular measuring range. The longer the focal length the larger is the linear displacement for a given reflector tilt, but the maximum reflector tilt which can be accommodated is consequently reduced. Sensitivity is therefore traded against measuring range. The maximum separation between reflector and autocollimator, or “working distance”, is governed by the effective aperture of the objective and the angular measuring range of the instrument becomes reduced at long working distances. Increasing the maximum working distance by increasing the effective aperture then demands a larger reflector for satisfactory image contrast. Autocollimator design thus involves many conflicting criteria and for this reason a range of instruments is required to optimally cover every application.

Air currents in the optical path between the autocollimator and the target mirror cause fluctuations in the readings obtained. This effect is more pronounced as distance from autocollimator to target mirror increases. Further errors may also occur due to errors in flatness and reflectivity of the target mirror which should be of high quality.
When both the autocollimator and the target mirror gauge can remain fixed, extremely close readings may be taken and repeatability is excellent. When any of these has to be moved, great care is required.

**Tests for straightness**

It can be carried out by using spirit level or auto-collimator. 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. So first a straight line is drawn on the surface whose straightness is to be tested. Then it is divided into a number of sections, the length of each section being equal to the length of spirit level base or the plane reflector’s base in case of auto-collimator. Generally 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 whole of the surface of base does not touch the surface to be tested. This ensures that angular deviation obtained is between the specified two points. In this case length of each section must be equal to distance between the centre lines of two feet. The spirit level can be used only for the measurement of straightness of horizontal surfaces while auto-collimator method can be used on surfaces in any plane. In case of spirit level, the block is moved along the line on the surface to be tested in steps equal to the pitch distance between the centre lines of the feet and the angular variations of the direction of block are measured by the sensitive level on it. Angular variation can be correlated in terms of the difference of height between two points by knowing the least count of level and length of the base.

In case of measurement by auto-collimator, the instrument is placed at a distance of 0.5 to 0.75 metre from the surface to be tested on any rigid support which is independent of 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 reflector and the instrument are set such that the image of the cross wires of the collimator appears nearer the centre of the field and for the complete movement of reflect or 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 centre distance between the feet and the tilt of the reflector is noted down in seconds from the eyepiece.
Therefore, 1 sec. of arc will correspond to a rise or fall of 0.000006\*1 mm, where I is the distance between centers of feet in mm. The condition for initial and subsequent readings is shown in Fig. 7.2 in which the rise and fall of the surface is shown too much exaggerated.

With the reflector set at a-b (1st reading), the micrometer reading is noted and this line is treated as datum line. Successive readings at b-c, c-d, d-e etc. are taken till the length of the surface to be tested has been stepped along. In other to eliminate any error in previous set of readings, the second set of readings could be taken by stepping the reflector in the reverse direction and mean of two taken. This mean reading represents the angular position of the reflector in seconds relative to the optical axis or auto-collimator.

Column 1 gives the position of plane reflector at various places at intervals of ‘I’ e.g. a-b, b-c, c-d etc., column 2 gives the mean reading of auto-collimator or spirit level in seconds. In column 3, difference of each reading from the first is given in order to treat first reading as datum. These differences are then converted into the corresponding linear rise or fall in column 4 by multiplying column 3 by ‘I’. Column 5 gives the cumulative rise or fall, i.e., the heights of the support feet of the reflector above the datum line drawn through their first position. It should be noted that the values in column 4 indicate the inclinations only and are not errors from the true datum. For this the values are added cumulatively with due regard for sign. Thus it leaves a final displacement equal to L at the end of the run which of course does not represent the magnitude of error of the surface, but is merely the deviation from a straight line produced from the plane of the first reading. In column 5 each figure represents a point, therefore, an additional zero is put at the top representing the height of point a.

The errors of any surfaced may be required relative to any mean plane. If it be assumed that mean plane is one joining the end points then whole of graph must be swung round until the end point is on the axis. This is achieved by subtracting the length L proportionately from the readings in column 5. Thus if n readings be taken, then column 6 gives the adjustments— L/n, —
2L/n… etc., to bring both ends to zero. Column 7 gives the difference of columns 5 and 6 and represents errors in the surface from a straight line joining the end points. This is as if a straight edge were laid along the surface profile to be tested and touching the end points of the surface when they are in a horizontal plane and the various readings in column 7 indicate the rise and fall relative to this straight edge.

**Question Bank**

1. What are the uses of measurement?
2. What is legal metrology?
3. What are the objectives of metrology
4. What are the basic components of a measuring system?
5. Distinguish between Line standard and End standard.
6. Define the term Sensitivity of an instrument.
7. Differentiate between precision and accuracy.
8. Define the term reliability.
9. Give any four methods of measurement.
12. Distinguish between repeatability and reproducibility.
14. Distinguish between static and random error?
15. What are the sources of error?
16. Write short note on “Systematic errors”.
17. What are the factors affecting the accuracy of the measuring system?
18. Write short notes on the classification of error
19. What is the role of N.P.L
20. Explain the different types of units
MODULE 2

SYSTEM OF LIMITS, FITS, TOLERANCE AND GAUGING

CONTENTS

2.1 Definition
2.2 Limits of Size & Tolerance
2.3 System of Fits
2.4 Geometrical Tolerances
2.5 System of Tolerances
2.6 Comparators
   2.6.1 Classification of comparators
   2.6.2 Mechanical Comparator
   2.6.3 Electrical Comparators
   2.6.4 Pneumatic Comparators (Solex Gauge)

OBJECTIVES

Students will be able to

1. Understand the basic principles of fits and tolerances,
2. Explain various types of fits and their applications,
3. Analyses the various types of tolerances and applications, and
4. Know the fundamental of the systems of fits.
2.1 Definition:

Limits

The maximum and minimum permissible sizes within which the actual size of a component lies are called Limits.

Tolerance:

It is impossible to make anything to an exact size, therefore it is essential to allow a definite tolerance or permissible variation on every specified dimension.

Why Tolerances are specified?

· Variations in properties of the material being machined introduce errors.
· The production machines themselves may have some inherent inaccuracies.
· It is impossible for an operator to make perfect settings. While setting up the tools and workpiece on the machine, some errors are likely to creep in.

Consider the dimension shown in fig. When trying to achieve a diameter of 40 mm (Basic or Nominal diameter), a variation of 0.05 mm on either side may result. If the shaft is satisfactory even if its diameter lies between 40.05 mm & 39.95 mm, the dimension 40.05 mm is known as Upper limit and the dimension 39.95 mm is known as Lower limit of size. Tolerance in the above example is (40.05-39.95) = 0.10 mm Tolerance is always a positive quantitative number.

Unilateral Tolerance:

· Tolerances on a dimension may either be unilateral or bilateral.
· When the two limit dimensions are only on one side of the nominal size, (either above or below) the tolerances are said to be unilateral.
· For unilateral tolerances, a case may occur when one of the limits coincide with the basic size.
Bilateral Tolerance: When the two limit dimensions are above and below nominal size, (i.e. on either side of the nominal size) the tolerances are said to be bilateral. Unilateral tolerances, are preferred over bilateral because the operator can machine to the upper limit of the shaft (or lower limit of a hole) still having the whole tolerance left for machining to avoid rejection of parts.

Schematic representation of tolerances:
Tolerance Accumulation (or) Tolerance Build up:

If a part comprises of several steps, each step having some tolerance specified over its length, then the overall tolerance on the complete length will be the sum of tolerances on individual lengths.

The effect of accumulation of tolerances can be minimized by adopting progressive dimensioning from a common datum.

Another example of tolerance build up is shown below.
**Compound Tolerances:**

A compound tolerance is one which is derived by considering the effect of tolerances on more than one dimension.

For ex, the tolerance on the dimension $L$ is dependent on the tolerances on $D$, $H$ & $q$.

The dimension $L$ will be maximum when the base dimension is $(D+a)$, the angle is $(q+a)$, and the vertical dimension is $(H-d)$.

The dimension $L$ will be minimum when the base dimension is $(D-b)$, the angle is $(q-b)$, and the vertical dimension is $(H+c)$.

### 2.2 LIMITS OF SIZE & TOLERANCE

**Terminology of limit systems:**

**Limits of size:** The two extreme permissible sizes of a component between which the actual size should lie including the maximum and minimum sizes of the component.

**Nominal size:** It is the size of the component by which it is referred to as a matter of convenience.

**Basic size:** It is the size of a part in relation to which all limits of variation are determined.

**Zero Line:** It is the line w.r.t which the positions of tolerance zones are shown.

**Deviation:** It is the algebraic difference between a limit of size and the corresponding basic size.

**Upper Deviation:** It is the algebraic difference between the maximum limit of size and the corresponding basic size. It is denoted by letters ‘ES’ for a hole and ‘es’ for a shaft.
**Lower Deviation:** It is the algebraic difference between the minimum limit of size and the corresponding basic size. It is denoted by letters ‘**EI**’ for a hole and ‘**ei**’ for a shaft.

**Fundamental Deviation:** It is the deviation, either upper or lower deviation, which is nearest to the zero line for either a hole or a shaft. It fixes the position of the tolerance zone in relation to the zero line.

**Allowance:** It is the intentional difference between the hole dimensions and shaft dimension for any type of fit.

**Size of tolerance:** It is the difference between the maximum and minimum limits of size.

### 2.3 SYSTEM OF FITS

*Fit* is an assembly condition between ‘Hole’ & ‘Shaft’

**Hole:** A feature engulfing a component.

**Shaft:** A feature being engulfed by a component.

---

**Clearance fit:**

In this type of fit, the largest permitted shaft diameter is less than the smallest hole diameter so that the shaft can rotate or slide according to the purpose of the assembly.
Interference Fit:

It is defined as the fit established when a negative clearance exists between the sizes of holes and the shaft. In this type of fit, the minimum permitted diameter of the shaft is larger than the maximum allowable diameter of the hole. In case of this type of fit, the members are intended to be permanently attached.

*Ex:* Bearing bushes, Keys & key ways

Transition Fit:
In this type of fit, the diameter of the largest allowable hole is greater than the smallest shaft, but the smallest hole is smaller than the largest shaft, such that a small positive or negative clearance exists between the shaft & hole.

Ex: Coupling rings, Spigot in mating holes, etc.

**Interchangeability:**

Interchangeability occurs when one part in an assembly can be substituted for a similar part which has been made to the same drawing. Interchangeability is possible only when certain standards are strictly followed.

**Universal interchangeability** means the parts to be assembled are from two different manufacturing sources.

**Local interchangeability** means all the parts to be assembled are made in the same manufacturing unit.

**Selective Assembly:**

In selective assembly, the parts are graded according to the size and only matched grades of mating parts are assembled. This technique is most suitable where close fit of two components assembled is required.

Selective assembly provides complete protection against non-conforming assemblies and reduces machining costs as close tolerances can be maintained.

Suppose some parts (shafts & holes) are manufactured to a tolerance of 0.01 mm, then an automatic gauge can separate them into ten different groups of 0.001 mm limit for selective assembly of the individual parts. Thus high quality and low cost can be achieved.
Selective assembly is used in aircraft, automobile industries where tolerances are very narrow and not possible to manufacture at reasonable costs.

2.4 Geometrical Tolerances:

It is necessary to specify and control the geometric features of a component, such as straightness, flatness, roundness, etc. in addition to linear dimensions. Geometric tolerance is concerned with the accuracy of relationship of one component to another and should be specified separately.

Geometrical tolerance may be defined as the maximum possible variation of form or position of form or position of a feature.

Geometric tolerances define the shape of a feature as opposed to its size. There are three basic types of geometric tolerances:

**Form tolerances:**
Straightness, flatness, roundness, cylindricity

**Orientation tolerances:**
Perpendicularity, parallelism, angularity

**Position tolerances:**
Position, symmetry, concentricity

**FORM TOLERANCES**

<table>
<thead>
<tr>
<th>Characteristic or symbol</th>
<th>Function of geometric tolerance</th>
<th>Tolerance zone</th>
<th>Typical example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Straightness</strong></td>
<td>To control the straightness of the line on a surface.</td>
<td>Area between two parallel straight lines in the plane containing the considered line or axis. Tolerance value is the distance between them.</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Flatness</strong></td>
<td>To control the flatness of a surface.</td>
<td>Area between two planes. Tolerance value is the distance between them.</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Roundness</strong></td>
<td>To control the errors of roundness of a circle in the plane in which it lies.</td>
<td>Area between two concentric circles. Tolerance value is the radial distance between them.</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Roundness" /></td>
<td></td>
<td><img src="image2" alt="Roundness" /></td>
<td></td>
</tr>
<tr>
<td><strong>Cylindricity</strong></td>
<td>To control combination of roundness, straightness, and parallelism of a cylindrical surface.</td>
<td>Annular space between two cylinders that are co axial. Tolerance value is the radial distance between them.</td>
<td></td>
</tr>
<tr>
<td><img src="image3" alt="Cylindricity" /></td>
<td></td>
<td><img src="image4" alt="Cylindricity" /></td>
<td></td>
</tr>
</tbody>
</table>

**ORIENTATION TOLERANCES**

<table>
<thead>
<tr>
<th><strong>Parallelism</strong></th>
<th>To control the parallelism of a line or surface w.r.t some datum.</th>
<th>Area between two parallel lines or space between two parallel lines which are parallel to the datum</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5" alt="Parallelism" /></td>
<td></td>
<td><img src="image6" alt="Parallelism" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Squareness</strong></th>
<th>To control the perpendicularity of a line or surface w.r.t a datum.</th>
<th>Area between two parallel lines or space between two parallel lines which are perpendicular to the datum</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image7" alt="Squareness" /></td>
<td></td>
<td><img src="image8" alt="Squareness" /></td>
</tr>
</tbody>
</table>
2.5 SYSTEM OF TOLERANCES

Holes are designated by capital letter:
Letters A to G - oversized holes
Letters P to ZC - undersized holes

Shafts are designated by small letter:
Letters m to zc - oversized shafts
Letters a to g - undersized shafts

‘H’ is used for holes and ‘h’ is used for shafts whose fundamental deviation is zero.
**Basic shaft:** It is a shaft whose upper deviation is zero. i.e. the maximum limit of shaft coincides with the nominal size.(zero line). Eg: shaft ‘h’

**Basic hole:** It is a hole whose lower deviation is zero. i.e. the minimum limit of hole coincides with the nominal size.(zero line). Eg: shaft ‘H’

**Hole Basis:** In this system, the basic diameter of the hole is constant while the shaft size is varied according to the type of fit.

**Significance of Hole basis system:** The bureau of Indian Standards (BIS) recommends both hole basis and shaft basis systems, but their selection depends on the production methods. Generally, holes are produced by drilling, boring, reaming, broaching, etc. whereas shafts are either turned or ground.

If the shaft basis system is used to specify the limit dimensions to obtain various types of fits, number of holes of different sizes are required, which in turn requires tools of different sizes.

**Hole basis system:**

If the hole basis system is used, there will be reduction in production costs as only one tool is required to produce the hole and the shaft can be easily machined to any desired size. Hence hole basis system is preferred over shaft basis system.

**Shaft Basis system:**

In this system, the basic diameter of the shaft is constant while the hole size is varied according to the type of fit.

It may, however, be necessary to use shaft basis system where different fits are required along a long shaft.
For example, in the case of driving shafts where a single shaft may have to accommodate to a variety of accessories such as couplings, bearings, collars, etc., it is preferable to maintain a constant diameter for the permanent member, which is the shaft, and vary the bore of the accessories.

GRADES OF TOLERANCES

Grade is a measure of the magnitude of the tolerance. Lower the grade the finer the tolerance. There are total of 18 grades which are allocated the numbers IT01, IT0, IT1, IT2.....IT16.

Fine grades are referred to by the first few numbers. As the numbers get larger, so the tolerance zone becomes progressively wider. Selection of grade should depend on the circumstances. As the grades get finer, the cost of production increases at a sharper rate.

TOLERANCE GRADE

The tolerance grades may be numerically determined in terms of the standard tolerance unit ‘i’ where i in microns is given by (for basic size upto and including 500 mm) and (for basic size above 500 mm upto and including 3150 mm), where D is in mm and it is the geometric mean of the lower and upper diameters of a particular step in which the component lies.

The above formula is empirical and is based on the fact that the tolerance varies more or less parabolically in terms of diameter for the same manufacturing conditions. This is so because manufacture and measurement of higher sizes are relatively difficult.

The various diameter steps specified by ISI are: 1-3, 3-6, 6-10, 10-18, 18-30, 30-50, 50-80, 80-120, 180-250, 250-315, 315-400, and 400-500 mm. The value of ‘D’ is taken as the geometric mean for a particular range of size to avoid continuous variation of tolerance with size.

The fundamental deviation of type d,e,f,g shafts are respectively -16D^{0.44}, -11D^{0.41}, -5.5D^{0.41} & -2.5D^{0.34}

Tolerance: C - Clearance, T - Transition, I - Interference.
The fundamental deviation of type D, E, F, G shafts are respectively \(+16D^{0.44}\), \(+11D^{0.41}\), \(+5.5D^{0.41}\) & \(+2.5D^{0.34}\).

The relative magnitude of each grade is shown in the table below;

<table>
<thead>
<tr>
<th>Tol. Grade</th>
<th>IT 5</th>
<th>IT 6</th>
<th>IT 7</th>
<th>IT 8</th>
<th>IT 9</th>
<th>IT 10</th>
<th>IT 11</th>
<th>IT 12</th>
<th>IT 13</th>
<th>IT 14</th>
<th>IT 15</th>
<th>IT 16</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7i</td>
<td>10i</td>
<td>16i</td>
<td>25i</td>
<td>40i</td>
<td>64i</td>
<td>100i</td>
<td>160i</td>
<td>250i</td>
<td>400i</td>
<td>640i</td>
<td>1000i</td>
</tr>
</tbody>
</table>

It may be noted that from IT 6 onwards, every 5th step is 10 times the respective grade.
i.e. IT 11=10xIT6=10x10i=100 i, IT12=10xIT7=10x16i=160 i, etc.

**Numerical Problem 1:**
Calculate the limits of tolerance and allowance for a 25 mm shaft and hole pair designated by H_8d_9. Take the fundamental deviation for ‘d’ shaft is \(-16D^{0.44}\).

**Numerical Problem 2**
Determine the tolerances on the hole and the shaft for a precision running fit designated by 50 H_7g_6, given;
50 mm lies between 30-50 mm
i (in microns)=0.45(D)^{1/3}+0.001D
Fundamental deviation for ‘H’ hole=0
Fundamental deviation for g shaft =\(-2.5D^{0.34}\)
IT7=16i and IT6=10i
State the actual maximum and minimum sizes of the hole and shaft and maximum and minimum clearances.
Numerical Problem 3:
Calculate all the relevant dimensions of 35H7/f8 fit, dimension 35 mm falls in the step of 30-50 mm. The fundamental deviation for f shaft is \(-5.5D^{0.41}\). i (in microns) =0.45(D)^{1/3}+0.001D, IT7=16i and IT8=25i.

LIMIT GAUGES
A Go-No GO gauge refers to an inspection tool used to check a workpiece against its allowed tolerances. It derives its name from its use: the gauge has two tests; the check involves the workpiece having to pass one test (Go) and fail the other (No Go).

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

A Go - No Go gauge is a measuring tool that does not return a size in the conventional sense, but instead returns a state. The state is either acceptable (the part is within tolerance and may be used) or it is unacceptable (and must be rejected).

They are well suited for use in the production area of the factory as they require little skill or interpretation to use effectively and have few, if any, moving parts to be damaged in the often hostile production environment.

PLAIN GAUGES
Gauges are inspection tools which serve to check the dimensions of the manufactured parts. Limit gauges ensure the size of the component lies within the specified limits. They are non-recording and do not determine the size of the part. Plain gauges are used for checking plain (Unthreaded) holes and shafts.

Plain gauges may be classified as follows;
According to their type:
(a) 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 some snugness.
(b) **Limit Gauges**

These are also called ‘go’ and ‘no go’ gauges. These 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 maximum and the other end 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.

**According to their purpose:**

(a) **Work shop gauges:** Working gauges are those used at the bench or machine in gauging the work as it being made.

(b) **Inspection gauges:** These gauges are used by the inspection personnel to inspect manufactured parts when finished.

(c) **Reference or Master Gauges:** These are used only for checking the size or condition of other gauges.

**According to the form of tested surface:**

Plug gauges: They check the dimensions of a hole

Snap & Ring gauges: They check the dimensions of a shaft.

**According to their design:**

Single limit & double limit gauges

Single ended and double ended gauges

Fixed & adjustable gauges

**LIMIT GAUGING**

Limit gauging is adopted for checking parts produced by mass production. It has the advantage that they can be used by unskilled persons.

Instead of measuring actual dimensions, the conformance of product with tolerance specifications can be checked by a ‘GO’ and ‘NO GO’ gauges.

A ‘GO’ gauge represents the maximum material condition of the product (i.e. minimum hole size or maximum shaft size) and conversely a ‘NO GO’ represents the minimum material condition (i.e. maximum hole size or minimum shaft size).

**Plug gauges:**

Plug gauges are the limit gauges used for checking holes and consist of two cylindrical wear resistant plugs. The plug made to the lower limit of the hole is known as ‘GO’ end and this will enter any hole which is not smaller than the lower limit allowed. The plug made to the upper
limit of the hole is known as ‘NO GO’ end and this will not enter any hole which is smaller than the upper limit allowed. The plugs are arranged on either ends of a common handle.

Plug gauges are normally double ended for sizes upto 63 mm and for sizes above 63 mm they are single ended type.

The handles of heavy plug gauges are made of light metal alloys while the handles of small plug gauges can be made of some nonmetallic materials.

**Progressive plug gauges:**

For smaller through holes, both GO & NO GO gauges are on the same side separated by a small distance. After the full length of GO portion enters the hole, further entry is obstructed by the NO GO portion if the hole is within the tolerance limits.
Ring gauges:

Ring gauges are used for gauging shafts. They are used in a similar manner to that of GO & NO GO plug gauges. A ring gauge consists of a piece of metal in which a hole of required size is bored.

SNAP (or) GAP GAUGES:

A snap gauge usually consists of a plate or frame with a parallel faced gap of the required dimension. Snap gauges can be used for both cylindrical as well as non cylindrical work as compared to ring gauges which are conveniently used only for cylindrical work.

Double ended snap gauges can be used for sizes ranging from 3 to 100 mm. For sizes above 100 mm upto 250 mm a single ended progressive gauge may be used.

Desirable properties of Gauge Materials:
The essential considerations in the selection of material of gauges are;
1 Hardness to resist wear.
2 Stability to preserve size and shape
3 Corrosion resistance
4 Machinability for obtaining the required degree of accuracy.
5 Low coefficient of friction of expansion to avoid temperature effects.

Materials used for gauges:
High carbon steel: Heat treated Cast steel (0.8-1% carbon) is commonly used for most gauges.
Mild Steel: Case hardened on the working surface. It is stable and easily machinable.
Case hardened steel: Used for small & medium sized gauges.
Chromium plated & Hard alloys: Chromium plating imparts hardness, resistance to abrasion & corrosion. Hard alloys of tungsten carbide may also be used.
**Cast Iron:** Used for bodies of frames of large gauges whose working surfaces are hard inserts of tool steel or cemented carbides.

**Glass:** They are free from corrosive effects due to perspiration from hands. Also they are not affected by temperature changes.

**Invar:** It is a nickel-iron alloy (36% nickel) which has low coefficient of expansion but not suitable for usage over long periods.

(The name, Invar, comes from the word invariable, referring to its lack of expansion or contraction with temperature changes. It was invented in 1896 by Swiss scientist Charles Eduard Guillaume. He received the Nobel Prize in Physics in 1920 for this discovery, which enabled improvements in scientific instruments).

**Taylor’s Principle of Gauge Design:**

According to Taylor, ‘Go’ and ‘No Go’ gauges should be designed to check maximum and minimum material limits which are checked as below;

‘**GO**’ Limit. This designation is applied to that limit of the two limits of size which corresponds to the maximum material limit considerations, i.e. upper limit of a shaft and lower limit of a hole.

The GO gauges should be of full form, i.e. they should check shape as well as size.

‘**No Go**’ Limit:

This designation is applied to that limit of the two limits of size which corresponds to the minimum material condition. i.e. the lower limit of a shaft and the upper limit of a hole.

‘No Go’ gauge should check only one part or feature of the component at a time, so that specific discrepancies in shape or size can be detected. Thus a separate ‘No Go’ gauge is required for each different individual dimension.

![Diagram of GO and NO GO gauges](image-url)
Gauge Tolerance:

Gauges, like any other jobs require a manufacturing tolerance due to reasonable imperfections in the workmanship of the gauge maker. The gauge tolerance should be kept as minimum as possible though high costs are involved to do so. The tolerance on the GO & NO GO gauges is usually 10% of the work tolerance.

Wear Allowance:

The GO gauges only are subjected to wear due to rubbing against the parts during inspection and hence a provision has to be made for the wear allowance. Wear allowance is taken as 10% of gauge tolerance and is allowed between the tolerance zone of the gauge and the maximum material condition. *(i.e. lower limit of a hole & upper limit of a shaft).* If the work tolerance is less than 0.09 mm, wear allowance need not be given unless otherwise stated.

Present British System of Gauge & Wear Tolerance:

**PLUG GAUGES:** (For checking tolerances on holes)

![GO & NO GO Plug Gauges (For checking hole tolerance)]

**RING/SNAP GAUGES:** (For checking tolerances on shafts)

![GO & NO GO Ring Gauges (For checking shaft tolerance)]
**Numerical Problem 1:**
Calculate the dimensions of plug & ring gauges to control the production of 50 mm shaft & hole pair of H7d8 as per IS specifications. The following assumptions may be made: 50 mm lies in diameter step of 30-50 mm. Upper deviation for ‘d’ shaft is -16D0.44 and lower deviation for hole H is zero. Tolerance unit in ‘i’ in microns is =0.453/2D +0.001D and IT6=10i and above IT6 grade, the tolerance is multiplied by 10 at each 5th step.

**Numerical Problem 2**
Determine the actual dimensions to be provided for a shaft and hole 90 mm size for H8e9 type clearance fit. Size 90 mm falls in the diameter step of 80-100 mm. Value of standard tolerance unit =0.453/2D+0.001D . The values of tolerances for IT8 & IT9 grades are 25i & 40i respectively. Value of fundamental deviation for ‘e’ type shaft is -11D0.41. Also design the GO & NO GO gauges considering wear allowance as 10% of gauge tolerance.
2.6 COMPARATORS

Comparators can give precision measurements, with consistent accuracy by eliminating human error. They are employed to find out, by how much the dimensions of the given component differ from that of a known datum. If the indicated difference is small, a suitable magnification device is selected to obtain the desired accuracy of measurements. It is an indirect type of instrument and used for linear measurement. If the dimension is less or greater, than the standard, then the difference will be shown on the dial. It gives only the difference between actual and standard dimension of the workpiece. To check the height of the job H2 , with the standard job of height H1

![Diagram of comparator setup](a)

Initially, the comparator is adjusted to zero on its dial with a standard job in position as shown in Figure(a). The reading H1 is taken with the help of a plunger. Then the standard job is replaced by the work-piece to be checked and the reading H2 is taken. If H1 and H2 are different, then the change in the dimension will be shown on the dial of the comparator. Thus difference is then magnified 1000 to 3000 X to get the clear variation in the standard and actual job.

In short, Comparator is a device which

1) Picks up small variations in dimensions.
2) Magnifies it.
3) Displays it by using indicating devices, by which comparison can be made with some standard value.

Characteristics or Basic requirements of comparators

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 including devices must be such that readings are obtained in least possible time. The system should be free from backlash, wear effects and the inertia should be minimum.

3) Provision for maximum compensation to temperature effects.

4) The scale must be linear and must have straight line characteristics.

5) The instrument must be versatile i.e., its design must be such that it can be used for a wide range of measurements.

6) The measuring pressure should be low and constant.

7) The indicator (pointer, liquid column etc) should be clear and free from oscillations.

2.6.1 Classification of comparators:

1. Mechanical Comparator: It works on gears pinions, linkages, levers, springs etc.

2. Pneumatic Comparator: Pneumatic comparator works by using high pressure air, valves, back pressure etc.

3. Optical Comparator: Optical comparator works by using lens, mirrors, light source etc.

4. Electrical Comparator: Works by using step up, step down transformers.

5. Electronic Comparator: It works by using amplifier, digital signal etc.

6. Combined Comparator: The combination of any two of the above types can give the best result.

Characteristics of Good Comparators:

1. It should be compact.

2. It should be easy to handle.

3. It should give quick response or quick result.

4. It should be reliable, while in use.

5. There should be no effects of environment on the comparator.

6. Its weight must be less.

7. It must be cheaper.

8. It must be easily available in the market.

9. It should be sensitive as per the requirement.

10. The design should be robust.

11. It should be linear in scale so that it is easy to read and get uniform response.

12. It should have less maintenance.

13. It should have hard contact point, with long life.
2.6.2 Mechanical Comparator:

It is self controlled and no power or any other form of energy is required. It employs mechanical means for magnifying the small movement of the measuring stylus. The movement is due to the difference between the standard and the actual dimension being checked.

The method for magnifying the small stylus movement in all the mechanical comparators is by means of levers, gear trains or combination of these. They are available of different make and each has its own characteristic. The various types of mechanical comparators are dial indicator, rack and pinion, sigma comparator, Johansson mikrokator.

a. Dial Indicator:

It operates on the principle, that a very slight upward pressure on the spindle at the contact point is multiplied through a system of gears and levers. It is indicated on the face of the dial by a dial finger. Dial indicators basically consists of a body with a round graduated dial and a contact point connected with a spiral or gear train so that hand on the dial face indicates the amount of movement of the contact point. They are designed for use on a wide range of standard measuring devices such as dial box gauges, portal dial, hand gauges, dial depth gauges, diameter gauges and dial indicator snap gauge.
Corresponds to a spindle movement of 1 mm. The movement mechanism of the instrument is housed in a metal case for its protection. The large dial scale is graduated into 100 divisions. The indicator is set to zero by the use of slip gauges representing the basic size of part.

Requirements of Good Dial Indicator:
1. It should give trouble free and dependable readings over a long period.
2. The pressure required on measuring head to obtain zero reading must remain constant over the whole range.
3. The pointer should indicate the direction of movement of the measuring plunger.
4. The accuracy of the readings should be within close limits of the various sizes and ranges.
5. The movement of the measuring plunger should be in either direction without affecting the accuracy.
6. The pointer movement should be damped, so that it will not oscillate when the readings are being taken.

Applications:
1. Comparing two heights or distances between narrow limits.
2. To determine the errors in geometrical form such as ovality, roundness and taper.
3. For taking accurate measurement of deformation such as intension and compression.
4. To determine positional errors of surfaces such as parallelism, squareness and alignment.
5. To check the alignment of lathe centers by using suitable accurate bar between the centers.
6. To check trueness of milling machine arbours and to check the parallelism of shaper arm with table surface or vice.

b) Johansson Mikrokator:
This comparator was developed by C.F. Johansson.

Principle:
It works on the principle of a Button spring, spinning on a loop of string like in the case of Children’s toys.

Construction:
The method of mechanical magnification is shown in Figure. It employs a twisted metal strip. Any pull on the strip causes the centre of the strip to rotate. A very light pointer made of glass tube is attached to the centre of the twisted metal strip. The measuring plunger is on the slit washer and transmits its motion through the bell crank lever to the twisted metal strip. The other
end of the twisted metal strip is fastened to the cantilever strip. The overhanging length of the cantilever strip can be varied to adjust the magnification of the instrument. The longer the length of the cantilever, the more it will deflect under the pull of the twisted metal strip and less rotation of the pointer is obtained.

When the plunger moves by a small distance in upward direction the bell crank lever turns to the right hand side. This exerts a force on the twisted strip and it causes a change in its length by making it further twist or untwist. Hence the pointer at the centre rotates by some amount. Magnification up to 5000X can be obtained by this comparator

**Advantages of Mechanical Comparator:**

1. They do not require any external source of energy.
2. These are cheaper and portable.
3. These are of robust construction and compact design.
4. The simple linear scales are easy to read.
5. These are unaffected by variations due to external source of energy such as air, electricity etc.

**Disadvantages:**

1. Range is limited as the pointer moves over a fixed scale.
2. Pointer scale system used can cause parallax error.
3. There are number of moving parts which create problems due to friction, and ultimately the accuracy is less.
4. The instrument may become sensitive to vibration due to high inertia.
c) Mechanical - Optical Comparator:

**Principle:**

In mechanical optical comparator, small variation in the plunger movement is magnified: first by mechanical system and then by optical system.

**Construction:**

The movement of the plunger is magnified by the mechanical system using a pivoted lever. From the Figure the mechanical magnification = \( \frac{x_2}{x_1} \). High optical magnification is possible with a small movement of the mirror. The important factor is that the mirror used is of front reflection type only.

![Mechanical Optical Comparator Diagram](image-url)

The back reflection type mirror will give two reflected images as shown in Figure, hence the exact reflected image cannot be identified.

**Advantages:**

1. These Comparators are almost weightless and have less number of moving parts, due to this there is less wear and hence less friction.
2. Higher range even at high magnification is possible as the scale moves past the index.
3. The scale can be made to move past a datum line and without having any parallax errors.
4. They are used to magnify parts of very small size and of complex configuration such as intricate grooves, radii or steps.
**Disadvantages:**

1. The accuracy of measurement is limited to 0.001 mm
2. They have their own built in illuminating device which tends to heat the instrument.
3. Electrical supply is required.
4. Eyepiece type instrument may cause strain on the operator.
5. Projection type instruments occupy large space and they are expensive.
6. When the scale is projected on a screen, then it is essential to take the instrument to a dark room in order to take the readings easily.

**d) Sigma Comparator:**

The plunger is attached to a bar which is supported between the bending plates at the top and bottom portion.

The bar is restricted to move in the vertical direction. A knife edge is fixed to the bar. The knife edge is attached to the sapphire plate which is attached to the moving block. The knife edge extorts a force on the moving block through sapphire plate. Moving block is attached to the fixed block with the help of crossed strips as shown in Figure (b). When the force is applied on the moving block, it will give an angular deflection. A Y-arm which is attached to the moving block transmits the rotary motion to the driving drum of radius r. This deflects the pointer and then the reading is noted.
If \(l\) = Distance from hinge pivot to the knife edge
L = Length of y-arm
R = Driving drum radius
D Length of the pointer
Then the total magnification = \((L/l) \times (D/R)\)

### 2.6.3 Electrical Comparators

Electrical comparators give a wide range of advantages. As we know, components like levers, gears, racks and pinions, activate mechanical devices. The accuracy and life of the instruments are affected as they are subjected to wear and friction.

Electrical comparators have no moving parts. Thus a high degree of reliability is expected from these instruments. Generally there are two important applications of electrical comparators:

1. Used as measuring heads
2. Used for electrical gauging heads, to provide usual indication to check the dimensions within the limits laid down.

The first application is very important when there is a requirement for precise measurement for e.g. Checking or comparison of workshop slip gauges against inspection slip gauges. The second application is used to indicate with a green light if a dimension is within the limits. A red lamp indicates an undersize dimension; a yellow lamp indicates an oversize dimension. So the operator is not required to be aware of the actual tolerances on the dimension. After setting the instrument correctly, all that needs to be done is to place the component under
the plunger of the gauging head. The signal lamps provide in standard positive indication of the acceptability of the dimension under test.

**Advantages:**
1. Measuring units can be remote from indicating units.
2. Variable sensitivity which can be adjusted as per requirement.
3. No moving parts, hence it can retain accuracy over long periods.
4. Higher magnification is possible as compared to mechanical comparator.

**Disadvantages:**
1. The accuracy of working of these comparators is likely to be affect due to temperature and humidity.
2. It is not a self contained unit; it needs stabilized power supply for its operation.
3. Heating of coils can cause zero drifts and it may alter calibration.
4. It is more expensive than mechanical comparator.

### 2.6.4 Pneumatic Comparators (Solex Gauge):

**Principle:**

It works on the principle of pressure difference generated by the air flow. Air is supplied at constant pressure through the orifice and the air escapes in the form of jets through a restricted space which exerts a back pressure. The variation in the back pressure is then used to find the dimensions of a component.

**Working:**

The air is compressed in the compressor at high pressure which is equal to Water head H. The excess air escapes in the form of bubbles. Then the metric amount of air is passed through the orifice at the constant pressure. Due to restricted area, at A1 position, the back pressure is generated by the head of water displaced in the manometer tube. To determine the roundness of the job, the job is rotated along the jet axis, if no variation in the pressure reading is obtained then we can say that the job is perfectly circular at position A1.

Then the same procedure is repeated at various positions A2, A3, A4, position and variation in the pressure reading is found out. Also the diameter is measured at position A1 corresponding to the portion against two jets and diameter is also measured at various position along the length of the bore.
Any variation in the dimension changes the value of h, e.g. Change in dimension of 0.002 mm changes the value of h from 3 to 20 mm. Moderate and constant supply pressure is required to have the high sensitivity of the instrument.

**Advantages:**
1. It is cheaper, simple to operate and the cost is low.
2. It is free from mechanical hysteresis and wear.
3. The magnification can be obtained as high as 10,000 X.
4. The gauging member is not in direct contact with the work.
5. Indicating and measuring is done at two different places.
6. Tapers and ovality can be easily detected.
7. The method is self cleaning due to continuous flow of air through the jets and this makes the method ideal to be used on shop floor for online controls.

**Disadvantages:**
1. They are very sensitive to temperature and humidity changes.
2. The accuracy may be influenced by the surface roughness of the component being checked.
3. Different gauging heads are needed for different jobs.
4. Auxiliary equipments such as air filters, pressure gauges and regulators are needed.
5. Non-uniformity of scale is a peculiar aspect of air gauging as the variation of back pressure is linear, over only a small range of the orifice size variation.

**OUTCOMES**
Students will be able to
1. Understand the concept of limits, fits, gauges
2. Analysis types of fits and gauges.
SELF ASSESSMENT QUESTIONS

1. What is a fit?
2. What is the difference between clearance and interference?
3. Mention the applications of clearance, interference and transitions fits.
4. Which of the following are clearance, transition and interference fits?
   i. Push fit,
   ii. Wringing fit,
   iii. Force fit, and
   iv. Slide fit.
5. Differentiate between „Hole basis system“ and „Shaft basis system“.

FURTHER READING

UNIT 3

COMPARATORS AND ANGULAR MEASUREMENT

CONTENTS

3 Comparators
   3.1 Introduction to comparators
   3.2 Characteristics
   3.3 Uses of Comparators
   3.4 Classification of comparators
   3.5 Mechanical comparators
      3.5.1 Dial indicator
      3.5.2 Johnson Mikrokator
      3.5.3 Sigma comparators
   3.6 Optical comparators
      3.6.1 Principles,
      3.6.2 Zeiss ultra optimeter,
   3.7 Electric and electronic comparators principles,
      3.7.1 LVDT,
   3.8 Pneumatic comparators,
      3.8.1 Back pressure gauges,
      3.8.2 Solex comparators.
   3.9 Angular Measurements
      3.9.1 Introduction,
      3.9.2 Bevel protractor,
      3.9.3 Sine principle
      3.9.4 Uses of sine bars,
      3.9.5 Sine centre,
      3.9.6 Use of angle gauges
      3.9.7 Numerical on building angles
      3.9.8 Clinometers.

OBJECTIVES
Comparators can give precision measurements, with consistent accuracy by eliminating human error. They are employed to find out, by how much the dimensions of the given component differ from that of a known datum. If the indicated difference is small, a suitable magnification device is selected to obtain the desired accuracy of measurements. It is an indirect type of instrument and used for linear measurement. If the dimension is less or greater, than the standard, then the difference will be shown on the dial. It gives only the difference between actual and standard dimension of the workpiece. To check the height of the job H2, with the standard job of height H1.

Initially, the comparator is adjusted to zero on its dial with a standard job in position as shown in Figure (a) The reading H1is taken with the help of a plunger. Then the standard job is replaced by the work-piece to be checked and the reading H2 is taken. If H1and H2 are different, then the change in the dimension will be shown on the dial of the comparator. Thus difference is then magnified 1000 to 3000 X to get the clear variation in the standard and actual job.

In short, Comparator is a device which
(1) Picks up small variations in dimensions.
(2) Magnifies it.
(3) Displays it by using indicating devices, by which comparison can be made with some standard value.
Classification:
1. Mechanical Comparator: It works on gears pinions, linkages, levers, springs etc.
2. Pneumatic Comparator: Pneumatic comparator works by using high pressure air, valves, back pressure etc.
3. Optical Comparator: Optical comparator works by using lens, mirrors, light source etc.
4. Electrical Comparator: Works by using step up, step down transformers.
5. Electronic Comparator: It works by using amplifier, digital signal etc.
6. Combined Comparator: The combination of any two of the above types can give the best result.

Characteristics of Good Comparators:
1. It should be compact.
2. It should be easy to handle.
3. It should give quick response or quick result.
4. It should be reliable, while in use.
5. There should be no effects of environment on the comparator.
6. Its weight must be less.
7. It must be cheaper.
8. It must be easily available in the market.
9. It should be sensitive as per the requirement.
10. The design should be robust.
11. It should be linear in scale so that it is easy to read and get uniform response.

Mechanical Comparator:

It is self controlled and no power or any other form of energy is required. It employs mechanical means for magnifying the small movement of the measuring stylus. The movement is due to the difference between the standard and the actual dimension being checked.

The method for magnifying the small stylus movement in all the mechanical comparators is by means of levers, gear trains or combination of these. They are available of different make and each has it's own characteristic. The various types of mechanical comparators are dial indicator, rack and pinion, sigma comparator, Johansson mikrokator.
a. Dial Indicator:
It operates on the principle, that a very slight upward pressure on the spindle at the contact point is multiplied through a system of gears and levers. It is indicated on the face of the dial by a dial finger. Dial indicators basically consists of a body with a round graduated dial and a contact point connected with a spiral or gear train so that hand on the dial face indicates the amount of movement of the contact point. They are designed for use on a wide range of standard measuring devices such as dial box gauges, portal dial, hand gauges, dial depth gauges, diameter gauges and dial indicator snap gauge.

Corresponds to a spindle movement of 1mm. The movement mechanism of the instrument is housed in a metal case for its protection. The large dial scale is graduated into 100 divisions. The indicator is set to zero by the use of slip gauges representing the basic size of part.

**Requirements of Good Dial Indicator:**
1. It should give trouble free and dependable readings over a long period.
2. The pressure required on measuring head to obtain zero reading must remain constant over the whole range.
3. The pointer should indicate the direction of movement of the measuring plunger.
4. The accuracy of the readings should be within close limits of the various sizes and ranges
5. The movement of the measuring plunger should be in either direction without affecting the accuracy.
6. The pointer movement should be damped, so that it will not oscillate when the readings are being taken.

**Applications:**
1. Comparing two heights or distances between narrow limits.
2. To determine the errors in geometrical form such as ovality, roundness and taper.
3. For taking accurate measurement of deformation such as intension and compression.
4. To determine positional errors of surfaces such as parallelism, squareness and alignment.
5. To check the alignment of lathe centers by using suitable accurate bar between the centers.
6. To check trueness of milling machine arbours and to check the parallelism of shaper arm with table surface or vice.

**b) Johansson Mikrokator:**

This comparator was developed by C.F. Johansson.

**Principle:**

It works on the principle of a Button spring, spinning on a loop of string like in the case of Children’s toys.

**Construction:**

The method of mechanical magnification is shown in Figure. It employs a twisted metal strip. Any pull on the strip causes the centre of the strip to rotate. A very light pointer made of glass tube is attached to the centre of the twisted metal strip. The measuring plunger is on the slit washer and transmits its motion through the bell crank lever to the twisted metal strip. The other end of the twisted metal strip is fastened to the cantilever strip. The overhanging length of the cantilever strip can be varied to adjust the magnification of the instrument. The longer the length of the cantilever, the more it will deflect under the pull of the twisted metal strip and less rotation of the pointer is obtained.
When the plunger moves by a small distance in upward direction the bell crank lever turns to the right hand side. This exerts a force on the twisted strip and it causes a change in its length by making it further twist or untwist. Hence the pointer at the centre rotates by some amount. Magnification up to 5000X can be obtained by this comparator

**Advantages of Mechanical Comparator:**

1. They do not require any external source of energy.
2. These are cheaper and portable.
3. These are of robust construction and compact design.
4. The simple linear scales are easy to read.
5. These are unaffected by variations due to external source of energy such as air, electricity etc.

**Disadvantages:**

1. Range is limited as the pointer moves over a fixed scale.
2. Pointer scale system used can cause parallax error.
3. There are number of moving parts which create problems due to friction, and ultimately the accuracy is less.
4. The instrument may become sensitive to vibration due to high inertia.

**c) Mechanical - Optical Comparator:**

**Principle:**

In mechanical optical comparator, small variation in the plunger movement is magnified: first by mechanical system and then by optical system.
**Construction:**
The movement of the plunger is magnified by the mechanical system using a pivoted lever. From the Figure the mechanical magnification = \( x_2 / x_1 \). High optical magnification is possible with a small movement of the mirror. The important factor is that the mirror used is of front reflection type only.

The back reflection type mirror will give two reflected images as shown in Figure, hence the exact reflected image cannot be identified.

**Advantages:**
1. These Comparators are almost weightless and have less number of moving parts, due to this there is less wear and hence less friction.
2. Higher range even at high magnification is possible as the scale moves past the index.
3. The scale can be made to move past a datum line and without having any parallax errors.
4. They are used to magnify parts of very small size and of complex configuration such as intricate grooves, radii or steps.

**Disadvantages:**
1. The accuracy of measurement is limited to 0.001 mm
2. They have their own built in illuminating device which tends to heat the instrument.
3. Electrical supply is required.
4. Eyepiece type instrument may cause strain on the operator.
5. Projection type instruments occupy large space and they are expensive.
6. When the scale is projected on a screen, then it is essential to take the instrument to a dark room in order to take the readings easily.

**d) Sigma Comparator:**

The plunger is attached to a bar which is supported between the bending plates at the top and bottom portion as shown in Figure (a)

![Diagram of Sigma Comparator](image)

The bar is restricted to move in the vertical direction. A knife edge is fixed to the bar. The knife edge is attached to the sapphire plate which is attached to the moving block. The knife edge extorts a force on the moving block through sapphire plate. Moving block is attached to the fixed block with the help of crossed strips as shown in Figure (b). When the force is applied on the moving block, it will give an angular deflection. A Y-arm which is attached to the moving block transmits the rotary motion to the driving drum of radius r. This deflects the pointer and then the reading is noted.

If \( l = \) Distance from hinge pivot to the knife edge

\[ L = \text{Length of y-arm} \]

\[ R = \text{Driving drum radius} \]
D Length of the pointer
Then the total magnification = \((L/l) \times (D/R)\)

**Electrical Comparators:**

Electrical comparators give a wide range of advantages. As we know, components like levers, gears, racks and pinions, activate mechanical devices. The accuracy and life of the instruments are affected as they are subjected to wear and friction.

Electrical comparators have no moving parts. Thus a high degree of reliability is expected from these instruments. Generally there are two important applications of electrical comparators: 1. Used as measuring heads 2. Used for electrical gauging heads, to provide usual indication to check the dimensions within the limits laid down. The first application is very important when there is a requirement for precise measurement for e.g. Checking or comparison of workshop slip gauges against inspection slip gauges. The second application is used to indicate with a green light if a dimension is within the limits. A red lamp indicates an undersize dimension; a yellow lamp indicates an oversize dimension. So the operator is not required to be aware of the actual tolerances on the dimension. After setting the instrument correctly, all that needs to be done is to place the component under the plunger of the gauging head. The signal lamps provide in standard positive indication of the acceptability of the dimension under test

**Advantages:**

1. Measuring units can be remote from indicating units.
2. Variable sensitivity which can be adjusted as per requirement.
3. No moving parts, hence it can retain accuracy over long periods.
4. Higher magnification is possible as compared to mechanical comparator.
5. Compact sizes of probes are available.

**Disadvantages:**

1. The accuracy of working of these comparators is likely to be affect due to temperature and humidity.
2. It is not a self contained unit; it needs stabilized power supply for its operation.
3. Heating of coils can cause zero drifts and it may alter calibration.
4. It is more expensive than mechanical comparator.

**Pneumatic Comparators (Solex Gauge):**

**Principle:**
It works on the principle of pressure difference generated by the air flow. Air is supplied at constant pressure through the orifice and the air escapes in the form of jets through a restricted space which exerts a back pressure. The variation in the back pressure is then used to find the dimensions of a component.

**Working:**
As shown in Figure (a) the air is compressed in the compressor at high pressure which is equal to Water head H. The excess air escapes in the form of bubbles. Then the metric amount of air is passed through the orifice at the constant pressure. Due to restricted area, at A1 position, the back pressure is generated by the head of water displaced in the manometer tube. To determine the roundness of the job, the job is rotated along the jet axis, if no variation in the pressure reading is obtained then we can say that the job is perfectly circular at position A1.

Then the same procedure is repeated at various positions A2, A3, A4, position and variation in the pressure reading is found out. Also the diameter is measured at position A1 corresponding to the portion against two jets and diameter is also measured at various position along the length of the bore.
Any variation in the dimension changes the value of h, e.g. Change in dimension of 0.002 mm changes the value of h from 3 to 20 mm. Moderate and constant supply pressure is required to have the high sensitivity of the instrument.

**Advantages:**

1. It is cheaper, simple to operate and the cost is low.
2. It is free from mechanical hysteresis and wear.
3. The magnification can be obtained as high as 10,000 X.
4. The gauging member is not in direct contact with the work.
5. Indicating and measuring is done at two different places.
6. Tapers and ovality can be easily detected.
7. The method is self cleaning due to continuous flow of air through the jets and this makes the method ideal to be used on shop floor for online controls.

**Disadvantages:**

1. They are very sensitive to temperature and humidity changes.
2. The accuracy may be influenced by the surface roughness of the component being checked.
3. Different gauging heads are needed for different jobs.
4. Auxiliary equipments such as air filters, pressure gauges and regulators are needed.
5. Non-uniformity of scale is a peculiar aspect of air gauging as the variation of back pressure is linear, over only a small range of the orifice size variation.
Introduction to Angular Measurements:

For measuring the angle, no absolute standard is required. The measurement is done in degrees, minutes and seconds. The measurement of angular and circular divisions is an important part of inspection. It is concerned with the measurement of individual angles, angular changes and deflections on components, gauges and tools. For precision measurement of angles more skill is required. Like linear measurement, angular measurements have their own importance. The basic difference between the linear and angular measurement is that no absolute standard is required for angular measurement. There are several methods of measuring angles and tapers. The various instruments used are angle gauges, clinometers, bevel protractor, sine bar, sine centers, taper plug and ring gauges.

Sine Bars:

It is used for measurement of an angle of a given job or for setting an angle. They are hardened and precision ground tools for accurate angle setting. It can be used in conjunction with slip gauge set and dial gauge for measurement of angles and tapers from horizontal surface. As shown in Figure, two accurately lapped rollers are located at the extreme position. The center to center distance between the rollers or plugs is available for fixed distance i.e. $l = 100, 200, 250, 300$ mm. The diameter of the plugs or roller must be of the same size and the center distance between them is accurate. The important condition for the sine bar is that the surface of sine bar must be parallel to the center lines of the plug.

Principle of Working:

As shown in Figure the taper angle $\theta$ of the job W X YZ is to be measured by the sine bar. The job is placed over the surface plate. The sine bar is placed over the job with plug or roller of one end of the bar touching the surface plate. One end of the sine bar is rested on the surface plate and the other end is rested on the slip gauges.
The angle of the job is then first measured by some non-precision instrument, such as bevel protector. That angle gives the idea of the approximate slip gauges required, at the other end of sine bar. And finally the exact number of slip gauges are added equal to height h, such that, the top most slip gauges touches the lower end of the roller. The height of the slip gauges required is then measured. Then the taper angle can be measured by making sine bar as a hypotenuse of right angle triangle and slide gauge as the opposite side of the triangle as shown in Figure

\[ h = \text{Height in mm} \]
\[ L = \text{Center distance in mm} \]
\[ \sin \theta = \frac{\text{Opp}}{\text{Hyp}} = \frac{h}{L} \]

**Use of Sine Bar.**

1. Measuring known angles or locating any work to a given angle.

For this purpose the surface plate is assumed to be having a perfectly flat surface, so that its surface could be treated as horizontal. One of the cylinders or rollers of sine bar is placed on the surface plate and other roller is placed on the slip gauges of height h. Let the sine bar be set at an angle \( \theta \). Then \( \sin \theta = h/l \), where \( l \) is the distance between the centres of the rollers. Thus knowing
θ, h can be found out and any work could be set at this angle as the top face of sine bar is inclined at angle θ to the surface plate. The use of angle plates and clamps could also be made in case of heavy components. For better results, both the rollers could also be placed on slip gauges, of height h1 and h2 respectively.

Then \( \sin \theta = \frac{(h_2 - h_1)}{l} \)

(2) Checking of unknown angles.

Many a times, angle of a component to be checked is unknown. In such a case, it is necessary to first find the angle approximately with the help of a bevel protractor. Let the angle be θ. Then the sine bar is set at an angle θ and clamped to an angle plate. Next, the work is placed on the sine bar and clamped to the angle plate as shown in Fig. and a dial indicator is set at one end of the work and moved to the other, and deviation is noted. Again slip gauges are so adjusted (according to this deviation) that dial indicator reads zero across the work surface.

If deviation noted down by the dial indicator is \( \delta h \) over a length \( l' \) of work, then height of slip gauges by which it should be adjusted is equal to \( \delta h \times \left( \frac{l}{l'} \right) \).

(3) Checking of unknown angles of heavy component.

In such cases where components are heavy and can’t be mounted on the sine bar, then sine bar is mounted on the component as shown in Fig. The height over the rollers can then be measured by
a vernier height gauge; using a dial test gauge mounted on the anvil of height gauge as the fiducial indicator to ensure constant measuring pressure. The anvil on height gauge is adjusted with probe of dial test gauge showing same reading for the top most position of rollers of sine bar. Fig. 8.18 shows the use of height gauge for obtaining two readings for either of the roller of sine bar. The difference of the two readings of height gauge divided by the centre distance of sine bar gives the sine of the angle of the component to be measured. Where greater accuracy is required, the position of dial test gauge probe can be sensed by adjusting a pile of slip gauges till dial indicator indicates same-reading over roller of sine bar and the slip gauges.

**Advantages of sine bar:**

1. It is used for accurate and precise angular measurement.
2. It is available easily.
3. It is cheap.

**Disadvantages:**

1. The application is limited for a fixed center distance between two plugs or rollers.
2. It is difficult to handle and position the slip gauges.
3. If the angle exceeds 45°, sine bars are impracticable and inaccurate.
4. Large angular error may result due to slight error in sine bar.

**Sine Centers:**

It is the extension of sine bars where two ends are provided on which centers can be clamped, as shown in Figure. These are useful for testing of conical work centered at each end, up to 60°. The centers ensure correct alignment of the work piece. The procedure of setting is the same as for sine bar. The dial indicator is moved on to the job till the reading is same at the extreme position. The necessary arrangement is made in the slip gauge height and the angle is calculated as \( \theta = \sin^{-1} \left( \frac{h}{L} \right) \).
Universal Bevel Protractor:
It is used to measure angles accurately to 5 minutes. It is finely made tool with dial, graduated in degrees, a base and a sliding blade. The blade can be locked against dial by tightening the blade clamp nut. The blade and dial can be rotated as one unit to any position and locked by tightening the dial clamp nut for accurate measurement, a vernier or a fine adjustment device, is fitted on the dial. The dial is graduated into, I treads, , The vernier scale is divided into twelve equal parts on each side of zero, every third division is numbered 0, 15, 30, 45, 60 representing minutes.

Angle Gauges:
In this method, the auto collimator used in conjunction with the angle gauges. It compares the angle to be measured of the given component with the angle gauges. Angles gauges are wedge shaped block and can be used as standard for angle measurement. They reduce the setuptime and minimize the error. These are 13 pieces, divided into three types such as degrees, minutes and seconds. The first series angle are 1°, 3°, 9°, 27° and 41 ° and the second series angle are 1', 3', 9' and27' And the third series angle are 3", 6", 18" and 30"
These gauges can be used for large number of combinations by adding or subtracting these gauges, from each other.
Clinometer:

A clinometer is a special case of the application of spirit level. In clinometer, the spirit level is mounted on a rotary member carried in a housing. One face of the housing forms the base of the instrument. On the housing, there is a circular scale. The angle of inclination of the rotary member carrying the level relative to its base can be measured by this circular scale. The clinometer mainly used to determine the included angle of two adjacent faces of workpiece. Thus for this purpose, the instrument base is placed on one face and the rotary body adjusted till zero reading of the bubble is obtained. The angle of rotation is then noted on the circular scale against the index. A second reading is then taken in the similar manner on the second face of workpiece. The included angle between the faces is then the difference between the two readings.

Clinometers are also used for checking angular faces, and relief angles on large cutting tools and milling cutter inserts.

These can also be used for setting inclinable table on jig boring; machines and angular work on grinding machines etc.

The most commonly used clinometer is of the Hilger and Watts type. The circular glass scale is totally enclosed and is divided from 0° to 360° at 10′ intervals. Sub-division of 10′ is possible by the use of an optical micrometer. A coarse scale figured every 10 degrees is provided outside the body for coarse work and approximate angular reading. In some instruments worm and quadrant arrangement is provided so that reading upto 1′ is possible.

In some clinometers, there is no bubble but a graduated circle is supported on accurate ball bearings and it is so designed that when released, it always takes up the position relative to the true vertical. The reading is taken against the circle to an accuracy of 1 second with the aid of vernier.
MODULE 5
MEASUREMENTS OF FORCE, TORQUE AND PRESSURE

CONTENTS

5.1 Introduction
5.2 Analytical Balance (Equal arm balance)
5.3 Unequal arm balance
5.4 Platform Balance (Multiple Lever System)
5.5 Proving Ring
5.6 Torque Measurement
5.7 Pressure Measurements
5.8 Temperature Measurements
5.9 Strain Measurements

OBJECTIVES

1. Is to get knowledge of force, pressure and temperature measuring devices and their applications.
5.1 Introduction

A force is defined as the reaction between two bodies. This reaction may be in the form of a tensile force (pull) or it may be a compressive force (push). Force is represented mathematically as a vector and has a point of application. Therefore the measurement of force involves the determination of its magnitude as well as its direction. The measurement of force may be done by any of the two methods.

- Direct method: This involves a direct comparison with a known gravitational force on a standard mass example by a physical balance.
- Indirect method: This involves the measurement of the effect of force on a body. For example.

a) Measurement of acceleration of a body of known mass which is subjected to force.
b) Measurement of resultant effect (deformation) when the force is applied to an elastic member.

Direct method

A body of mass “m” in the earth’s gravitational field experiences a force F which is given by F = ma = W.

Where ‘W’ is the weight of the body ‘a’ is the acceleration due to gravity. Any unknown force may be compared with the gravitational force (ma) on the standard mass ‘m’. The values of ‘m’ and ‘a’ should be known accurately in order to know the magnitude of the gravitation force.

Mass is a fundamental quantity and its standard kilogram is kept at France. The other masses can be compared with this standard with a precision of a few parts in109. On the other hand, ‘a’ is a derived quantity but still makes a convenient standard. Its value can be measured with an accuracy of 1 part in 106. Therefore any unknown force can be compared with the gravitational force with an accuracy of about this order of magnitude.

5.2 Analytical Balance : (Equal arm balance)

Direct comparison of an unknown force with the gravitational force can be explained with the help of an analytical balance. The direction of force is parallel to that of the gravitational force, and hence only its magnitude needs to be determined. The constructional details of an analytical balance are as shown in Fig.
The balance arm rotates about the point “O” and two forces $W_1$ and $W_2$ are applied at the ends of the arm. $W_1$ is an unknown force and $W_2$ is the known force due to a standard mass. Point $G$ is the centre of gravity of the balance arm, and $W_B$ is the weight of the balance arm and the pointer acting at $G$. The above figure show the balance is unbalanced position when the force $W_1$ and $W_2$ are unequal. This unbalance is indicated by the angle $\theta$ which the pointer makes with the vertical.

In the balanced position $W_1 = W_2$, and hence $\theta$ is zero. Therefore, the weight of the balance arm and the pointer do not influence the measurements.

The sensitivity $S$ of the balance is defined as the angular deflection per unit of unbalance is between the two weight $W_1$ and $W_2$ and is given by

$$S = \frac{\theta}{W_1 - W_2} = \frac{\theta}{\Delta W}$$
where, $\Delta W$ is the difference between $W_1$ and $W_2$. The sensitivity $S$ can be calculated by writing the moment equation at equilibrium as follows:

$$W_1 (L \cos \theta - dB \sin \theta) = W_2 (L \cos \theta + dB \sin \theta) + W_B d_G \sin \theta$$

where the distances $dB$, $d_G$ and $L$ are shown in Fig. For small deflection angles $\sin \theta = \theta$ and $\cos \theta = 1$ and the above equation becomes

$$W_1 (L - dB \theta) = W_2 (L + dB \theta) + W_B d_G \theta$$

**: The Sensitivity**

$$S = \frac{\theta}{w_1 - w_2} = \frac{L}{(w_1 + w_2)dB + d_G W_B}$$

Near Equilibrium, $W_1 = W_2 = W$ and hence

$$S = \frac{\theta}{\Delta w} = \frac{L}{2WdB + W_B d_G}$$

The sensitivity of the balance will be independent of the weight $W$ Provided it is designed such that $dB = 0$ then

$$S = \frac{L}{W_B d_G}$$

The sensitivity depends on the construction parameters of the balance arm and is independent of the weights being compared. The sensitivity can be improved by decreasing both $d_G$ and $W_B$ and increasing $L$. A compromise however, is to be struck between the sensitivity and stability of the balance.

### 5.3 Unequal Arm Balance

An equal arm analytical balance suffers from a major disadvantage. It requires a set of weights which are at least as heavy as the maximum weight to be measured. In order that the heavier weights may be measured with the help of lighter weights, balances with unequal arms are used.

The unequal arm balance uses two arms. One is called the **load arm** and the other is called the **power arm**. The load arm is associated with load i.e., the weight force to be measured,
while power arm is associated with power i.e. the force produced by counter posing weights required to set the balance in equilibrium.

Fig. shows a typical unequal arm balance. Mass ‘m’ acts as power on the beam and exerts a force of $F_g$ due to gravity where $F_g = m \times g$. This force acts as counterposing force against the load which may be a test force $F_t$.

![Fig. Schematic of Unequal Arm Balance](image_url)

The beam is pivoted on a knife edge ‘q’. The test force $F_t$ is applied by a screw or a lever through a knife edge ‘p’ until the pointer indicates that the beam is horizontal.

For balance of moments, $F_t(a) = F_g(b)$

or test force $F_t = F_g(b/a)$

$$= m \times g \times b/a$$

$$= \text{constant} \times b \ (\text{provided that } g \text{ is constant}).$$

Therefore the test force is proportional to the distance 'b' of the mass from the pivot. Hence, if mass 'm' is constant and the test force is applied at a fixed distance 'a' from the knife edge 'q' (i.e., the load arm is constant), the right hand of the beam (i.e., the power arm) may be
calibrated in terms of force $F_t$. If the scale is used in different gravitational fields, a correction may be made for change in value of 'g'.

The set-up shown in Fig. is used for measurement of tensile force. With suitable modifications, it can be used for compression, shearing and bending forces.

This machine can also be used for the measurement of unknown mass. Suppose force $F_t$ is produced by an unknown mass $m_1$.

Therefore $F_t = m_1 g$

Hence, for balance, $m_1 \times g \times a = m \times g \times b$

or $m_1 = m \times \frac{b}{a} = a \text{ constant} \times b$

Therefore, the power arm $b$ may be calibrated to read the unknown mass $m_1$ directly if ‘m’ and ‘a’ are fixed. This forms the basis of countless weighing (i.e., mass measuring) machine.

### 5.4 Platform Balance (Multiple Lever System)

![Schematic of Multiple Lever System](image)

An equal and unequal arm balances are not suited for measurement of large weights. When measurement of large weights is involved, multiple lever systems shown in Fig. are used.
In these systems, a large weight $W$ is measured in terms of two smaller weights $W_p$ and $W_s$ where, $W_p$ = weight of poise and $W_s$ = Weight of Pan

The system is provided with an adjustable counterpoise which is used to get an initial balance. Before the unknown load $W$ is applied to the platform, the poise weight $W_p$ is set at zero of the beam scale and counter piece is adjusted to obtain initial zero balance.

In order to simplify the analysis it is assumed that the weight $W$ can be replaced by two arbitrary weights $W_1$ and $W_2$. Also it is assumed that the poise weight $W_p$ is at zero and when the unknown weight $W$ is applied it is entirely balanced by the weight, $W_s$ in the pan.

Therefore $T \times b = W_s \times a \ldots (1)$

and $T \times c = W_1 \frac{f}{d} e + W_2 h \ldots (2)$

If the links are so proportioned that $h/e = f/d$

We get : $T \times c = h (W_1 + W_2) hW \ldots (3)$

From the above equation (3) it is clear that the weight $W$ may be placed anywhere on the platform and its position relative to the two knife edges of the platform is immaterial.

$T$ can be eliminated from equations. (1) and (3) to give

$$WS \frac{a}{b} = \frac{Wh}{d}$$

**Unknown weight** $W = \frac{a}{b} \frac{c}{h} W_s$

where $m = \frac{a}{b} \frac{c}{h}$ is called the multiplication ratio of the scale

The multiplication ratio $M$, is indicative of weight that should be put in the pan to balance the weight on the platform. Suppose the scale has a multiplication ratio of 1000. It means that a weight of 1 kg put in the pan can balance a weight of 1000 kg put on the platform. Scales are available which have multiplication ratios as high as 10,000.

If the beam scale is so divided that a movement of poise weight $W_p$ by 1 scale division represents a force of $x$ kg, then a poise movement of $y$ scale divisions should produce the same result as a weight $W_p$ placed on the pan at the end of the beam. Hence,

$$W_p \ y = x \ y \ a$$

or $$x = \frac{W_p}{a}$$
The above equation represents a relationship that determines the required scale divisions on the beam for any poise weight Wp.

5.5 Proving Ring

This device has long been the standard for calibrating tensile testing machines and is in general, the means by which accurate measurement of large static loads may be obtained. A proving ring is a circular ring of rectangular cross section as shown in the Fig. which may be subjected to tensile or compressive forces across its diameter. The force-deflection relation for a thin ring is

\[ F = \frac{16}{\pi^2} \frac{EI}{d^3} y \]

where, \( F \) is the force, \( E \) is the young’s modulus, \( I \) is the moment of inertia of the section about the centroidal axis of bending section. \( D \) is the outside diameter of the ring, \( y \) is the deflection. The above equation is derived under the assumption that the thickness of the ring is small compared to the radius. And also it is clear that the displacement is directly proportional to the force.

The deflection is small and hence the usefulness of the proving ring as a calibration device depends on the accuracy with which this small deflection is measured. This is done by using a precision micrometer shown in the figure. In order to obtain precise measurements one edge of the micrometer is mounted on a vibrating reed device which is plucked to obtain a vibratory motion.
The micrometer contact is then moved forward until a noticeable damping of the vibration is observed.

Proving rings are normally used for force measurement within the range of 1.5 KN to 1.5 MN. The maximum deflection is typically of the order of 1% of the outside diameter of the ring.

5.6 Torque Measurement

The force, in addition to its effect along its line of action, may exert a turning effort relative to any axis other than those intersecting the line of action as shown in Fig. Such a turning effect is called torque or couple.

Torque or couple = \( Fb_1 - Fb_3 \) = \( Fb_2 \)

The important reason for measuring torque is to obtain load information necessary for stress or deflection analysis. The torque \( T \) may be computed by measuring the force \( F \) at a known radius \( 'r' \) from the following relation \( T=Fr \).

However, torque measurement is often associated with determination of mechanical power, either power required to operate a machine or power developed by the machine. The power is calculated from the relation.

\[
P = 2 \pi NT
\]

where \( N \) is the angular speed in revolutions per second. Torque measuring devices used in this connection are commonly known as \textbf{dynamometers}. 
There are basically three types of dynamometers.

1. **Absorption dynamometers**: They absorb the mechanical energy as torque is measured, and hence are particularly useful for measuring power or torque developed by power sources such as engines or electric motors.

2. **Driving dynamometers**: These dynamometers measure power or torque and as well provide energy to operate the devices to be tested. They are, therefore, useful in determining performance characteristics of devices such as pumps, compressors etc.

3. **Transmission dynamometers**: These are passive devices placed at an appropriate location within a machine or in between machines to sense the torque at that location. They neither add nor subtract the transmitted energy or power and are sometimes referred to as **torque meters**.

The first two types can be grouped as mechanical and electrical dynamometers.

These dynamometers are of absorption type. The most device is the prony brake as shown in Fig.

![Fig. Schematic of Prony Brake](image)

Two wooden blocks are mounted diametrically opposite on a flywheel attached to the rotating shaft whose power is to be measured. One block carries a lever arm, and an arrangement is provided to tighten the rope which is connected to the arm. The rope is tightened so as to increase the frictional resistance between the blocks and the flywheel. The torque exerted by the prony brake is $T = F.L$
where force $F$ is measured by conventional force measuring instruments, like balances or load cells etc. The power dissipated in the brake is calculated by the following equation.

$$P = \frac{2\pi NT}{60} = \frac{2\pi FLN}{60} \text{ Watts.}$$

where force $F$ is in Newtons, $L$ is the length of lever arm in meters, $N$ is the angular speed in revolution per minute, and $P$ in watts. The prony brake is inexpensive, but it is difficult to adjust and maintain a specific load.

**Limitation**: The prony brake is inherently unstable. Its capacity is limited by the following factors.

i). Due to wear of the wooden blocks, the coefficient of friction varies between the blocks and the flywheel. This requires continuous tightening of clamp. Therefore, the system becomes unsuitable for measurement of large powers especially when used for long periods.

ii) The use of prony brake results in excessive temperature rise which results in decrease in coefficient of friction leading to brake failure. In order to limit the temperature rise, cooling is required. This is done by running water into the hollow channel of the flywheel.

iii) When the machine torque is not constant, the measuring arrangement is subjected to oscillations. There may be changes in coefficient of friction and hence the reading of force $F$ may be difficult to take.

**Hydraulic Dynamometer**

![Fig. Section through a typical water brake](image)
Fig. shows a hydraulic dynometer in its simplest form which acts as a water brake. This is a power sink which uses fluid friction for dissipation of the input energy and thereby measures the input torque-or power.

The capacity of hydraulic dynamometer is a function of two factors, speed and water level. The power consumed is a function of cube of the speed approximately. The torque is measured with the help of a reaction arm. The power absorption at a given speed may be controlled by adjustment of the water level in the housing. This type of dynamometer may be made in considerably larger capacities than the simple prony brake because the heat generated can be easily removed by circulating the water into and out of the housing. Trunnion bearings support the dynamometer housing, allowing it a freedom to rotate except for the restraint imposed by the reaction arm.

In this dynamometer the power absorbing element is the housing which tends to rotate with the input shaft of the driving machine. But, such rotation is constrained by a force-measuring device, such as some form of scales or load cell, placed at the end of a reaction arm of radius. By measuring the force at the known radius, the torque $T$ may be computed by the simple relation.

**Advantages of hydraulic dynamometers over mechanical brakes**

- In hydraulic dynamometer constant supply of water running through the breaking medium acts as a coolant.
- The brake power of very large and high speed engines can be measured.
- The hydraulic dynamometer may be protected from hunting effects by means of dashpot damper.
- In hydraulic dynamometer there is a flexibility in controlling the operation

### 5.7 Pressure Measurements

**Introduction**

Pressure is represented as a force per unit area exerted by a fluid on a container. The standard SI unit for pressure is Newton / Square meter (N/m²) or Pascal (Pa). High pressures can be conveniently expressed in KN/m² while low pressure are expressed in terms of mm of water or mm of mercury.

Pressure is the action of one force against another over, a surface. The pressure $P$ of a force $F$ distributed over an area $A$ is defined as: $P = F/A$. 
Absolute Pressure.

It refers to the absolute value of the force per unit area exerted on the containing wall by a fluid.

Atmospheric Pressure

It is the pressure exerted by the earth’s atmosphere and is usually measured by a barometer. At sea level. Its value is close to $1.013 \times 10^5$ N/m$^2$ absolute and decreases with altitude.

Gage Pressure

It represents the difference between the absolute pressure and the local atmosphere pressure.

Vacuum

It is an absolute pressure less the atmospheric pressure i.e. a negative gage pressure.

Static and Dynamic pressures

If a fluid is in equilibrium, the pressure at a point is identical in all directions and independent of orientation is referred as pressure. In dynamic pressure, there exist a pressure gradient within the system. To restore equilibrium, the fluid flows from regions of higher pressure to regions of lower pressure.

Types of Pressure Measuring Devices

(i) Mechanical Instruments: These devices may be of two types. The first type includes those devices in which the pressure measurement is made by balancing an unknown pressure with a
known force. The second types include those employing quantitative deformation of an elastic member for pressure measurements.

(ii) Electro-mechanical Instruments: this instrument employs a mechanical means for detecting the pressure and electrical means for indicating or recording the detected pressure.

(iii) Electronic Instruments: these instruments depend on some physical change which can be detected and indicated or recorded electronically.

**Use of Elastic Members in Pressure Measurement**

Application of pressure to certain materials causes elastic deformations. The magnitude of this elastic deformation can be related either analytically or experimentally to the applied pressure. Following are the three important elastic members used in the measurement of pressure.

(i) Bourdon tube,

(ii) Diaphragms and

(iii) Bellows

**Sensing Elements**

The basic pressure sensing element can be configured as a C-shaped Bourdon tube (A); a helical Bourdon tube (B); flat diaphragm (C); a convoluted diaphragm (D); a capsule (E); or a set of bellows (F).

**The Bridgman Gage**

The resistance of fine wires changes with pressure according to the following linear relationship. \( R = R_1 (1 + \alpha p) \)
Where \( R_1 \) Resistance at 1 atmosphere (100 KN/m\(^2\)) in ohms
\( \alpha \) Pressure coefficient of resistance in ohms/100 KN M-2
\( p \) gage pressure in KN/m\(^2\).

The above said resistance change may be used for measurement of pressures as high as 100,000 atm., 10.00KN/m\(^2\). A pressure transducer based on this principle is called a Bridgman gage. A typical gage uses a fine wire of manganin (84% Cu, 12% Mn, 4% Ni) wound in a coil and enclosed in a suitable pressure container. The pressure coefficient of resistance for this material is about \( 2.5 \times 10^{-11} \) Pa-1. The total resistance of the wire is about 100\( \Omega \) and conventional bridge circuits are employed for measuring the change in the resistance. Such gages are subjected to aging over a period of time, so that frequent calibration is required. However, when properly calibrated, the gage can be used for high pressure measurement with an accuracy of 0.1%. The transient response of the gage is exceedingly good. The resistance wire itself can respond of variations in the mega hertz range. Of course, the overall frequency response of the pressure-measurement system would be limited to much lower values because of the acoustic response of the transmitting fluid.

**Low-Pressure measurement**

In general, pressures below atmospheric may be called low pressures or vacuums. Its unit is micron, which is one-millionth of a meter (0.001 mm) of mercury column. Very low pressures may be defined as that pressures which are below 1 mm (1 torr) of mercury. An Ultra low pressure is one which has pressure less than a millimicron(10-3 micron). An ultralow pressure is one which has pressure less than a millimicron (10-3 micron). Following are the two methods of measuring low pressure.

**Direct Method**: In this, direct measurement resulting in displacement caused by the action of pressure. Devices used in this method are Bourdon tubes, flat and corrugated-diaphragms, capsules and various forms of manometers. These devices are limited to a lowest pressure measurement of about 10mm of mercury.

**Indirect or Inferential method**: In this pressure is determined through the measurement of certain other pressure-controlled properties, such as volume, thermal conductivity etc.
The Mcleod Gage

The operation of McLeod gage is based on Boyle’s law.

\[ p_1 = \frac{p_2 v_2}{v_1} \]

Where, \( p_1 \) and \( p_2 \) are pressures at initial and final conditions respectively, and \( v_1 \) and \( v_2 \) are volumes at the corresponding conditions. By compressing a known volume of low pressure gas to a higher pressure and measuring the resulting volume and pressure we can calculate the initial pressure.

The McLeod gage is a modified mercury manometer as shown in the Fig. 11.2. The movable reservoir is lowered until the mercury column drops below the opening O.

The Bulb B and capillary tube C are then at the same pressure as that of the vacuum pressure \( P \). The reservoir is subsequently raised until the mercury fills the bulb and rises in the capillary tube to a point where the level in the reference capillary \( R \) is located at the zero point. If the volume of the capillary tube per unit length is ‘a’ then the volume of the gas in the capillary tube is \( V_c = ay \)\( \text{---(1)} \).

Where ‘\( y \)’ is the length of gas occupied in capillary tube.

If the volume of capillary tube, bulb and the tube down to the opening is \( V_B \). Assuming isothermal Compression, the pressure of the gas in the capillary tube is
The pressure indicated by the capillary tube is

\[ P_c = P \frac{V_B}{V_C} \]  

--------(2)

The pressure indicated by the capillary tube is

\[ P_c - P = \text{--------}(3) \]

Where, we are expressing the pressure in terms of the height of the mercury column. And combining equations (1), (2) and (3)

\[ P = \frac{ay^2}{V_B - ay} \]

Usually \( ay \ll VB \)

\[ \therefore \text{Vacuumpressur, } P = \frac{ay^2}{V_B} \]

In commercial McLeod gages the capillary tube is directly calibrated in micrometers. This gage is sensitive to condensed vapours which may be present in the sample because they can condense upon compression. For dry gases the gage can be used from \( 10^{-2} \) to \( 10^2 \) \( \mu \)m of pressure.

**Thermal Conductivity Gages**

The temperature of a given wire through which an electric current is flowing depend, on
(i) the magnitude of the current (ii) resistivity and (iii) the rate at which the heat is dissipated. The rate of heat dissipation largely depends on the conductivity of the surrounding media. As the pressure reduces, the thermal conductivity also reduces and consequently the filament temperature becomes higher for a given electric energy input. This is the basis for two different forms of gages to measure low pressures.

i). Pirani thermal conductivity gage

ii). Thermocouple vacuum gage

**Pirani Thermal Conductivity Gages**

The pirani gage as shown in the Fig. operates on the principle that if a heated wire is placed in a chamber of gas, the thermal conductivity of the gas depends on pressure. Therefore the transfer of energy from the wire to the gas is proportional to the gas pressure. If the supply of
heating energy to the filament is kept constant and the pressure of the gas is varied, then the temperature of the filament will alter and is therefore a method of pressure measurement.

To measure the resistance of the filament wire a resistance bridge circuit is used. The usual method is to balance the bridge at some datum pressure and use the out-of-balance currents at all other pressures as a measure of the relative pressures.

**Pirani gage arrangement to compensate for ambient temperature Changes**

The heat loss from the filament is also a function of ambient temperature and compensation for this effect may be achieved by connecting two gages in series as shown in Fig. The measuring gage is first evacuated and both the measuring and sealed gages are exposed to the same environment conditions. The bridge circuit is then adjusted through the resistor $R2$ to get a null condition. When the measuring gage is exposed to the test vacuum pressure, the
deflection of the bridge from the null position will be compensated for changes in environment temperature.

Pirani gages require calibration and are not suitable for use at pressures below 1) 1m and upper limit is about 1 torr. For higher pressures, the thermal conductivity changes very little with pressure. It must be noted that the heat loss from the filament is also a function of the conduction losses to the filament supports and radiation losses to the surroundings. The transient response of the pirani gage is poor. The time required for achieving thermal equilibrium may be of several minutes at low pressures.

**Thermocouple Vacuum gage**

This gage works on the same principle as that of a pirani gage, but differs in the means for measuring the filament temperature. In this gage the filament temperature is measured directly by means of thermocouples welded directly to them as shown in the Fig. 11.5. It consists of heater filament and thermocouple enclosed in a glass or metal envelope.

The filament is heated by a constant current and its temperature depends upon the amount of heat lost to the surroundings by conduction and convection. At low pressures, the temperature of the filament is a function of the pressure of surrounding gas. Thus, the thermocouple provides an output voltage which is a function of temperature of the filament and consequently the pressure of the surrounding gas. The moving coil instrument may be directly calibrated to read the pressure.
5.8 Temperature Measurements

Introduction

Temperature measurement is the most common and important measurement in controlling any process. Temperature may be defined as an indication of intensity of molecular kinetic energy within a system. It is a fundamental property similar to that of mass, length and time, and hence it is difficult to define. Temperature cannot be measured using basic standards through direct comparison. It can only be determined through some standardized calibrated device.

Change in temperature of a substance causes a variety of effects such as:

i) Change in physical state,
ii) Change in chemical state,
iii) Change in physical dimensions,
iv) Change in electrical properties and
v) Change in radiating ability.

The change in physical and chemical states cannot be used for direct temperature measurement. However, temperature standards are based on changes in physical state. A change in physical dimension due to temperature shift forms the basis of operation for liquid in- glass and bimetallic thermometers. Changes in electrical properties such as change in electrical conductivity and thermoelectric effects which produce electromotive force forms the basis for thermocouples. Another temperature-measuring method using the energy radiated from a hot body forms the basis of operation of optical radiation and infrared pyrometers.

Temperature Measurement by Electrical Effects

Electrical methods of temperature measurement are very convenient because they provide a signal that can be easily detected, amplified, or used for control purposes. In addition, they are quite accurate when properly calibrated and compensated. Several temperature-sensitive electrical elements are available for measuring temperature. Thermal emf and both positive and negative variations in resistance with temperature are important among them.
Thermo resistive Elements

The electrical resistance of most materials varies with temperature. Resistance elements which are sensitive to temperature are made of metals and are good conductors of electricity. Examples are nickel, copper, platinum and silver. Any temperature-measuring device which uses these elements is called resistance thermometers or resistance temperature detectors (RTD). If semiconducting materials like combination of metallic oxides of cobalt, manganese and nickel having large negative resistance co-efficient are used then such devices are called thermistors.

The differences between these two kinds of devices are:

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Resistance Thermometer</th>
<th>Thermistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>In this resistance change with temperature shift is small and positive.</td>
<td>In this resistance change with temperature shift is relatively large and negative</td>
</tr>
<tr>
<td>2</td>
<td>Provides nearly a linear temperature-resistance relation</td>
<td>Non-linear temperature resistance relation.</td>
</tr>
<tr>
<td>3</td>
<td>Practical operating temperature range is -250 to 1000°C</td>
<td>Practical operating temperature range is -100 to 275°C.</td>
</tr>
<tr>
<td>4</td>
<td>More time-stable hence provide better reproducibility with low hysteresis</td>
<td>Not time-stable</td>
</tr>
</tbody>
</table>

Electrical Resistance Thermometers

The desirable properties of resistance-thermometer materials are:

i) The material should permit fabrication in convenient sizes.

ii) Its thermal coefficient of resistivity should be high and constant

iii) They must be corrosion-resistant and should not undergo phase changes with in the temperature ranges.

iv) Provide reproducible and consistent results.

Electrical Resistance Thermometers

Unfortunately, there is no universally acceptable material and the selection of a particular material depends on the compromises. Although the actual resistance-temperature relation must be determined experimentally, for most metals the following empirical equation may be used.

\[ R_T = R_0 (1 + aT + bT^2) \]
Where, \( R_t \) is the resistance at temperature \( T \), \( R_0 \) is the resistance at the reference temperature, \( T \) is the temperature and \( a \) and \( b \) are constants depending on the material.

Usually platinum, nickel and copper are the most commonly used materials, although others like tungsten, silver and iron can also be used.

Fig. shows the construction of two forms of resistance thermometer In Fig. (a) the element consists of a number of turns of resistance wire wrapped around a solid silver core. Heat is transmitted quickly from the end flange through the core to the windings.

Another form of construction is shown in Fig. (b) in which the resistance wire is wrapped around a mica strip and sandwiched between two additional mica strips. These resistance thermometers may be used directly. But, when permanent installation with corrosion and mechanical protection is required a well or socket may be used.

**Instrumentation for Resistance Thermometers**

Some type of bridge circuit is normally used to measure resistance change in the thermometers. Leads of appropriate length are normally required, and any resistance change in them due to any cause affects the measurement. Hence, the lead resistance must be as low as possible relative to the element resistance.
Three methods of compensating lead resistance error are as shown in the Fig. The arms AD and DC each contain the same length of leads. If the leads have identical properties and are at identical ambient conditions, then the effects introduced by one arm will be cancelled by the other arm.

Methods of Compensating Lead Resistance Error

The Siemen's three-lead arrangement is the simplest corrective circuit. At balance conditions the centre lead carries no current, and the effect of the resistance of the other two leads is cancelled out. The Siemen's three-lead arrangement is the simplest corrective circuit. At balance conditions the centre lead carries no current, and the effect of the resistance of the other two leads is cancelled out. The calendar's four-lead arrangement solves the problem by inserting two additional lead wires in the adjustable leg of the bridge so that the effect of the lead wires on the resistance thermometer is cancelled out. The floating-potential arrangement is same as the Siemens' connection, but with an extra lead. This extra lead may be used to check the equality of lead resistance. The thermometer reading may be taken in the position shown, followed by additional readings with the two right and left leads interchanged, respectively. By averaging these readings, more accurate results may be obtained.

Usually, null-balance bridge is used but is limited to static or slowly changing temperatures. While the deflection bridge is used for rapidly changing temperatures.
1. Seebeck Effect:

When two dissimilar metals are joined together as shown in the Fig. an electromotive force (emf) will exist between the two points A and B, which is primarily a function of the junction temperature. This phenomenon is called the seebeck effect.

![Junction of Two Dissimilar Metals](image)

2. Peltier effect

If the two metals are connected to an external circuit in such a way that a current is drawn, the emf may be altered slightly owing to a phenomenon called the peltier effect.

3. Thomson effect

Further, if a temperature gradient exists along either or both of the metals, the junction emf may undergo an additional slight alteration. This is called the Thomson effect.

Hence there are, three emfs present in a thermoelectric circuit:

i) The Seebeck emf, caused by the junction of dissimilar metals
ii) The Peltier emf, caused by a current flow in the circuit and
iii) The Thomson emf, resulting from a temperature gradient in the metals.

The Seebeck emf is important since it depends on the junction temperature.

If the emf generated at the junction of two dissimilar metals is carefully measured as a function of temperature, then such a junction may be used for the measurement of temperature.

The above effects forms the basis for a thermocouple which is a temperature measuring element.

**Thermocouple**

If two dissimilar metals are joined an emf exists which is a function of several factors including the temperature. When junctions of this type are used to measure temperature, they are called thermocouples.
The principle of a thermocouple is that if two dissimilar metals $A$ and $B$ are joined to form a circuit as shown in the Fig. It is found that when the two junctions $J_1$ and $J_2$ are at two different temperatures $T_1$ and $T_2$, small emf's $e_1$ and $e_2$ are generated at the junctions. The resultant of the two emf's causes a current to flow in the circuit. If the temperatures $T_1$ and $T_2$ are equal, the two emf's will be equal but opposed, and no current will flow. The net emf is a function of the two materials used to form the circuit and the temperatures of the two junctions. The actual relations, however, are empirical and the temperature-emf data must be based on experiment. It is important that the results are reproducible and therefore provide a reliable method for measuring temperature.

![Basic Thermocouple Circuit](image)

**Basic Thermocouple Circuit**

It should be noted that two junctions are always required, one which senses the desired or unknown temperature is called the **hot** or **measuring** junction. The other junction maintained at a known fixed temperature is called the **cold** or **reference** junction.

**Laws of Thermocouples**

The two laws governing the functioning of thermocouples are:

**i) Law of Intermediate Metals:**

It states that the insertion of an intermediate metal into a thermocouple circuit will not affect the net emf, provided the two junctions introduced by the third metal are at identical temperatures.

Application of this law is as shown in Fig. In Fig. (a), if the third metal $C$ is introduced and the new junctions $R$ and $S$ are held at temperature $T_3$, the net emf of the circuit will remain unchanged. This permits the insertion of a measuring device or circuit without affecting the temperature measurement of the thermocouple circuit.
In the Fig. (b) the third metal is introduced at either a measuring or reference junction. As long as junctions $P_1$ and $P_2$ are maintained at the same temperature $T_P$ the net emf of the circuit will not be altered. This permits the use of joining metals, such as solder used in fabricating the thermocouples. In addition, the thermocouple may be embedded directly into the surface or interior of a conductor without affecting the thermocouple's functioning.

i) Law of Intermediate Temperatures:

It states that "If a simple thermocouple circuit develops an emf, $e_1$ when its junctions are at temperatures $T_1$ and $T_2$, and an emf $e_2$, when its junctions are at temperature $T_2$ and $T_3$. And the same circuit will develop an emf $e_3 = e_1 + e_2$, when its junctions are at temperatures $T_1$ and $T_3$."

This is illustrated schematically in the above Fig. This law permits the thermocouple calibration for a given temperature to be used with any other reference temperature through the use of a suitable correction. Also, the extension wires having the same thermo-electric characteristics as those of the thermocouple wires can be introduced in the circuit without affecting the net emf of the thermocouple.

Measurement of Thermal emf

The magnitude of emf developed by the thermocouples is very small (0.01 to 0.07 millivolts/°C), thus requires a sensitive devices to measure. Measurement of thermocouple output may be obtained by various ways. like millivolt meter or voltage-balancing potentiometer
Temperature measuring Arrangement using Thermocouple

Advantages and Disadvantages of Thermocouples

Advantages
1. Thermocouples are cheaper than the resistance thermometers.
2. Thermocouples follow the temperature changes with small time lag thus suitable for recording rapidly changing temperatures.
3. They are convenient for measuring the temperature at a particular point.

Disadvantages
1. Possibility of inaccuracy due to changes in the reference junction temperature hence they cannot be used in precision work.
2. For long life, they should be protected to prevent contamination and have to be chemically inert and vacuum tight.

3. When thermocouples are placed far from the measuring systems, connections are made by extension wires. Maximum accuracy is obtained only when compensating wires are of the same material as that of thermocouple wires, thus the circuit becomes complex.

**Principles used for Radiation Temperature Measuring Devices**

1. **Total Radiation Pyrometry:**

   In this case the total radiant energy from a heated body is measured. This energy is represented by the area under the curves of above Fig. and is given by Stefen – Boltzmann law. The radiation pyrometer is intended to receive maximum amount of radiant energy at wide range of wavelengths possible.

2. **Selective Radiation Pyrometry:**

   This involves the measurement of spectral radiant intensity of the radiated energy from a heated body at a given wavelength. For example, if a vertical line is drawn in Fig. the variation of intensity with temperature for given wavelength can be found. The optical pyrometer uses this principle.

**Total Radiation Pyrometers**

The total radiation pyrometers receives all the radiations from a hot body and focuses it on to a sensitive temperature transducer like thermocouple, resistance thermometer etc. It consists of a radiation-receiving element and a measuring device to indicate the temperature. The most common type is shown in the Fig. A lens is used to concentrate the total radiant energy from the source on to the temperature sensing element. The diaphragms are used to prevent reflections. When lenses are used, the transmissibility of the glass determines the range of frequencies passing through. The transmission bands of some of the lens materials are shown in the Fig. The radiated energy absorbed by the receiver causes a rise of temperature. A balance is established between the energy absorbed by the receiver and that dissipated to the surroundings. Then the receiver equilibrium temperature becomes the measure of source temperature, with the scale established by calibration.
Schematic of Lens Type Radiation Receiving Device

The mirror type radiation receiver is another type of radiation pyrometer as shown in the Fig. Here the diaphragm unit along with a mirror is used to focus the radiation onto a receiver. The distance between the mirror and the receiver may be adjusted for proper focus. Since there is no lens, the mirror arrangement has an advantage as absorption and reflection effects are absent.

Mirror Focussing Type Radiation Receiving Device

Although radiation pyrometers may theoretically be used at any reasonable distance from a temperature source, there are practical limitations.

i) The size of target will largely determine the degree of temperature averaging, and in general, the greater the distance from the source, the greater the averaging.

ii) The nature of the intervening atmosphere will have a decided effect on the pyrometer indication. If smoke, dust or certain gases present considerable energy absorption may occur.
This will have a particular problem when such absorbents are not constant, but varying with time. For these reasons, minimum practical distance is recommended.

**Optical pyrometers**

Optical pyrometers use a method of matching as the basis for their operation. A reference temperature is provided in the form of an electrically heated lamp filament, and a measure of temperature is obtained by optically comparing the visual radiation from the filament with that from the unknown own source. In principle, the radiation from one of the sources, as viewed is adjusted to match with that from the other source. The two methods used are:

i) The current through the filament may be controlled electrically with the help of resistance adjustment or

ii) The radiation received by the pyrometer from the unknown source may be adjusted optically by means of some absorbing devices.

In both the cases the adjustment required, forms the means of temperature measurement. The variable intensity optical pyrometer is, as shown in the Fig. The pyrometer is positioned towards an unknown temperature such that the objective lens focuses the source in the plane of the lamp filament.

![Schematic of an Optical Pyrometer](image)

The eyepiece is then adjusted such that the filament and the source appear superimposed. The filament may appear either hotter or colder than the unknown source as shown in the Fig. The current through the filament is adjusted by means of rheostat.
Filament Appearance

When the current passing through the filament is too low, the filament will emit radiation of lesser intensity than that of the source, it will thus appear dark against a bright background as in Fig. (a). When the current is too high it will appear brighter than the background as in Fig. (b). But when correct current is passed through the filament. The filament “disappears” into the background as in Fig. because it is radiating at the same intensity as the source. In this way the current indicated by the ammeter which disappears the filament may be used as the measure of temperature. The purpose of the red filter is to obtain approximately monochromatic conditions, while an absorption filter is used so that the filament may be operated at reduced intensity.
5.9 Strain Measurements

When a system of forces or loads act on a body, it undergoes some deformation. This deformation per unit length is known as **unit strain** or simply a strain mathematically

\[ \varepsilon = \frac{\delta l}{l} \]

where, \( \delta l = \) change in length of the body

\( l = \) original length of the body.

If a net change in dimension is required, then the term, **total strain** will be used. Since the strain applied to most engineering materials are very small they are expressed in “**micro strain**”

Strain is the quantity used for finding the stress at any point. For measuring the strain, it is the usual practice to make measurements over shortest possible gauge lengths. This is because, the measurement of a change in given length does not give the strain at any fixed point but rather gives the average value over the length. The strain at various points might be different depending upon the strain gradient along the gauge length, then the average strain will be the point strain at the middle point of the gauge length. Since, the change in length over a small gauge length is very small, a high magnification system is required and based upon this, the strain gauges are classified as follows:

i) Mechanical strain gauges

ii) Optical strain gauges

iii) Electrical strain gauges

**Mechanical Strain Gauges**

This type of strain gauges involves mechanical means for magnification. Extensometer employing compound levers having high magnifications was used. Fig. shows a simple mechanical strain gauge. It consists of two gauge points which will be seated on the specimen whose strain is to be measured. One gauge point is fixed while the second gauge paint is connected to a magnifying lever which in turn gives the input to a dial indicator. The lever magnifies the displacement and is indicated directly on the calibrated dial indicator. This displacement is used to calculate the strain value. The most commonly used mechanical strain gauges are Berry-type and Huggen berger type. The Berry extensometer as shown in the Fig. is used for structural applications in civil engineering for long gauge lengths of up to 200 mm.
Advantages
1. It has a self contained magnification system.
2. No auxiliary equipment is needed as in the case of electrical strain gauges.

Disadvantages
1. Limited only to static tests.
2. The high inertia of the gauge makes it unsuitable for dynamic measurements and varying strains.
3. The response of the system is slow and also there is no method of recording the readings automatically.
4. There should be sufficient surface area on the test specimen and clearance above it in order to accommodate the gauge together with its mountings.

OUTCOME
Students will be able to
1. Learn the concepts of force, torque, pressure, temperature measuring devices.
SELF-ASSESSMENT QUESTIONS

1. With a neat sketch explain force measuring devices.
2. With a neat sketch explain torque measuring devices.
3. With a neat sketch explain pressure measuring devices.
4. With a neat sketch explain temperature measuring devices.

FURTHER READING