NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE MATERIALS

ME312 METROLOGY AND INSTUMENTATION

VISION OF THE INSTITUTION

To mould true citizens who are millennium leaders and catalysts of change through excellence in education.

MISSION OF THE INSTITUTION

NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values.

We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

ABOUT DEPARTMENT

- Established in: 2002
- Course offered : B.Tech in Mechanical Engineering

- Approved by AICTE New Delhi and Accredited by NAAC
- Affiliated to the University of Dr. A P J Abdul Kalam Technological University.

DEPARTMENT VISION

Producing internationallycompetitive Mechanical Engineerswith social responsibility & sustainable employability through viable strategies as well as competent exposure oriented quality education.

DEPARTMENT MISSION

1. Imparting high impacteducation by providing conductive teaching learning environment.
2. Fostering effective modes of continuous learning process with moral & ethical values.
3. Enhancing leadership qualities with social commitment, professional attitude, unity, team spirit & communication skill.
4. Introducing the present scenario in research & development through collaborative efforts blended with industry & institution.

PROGRAMME EDUCATIONAL OBJECTIVES

PEO1: Graduates shall have strong practical & technical exposures in the field of Mechanical Engineering & will contribute to the society through innovation & enterprise.

PEO2: Graduates will have the demonstrated ability toanalyze, formulate & solve design engineering / thermal engineering / materials & manufacturing / design issues & real life problems.

PEO3: Graduates will be capable of pursuing Mechanical Engineering profession with good communication skills, leadership qualities, team spirit & communication skills.

PEO4: Graduates will sustain an appetite for continuous learning by pursuing higher education & research in the allied areas of technology.

PROGRAM OUTCOMES (POS)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **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.

4. **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.
5. **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.
6. **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.
7. **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.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and teamwork**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **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.
11. **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.
12. **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)

PSO1: graduates able to apply principles of engineering, basic sciences & analytics including multi variant calculus & higher order partial differential equations..

PSO2: Graduates able to perform modeling, analyzing, designing & simulating physical systems, components & processes.

PSO3: Graduates able to work professionally on mechanical systems, thermal systems & production systems.

COURSE OUTCOMES

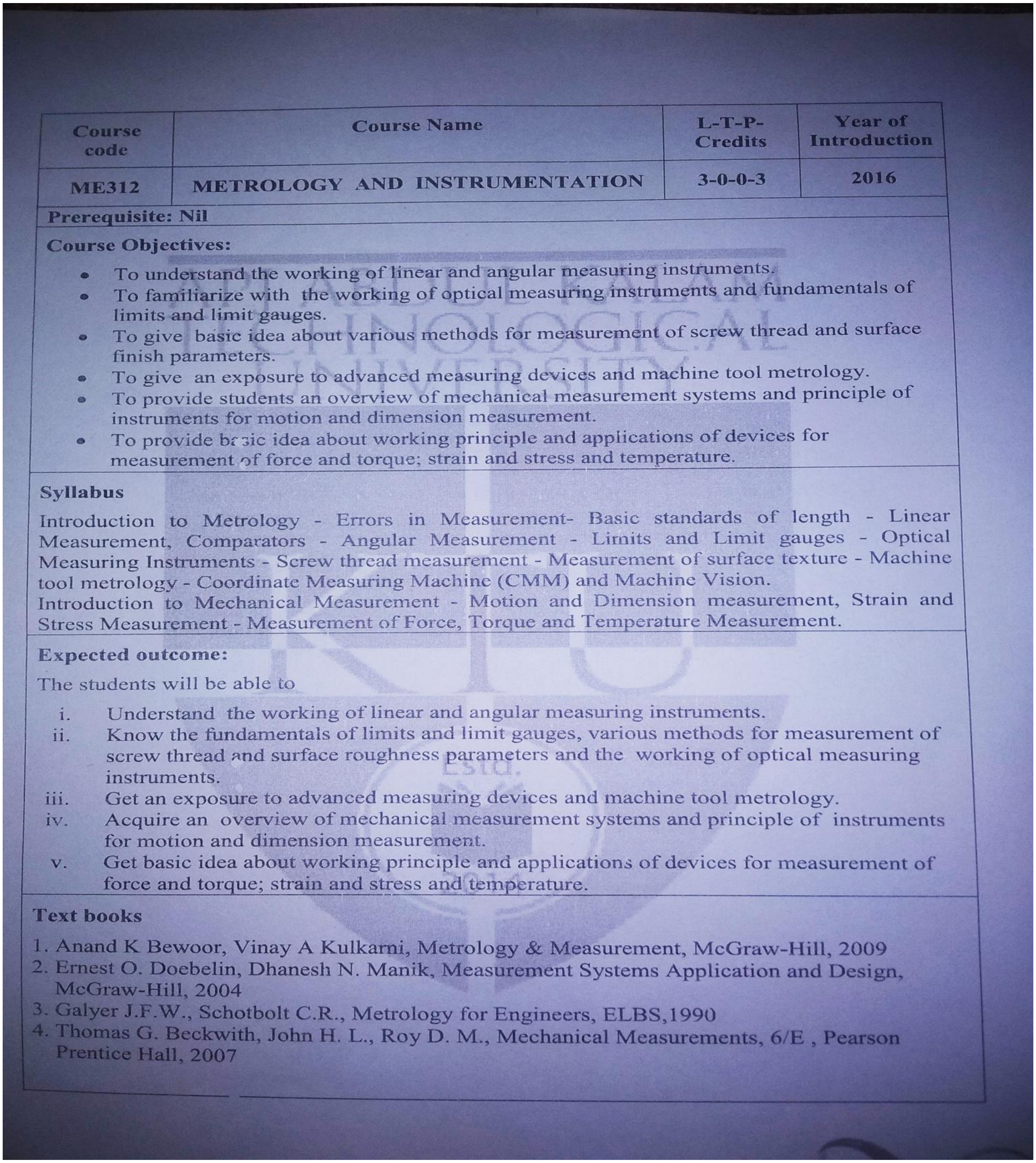
CO1	Construction and application of different linear and angular measurement instruments, compute errors and its classification related to mechanical measurements.
CO2	Fundamentals of Limits, Fits and Tolerance, Gauge design and applications of interferometers.
CO3	Measurement of different parameters of screw thread and compute surface roughness using different techniques
CO4	Demonstrate working principle and applications of CMM, Machine vision and alignment testing of machine tools.
CO5	Explain the stages in a generalized measurement system, analyse its performance characteristics and discuss the classification of transducers.
CO6	Demonstrate the working principle and applications of strain, force, torque, vibration and temperature measurement devices.

MAPPING OF COURSE OUTCOMES WITH PROGRAM OUTCOMES

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	-	-	-	-	-	-	-	-	-	3	2	3	-
CO2	3	3	3	-	-	2	-	-	-	-	-	3	2	3	-
CO3	3	3	-	-	-	-	-	-	-	-	-	3	2	3	-
CO4	3	-	-	-	3	-	-	-	-	-	-	3	2	3	-
CO5	3	-	-	-	-	-	-	-	-	-	-	3	2	3	-
CO6	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: H-Highly correlated=3, M-Medium correlated=2, L-Less correlated=1

SYLLABUS



Course code	Course Name	L-T-P-Credits	Year of Introduction
ME312	METROLOGY AND INSTRUMENTATION	3-0-0-3	2016

Prerequisite: Nil

Course Objectives:

- To understand the working of linear and angular measuring instruments.
- To familiarize with the working of optical measuring instruments and fundamentals of limits and limit gauges.
- To give basic idea about various methods for measurement of screw thread and surface finish parameters.
- To give an exposure to advanced measuring devices and machine tool metrology.
- To provide students an overview of mechanical measurement systems and principle of instruments for motion and dimension measurement.
- To provide basic idea about working principle and applications of devices for measurement of force and torque; strain and stress and temperature.

Syllabus

Introduction to Metrology - Errors in Measurement- Basic standards of length - Linear Measurement, Comparators - Angular Measurement - Limits and Limit gauges - Optical Measuring Instruments - Screw thread measurement - Measurement of surface texture - Machine tool metrology - Coordinate Measuring Machine (CMM) and Machine Vision.

Introduction to Mechanical Measurement - Motion and Dimension measurement, Strain and Stress Measurement - Measurement of Force, Torque and Temperature Measurement.

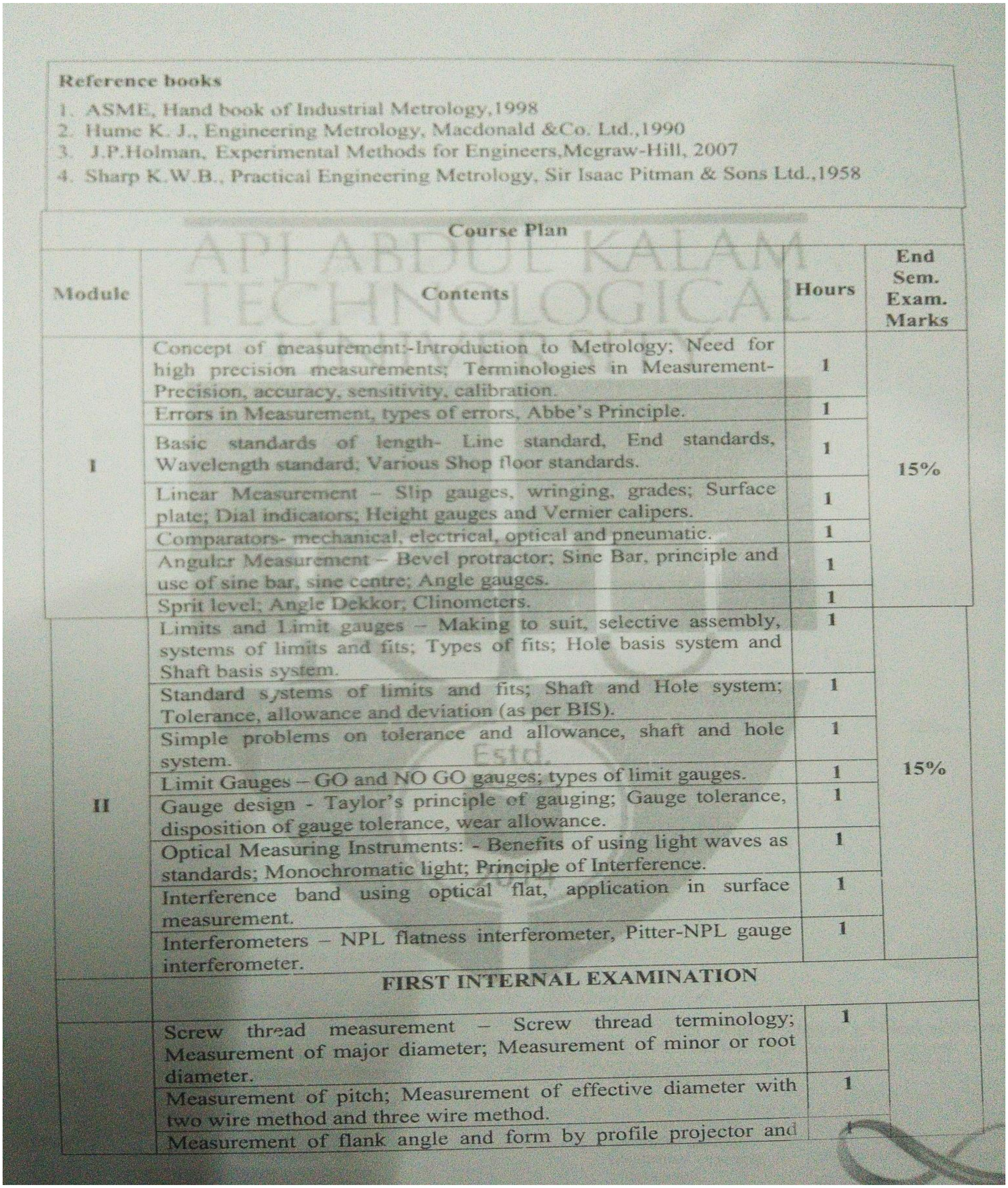
Expected outcome:

The students will be able to

i. Understand the working of linear and angular measuring instruments.
ii. Know the fundamentals of limits and limit gauges, various methods for measurement of screw thread and surface roughness parameters and the working of optical measuring instruments.
iii. Get an exposure to advanced measuring devices and machine tool metrology.
iv. Acquire an overview of mechanical measurement systems and principle of instruments for motion and dimension measurement.
v. Get basic idea about working principle and applications of devices for measurement of force and torque; strain and stress and temperature.

Text books

1. Anand K Bewoor, Vinay A Kulkarni, Metrology & Measurement, McGraw-Hill, 2009
2. Ernest O. Doebelin, Dhanesh N. Manik, Measurement Systems Application and Design, McGraw-Hill, 2004
3. Galyer J.F.W., Schotbolt C.R., Metrology for Engineers, ELBS,1990
4. Thomas G. Beckwith, John H. L., Roy D. M., Mechanical Measurements, 6/E , Pearson Prentice Hall, 2007

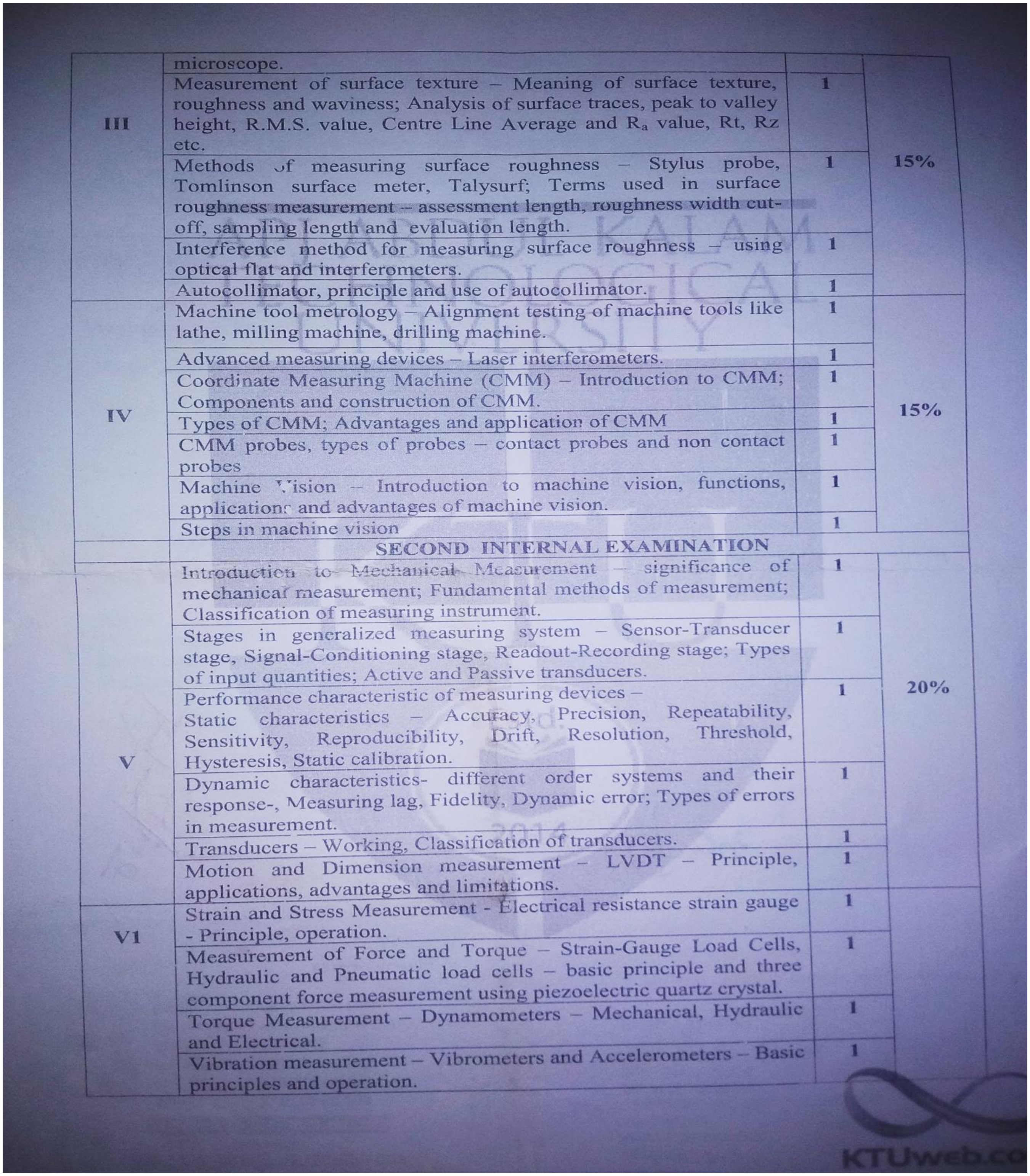


Reference books

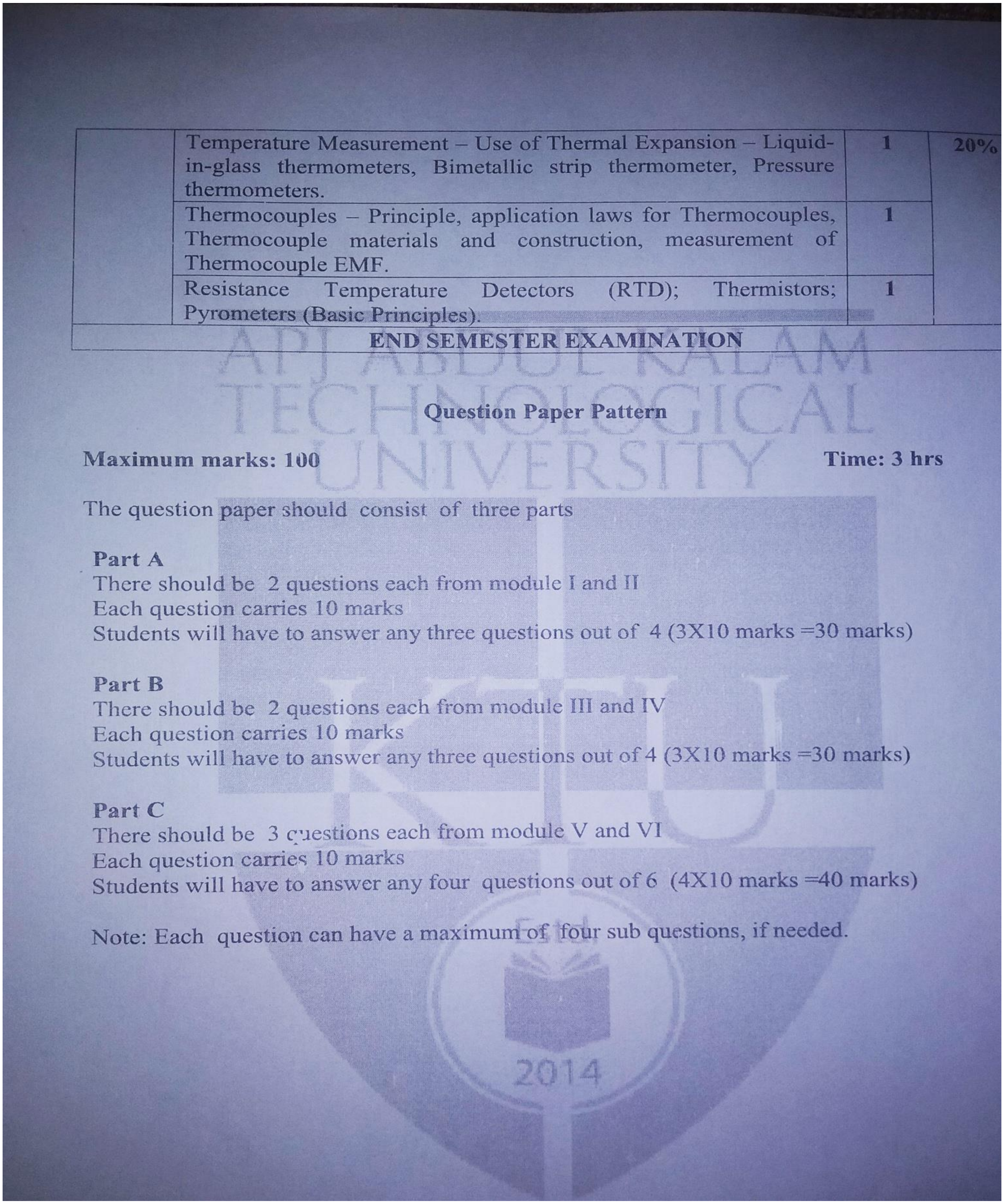
1. ASME, Hand book of Industrial Metrology,1998
2. Hume K. J., Engineering Metrology, Macdonald &Co. Ltd.,1990
3. J.P.Holman, Experimental Methods for Engineers,Mcgraw-Hill, 2007
4. Sharp K.W.B., Practical Engineering Metrology, Sir Isaac Pitman & Sons Ltd.,1958

Course Plan

Module	Contents	Hours	End Sem. Exam. Marks
I	Concept of measurement:-Introduction to Metrology; Need for high precision measurements; Terminologies in Measurement-Precision, accuracy, sensitivity, calibration.	1	15%
	Errors in Measurement, types of errors, Abbe's Principle.	1	
	Basic standards of length- Line standard, End standards, Wavelength standard, Various Shop floor standards.	1	
	Linear Measurement – Slip gauges, wringing, grades; Surface plate; Dial indicators; Height gauges and Vernier calipers.	1	
	Comparators- mechanical, electrical, optical and pneumatic.	1	
	Angular Measurement – Bevel protractor; Sine Bar, principle and use of sine bar, sine centre; Angle gauges.	1	
	Sprit level; Angle Dekkor; Clinometers.	1	
II	Limits and Limit gauges – Making to suit, selective assembly, systems of limits and fits; Types of fits; Hole basis system and Shaft basis system.	1	15%
	Standard systems of limits and fits; Shaft and Hole system; Tolerance, allowance and deviation (as per BIS).	1	
	Simple problems on tolerance and allowance, shaft and hole system.	1	
	Limit Gauges – GO and NO GO gauges; types of limit gauges.	1	
	Gauge design - Taylor's principle of gauging; Gauge tolerance, disposition of gauge tolerance, wear allowance.	1	
	Optical Measuring Instruments: - Benefits of using light waves as standards; Monochromatic light; Principle of Interference.	1	
	Interference band using optical flat, application in surface measurement.	1	
	Interferometers – NPL flatness interferometer, Pitter-NPL gauge interferometer.	1	
	FIRST INTERNAL EXAMINATION		
	Screw thread measurement – Screw thread terminology; Measurement of major diameter; Measurement of minor or root diameter.	1	
	Measurement of pitch; Measurement of effective diameter with two wire method and three wire method.	1	
	Measurement of flank angle and form by profile projector and	1	



III	microscope.		15%
	Measurement of surface texture – Meaning of surface texture, roughness and waviness; Analysis of surface traces, peak to valley height, R.M.S. value, Centre Line Average and R_a value, Rt, Rz etc.	1	
	Methods of measuring surface roughness – Stylus probe, Tomlinson surface meter, Talysurf; Terms used in surface roughness measurement – assessment length, roughness width cut-off, sampling length and evaluation length.	1	
	Interference method for measuring surface roughness – using optical flat and interferometers.	1	
	Autocollimator, principle and use of autocollimator.	1	
IV	Machine tool metrology – Alignment testing of machine tools like lathe, milling machine, drilling machine.	1	15%
	Advanced measuring devices – Laser interferometers.	1	
	Coordinate Measuring Machine (CMM) – Introduction to CMM; Components and construction of CMM.	1	
	Types of CMM; Advantages and application of CMM	1	
	CMM probes, types of probes – contact probes and non contact probes	1	
	Machine Vision – Introduction to machine vision, functions, applications and advantages of machine vision.	1	
	Steps in machine vision	1	
	SECOND INTERNAL EXAMINATION		
V	Introduction to Mechanical Measurement – significance of mechanical measurement; Fundamental methods of measurement; Classification of measuring instrument.	1	20%
	Stages in generalized measuring system – Sensor-Transducer stage, Signal-Conditioning stage, Readout-Recording stage; Types of input quantities; Active and Passive transducers.	1	
	Performance characteristic of measuring devices – Static characteristics – Accuracy, Precision, Repeatability, Sensitivity, Reproducibility, Drift, Resolution, Threshold, Hysteresis, Static calibration.	1	
	Dynamic characteristics- different order systems and their response-, Measuring lag, Fidelity, Dynamic error; Types of errors in measurement.	1	
	Transducers – Working, Classification of transducers.	1	
	Motion and Dimension measurement – LVDT – Principle, applications, advantages and limitations.	1	
V1	Strain and Stress Measurement - Electrical resistance strain gauge - Principle, operation.	1	
	Measurement of Force and Torque – Strain-Gauge Load Cells, Hydraulic and Pneumatic load cells – basic principle and three component force measurement using piezoelectric quartz crystal.	1	
	Torque Measurement – Dynamometers – Mechanical, Hydraulic and Electrical.	1	
	Vibration measurement – Vibrometers and Accelerometers – Basic principles and operation.	1	



	Temperature Measurement – Use of Thermal Expansion – Liquid-in-glass thermometers, Bimetallic strip thermometer, Pressure thermometers.	1	20%
	Thermocouples – Principle, application laws for Thermocouples, Thermocouple materials and construction, measurement of Thermocouple EMF.	1	
	Resistance Temperature Detectors (RTD); Thermistors; Pyrometers (Basic Principles).	1	
END SEMESTER EXAMINATION			

Question Paper Pattern

Maximum marks: 100 **Time: 3 hrs**

The question paper should consist of three parts

Part A
There should be 2 questions each from module I and II
Each question carries 10 marks
Students will have to answer any three questions out of 4 (3X10 marks =30 marks)

Part B
There should be 2 questions each from module III and IV
Each question carries 10 marks
Students will have to answer any three questions out of 4 (3X10 marks =30 marks)

Part C
There should be 3 questions each from module V and VI
Each question carries 10 marks
Students will have to answer any four questions out of 6 (4X10 marks =40 marks)

Note: Each question can have a maximum of four sub questions, if needed.

QUESTION BANK

MODULE I

Q:NO:	QUESTIONS	CO	KL
1	What do you mean by term Engineering Metrology?	CO1	K2
2	Differentiate Precision with Accuracy. Illustrate the ideas using suitable diagrams.	CO1	K3
3	Define the term sensitivity?	CO1	K2
4	What is the relevance of introducing calibration in measurements?	CO1	K4
5	Write a detailed note on different types of errors that are possible to happen while doing measurements.	CO1	K2
6	Discuss the different standards in metrology.	CO1	K2
7	What are the different equipments used to carry out linear measurement?	CO1	K2
8	What are the different types of comparators? Write a note on each.	CO1	K4
9	How can we do angular measurements in Metrology?	CO1	K2
10	Explain the working principle of sine bar?	CO1	K2
11	What is the purpose of Angle Dekkor?	CO1	K2

MODULE II

Q:NO:	QUESTIONS	CO	KL
1	What are limit gauges?	CO2	K2
2	Explain Go and No go gauges.	CO2	K4
3	Write note on gauge design.	CO2	K2
4	Define Taylor’s principle of gauging.	CO2	K5
5	Explain wear allowance and gauge tolerance.	CO2	K5
6	Write note on Optical Measuring Instruments.	CO2	K3
7	Explain the principle of interference.	CO2	K5
8	Briefly explain the working of Interferometers.	CO2	K4
9	Explain NPL flatness interferometers.	CO2	K2

MODULE III

Q:NO:	QUESTIONS	CO	KL
1	What you mean by drunken thread.	CO3	K3
2	Explain different method of measuring major and minor diameter.	CO3	K3
3	Explain one , two, three wire methods for measuring effective diameter.	CO3	K2
4	Derive the expression for best wire diameter in effective diameter	CO3	K3

	measurement.		
5	Derive an expression for calculating effective diameter in three wire method.	CO3	K5
6	State the advantage and limitations of thread micrometer.	CO3	K3
7	Explain different methods for measuring pitch diameter.	CO3	K2
8	What are the applications of tool makers microscope?	CO3	K5
9	Explain different types of thread gauges.	CO3	K5
10	Explain the terminology in surface texture.	CO3	K2

MODULE IV

1	Machine tool metrology is primarily concerned with what?	CO4	K2
2	Discuss alignment tests on lathe	CO4	K1
3	What are the alignment tests on milling machine	CO4	K2
4	Explain laser interferometers sketch	CO4	K3
5	Discuss various CMM with sketches	CO4	K1
6	Explain the mode of operation of CMM	CO4	K2
7	Discuss the Stages of Machine Vision	CO4	K3
8	Applications of Machine Vision in Inspection	CO4	K3

MODULE V

1	What are significance of mechanical measurement	CO5	K2
2	Give Fundamental methods of measurement	CO5	K4
3	Classification of measuring instrument	CO5	K44
4	Stages in generalized measuring system	CO5	K2
5	Different types of Sensor-Transducer stage	CO5	K3
6	What is Signal-Conditioning	CO5	K2
7	Different Types of input quantities	CO5	K2
8	What are the Performance characteristic of measuring devices	CO5	K3
9	Give Dynamic characteristics	CO5	K3

MODULE VI

1	Types of Strain and Stress Measurement	CO6	K3
2	Give the different Measurement of Force and Torque	CO6	K2
3	Methods of Torque Measurement	CO6	K3
4	Different types of Vibration measurement	CO6	K2
5	Explain the types of Temperature Measurement	CO6	K3

6	What are the applications of Thermocouples	CO6	K2
7	Discuss the types of Resistance measurements	CO6	K2

APPENDIX 1

CONTENT BEYOND THE SYLLABUS

S:NO.	WEB SOURCE REFERENCES
1	https://amesweb.info/fits-tolerances/limits-fits-tolerances-standards.aspx
2	https://nptel.ac.in/noc/courses/noc18/SEM1/noc18-me30/
3	https://gaugehow.com/2019/10/08/30-measuring-instruments-for-mechanical-engineer/
4	https://www.watelectronics.com/different-types-of-comparators/
5	https://www.keyence.com/ss/products/measure-sys/measurement-selection/type/3d.jsp

Module- I

Engineers design physical systems in the form of machines to serve some specified functions. The behavior of the parts of the machine during the operation of the machine needs to be examined or analyzed or designed such that it functions reliably. Such an activity needs data regarding the machine parts in terms of material properties. These are obtained by performing measurements in the laboratory.

1.1 Introduction to Metrology

- Metrology word is derived from two Greek words such as metro, which means measurement and logy, means science.
- Metrology is the science of precision measurement.
- It is the science of measurement of lengths and angles and all related quantities like width, depth, diameter and straightness with high accuracy.
- Metrology demands pure knowledge of certain basic mathematical and physical principles. The development of the industry largely depends on the engineering metrology.
- Metrology is concerned with the establishment, reproduction and conservation and transfer of units of measurements and their standards.

1.1.1 Measurements

- Measurement is a comparison of a given quantity with one of its predetermined standard values opted as a unit.

- Measurement is defined as the process of numerical evaluation of a dimension or the process of comparison with standard measuring instruments.

- The elements of measuring system include the instrumentation, calibration standards, envi-ronmental influence, human operator limitations and features of the work-piece.

- The basic aim of measurement in industries is to check whether a component has been manu-factured to the requirement of a specification or not. There are two important requirements of the measurement:

  – The standards used for comparison must accurate and internationally accepted.

  – The apparatus or instrument and the process used for information must be provable.

1.1.2 Need for Measurement

- To determine the true dimensions of a part.
- To convert physical parameters into meaningful numbers.
- Thorough evaluation of newly developed products, and to ensure that components are within the specified dimensions.

- To evaluate the performance of a system.
- To reduce the cost of inspection, rejections and rework.
- To evaluate the response of the system to a particular point.
- To check the limitations of theory in practical situations.
- To establish the validity of design and for finding new data and new designs.

1.2 Terminologies in measurement

Sensitivity:

– Sensitivity of the instrument is defined as the ratio of the magnitude of the output signal to the magnitude of the input signal.

– It denotes the smallest change in the measured variable to which the instruments responds.

– Sensitivity has no unique unit. It has wide range of the units which dependent up on the instrument or measuring system.

– Sensitivity is represented by the slope of the calibration curve.

– Sensitivity of the instrument system is usually required to be as high as possible as it becomes easier to take the measurement.

Accuracy:

– Accuracy may be defined as the ability of instruments to respond to a true value of a measured variable under the reference conditions.

– It refers to how closely the measured value agrees with the true value.

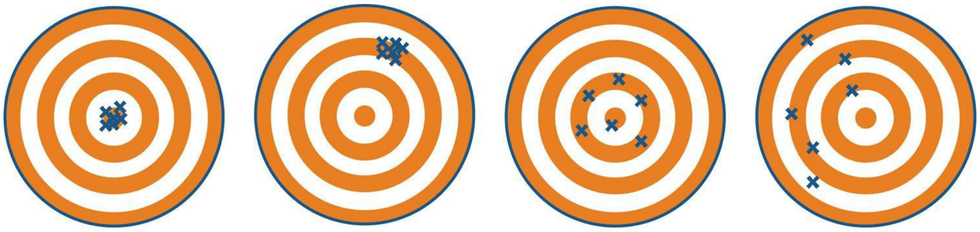
– Accuracy of a measurement means conformity to truth.

– When an instrument has uniform scale, its accuracy may' be expressed in terms of scale range.

– For example, the accuracy of a thermometer having a range of 500^0C may be expressed as ± 0.5 percent of scale range.

– This, means that the accuracy ,of the thermometer when the reading is 500^0C is ±0.5 percent.

- Accuracy of an instrument is influenced by factors like static error, dynamic error, reproducibility, dead zone.



High Accuracy High Precision | **Low Accuracy High Precision** | **High Accuracy Low Precision** | **Low Accuracy Low Precision**

Figure: Accuracy and Precision

Precision:

- Precision is defined as the degrees of exactness for which an instrument is designed or intended to perform.

- It refers to repeatability or consistency of measurement when the instruments are carried out under identical conditions at a short interval of time.

- It can also defined as the ability of the instruments to reproduce a group of the instru-ments as the same measured quantity under the same conditions.

- It is a measure of the reproducibility of the measurements. precision is the degree of closeness with which a given value may be repeatedly measured.

- A quantity called precision index describes the spread, or dispersion of repeated result about some central value.

- High precision means a tight cluster of repeated results while low precision indicates a broad scattering of results.

Calibration:

- Calibration is the process of determining and adjusting an instruments accuracy to make sure its accuracy is with in manufacturing specifications.

- It is the process of determining the values of the quantity being measured corresponding to a pre-established arbitrary scale. It is the measurement of measuring instrument. The quantity to be measured is the input to the measuring instrument.

– The input affects some parameter which is the output & is read out. The amount of output is governed by that of input. Before we can read any instrument, a scale must be framed for the output by successive application of some already standardized (inputs) signals. This process is known as calibration. In performing a calibration, the following steps are necessary:

1. Examine the construction of the instrument, and identify and list all the possible inputs.

2. Decide which of the inputs will be significant in the application for which the instrument is to be calibrated.

3. Procure apparatus that will allow you to vary all the significant inputs over the ranges considered necessary. Procure standards to measure each input.

4. By holding some inputs constant, varying others, and recording the output(s), develop the desired static input-output relations.

1.3 Errors in measurement

Error is the difference between the measured value and the true value. Error in measurement = Measured Value - True value.

The errors in measurement can be expressed either as an absolute error or an relative error.

1. Absolute error

The absolute error is classified into two types:

(a) True absolute error

Algebraic difference between the results of measurement to the true value of the quantity measured is called true absolute error.

(b) Apparent absolute error

While taking the series of measurement, the algebraic difference between one of the results of measurement to the arithmetic mean is called as apparent absolute error.

2. Relative error

Relative error is defined as the results of the absolute error and the value of comparison used for calculation of that absolute error. The comparison may be true value or conventional true value or arithmetic mean for series of measurement.

1.3.1 Common types of errors

The errors in a scale and pointer type of measuring instrument can be of following three types :

1. Inherent shortcomings in instruments

   These errors may be due to construction, calibration, or operation of the instruments.

2. Assembly errors

   These can be due to the following :

   - Displaced scale, i.e. incorrect fitting of the scale zero with respect to the actual zero position of the movement.
   - Non-uniform division of the scale.
   - Bent or distorted pointer.

   Errors of this type can be easily discovered and rectified as they remain constant with time.

3. Environmental errors

   These errors are much more troublesome than assembly errors as these change with time in an unpredictable manner.

   These are introduced due to using an instrument in different conditions than in which it was assembled and calibrated. The different conditions of use can be temperature, humidity, altitude, etc. These errors can be eliminated or reduced by, taking the following precautions :

- Using instrument in controlled conditions of pressure, temperature and humidity in which it was originally assembled and calibrated.

- If the above one is not possible then deviations in local conditions must be measured and suitable corrections to instrument readings applied.

- Automatic compensation using sophisticated devices for such deviations is also possible and usually applied.

- Altogether new calibration may be made in the new conditions.

4. Misuse of instruments

   A good instrument used in an unintelligent way may give erroneous results.

5. Observation errors

   These occur due to carelessness of operators. Parallax errors can be taken care of. Digital readouts also reduce such errors.

6. Random errors

   These vary in an unpredictable manner and it is very difficult to list out all the sources of errors in this class. The most common causes are: Friction in instrument movement, Backlash in the movement.

1.3.2 Classification of errors

The errors can be classified into

1. Static errors
2. Loading errors
3. Dynamic error

1. Static error

   It causes due to the physical nature of the various components of the measuring system. The static errors due to environmental effect and the other properties which influence the apparatus are also reasons for stall errors.

   (a) Characteristic error

   The deviation of the output of the measuring system from the nominal performance specifications is called characteristic error. The linearity, repeatability, hysteresis and resolution are part of the characteristic error.

   (b) Reading error

   It is exclusively applied to the read out device. The reading err< describes the factors parallax error and interpolation error. The use of mirror behind the readout indicator eliminates- the occurrence of parallax error. Interpolation error is a reading error resulting from the inexact evaluation of the position of index. The use of digital readout device eliminates the subjective error.

(c) Environmental error

Every instrument is manufactured and calibrated at one place and is used in some other place where the environmental conditions such as temperature, pressure, and humidity change. So, the change in environment influences the readings of the instrument. This change in environment is called environment error.
By following the below conditions, the environmental errors are eliminated.

i. Monitoring the atmospheric conditions.

ii. By calibration of instrument at the place of use.

iii. Automatic devices are used to compensate the effects.

2. Loading error

As the measured quantity looses energy due to the act of measurement, an error is introduced known as loading error, Loading means the measuring instrument always taking the input from the signal source. Due to this, the signal source will always be tired by the act of measurement known loading.

Example: If steam flows through the nozzle, it is very difficult to find the perfect flow rate. This is called loading error.

3. Dynamic error

This is due to time variations in the measurand. The dynamic errors are caused by inertia, friction and clamping action. The dynamic errors re mainly classified into

(a) Systematic errors or Controllable errors

(b) Random errors

(a) Systematic error

The systematic are constant and similar in form. These are controllable in both their sense and magnitude. The systematic errors are easily determined and reduced, hence these are also called as controllable errors. Systematic errors includes

i. Calibration error

Calibration is a process of giving a known input to the measurement system and also taking necessary actions to see that the output of the measurement system matches with its input.

If the instrument is not calibrated, the instrument will show very high degree of error. Calibration errors are fixed errors.

ii. Ambient error

This is due to variation in atmospheric conditions (Example: Pressure, Temperature and moisture) normally the instruments are calibrated at particular pressure and temperatures. Temperature will not be equal at all places. If the temperature and pressure vary, the ambient error will form. Standard temperature of 20^0C and pressure of 760 mm of Hg are taken as ambient conditions.

iii. Avoidable errors

This type of error is due to parallax, non-alignment of work piece centers, and improper location of measuring instrument. For example placing a thermometer in sunlight to measure air temperature will cause the instrument location error.

iv. Stylus pressure

Whenever a component is measured under particular pressure, the deformation of the work piece and surface deflection will occur. The pressure involved is generally small but this is sufficient to cause appreciable deformation on stylus and the work piece.

(b) Random errors

These errors are due to unknown causes and occur even when all systematic errors have been accounted. Random errors are generally an accumulation of a large number of small effects and may be of r concern only in measurements requiring a high degree of accuracy. These errors are due to unknown causes, not determinable in ordinary process of making measurements. Such errors are normally sn and follow the laws of probability. Random errors can thus be treated mathematically.

The sources for this type of errors are:

i. Displacement of level joints in the measuring instrument.

ii. Small variation in the position of settings.

iii. Reading scale error due to operator.

1.4 **Systematic and Random errors**

	Systematic error	Random error
1	It can be controlled by magnitude and sense.	It cannot be determined from the knowledge of measuring system.
2	It is repetitive in nature.	It is inconsistent.
3	Property analyzed and can be determined and reduced.	Cannot be eliminated.
4	These types of errors are due to improper conditions or procedures.	Random errors are inherent in the measuring system.
5	These include the variation in atmospheric conditions, misalignment errors.	It includes errors due to displacement of level joints, errors due to friction.

1.5 Abbe's Principle of Alignment

- The Abbe's principle of alignment is named after the German Professor Earnst Abbe. In 1890, he proposed a set of rules for taking linear measurements.

His principle consists of the following 3 points :

1. For best results, a linear reading should be taken either inline or sideways of the object.

2. In case the above is not possible, the measurement can be taken at a distance parallel to the line being measured. In this case, the distance separating the object and the scale is known as the **Abbe Offset**. The Abbe Offset introduces no more than a second order error and is negligible.

3. If the parallelism between the object and the measuring instrument is not respected, a first order error will be introduced. The error will be a function of the angle the scale makes with the object and the distance separating the two. This error is known as **Abbe Error**.

Practical Implications

- By design, Vernier calipers do not conform to the Abbe's rule of alignment. It is therefore possible to introduce Abbe errors when taking measurements with one.
- On the other hand, Micrometers follow the principle. This means that no error of this type can be introduced when using it.

1.6 Standards of Measurement

The term standard is used to denote universally accepted specifications for devices.

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.

A standard provides a reference for assigning a numerical value to a measured quantity.

The role of standards is to achieve uniform, consistent and repeatable measurements through-out the world.

Different standards have been developed for various units including fundamental as well as derived units. All these standards are preserved at the international Bureau of Weight and Measures at Severs, Paris.

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".

1.6.1 International Prototype meter

It is defined as the straight line distance, at 0^0C, 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.

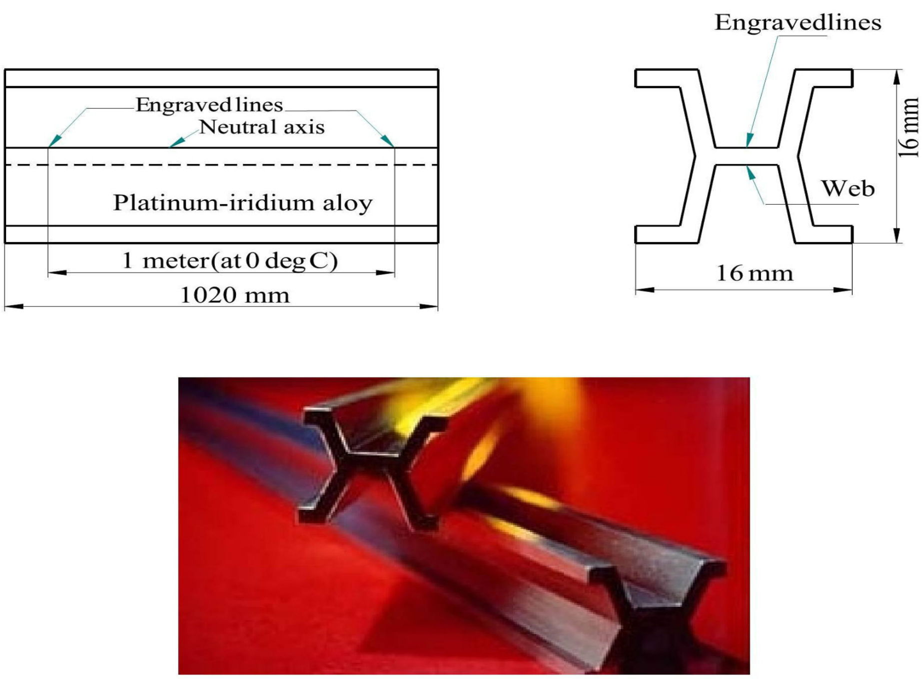


Figure: Historical International Prototype Meter bar, made of an alloy of platinum and iridium, that was the standard from 1889 to 1960.

1. 6.2 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 62^0F. 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.

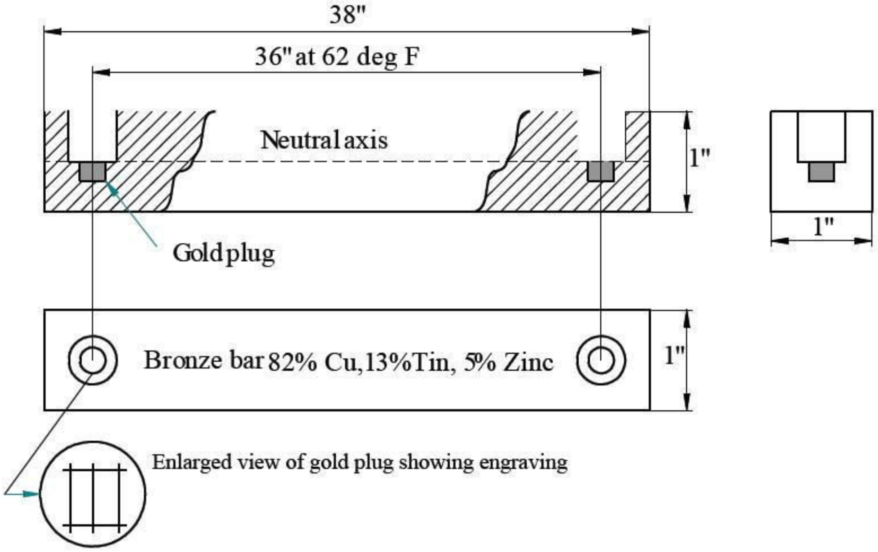


Figure: Imperial Standard yard.

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. 6.3 Line standards and End standards

Line standards
When the length being measured is expressed as the distance between two lines, then it is called "Line Standard".

Examples: Measuring scales, Imperial standard yard, International prototype meter, etc.

Characteristics of Line Standards

– 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.

– A scale is quick and easy to use over a wide range of measurements.

– The wear on the leading ends results in ‘under sizing’

– 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’.

– Scales are subjected to parallax effect, which is a source of both positive & negative reading errors.

– 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. Examples: Slip gauges, Gap gauges, Ends of micrometer anvils, etc.

Characteristics of End Standards

– End standards are highly accurate and are well suited for measurements of close tolerances as small as 0.0005 mm.

– They are time consuming in use and prove only one dimension at a time.

– End standards are subjected to wear on their measuring faces.

– End standards have a ‘built in’ datum, because their measuring faces are flat & parallel and can be positively located on a datum surface.

– They are not subjected to the parallax effect since their use depends on “feel”.

– Groups of blocks may be “wrung” together to build up any length. But faulty wringing leads to damage.

– The accuracy of both end & line standards are affected by temperature change.

1. 6.4 Light (Optical) wave Length Standard

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

Meter as on Today: In 1983, the 17th general conference on weights & measures proposed the use of speed of light as a technically feasible & practicable definition of meter. Meter is now defined as the length of path of travelled by light in vacuum in (1/ 299792458) second. The light used is Iodine stabilized Helium-Neon laser.

Advantages of using wave length standards:

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

1. 6.5 Subdivision of standards

Depending on the functions and applications, different types of standards of measurement are further classified as follows:

1. International Standards

   International standards are defined by international agreement. They are periodically evalu-ated and checked by absolute measurements in terms of fundamental units of physics. They represent certain units (measurement to the closest possible accuracy attainable by the science and technology of measurement. These international standards are not available to ordinary uses like measurement and calibrations.

2. Primary Standards

   The main function of primary standard is the calibration and verification of secondary standards. Primary standards are maintained at the National Standards Laboratories in different countries. For India, it is at National Physical Laboratory at New Delhi. The primary standards are not available for the use outside the National Laboratory. These primary standards are absolute standards of high accuracy that can be used as ultimate reference standards to check calibrate and certify the secondary standards.

3. Secondary Standards

Secondary standards are basic reference standards used by the measurement and calibration laboratories in industries. These secondary standards are maintained by the particular industry to which they belong. Each industry has its own secondary standard. Each laboratory periodically sends its secondary standard to the national standard laboratory for calibration and comparison against the primary standard After comparison and calibration, the National Standards Laboratory returns the secondary standards to the particular industrial laboratory with a certification of measuring accuracy in terms of primary standards.

4. Working Standards

Working standards are the main tools of a measuring laboratory. These standards are used to check and calibrate laboratory instrument for accuracy and performance. For example, manufacturing of mechanical components such as shafts, bearings, gears etc, use a standard called working standard for checking the component dimensions. Example: Plug gauge is used for checking the bore diameter of bearings.

1.7 LINEAR MEASUREMENT

Vernier calliper and vernier micrometer are the most widely used linear measuring instruments in machine shops and tool rooms. Measuring instruments are designed either for line measurements (e.g., steel rule or vernier calliper) or for end measurements in order to measure the distance between two surfaces using an instrument (e.g., screw gauge). Callipers and dividers, which are also linear measurement devices, are basically *dimension transfer instruments*. Most people's first contact with linear measurement is with a steel rule or a tape measure. However, today's engineer has a choice of a wide range of instruments—from purely mechanically operated instruments to digital electronics instruments. One has to consider only the nature of application and cost of measurement to decide which instrument is the best for an application.

1.7.1 DESIGN OF LINEAR MEASUREMENT INSTRUMENTS

The modern industry demands manufacture of components and products to a high degree of dimensional accuracy and surface quality. Linear measurement instruments have to be designed to meet stringent demands of accuracy and precision. At the same time, the instruments should be simple to operate and low priced to make economic sense for the user. Proper attachments need to be provided to make the instrument versatile to capture dimensions from a wide range of components, irrespective of the variations in cross-sections and shapes. The following points highlight important considerations that have to be addressed in the design of linear measurement instruments:

1. The measuring accuracy of line-graduated instruments depends on the original accuracy of the line graduations. Excessive thickness or poor definition of graduated lines affects the accuracy of readings captured from the instrument.

2. Any instrument incorporating a scale is a suspect unless it provides compensation against wear.

3. Attachments can enhance the versatility of instruments. However, every attachment used along with an instrument, unless properly deployed, may contribute to accumulated error. Wear and tear of attachments can also contribute to errors. Use attachments when their presence improves reliability more than their added chance for errors decreasing it.

4. Instruments such as callipers depend on the feel of the user for their precision. Good quality of the instrument promotes reliability, but it is ultimately the skill of the user that ensures accuracy. Therefore, it is needless to say that proper training should be imparted to the user to ensure accurate measurements.

5. The principle of alignment states that the line of measurement and the line of dimension being measured should be coincident. This principle is fundamental to good design and ensures accuracy and reliability of measurements.

6. Dial versions of instruments add convenience to reading. Electronic versions provide digital readouts that are even easier to read. However, neither of these guarantees accuracy and reliability of measurements unless basic principles are adhered to.

7. One important element of reliability of an instrument is its *readability*. For instance, the smallest division on a micrometer is several times larger than that on a steel rule of say 0.1 mm resolution, which is difficult to read. However, the micrometer provides better least count, say up to 0.01 mm, compared to the same steel rule. Therefore, all other things being equal, a micrometer is more reliable than even a vernier scale. However, micrometers have a lesser range than verniers.

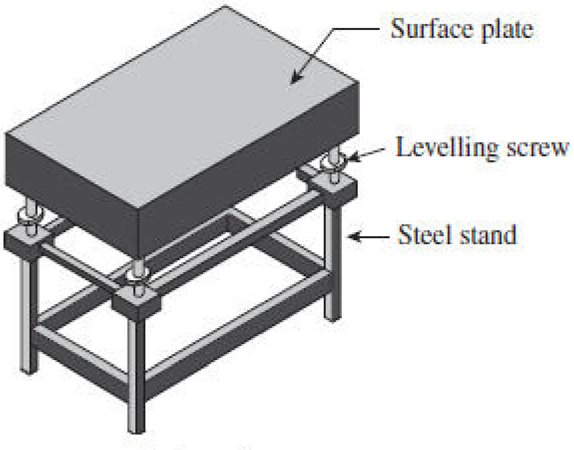
If cost is not an issue, digital instruments may be preferred.

9. Whenever a contact between the instrument and the surface of the job being measured is inevitable, the contact force should be optimum to avoid distortion. The designer cannot leave the fate of the instrument on the skill of the user alone. A proper device like a *ratchet stop* can limit the contact force applied on the job during measurements, thereby avoiding stress on the instrument as well as distortion of the job.

1.8 SURFACE PLATE

The foundation for all dimensional measurements is the 'datum plane', the most important one being the surface plate. A surface plate is a hard, solid, and horizontal flat plate, which is used as the reference plane for precision inspection, marking out, and precision tooling set-up Since a surface plate is used as the datum for all measurements on a job, it should be finished to a high degree of accuracy. It should also be robust to withstand repeated contacts with metallic workpieces and not be vulnerable to wear and tear.

The surface plates are made either from cast iron or from granite. Even though granite surface plates are perceived to be superior, cast iron surface plates are still in wide use. In fact, a cast iron surface plates is used as a tool for lapping granite surface plates to the required degree of accuracy. Cast iron allows itself to be impregnated with the lapping media over a large flat surface. In the following paragraphs, we will look into the construction and use of cast iron and granite surface plates in greater detail.



Surface plate

Cast Iron Surface Plates

Despite a drop in their usage, cast iron surface plates still retain popularity as surface masters. They are made of either plain or alloyed close-grained cast iron, reinforced with ribs to provide strength against bending or buckling. IS2285-1991 specifies the composition, size, and crosssectional details of ribs and thickness of plates. The plates are manufactured in three grades, namely grade 0, grade I, and grade II. While grade 0 and grade I plates are hand scraped to achieve the required degree of flatness, grade II plates are precision machined to the required degree of accuracy.

Granite Surface Plates

In recent times, granite has replaced cast iron as the preferred material for surface plates. Most surface plates are made of black granite, while pink granite is the next preferred choice. Granite has many advantages over cast iron. Natural granite that is seasoned in the open for thousands of years is free from warp age or deterioration. It is twice as hard as cast iron and not affected by temperature changes. It is not vulnerable to rusting and is non-magnetic.

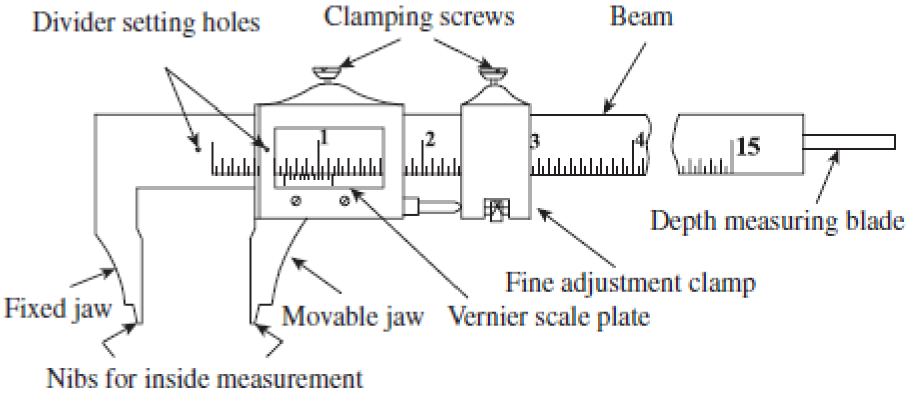
Glass Surface Plates

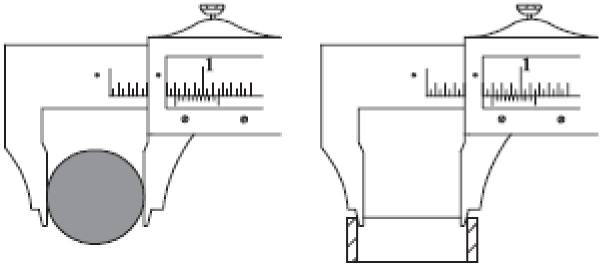
Glass is an alternative material for surface plates. It was used during World War II when material and manufacturing capacity were in short supply. Glass can be ground suitably and has the benefit that it chips rather than raising a burr, which is a problem in cast iron surface plates.

1.9 VERNIER CALLIPER

A vernier calliper consists of two main parts: the main scale engraved on a solid L-shaped frame and the vernier scale that can slide along the main scale. The sliding nature of the vernier has given it another name—*sliding calliper*. The main scale is graduated in millimeters, up to a least count of 1 mm. The vernier also has engraved graduations, which is either a forward vernier or a backward vernier. The vernier calliper is made of either stainless steel or tool steel, depending on the nature and severity of application.

Figure below illustrates the main parts of a vernier calliper. The L-shaped main frame also serves as the fixed jaw at its end. The movable jaw, which also has a vernier scale plate, can slide over the entire length of the main scale, which is engraved on the main frame or the beam. A clamping screw enables clamping of the movable jaw in a particular position after the jaws have been set accurately over the job being measured. This arrests further motion of the movable jaw, so that the operator can note down the reading in a convenient position. In order to capture a dimension, the operator has to open out the two jaws, hold the instrument over the job, and slide the movable jaw inwards, until the two jaws are in firm contact with the job. A fine adjustment screw enables the operator to accurately enclose the portion of the job where measurement is required by applying optimum clamping pressure. In the absence of the fine adjustment screw, the operator has to rely on his careful judgment to apply the minimum force that is required to close the two jaws firmly over the job. This is easier said than done, since any excessive application of pressure increases wear and tear of the instrument and may also cause damage to delicate or fragile jobs. The two jaws are shaped in such a manner that they can be used to measure both inside and outside dimensions.





(a) (b)

Measurement of dimensions (a) Outside dimension
(b) Inside dimension

The following guidelines are useful for the proper use of a vernier calliper:

1. Clean the vernier calliper and the job being measured thoroughly. Ensure that there are no burrs attached to the job, which could have resulted from a previous machining operation.

2. When a calliper's jaws are fully closed, it should indicate zero. If it does not, it must be recalibrated or repaired.

3. Loosen the clamping screw and slide the movable jaw until the opening between the jaws is slightly more than the feature to be measured.

4. Place the fixed jaw in contact with the reference point of the feature being measured and align the beam of the calliper approximately with the line of measurement.

5. Slide the movable jaw closer to the feature and operate the fine adjustment screw to establish a light contact between the jaws and the job.

6. Tighten the clamp screw on the movable jaw without disturbing the light contact between the calliper and the job.

7. Remove the calliper and note down the reading in a comfortable position, holding the graduations on the scale perpendicular to the line of sight.

8. Repeat the measurement a couple of times to ensure an accurate measurement.

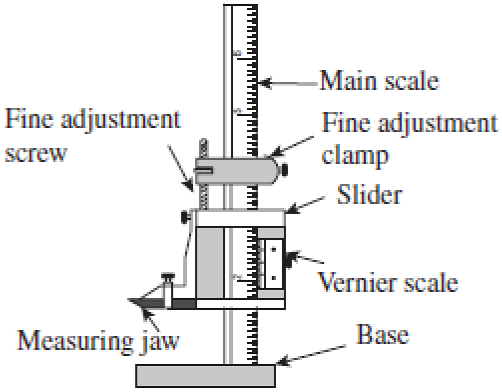
9. After completing the reading, loosen the clamping screw, open out the jaws, and clean and lubricate them.

10. Always store the calliper in the instrument box provided by the supplier. Avoid keeping the vernier calliper in the open for long durations, since it may get damaged by other objects or contaminants.

11. Strictly adhere to the schedule of periodic calibration of the vernier calliper.

1.10 VERNIER HEIGHT GAUGE

In a vernier height gauge, the graduated scale or bar is held in a vertical position by a finely ground and lapped base. A precision ground surface plate is mandatory while using a height gauge. The feature of the job to be measured is held between the base and the measuring jaw. The measuring jaw is mounted on a slider that moves up and down, but can be held in place by tightening of a nut. A fine adjustment clamp is provided to ensure very fine movement of the slide in order to make a delicate contact with the job. Unlike in depth gauge, the main scale in a height gauge is stationary while the slider moves up and down. The vernier scale mounted on the slider gives readings up to an accuracy of 0.01 mm. Vernier height gauges are available in sizes ranging from 150 to 500 mm for precision tool room applications. Some models have quick adjustment screw release on the movable jaw, making it possible to directly move to any point within the approximate range, which can then be properly set using the fine adjustment mechanism. Vernier height gauges find applications in tool rooms and inspection departments. Modern variants of height gauges such as optical and electronic height gauges are also becoming increasingly popular.



Vernier height gauge

1.11 SLIP GAUGES

The instruments such as vernier calliper, depth gauge, and micrometer, can facilitate measurement to a fairly high degree of accuracy and precision. All these measurements involve line standards. The accuracy of these instruments depends on the accuracy of the workmanship involved in their manufacture. Any minor misalignment or error in a screw can lead to errors in measurement. Repetitive use of a screw or joint results in rapid wear and tear, which can lead to accumulation of errors in measurement within a short time. Slip gauges, also called gauge blocks, can counter some of these limitations and provide a high degree of accuracy as *end standards*. In fact, slip gauges are a direct link between the measurer and the international length standards.

The modern-day slip gauges or gauge blocks owe their existence to the pioneering work done by C.E. Johansson, a Swedish armory inspector. Therefore, gauge blocks are also known as *Johansson gauges*.

Slip gauge is made of hardened alloy steel having a 30 mm × 10 mm cross section. Steel is the preferred material since it is economical and has the same coefficient of thermal expansion as a majority of steel components used in production. Hardening is required to make the slip gauge resistant to wear. Hardening is followed by stabilizing at a sub-zero temperature to relieve stresses developed during heat treatment. This is followed by finishing the measuring faces to a high degree of accuracy, flatness, and surface finish. The height of a slip gauge is engraved on one of the rectangular faces, which also features a symbol to indicate the two measured planes. The length between the measuring surfaces, flatness, and surface conditions of measuring faces are the most important requirements of slip gauges. Carbide gauge blocks are used for their superior wear resistance and longer life. They also have low coefficient of thermal expansion. However, they are quite expensive and used when rapid wear of gauges is to be avoided.

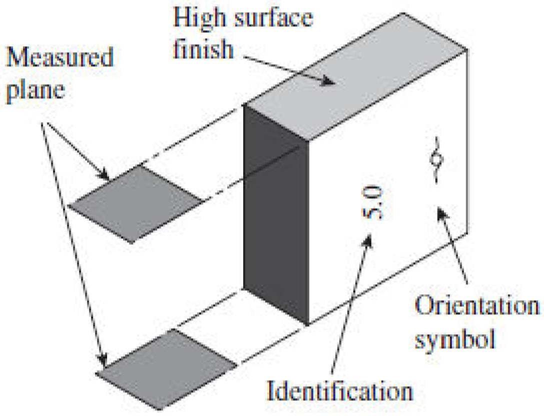
Several slip gauges are combined together temporarily to provide the end standard of a specific length. A set of slip gauges should enable the user to stack them together to provide an accuracy of up to one-thousandth of a millimeter or better. The surfaces of neighboring slip gauges should stick so close together that there should not be any scope for even a layer of air to be trapped between them, which can add error to the final reading. For this to happen, there should be absolute control over the form, flatness, parallelism, surface finish, dimensional stability of material, and homogeneity of gauging surfaces. While building slip gauges to the required height, the surfaces of slip gauges are pressed into contact by imparting a small twisting motion while maintaining the contact pressure. The slip gauges are held together due to molecular adhesion between a liquid film and the mating surfaces. This phenomenon is known as ‘wringing’.

1.11.1 Wringing of Slip Gauges

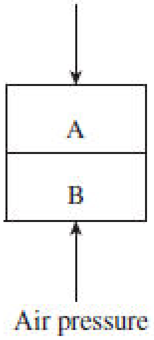
Wringing is the phenomenon of adhesion of two flat and smooth surfaces when they are brought into close contact with each other. The force of adhesion is such that the stack of a set of blocks will almost serve as a single block, and can be handled and moved around without disturbing the position of individual blocks. More importantly, if the surfaces are clean and flat, the thin layer of film separating the blocks will also have negligible thickness. This means that stacking of multiple blocks of known dimensions will give the overall dimension with minimum error.

1.11.2 Wringing Phenomenon

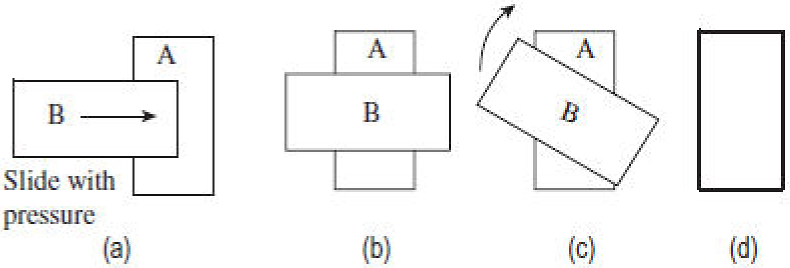
When two surfaces are brought into contact, some amount of space exists between them. This is because of surface irregularities and presence of dirt, oil, grease, or air pockets. Let us assume that the two surfaces are perfectly flat with highly finished surfaces, free from dirt and oil, and firmly pressed together. Now the air gap becomes so small that it acts in the same way as a liquid film. The thickness of this film can be as low as 0.00001 mm. Now a question arises as to why the blocks stick together so firmly that even a high magnitude of force acting perpendicular to their surfaces will not be able to separate them. A combination of two factors appears to ensure this high adhesion force. First, an atmospheric force of 1 bar is acting in the direction shown by the two arrows. This is contributing to the adhesion of the surfaces of the two slip gauges. Secondly, the surfaces are in such close proximity that there is molecular adhesion of high magnitude that creates a high adhesion force. Since the slip gauge surfaces undergo lapping as a super finishing operation, material removal takes place at the molecular level. Since some molecules are lost during the lapping operation, the material is receptive to molecules of the mating surface, which creates high molecular adhesion. These two factors collectively ensure adhesion of slip gauges with minimum air gap between them. Therefore, a stack of slip gauges will have a length equal to the sum of the individual heights.



Functional features of a slip gauge



Wringing phenomenon



Technique of wringing slip gauges (a) Step 1 (b) Step 2 (c) Step 3 (d) Step 4

1.11.3 Technique of Wringing Slip Gauges

The ability of a given gauge block to wring is called *wringability*; it is defined as 'the ability of two surfaces to adhere tightly to each other in the absence of external means'. The minimum conditions for wringability are a surface finish of 0.025 µm or better, and a flatness of at least 0.13 µm.

The following are the preferred steps in the wringing of slip gauges:

1. Clean slip gauge surfaces with a fine hairbrush (camel hairbrushes are often recommended) and a dry pad.

2. Overlap gauging surfaces by about one-fourth of their length.

3. Slide one block perpendicularly across the other by applying moderate pressure. The two blocks should now form the shape.

4. Now, gently rotate one of the blocks until it is in line with the other block.

1.11.4 Gauge Block Shapes, Grades, and Sizes

Slip gauges are available in three basic shapes: rectangular, square with a central hole, and square without a central hole. Rectangular blocks are the most commonly used since they can be used conveniently where space is restricted and excess weight is to be avoided. Square slip gauges have larger surface area and lesser wear rate because of uniform distribution of stresses during measurements. They also adhere better to each other when wrung together. Square gauge blocks with central holes permit the use of tie rods, which ensure that the built-up slip gauges do not fall apart.

Slip gauges are classified into grades depending on their guaranteed accuracy. The grade defines the type of application for which a slip gauge is suited, such as inspection, reference, or calibration. Accordingly, slip gauges are designated into five grades, namely grade 2, grade 1, grade 0, grade 00, and inspection grade.

Grade 2 This is the workshop-grade slip gauge. Typical uses include setting up machine tools, milling cutters, etc., on the shop floor.

Grade 1 This grade is used for tool room applications for setting up sine bars, dial indicators, calibration of vernier, micrometer instruments, and so on.

Grade 0 This is an inspection-grade slip gauge. Limited people will have access to this slip gauge and extreme care is taken to guard it against rough usage.

Grade 00 This set is kept in the standards room and is used for inspection/calibration of high precision only. It is also used to check the accuracy of the workshop and grade 1 slip gauges.

Calibration grade: This is a special grade, with the actual sizes of slip gauges stated on a special chart supplied with the set of slip gauges. Calibration-grade slip gauges are not necessarily available in a set of preferred sizes, but their sizes are explicitly specified up to the third or fourth decimal place of a millimeter.

Slip gauges are available in standard sets in both metric and inch units. In metric units, sets of 31, 48, 56, and 103 pieces are available. For instance, the set of 103 pieces consists of the following:

1. One piece of 1.005 mm
2. 49 pieces ranging from 1.01 to 1.49 mm in steps of 0.01 mm
3. 49 pieces ranging from 0.5 to 24.5 mm in steps of 0.5 mm
4. Four pieces ranging from 25 to 100 mm in steps of 25 mm

A set of 56 slip gauges consists of the following:

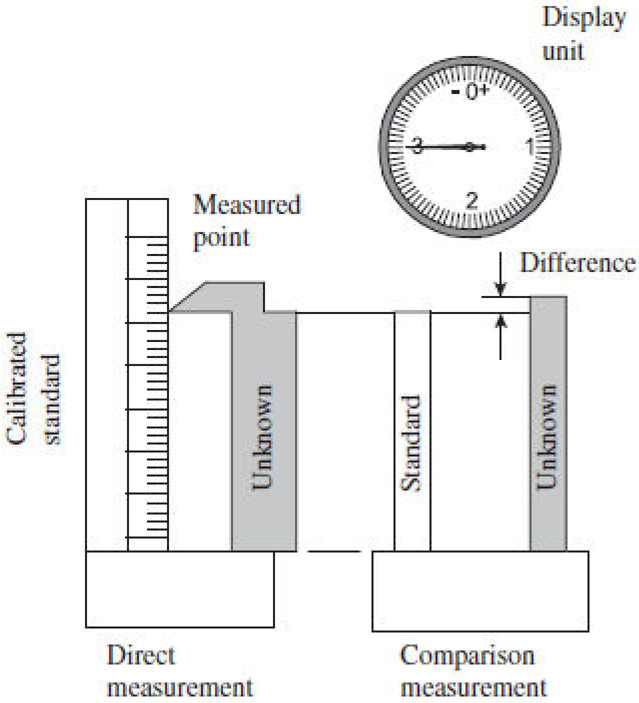
1. One piece of 1.0005 mm
2. Nine pieces ranging from 1.001 to 1.009 mm in steps of 0.001 mm
3. Nine pieces ranging from 1.01 to 1.09 mm in steps of 0.01 mm
4. Nine pieces ranging from 1.0 to 1.9 mm in steps of 0.1 mm
5. 25 pieces ranging from 1 to 25 mm in steps of 1.0 mm
6. Three pieces ranging from 25 to 75 mm in steps of 25 mm

1.12 COMPARATORS

In linear measurement instruments such as the vernier calliper, the standards are in-built and calibrated. Hence, these instruments enable us to directly measure a linear dimension up to the given degree of accuracy.

On the other hand, in certain devices the standards are separated from the instrument. It compares the unknown length with the standard. Such measurement is known as *comparison measurement* and the instrument, which provides such a comparison, is called a *comparator*. In other words, a comparator works on relative measurement. It gives only dimensional differences in relation to a basic dimension or master setting. Comparators are generally used for linear measurements.

Figure below illustrates the difference between direct and comparison measurements. As can be seen in the figure, a calibrated standard directly gives the measured value in case of direct measurement. On the other hand, a comparator has to be set to a reference value (usually zero setting) by employing a standard.



Direct measurement versus comparison measurement

1.12.1 FUNCTIONAL REQUIREMENTS

1. A comparator should have a high degree of accuracy and precision.

2. The scale should be linear and have a wide range.

3. A comparator is required to have high amplification. It should be able to amplify changes in the input value, so that readings can be taken and recorded accurately and with ease.

4. A comparator should have good resolution, which is the least possible unit of measurement that can be read on the display device of the comparator.

5. There should be a provision incorporated to compensate for temperature effects.

6. Finally, the comparator should be versatile. It should have provisions to select different ranges, attachments, and other flexible means, so that it can be put to various uses

1.13 CLASSIFICATION OF COMPARATORS

With respect to the principle used for amplifying and recording measurements, comparators are classified as follows:

1. Mechanical comparators

2. Mechanical–optical comparators

3. Electrical and electronic comparators

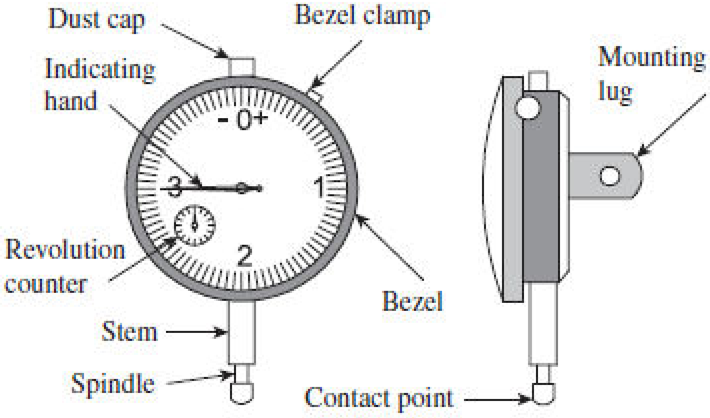
4. Pneumatic comparators

5. Other types such as projection comparators and multi-check comparators

1.13.1 MECHANICAL COMPARATORS

Dial Indicator

The dial indicator or the dial gauge is one of the simplest and the most widely used comparator. It is primarily used to compare work pieces against a master. The basic features of a dial gauge consist of a body with a circular graduated dial, a contact point connected to a gear train, and an indicating hand that directly indicates the linear displacement of the contact point. The contact point is first set against the master, and the dial scale is set to zero by rotating the bezel. Now, the master is removed and the work piece is set below the contact point; the difference in dimensions between the master and the work piece can be directly read on the dial scale. Dial gauges are used along with V-blocks in a metrology laboratory to check the roundness of components. A dial gauge is also part of standard measuring devices such as bore gauges, depth gauges, and vibrometers. Figure below illustrates the functional parts of a dial indicator.



Functional parts of a dial indicator

Use of Dial Indicators

A dial indicator is frequently built into other measuring instruments or systems, as a read-out device. It is more often used as a comparator in order to determine the deviation in a dimension from a set standard. The setting of the indicator is done using a master or gauge block. A dial gauge is used along with a stand, as shown in Figure.

The following guidelines are recommended for the proper use of dial indicators:

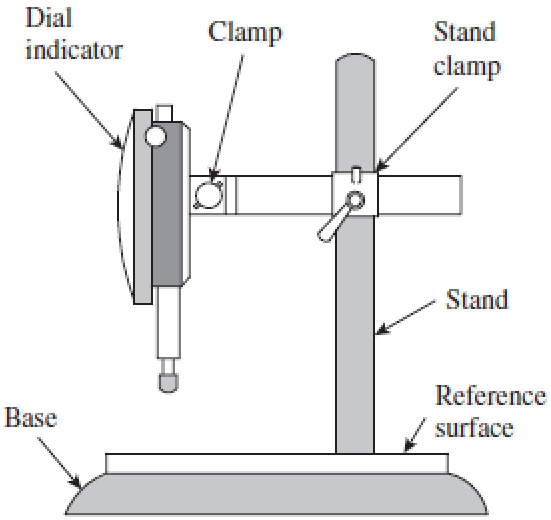
1. A dial indicator is a delicate instrument as the slender spindle can be damaged easily. The user should avoid sudden contact with the work piece surface, over-tightening of contact points, and side pressure.

2. Any sharp fall or blow can damage the contact points or upset the alignment of bearings, and hence should be avoided.

3. Standard reference surfaces should be used. It is not recommended to use non-standard attachments or accessories for reference surfaces.

4. The dial indicator should be cleaned thoroughly before and after use.

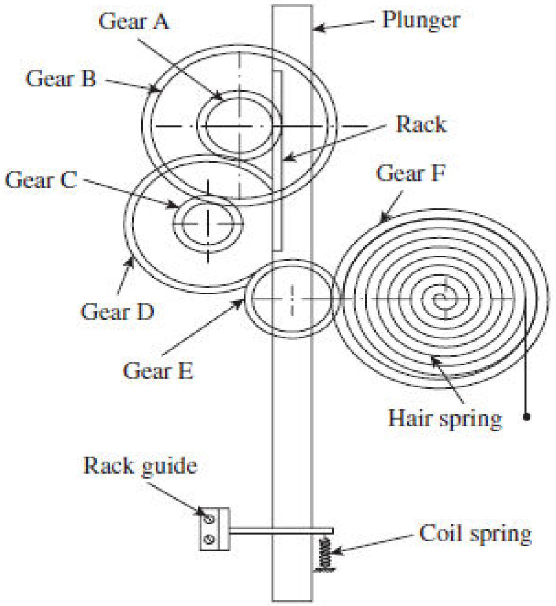
5. Periodic calibration of the dial gauge is a must.



Dial indicator mounted on a stand

Working Mechanism of Dial Indicators

Figure below illustrates the mechanism used in a dial indicator in order to achieve high magnification using a set of gears and pinions. The plunger and spindle are usually one piece. The spindle attached to the bottom of the rack is the basic sensing element. A coil spring resists the measurement movement and thereby applies the necessary gauging pressure. Thus, the application of gauging pressure is built into the mechanism.. It also returns the mechanism to the 'at-rest' position after each measurement.

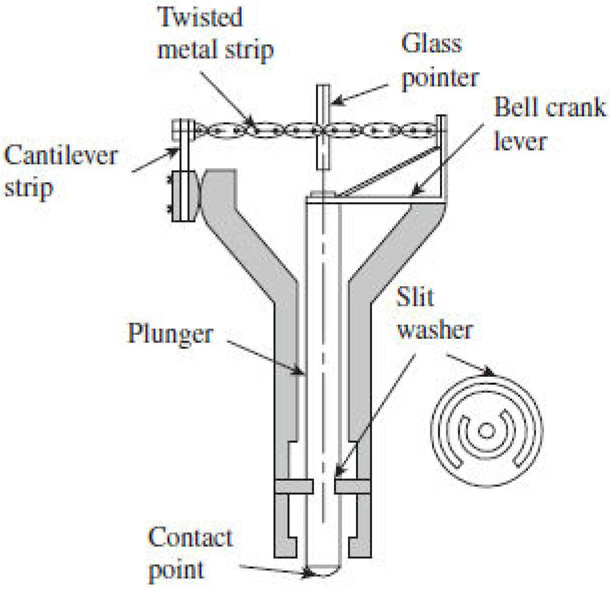


Working mechanism of a dial indicator

The plunger carries a rack, which meshes with a gear (marked gear A in the figure). A rack guide prevents the rotation of the plunger about its own axis. A small movement of the plunger causes the rack to turn gear A. A larger gear, B, mounted on the same spindle as gear A, rotates by the same amount and transfers motion to gear C. Attached to gear C is another gear, D, which meshes with gear E. Gear F is mounted on the same spindle as the indicator pointer. Thus, the overall magnification obtained in the gear train A–B–C–D–E is given by $TD/TE \times TB/TC$, where TD, TE, TB, and TC are the number of teeth on the gears D, E, B, and C, respectively. The magnification is further enhanced at the tip of the pointer, depending on the length of the pointer. A hair spring loads all the gears in the train against the direction of gauging movement. This eliminates backlash that would be caused by gear wear. The gears are precision cut and usually mounted on jewelled bearings.

Johansson Mikrokator

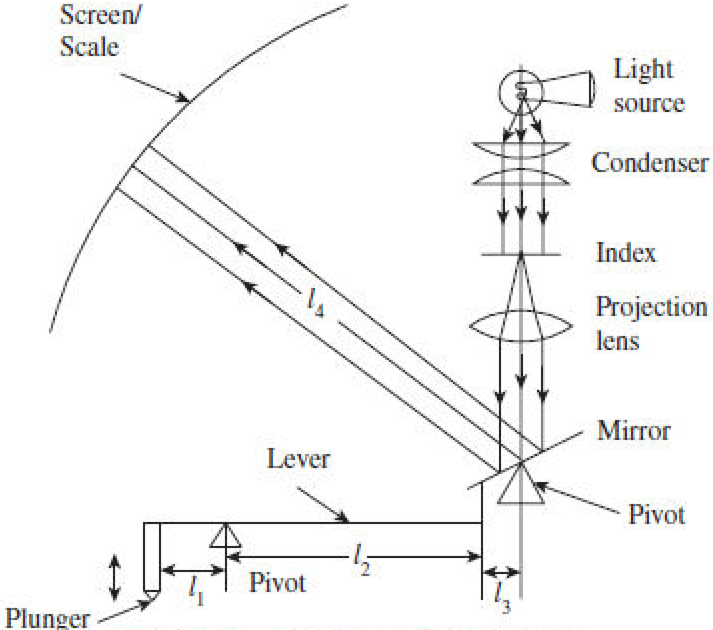
The basic element in this type of comparator is a light pointer made of glass fixed to a thin twisted metal strip. The two halves of the thin metal strip, which carries the light pointer, are twisted in opposite directions. Therefore, any pull on the strip will cause the pointer to rotate. While one end of the strip is fixed to an adjustable cantilever link, the other end is anchored to a bell crank lever, as shown in Figure. The other end of the bell crank lever is fixed to a plunger. Any linear motion of the plunger will result in a movement of the bell crank lever, which exerts either a push or a pull force on the metal strip. Accordingly, the glass pointer will rotate either clockwise or anticlockwise, depending on the direction of plunger movement. The comparator is designed in such a fashion that even a minute movement of the plunger will cause a perceptible rotation of the glass pointer. A calibrated scale is employed with the pointer so that any axial movement of the plunger can be recorded conveniently.



Johansson mikrokator

1.13.2 MECHANICAL–OPTICAL COMPARATOR

This is also termed as Cooke's Optical Comparator. As the name of the comparator itself suggests, this has a mechanical part and an optical part. Small displacements of a measuring plunger are initially amplified by a lever mechanism pivoted about a point, as shown in Figure. The mechanical system causes a plane reflector to tilt about its axis. This is followed by a simple optical system wherein a pointed image is projected onto a screen to facilitate direct reading on a scale.



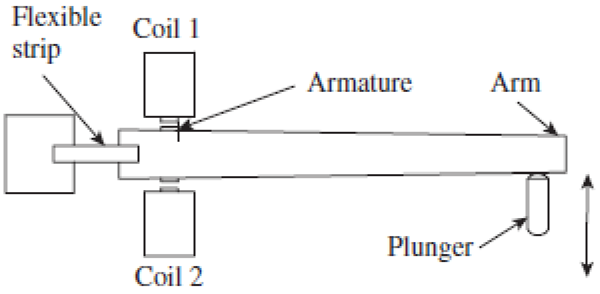
Principle of a mechanical optical comparator

The plunger is spring loaded such that it is biased to exert a downward force on the work part. This bias also enables both positive and negative readings, depending on whether the plunger is moving up or down. The scale is set to zero by inserting a reference gauge below the plunger. Now, the reference gauge is taken out and the work part is introduced below the plunger. This causes a small displacement of the plunger, which is amplified by the mechanical levers.

The amplified mechanical movement is further amplified by the optical system due to the tilting of the plane reflector. A condensed beam of light passes through an index, which normally comprises a set of cross-wires. This image is projected by another lens onto the plane mirror. The mirror, in turn, reflects this image onto the inner surface of a ground glass screen, which has a scale. The difference in reading can be directly read on this calibrated screen, which provides the linear difference in millimeters or fractions of a millimeter. Optical magnifications provide a high degree of precision in measurements due to the reduction of moving members and better wear-resistance qualities. The overall magnification of the system is given by $2 \times (l4/l3) \times (l2/l1)$.

1.13.3 ELECTRICAL COMPARATORS

Electrical comparators generally depend on a Wheatstone bridge circuit for measurement. A direct current (DC) circuit comprising four resistors, two on each arm, is balanced when the ratios of the resistances in the two arms are equal. Displacement of the sensing element, a plunger, results in an armature connected to one of the arms of the bridge circuit to cause an imbalance in the circuit. This imbalance is registered as an output by a galvanometer which is calibrated to read in units of linear movement of the plunger. Magnifications of the order 104:1 are possible with electrical systems. The block diagram given illustrates the main elements of an electrical comparator. The plunger is the sensing element, the movement of which displaces an armature inside a pair of coils. Movement of the armature causes change in inductance in the two coils, resulting in a net change in inductance. This change causes an imbalance in the bridge circuit, resulting in an output. The output display device, whether analog or digital, is calibrated to show the readings in units of length, that is, linear displacement.



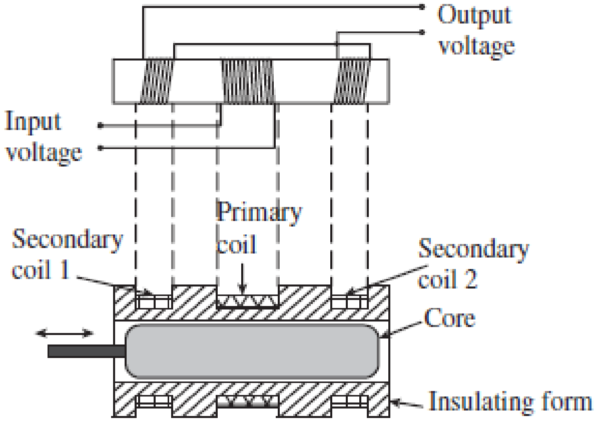
Elements of an electrical comparator

Linear Variable Differential Transformer

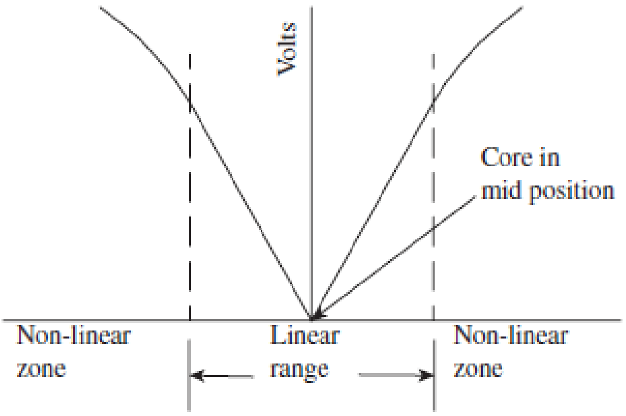
An LVDT provides an alternating current (AC) voltage output proportional to the relative displacement of a transformer core with respect to a pair of electrical windings. It provides a high degree of amplification and is very popular because of its ease of use. It is a non-contact-type device, where there is no physical contact between the plunger and the sensing element. As a consequence, friction is avoided, resulting in better accuracy and long life for the comparator. It can be conveniently packaged in a small cartridge. Figure below illustrates the construction of an LVDT.

An LVDT produces an output proportional to the displacement of a movable core within the field of several coils. As the core moves from its ‘null’ position, the voltage induced by the coils change, producing an output representing the difference in induced voltage. It works on the mutual inductance principle. A primary coil and two secondary coils, identical to each other, are wound on an insulating form. An external AC power source is applied to the primary coil and the two secondary coils are connected together in phase opposition. In order to protect the device from humidity, dust, and magnetic influences, a shield of ferromagnetic material is spun over the metallic end washers. The magnetic core is made of an alloy of nickel and iron.

The motion of the core varies the mutual inductance of secondary coils. This change in inductance determines the electrical voltage induced from the primary coil to the secondary coil. Since the secondary coils are in series, a net differential output results for any given position of the core. The characteristic curve of an LVDT is shown above. This curve shows the relationship between the differential output voltage and the position of the core with respect to the coils. It can be seen from this graph that if the core is centered in the middle of the two secondary windings, then the voltage induced in both the secondary coils will be equal in magnitude but opposite in phase, and the net output will be zero.



Construction details of an LVDT



Characteristic curve of an LVDT

An output voltage is generated when the core moves on either side of the null position. Theoretically, output voltage magnitudes are the same for equal core displacements on either side of the null balance. However, the phase relation existing between power source and output changes 180° through the null. The linear range of the instrument is limited.

Sensitivity of an LVDT is stated in terms of millivolts output per volt input per 1 mm core displacement. The per-volt input voltage refers to the exciting voltage that is applied to the circuit. Sensitivity varies from 0.1 to 1.5 mV for a range varying from 0.01 to 10 mm of core displacement. Sensitivity is directly proportional to excitation voltage, frequency of input power, and number of turns on the coils.

Advantages of LVDTs

1. It directly converts mechanical displacement into a proportional electrical voltage.

2. It cannot be overloaded mechanically. This is because the core is completely separated from the remainder of the device.

3. It is highly sensitive and provides good magnification.

4. It is relatively insensitive to temperature changes.

5. It is reusable and economical to use.

The only **disadvantage of an LVDT** is that it is not suited for dynamic measurement. Its core has appreciable mass compared, for example, to strain gauges. The resulting inertial effects may lead to wrong measurements.

1.13.4 ELECTRONIC COMPARATOR

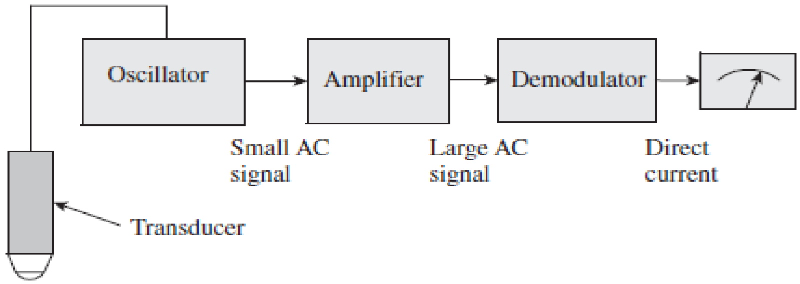
Generally, electrical and electronic comparators differ with respect to magnification and type of output. However, both rely on the mechanical contact with the work to be measured. While the electronic comparator is more complex, advances in integrated circuits have reduced the size and power consumption of the equipment. Electronic gauges are more accurate and reliable, which has made them the preferred choice in many applications.

The most significant advantage offered by electronic comparators is the speed of response. A measurement rate of 500 per minute is easily accomplished by an electronic comparator, making it well suited for *dynamic measurement*. For example, the thickness of a strip coming out of a rolling mill or deflection of a machine part under varying loads can be measured over a given period of time. The following advantages make electronic comparators superior to other types of comparators.

Advantages of electronic comparators

1. High accuracy and reliability
2. High sensitivity in all ranges
3. High speed of response
4. Easy provision for multiple amplification ranges
5. Versatility (a large number of measurement situations can be handled with standard accessories)
6. Easy integration into an automated system

Sigma Electronic Comparator



Components of an electronic comparator

The movement at the probe tip actuates the inductance transducer, which is supplied with an AC source from the oscillator. The transducer converts this movement into an electrical signal, which is then amplified and fed via an oscillator to the demodulator. The current, in DC form, then passes to the meter and the probe tip movement is displayed as a linear measurement over a circular scale. Various measuring and control units can be incorporated, which provide for a wide range of single or multiple measurements to be made simultaneously. Using various adaptors to suit the work, the comparator can be put to many applications such as external and internal gauging, flatness testing, thickness gauging, and tube wall thickness.

Advantages of Sigma electronic comparator

1. It is easy to use and provides a convenient means of measurement.

2. It has a high degree of accuracy and repeatability.

3. It has a provision to set several ranges of tolerances very easily.

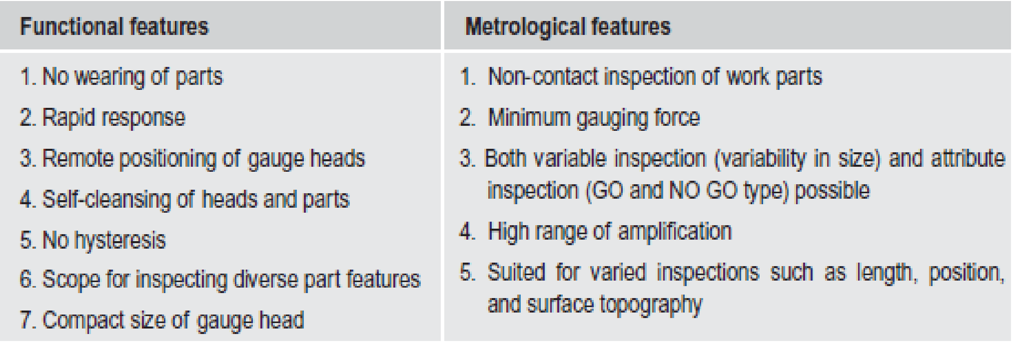
4. Light indications on its display unit enable fast inspection, since the inspector of components does not have to refer to the scale every time.

5. It can be easily integrated with a computer or micro-controller. Therefore, inspection data can be recorded for further analysis.

1.13.5 PNEUMATIC COMPARATORS

Pneumatic comparators use air as a means of measurement. The basic principle involved is that changes in a calibrated flow respond to changes in the part feature. This is achieved using several methods and is referred to as pneumatic gauging, air gauging, or pneumatic metrology. Since a pneumatic gauge lends itself to the gauging of several features at once, it has become an indispensable part of production inspection in the industry. It is possible to gauge length, diameter, squareness, parallelism, taper, concentricity, etc., using a simple set-up. For instance, if one is inspecting the bore of an engine cylinder, it is also possible to assess its size, taper, camber, and straightness in the same setting.

Functional and metrological features of pneumatic comparators

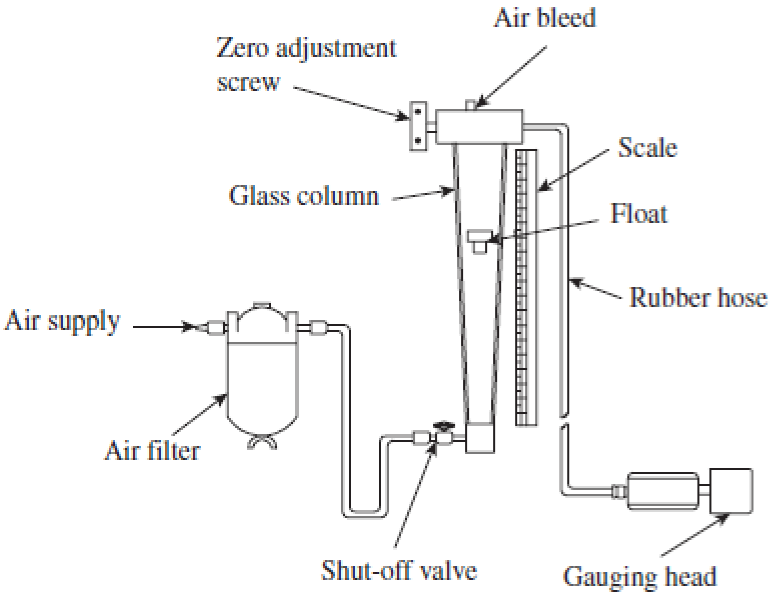


Functional features	Metrological features
1. No wearing of parts 2. Rapid response 3. Remote positioning of gauge heads 4. Self-cleansing of heads and parts 5. No hysteresis 6. Scope for inspecting diverse part features 7. Compact size of gauge head	1. Non-contact inspection of work parts 2. Minimum gauging force 3. Both variable inspection (variability in size) and attribute inspection (GO and NO GO type) possible 4. High range of amplification 5. Suited for varied inspections such as length, position, and surface topography

Pneumatic comparators are best suited for inspecting multiple dimensions of a part in a single setting ranging from 0.5 to 1000 mm. It is also amenable for on-line inspection of parts on board a machine tool or equipment. Based on the type of air gauge circuit, pneumatic gauges can be classified as *free flow gauges* and *back pressure gauges*.

Free Flow Air Gauge

This uses a simple pneumatic circuit. Compressed air with a pressure in the range 1.5–2 bar is passed through a tapered glass column that contains a small metal float. The air then passes through a rubber or plastic hose and exits to the atmosphere through the orifice in the gauging head. Since the gauging head is inserted inside the work part that is being inspected, there is a small clearance between the gauging head and the work part. This restricts the flow of air, thereby changing the position of the float inside the tapered glass column. The set-up is illustrated in Figure below. Compressed air from the factory line is filtered and reduced to the required pressure. A shut-off valve is provided to ensure shut-off of air supply when not in use. Air bleed and zero adjustment screws are provided to facilitate calibration of the gauge. The gauge head is mounted onto a handle, which provides a convenient way of handling the gauge head during inspection.



Free flow air gauge

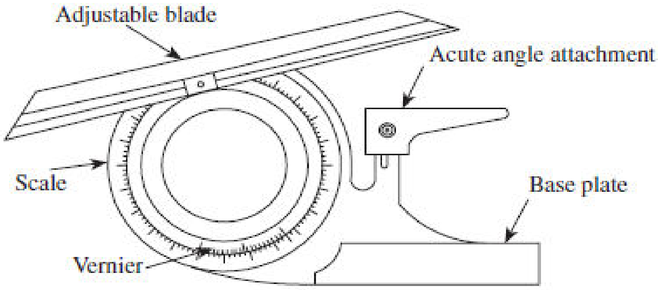
1.14 ANGULAR MEASUREMENT

The precise measurement of angles is an important requirement in workshops and tool rooms. Some of the typical measurements are tapers of bores, flank angle and included angle of a gear, angle made by a seating surface of a jig with respect to a reference surface, and taper angle of a jib. Different types of instruments used for measuring angles are discussed below.

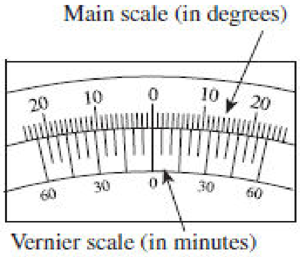
1.14.1 PROTRACTOR

A simple protractor is a basic device used for measuring angles. At best, it can provide a least count of 1° for smaller protractors and ½ ° for large ones. Similar to a steel rule, a simple protractor has limited usage in engineering metrology. However, a few additions and a simple mechanism, which can hold a main scale, a vernier scale, and a rotatable blade, can make it very versatile. A universal bevel protractor is one such instrument that has a mechanism that enables easy measurement and retention of a reading. A vernier scale improves the least count substantially.

Universal Bevel Protractor



Universal bevel protractor



Divisions on the vernier scale

The universal bevel protractor with 5' accuracy is commonly found in all tool rooms and metrology laboratories. Figure illustrates the construction of a universal bevel protractor. It has a base plate or stock whose surface has a high degree of flatness and surface finish. The stock is placed on the work piece whose angle is to be measured. An adjustable blade attached to a circular dial is made to coincide with the angular surface. It can be swiveled to the required angle and locked into position to facilitate accurate reading of the circular scale that is mounted on the dial. The main scale on the dial is graduated in degrees and rotates with the rotation of the adjustable blade. A stationary vernier scale mounted close to the dial, which enables measurements to a least count of 5' or less. An acute angle attachment is provided for the measurement of acute angles.

The main scale on the dial is divided into four quadrants, each measuring 90°. Each division on this scale reads 1°. The degrees are numbered from 0 to 90 on either side of the zeroth division. The vernier scale has 24 divisions, which correspond to 46 divisions on the main scale. However, the divisions on the vernier scale are numbered from 0 to 60 on either side of the zeroth division.

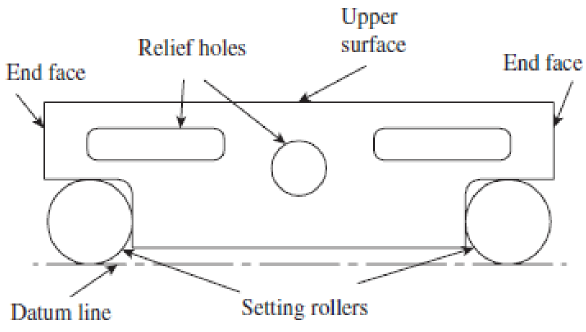
Calculation of Least Count

Value of one main scale division = 1°. 24 vernier divisions correspond to 46 main scale divisions. One vernier division equals 1/12th of 23°. Let us assume that the zeroth division on both the main and the vernier scales are lined up to coincide with each other. Now, as the dial rotates, a vernier division, starting from the fifth minute up to the 60th minute, progressively coincides with a main scale division until the zeroth division on the vernier scale moves over the main scale by 2°. Therefore, the least count is the difference between one vernier division and two main scale divisions, which is 1/12° or 5'.

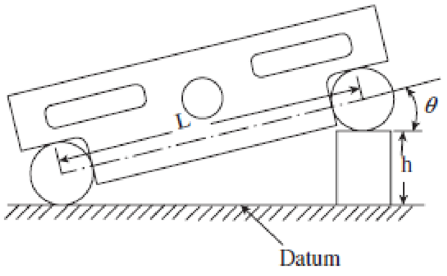
1.14.2 SINE BAR

Angles are measured using a sine bar with the help of gauge blocks and a dial gauge or a spirit level. The aim of a measurement is to measure the surface on which the dial gauge or spirit level is placed horizontal. For example, to measure the angle of a wedge, the wedge is placed on a horizontal table.

Principle of SINE BAR



Sine bar



Sine rule

Angles are measured using a sine bar with the help of gauge blocks and a dial gauge or a spirit level. The aim of a measurement is to measure the surface on which the dial gauge or spirit level is placed horizontal. For example, to measure the angle of a wedge, the wedge is placed on a horizontal table. The sine bar is placed over the inclined surface of the wedge. At this position, the top surface of the sine bar is inclined the same amount as the wedge. Using gauge blocks, the top surface is made horizontal. The sine of the angle of inclination of the wedge is the ratio of the height of the gauge blocks used and the distance between the centres of the cylinders.

- Proof of any angle can be traced to
  - dividing the circle
  - the sine principle
- Sine principle uses the ratio of two sides of a right triangle in deriving a given angle
  - any scale may be employed, as the ratio of the sides is used
- Dividing the circle is based upon the fact that the circle can be divided into any equal number of parts
  - the accuracy of the circular division is proven when the circle is closed.

Types

The simplest type consists of a lapped steel bar, at each end of which is attached an accurate cylinder, the axis of cylinder being mutually parallel and parallel to the upper surface of the bar. In the advanced type some holes are drilled in the body of the bar to reduce the weight and facilitate handling.

Sine centre

A special type of sine bar is sine centre which is used for conical objects having male and female parts. It cannot measure the angle more than 45 degrees

Sine table

A sine table (or sine plate) is a large and wide sine bar, typically equipped with a mechanism for locking it in place after positioning, which is used to hold workpieces during operations.

Compound sine table

It is used to measure compound angles of large workpieces. In this case, two sine tables are mounted one over the other at right angles. The tables can be twisted to get the required alignment.

Constructional Features of sine bar on which accuracy depends

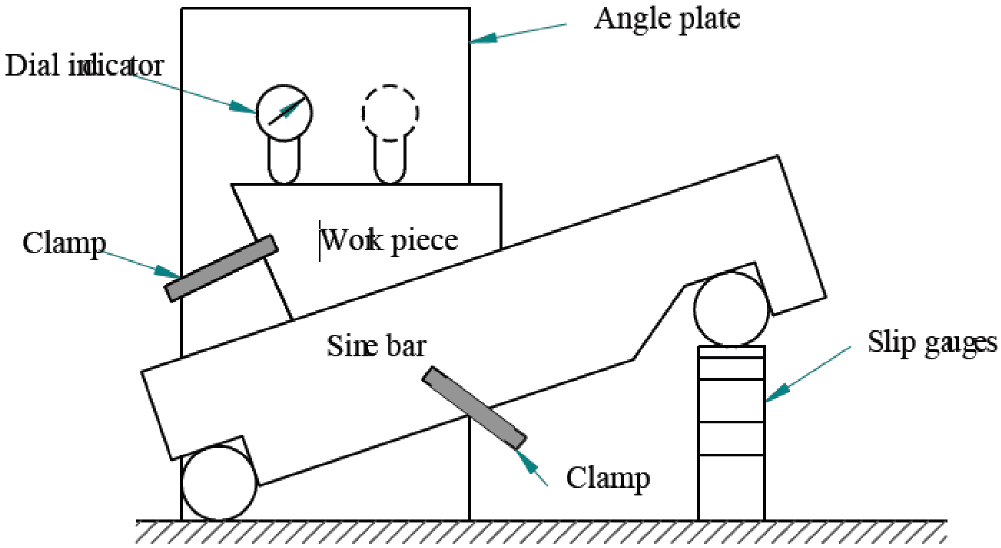
(i) The two rollers must have equal diameter and be true cylinders.

(ii) The rollers must be set parallel to each other and to the upper face.

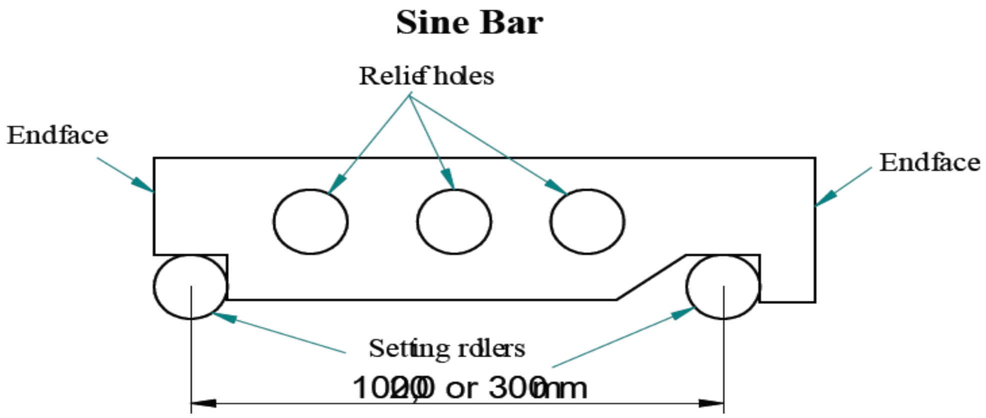
(iii) The precise centre distance between the rollers must be known.

(iv) The upper face must have a high degree of flatness.

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.



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 below 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.



SIMPLE FORM OF SINE BAR

Limitations of Sine bars:

The accuracy of sine bars is limited by measurement of centre distance between the two precision rollers & hence it cannot be used as a primary standard for angle measurements. Sine principle is fairly reliable at angles less than 15o, but becomes inaccurate as the angle increases.

For angles exceeding 45°, sine bars are not suitable for the following reasons:

1. The sine bar is physically clumsy to hold in position.

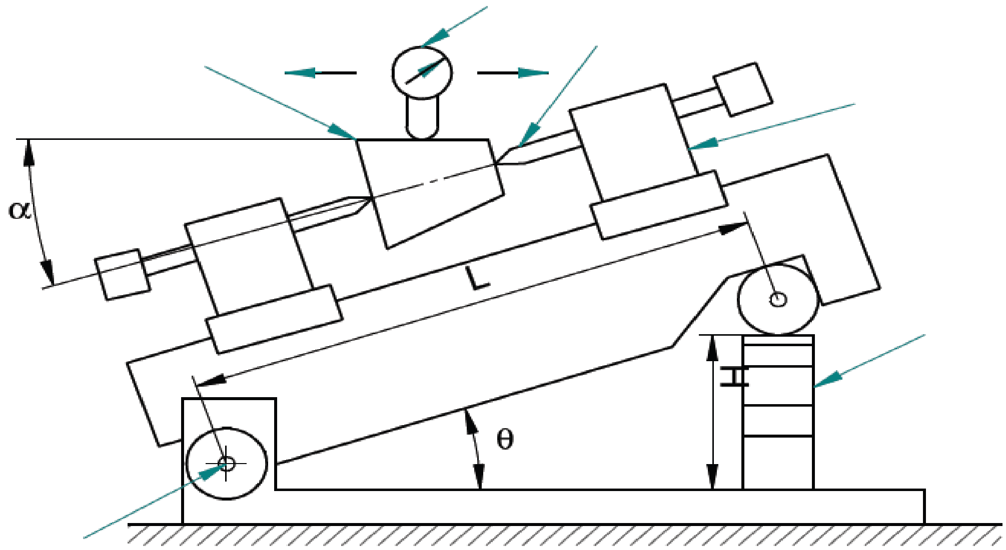
2. The body of the sine bar obstructs the gauge block stack, even if relieved.

3. Slight errors of the sine bar cause large angular errors.

4. Long gauge stacks are not nearly as accurate as shorter gauge blocks.

5. A difference in deformation occurs at the point of roller contact supporting the surface and to the gauge blocks, because at higher angles, the load is shifted more towards the fulcrum roller.

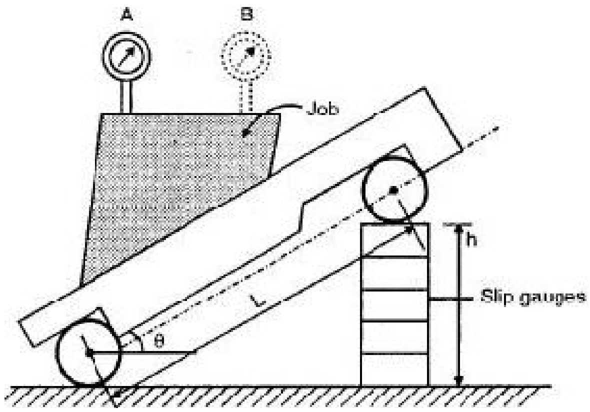
1.14.3 SINE CENTER:

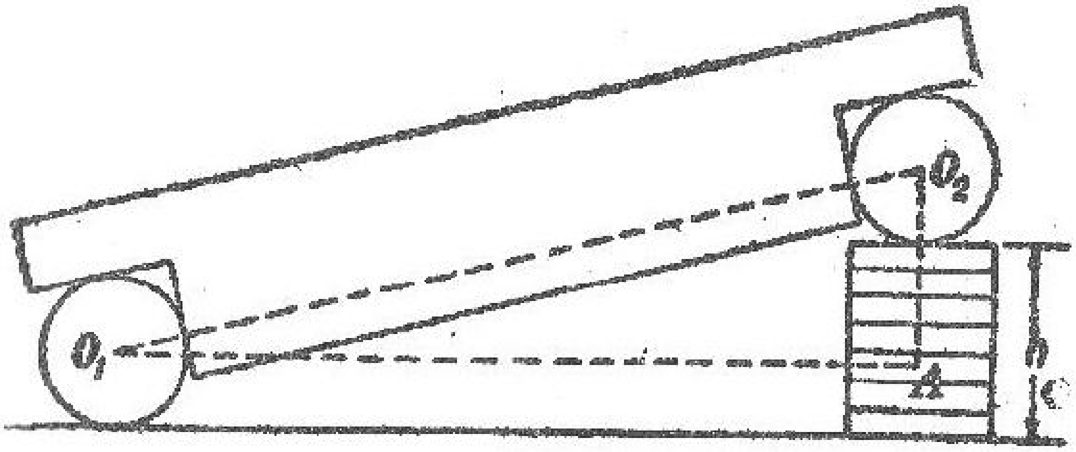


Sine centres are used for mounting conical work pieces which cannot be held on a conventional sine bar. Sine centre consists of a self-contained sine bar hinged at one roller and mounted on its own datum surface & the top surface of the bar is provided with clamps & centers to hold the work.

Use of sine bar

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



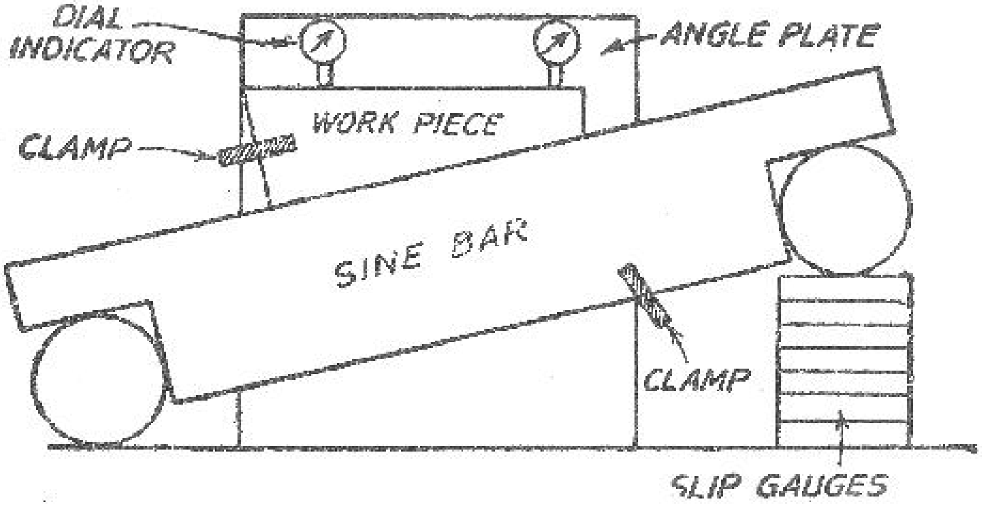


For this purpose the surface plate is assumed to be having a perfectly flat surface, so that its surface could be treated as horizontal. One of the cylinders or rollers of sine bar is placed on the surface plate and other roller is placed on the slip gauges of height h. Let the sine bar be set at an angle θ. Then sin θ = 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 h_1 and h_2 respectively.

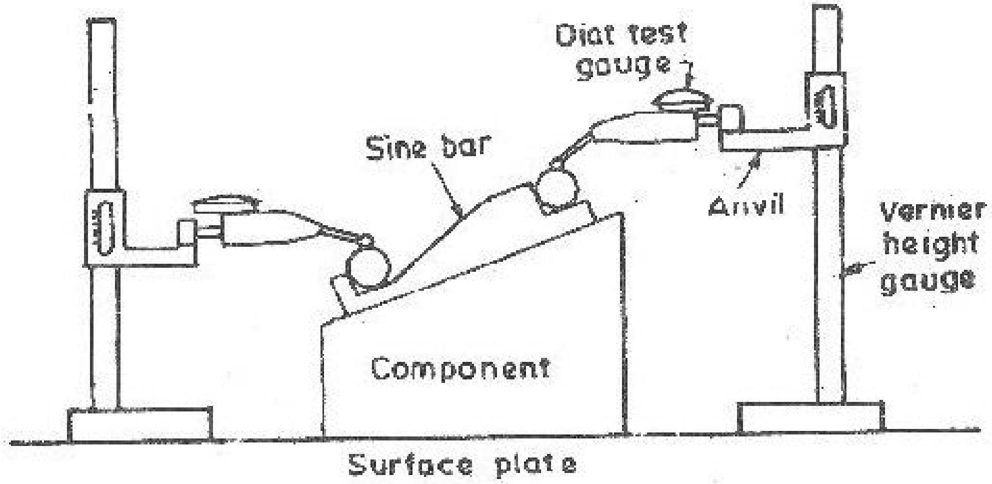
Then $\sin \theta = (h_2 - h_1)/L$

(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 δh over a length *L'* of work, then height of slip gauges by which it should be adjusted is equal to δh * (*L*/ *L'*)



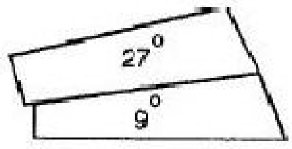
(3) **Checking of unknown angles of heavy component**.



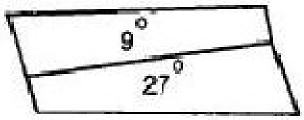
In such cases where components are heavy and can't be mounted on the sine bar, then sine bar is mounted on the component as shown in Fig. The height over the rollers can then be measured by a vernier height gauge ; using a dial test gauge mounted on the anvil of height gauge as the indicator to ensure 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. 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.

1.14.4 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. Angle 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°, 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.



(a) Addition



(b) Subtraction

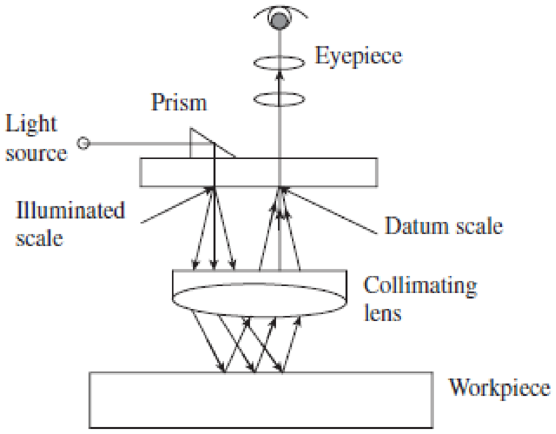
1.14.5 ANGLE DEKKOR

An angle dekkor is a small variation of the autocollimator. This instrument is essentially used as a comparator and measures the change in angular position of the reflector in two planes. It has an illuminated scale, which receives light directed through a prism. The light beam carrying the image of the illuminated scale passes through the collimating lens, as shown in Figure below, and falls onto the reflecting surface of the work piece. After getting reflected from the work piece, it is refocused by the lens in field view of the eyepiece. While doing so, the image of the illuminated scale would have undergone a rotation of 90° with respect to the optical axis. Now, the light beam will pass through the datum scale fixed across the path of the light beam. When viewed through the eyepiece, the reading on the illuminated scale measures angular deviations from one axis at 90° to the optical axis, and the reading on the fixed datum scale measures the deviation about an axis mutually perpendicular to this.

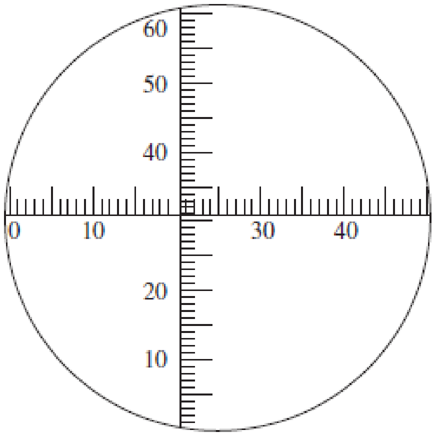
The view through the eyepiece, which gives the point of intersection of the two scales, is also shown in figure. The scales usually measure up to an accuracy of 1'. This reading actually indicates changes in angular position of the reflector in two planes. In other words, the initial reading of the angle dekkor corresponds to the reading on the two scales before shifting the position of the reflector. After the reflector undergoes an angular tilt, the second reading is noted down by recording the point of intersection on both scales. The difference in readings on the two scales indicates the tilt of the reflector in two planes at 90° to each other.

The optical system in an angle dekkor is enclosed in a tube, which is mounted on an adjustable bracket. It has a wide range of applications, as angular variations can be directly read through the eyepiece of the instrument. Some of the typical applications are as follows:

1. Measurement of sloping angle of V-blocks
2. Calibration of taper gauges
3. Measurement of angles of conical parts
4. Measurement of angles of work part surfaces, which are simultaneously inclined in two planes
5. Determination of a precise angular setting for machining operations, for example, milling a slot at some precise angle to a previously machined datum surface.



Angle dekkor



Intersection of two scales

1.14.6 SPIRIT LEVEL

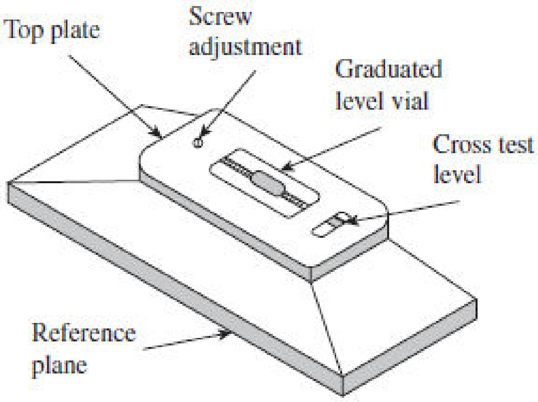
A spirit level is a basic 'bubble instrument', which is widely used in engineering metrology. It is derived from the practice in cold western countries. To combat freezing, the tubes were filled with 'spirits of wine', hence the general term spirit level. Spirit level is an angular measuring device in which the bubble always moves to the highest point of a glass vial. The details of a typical spirit level are shown in Figure. The base, called the reference plane, is seated on the machine part for which straightness or flatness is to be determined. When the base is horizontal, the bubble rests at the centre of the graduated scale, which is engraved on the glass. When the base of the spirit level moves out of the horizontal, then bubble shifts to the highest point of the tube. The position of the bubble with reference to the scale is a measure of the angularity of the machine part. This scale is calibrated to directly provide the reading in minutes or seconds. A cross test level provided at a right angle to the main bubble scale indicates the inclination in the other plane. A screw adjustment is provided to set the bubble to zero by referencing with a surface plate.

The performance of the spirit level is governed by the geometrical relationship between the bubble and the two references. The first reference is the effect of gravity acting at the centre of the bubble. The second is the scale against which the bubble position is read. The sensitivity of the spirit level depends on the radius of curvature of the bubble, which is formed against the inside surface of the glass vial, and the base length of its mount.

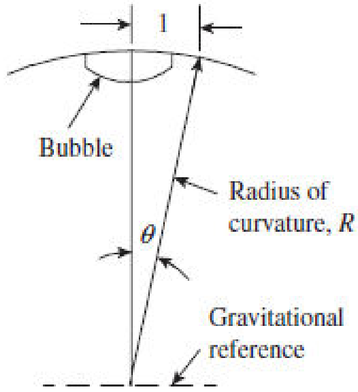
The sensitivity of the instrument depends on the radius of curvature of the bubble tube and the base length. Sensitivity can be increased by either increasing the radius of curvature or reducing the base length. The most useful sensitivity for precision measurement is 10" per division. The main use of a spirit level is not for measuring angles, but for measuring alignment of machine parts and determining flatness and straightness. Typically, the level is stepped along the surface in intervals of its own base length, the first position being taken as the datum.

The heights of all other points are determined relative to this datum. One should always keep in mind that the accuracy of a given spirit level depends on the setting of the vial relative to the base. There is bound to be a certain amount of error in the setting of the vial. In order to minimize this error, the following procedure is recommended while using a spirit level for precision measurement:

1. Take readings from both ends of the vial.
2. Reverse the base of the spirit level.
3. Repeat readings from both ends.
4. Average the four readings.
5. Repeat all steps for critical cases.



Spirit level

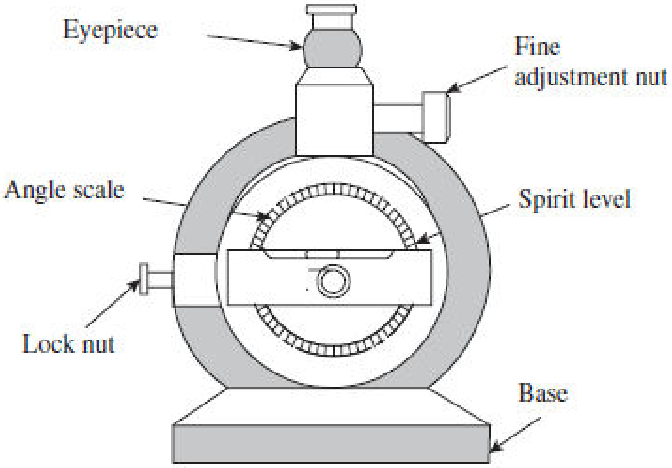


Relationship between radius of curvature and bubble scale reading

1.14.7 CLINOMETER

A clinometer is a special case of a spirit level. While the spirit level is restricted to relatively small angles, clinometers can be used for much larger angles. It comprises a level mounted on a frame so that the frame may be turned to any desired angle with respect to a horizontal reference. Clinometers are used to determine straightness and flatness of surfaces. They are also used for setting inclinable tables on jig boring machines and angular jobs on surface grinding machines. They provide superior accuracy compared to ordinary spirit levels.

To measure with clinometers, the base is kept on the surface of the work piece. The lock nut is loosened, and the dial comprising the circular scale is gently rotated until the bubble in the spirit level is approximately at the centre. Now, the lock nut is tightened and the fine adjustment nut is operated until the bubble is exactly at the centre of the vial scale. The reading is then viewed through the eyepiece. Most clinometers in a metrology laboratory provide readings up to an accuracy of 1'. Precision clinometers can be used if the accuracy requirement is up to 1". A recent advancement in clinometers is the electronic clinometer. It consists of a pendulum whose displacement is converted into electrical signals by a linear voltage differential transformer. This provides the advantage of electronic amplification. It is powered by an electronic chip that has a provision for recording and data analysis. Electronic clinometers have a sensitivity of 1". A major advantage of these clinometers is that the readings settle down within 1 second in contrast to the mechanical type, which requires a couple of seconds for the reading to settle down.



Clinometer

MODULE 2

2.1 LIMITS FITS AND TOLERANCES

Product Design for Manufacturing

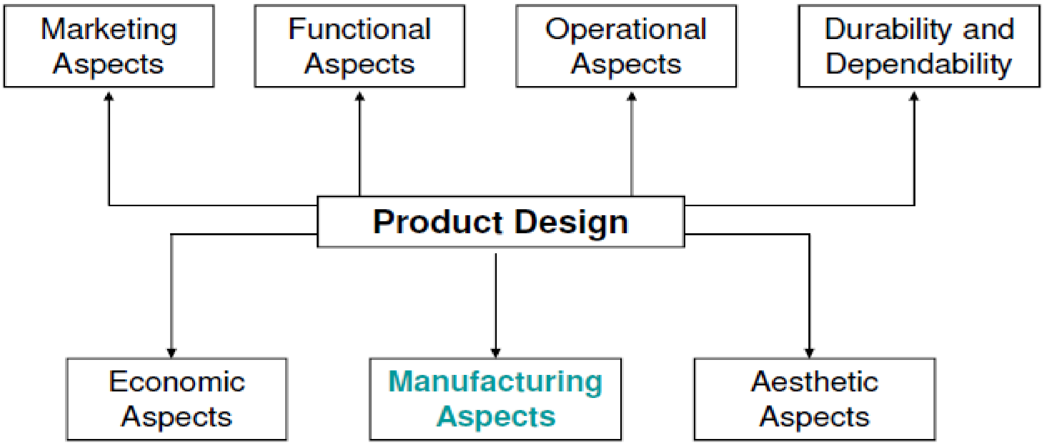
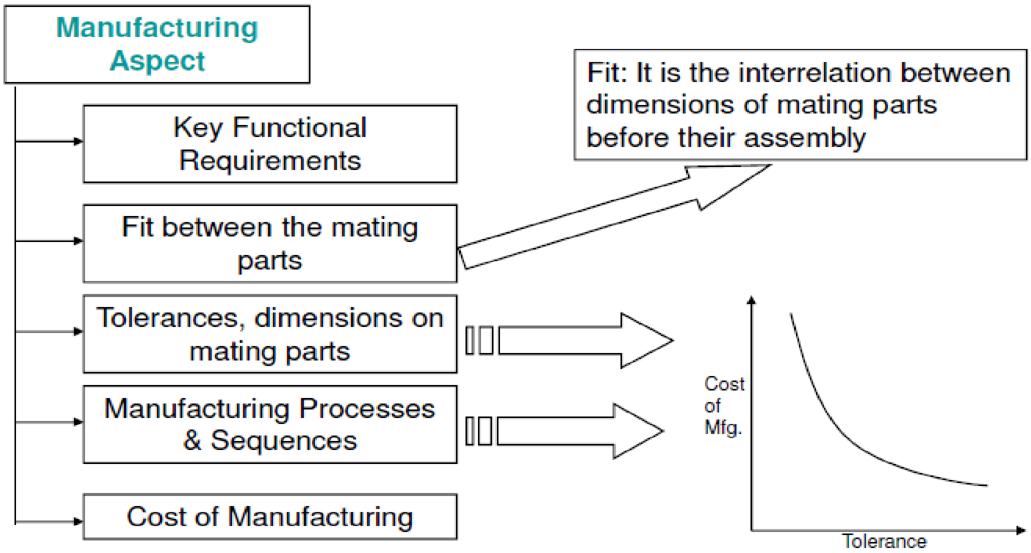


Fig. 1 Typical Stages in a Product Life Cycle

Role of Metrology in Design for Manufacturing



Fit: It is the interrelation between dimensions of mating parts before their assembly

Fig. 2 Implications of Manufacturing aspects

2.2 Interchangeability of Parts and Selective Assembly

Back before the Industrial Revolution machines were manufactured independently of one another. One engineer might make the whole machine. If a part broke on a machine it would have to be manufactured again to suit the machine in question. It was not possible to use the same part from another machine. Screws and nuts were manufactured to suit the machinist and their use. Standardization had not yet arrived.

During the Industrial Revolution a new concept in manufacturing was developed. Parts were manufactured by individuals and the individual stuck to making that part. Then the whole machine was assembled from these parts. Now that the parts were the same, if a part broke in a machine it could be replaced by the same part from another machine. This concept led to what we now call **Interchangeability of Parts**.

Interchangeability of Parts and other inventions around the same time revolutionized mass manufacture and reliability of machines. A machine could have spares at the ready that the owner new would work. If a screw or nut broke, another screw or nut of the same dimensions could be easily obtained. It also ensured that machinists became more specialized and therefore more accurate as their skills were honed in a specific direction as opposed to needing to have an overall knowledge.

Selective Assembly was the next step in the evolution of improved assembly manufacturing. A machinist would produce a large number of parts with a low tolerance. A mating part would be produced in the same numbers and to the same tolerance by another machinist. Each machinist would then grade the parts that they manufactured to similar higher tolerances. The parts could then be assembled by taking parts from the same grade and assembling them.

Selective Assembly has a number of advantages over earlier manufacturing methods. There are a larger number of acceptable parts as original tolerances are greater. This in turn allows the manufacture of cheaper parts as less will be consigned to the waste bin.

Selective Assembly assures better and more accurate assembly of parts by insuring closer tolerances between the mating parts.

2.3 Systems of Limits and Fits

2.3.1 Limits

When machining, it is impossible to manufacture a number of pieces to an exact measurement. There will always be some difference in size. As a result Limits are set. This means that what the machinist manufactures can differ from the proper size by the small amount stated by the Limits, and still be able to be used.

The required size of the component, before the Limits are set, is called the **Basic Size** or **Nominal Size**. Then the **Upper Limit** and the **Lower Limit** are set.

The Limits are the maximum and minimum sizes allowable.

E.g. 22.00 mm …. Nominal size

22.02 mm… upper limit

21.97 mm…. lower limit

To get the :

Upper Deviation ---- Subtract the Nominal Size from the Upper Limit. i.e. 0.02 mm
Lower Deviation ---- Subtract the Lower Limit from the Nominal Size. i.e. 0.03 mm

Limits are usually written in this way: $22.00^{+0.02}_{-0.03}$

These Limits tell the manufacturer that the component can be any size between 22.02mm and 21.97mm.

2.3.2 Tolerance

The Tolerance is the difference between the Upper Limit and the Lower Limit. i.e. 0.05 mm in this case.

The Tolerance is the total amount by which the size of the component can differ from the Nominal Size.

A Tolerance is said to be **Bilateral** if it is spread over both sides of the Nominal Size. The above example is an example of a Bilateral Tolerance.

A Tolerance is said to be **Unilateral** if it is only on one side of the Nominal Size. E.g. $22.00^{+0.02}_{0.00}$

These Limits tell the manufacturer that the component can be any size between 22.00mm and 22.02mm.

2.3.3 Types of Fit

In any machine, parts must fit together in certain ways in order to operate. An axle must be able to rotate in a bearing, but the bearing itself must be fixed into it's housing. The Fit is determined by the size of the mating parts. **Allowance** is what determines the type of Fit.

There are **3** Types of Fits:

- Clearance Fit
- Transition Fit
- Interference Fit

Clearance Fit

In the case of a Clearance fit, the shaft is always smaller than the hole.
eg. Axle in a bearing, the axle must be free to rotate without friction.

Transition Fit

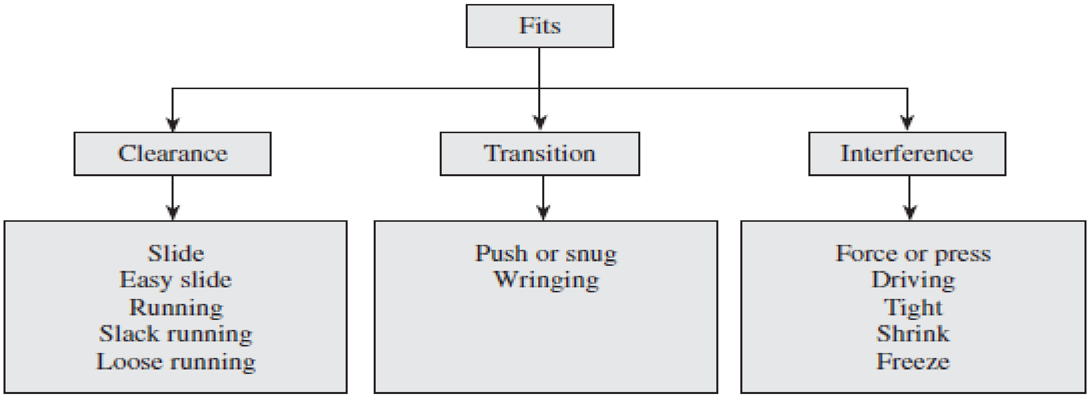
With a Transition Fit some shafts may be a little smaller than the hole and some may be a little larger.
eg. The lid of a pen. The lid must fit on securely but not be too difficult to remove. This is a push fit.

Interference Fit

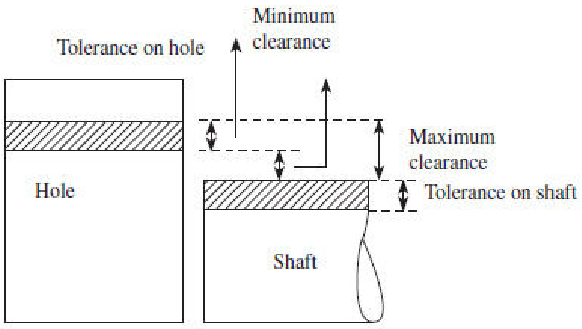
In the case of an Interference Fit, the shaft is always larger than the hole.
eg. Bearing in a chassis. The bearing must not rotate in the chassis. This is a force fit.

In a clearance fit, minimum clearance is the difference between minimum size of the hole, that is, low limit of the hole (LLH), and maximum size of the shaft, that is, high limit of the shaft (HLS), before assembly. In a transition or a clearance fit, maximum clearance is the arithmetical difference between the maximum size of the hole, that is, high limit of the hole (HLH), and the minimum size of the shaft, that is, low limit of the shaft (LLS), before assembly.

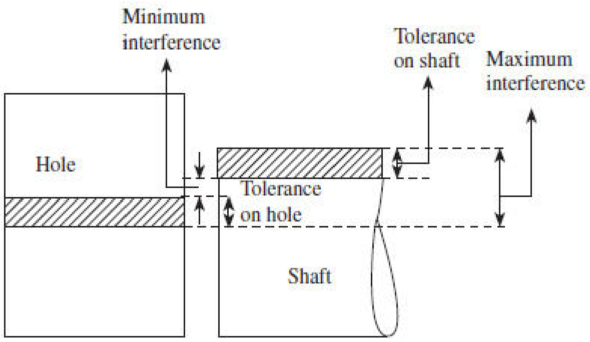
In an interference fit, minimum interference is the arithmetical difference between maximum size of the hole, that is, HLH, and minimum size of the shaft, that is, LLS, before assembly. In a transition or an interference fit, it is the arithmetical difference between minimum size of the hole, that is, LLH, and maximum size of the shaft, that is, HLS, before assembly. Thus, in order to find out the type of fit, one needs to determine HLH − LLS and LLH − HLS. If both the differences are positive, the fit obtained is a clearance fit, and if negative, it is an interference fit. If one difference is positive and the other is negative, then it is a transition fit.



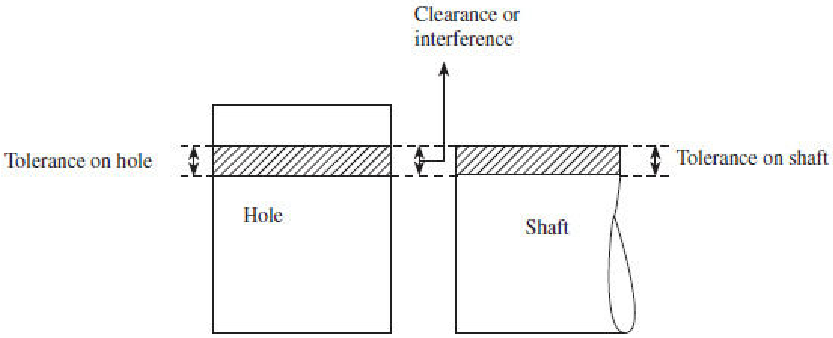
Detailed classification of fits



Clearance fit



Interference fit



Transition fit

2.3.4 Allowance

An allowance is the intentional difference between the maximum material limits, that is, LLH and HLS (minimum clearance or maximum interference) of the two mating parts. It is the prescribed difference between the dimensions of the mating parts to obtain the desired type of fit. Allowance may be positive or negative. Positive allowance indicates a clearance fit, and an interference fit is indicated by a negative allowance.

Allowance = LLH – HLS

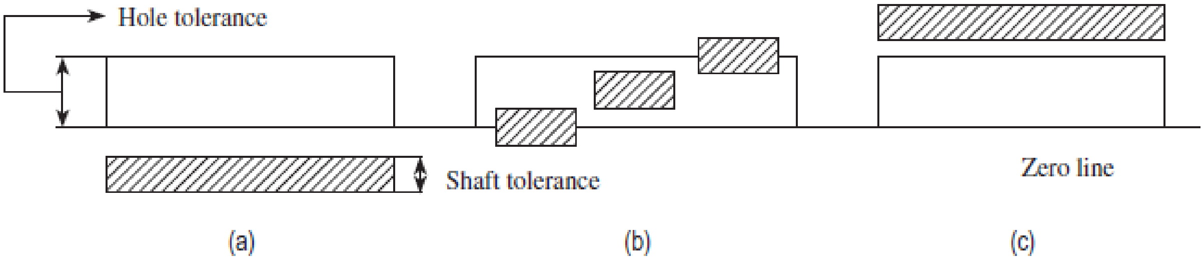
2.4 Hole Basis and Shaft Basis Systems

To obtain the desired class of fits, either the size of the hole or the size of the shaft must vary. Two types of systems are used to represent the three basic types of fits, namely clearance, interference, and transition fits. They are (a) hole basis system and (b) shaft basis system.

Although both systems are the same, hole basis system is generally preferred in view of the functional properties.

The Hole Basis System

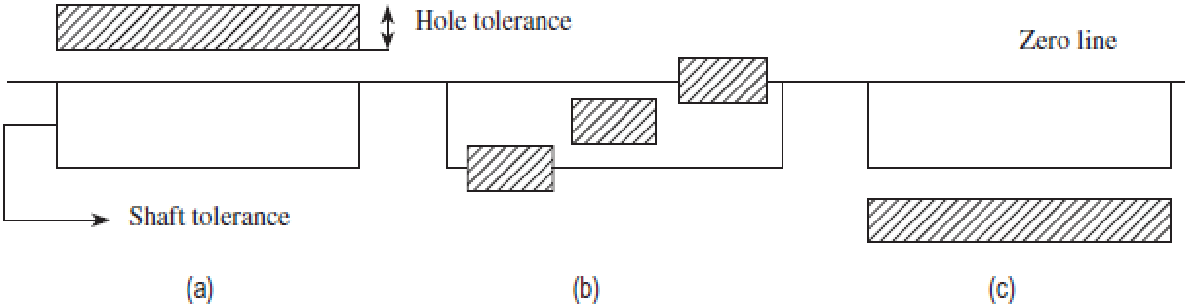
In this system the holes are drilled to a specific size and the size of shaft varies. Here, the lower deviation of hole is zero, i.e, the lower limit of hole is the same as the basic size. This is the preferred system as drills and reamers come in standard sizes and it is relatively easy to modify the size of a shaft.



Hole basis system (a) Clearance fit (b) Transition fit (c) Interference fit

The Shaft Basis System

In this system the shaft has a fixed size and the holes are varied to suit the type of fit necessary. Here, the upper deviation of shaft is zero, that is, the high limit of hole (HLH) equals the basic size. This is a relatively expensive system as a wide range of drills and reamers are required.



Shaft basis system (a) Clearance fit (b) Transition fit (c) Interference fit

2.5 General Terminology

The following are the commonly used terms in the system of limits and fits.

Basic size This is the size in relation to which all limits of size are derived. Basic or nominal size is defined as the size based on which the dimensional deviations are given. This is, in general, the same for both components.

Limits of size These are the maximum and minimum permissible sizes acceptable for a specific dimension. The operator is expected to manufacture the component within these limits. The maximum limit of size is the greater of the two limits of size, whereas the minimum limit of size is the smaller of the two.

Tolerance This is the total permissible variation in the size of a dimension, that is, the difference between the maximum and minimum limits of size. It is always positive.

Allowance It is the intentional difference between the LLH and HLS. An allowance may be either positive or negative.

Allowance = LLH – HLS

Grade This is an indication of the tolerance magnitude; the lower the grade, the finer the tolerance.

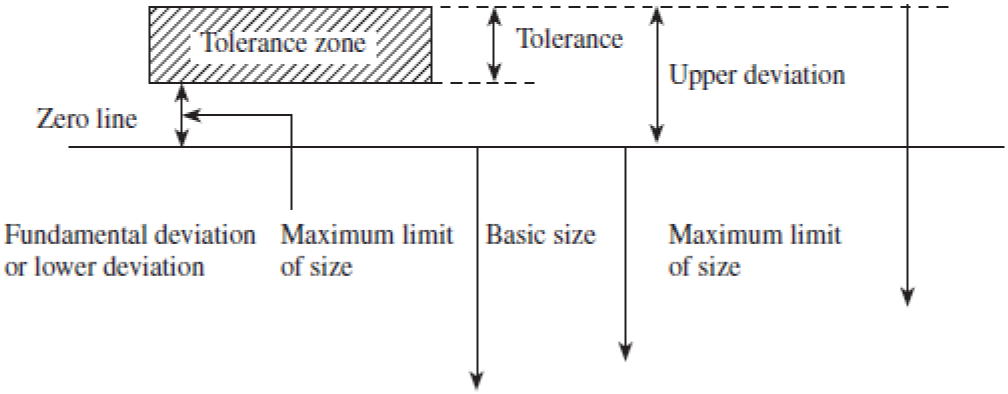
Deviation It is the algebraic difference between a size and its corresponding basic size. It may be positive, negative, or zero.

Upper deviation It is the algebraic difference between the maximum limit of size and its corresponding basic size. This is designated as 'ES' for a hole and as 'es' for a shaft.

Lower deviation It is the algebraic difference between the minimum limit of size and its corresponding basic size. This is designated as 'EI' for a hole and as 'ei' for a shaft.

Actual deviation It is the algebraic difference between the actual size and its corresponding basic size.

Fundamental deviation It is the *minimum* difference between the size of a component and its basic size. This is identical to the upper deviation for shafts and lower deviation for holes. It is the closest deviation to the basic size. The fundamental deviation for holes are designated by capital letters, that is, A, B, C, …, H, …, ZC, whereas those for shafts are designated by small letters, that is, a, b, c…, h…, zc. The relationship between fundamental, upper, and lower deviations is schematically represented in Figure below.



Relationship between fundamental, upper, and lower deviations

Zero line This line is also known as the line of zero deviation. The convention is to draw the zero line horizontally with positive deviations represented above and negative deviations indicated below. The zero line represents the basic size in the graphical representation.

Shaft and hole These terms are used to designate all the external and internal features of any shape and not necessarily cylindrical.

Fit It is the relationship that exists between two mating parts, a hole and a shaft, with respect to their dimensional difference before assembly.

Maximum metal condition This is the maximum limit of an external feature; for example, a shaft manufactured to its high limits will contain the maximum amount of metal. It is also the minimum limit of an internal feature; for example, a component that has a hole bored in it to its lower limit of size will have the minimum amount of metal removed and remain in its maximum metal condition, (i.e., this condition corresponds to either the largest shaft or the smallest hole). This is also referred to as the GO limit.

Least metal condition This is the minimum limit of an external feature; for example, a shaft will contain minimum amount of material, when manufactured to its low limits. It is also the maximum limit of an internal feature; for example, a component will have the maximum amount of metal removed when a hole is bored in it to its higher limit of size, this condition corresponds to either the smallest shaft or the largest hole. This is also referred to as the NO GO limit.

Tolerance zone The tolerance that is bound by the two limits of size of the component is called the tolerance zone. It refers to the relationship of tolerance to basic size.

International tolerance grade (IT) Tolerance grades are an indication of the degree of accuracy of the manufacture. Standard tolerance grades are designated by the letter IT followed by a number, for example, IT7. These are a set of tolerances that varies according to the basic size and provides a uniform level of accuracy within the grade.

Tolerance class It is designated by the letter(s) representing the fundamental deviation followed by the number representing the standard tolerance grade. When the tolerance grade is associated with letter(s) representing a fundamental deviation to form a tolerance class, the letters IT are omitted and the class is represented as H8, f7, etc.

Tolerance symbols These are used to specify the tolerance and fits for mating components. For example, in 40 H8f7, the number 40 indicates the basic size in millimeters; capital letter H indicates the fundamental deviation for the hole; and lower-case letter f indicates the shaft. The numbers following the letters indicate corresponding IT grades.

2.6 LIMIT GAUGES

- A limit gauge is not a measuring gauge. Just they are used as inspecting gauges.
- Limit gauge are mainly used for checking for cylindrical holes of identical components with a large numbers in mass production.
- This gives the information about the products which may be either within the prescribed limit or not.

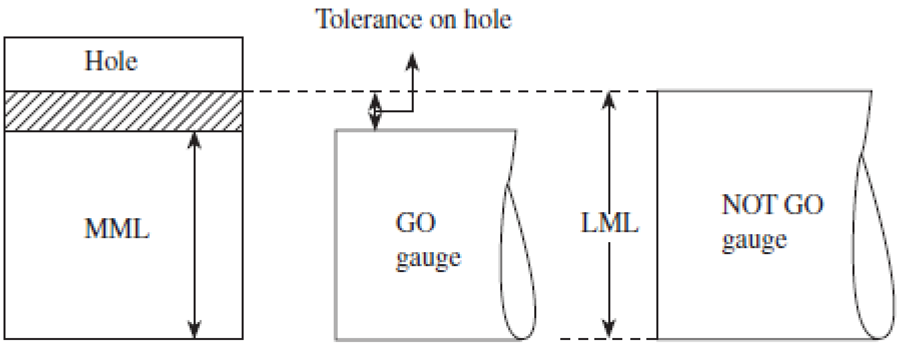
2.6.1 Purpose of using limit gauges

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

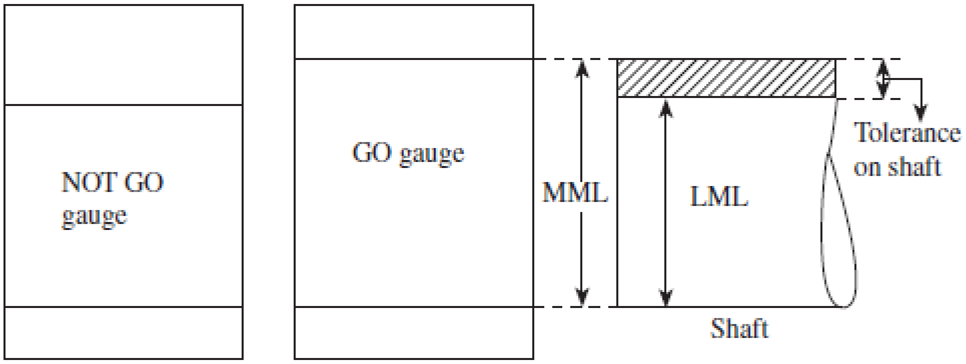
2.7 **GO and NO-GO GAUGES**

The gauges required to check the dimensions of the components correspond to two sizes conforming to the maximum and minimum limits of the components. They are called GO gauges or NO GO or NOT GO gauges which correspond, respectively, to the MML and LML of the component, as shown in Figures. MML is the lower limit of a hole and higher limit of the shaft and LML corresponds to the higher limit of a hole and lower limit of the shaft. The GO gauge manufactured to the maximum limit will assemble with the mating (opposed) part, whereas the NOT GO gauge corresponding to the low limit will not, hence the names GO and NOT GO gauges, respectively.

For gauging the MMLs of the mating parts, GO gauges are used. Whenever the components are gauged for their MMLs, if the GO gauges fail to assemble during inspection, the components should not be accepted under any circumstances. The minimum limits in a clearance fit of a product are not so critical because even if they exceed the specified limits and the NOT GO gauge assembles, its acceptance may result in functional degradation and because of the reduced quality the useful life of the product may get affected. Hence, it becomes essential that more care is taken especially when GO gauges are used, when compared to NOT GO gauges during inspection.



Metal limits for hole gauging



Metal limits for shaft gauging

2.8 CLASSIFICATION OF GAUGES

The detailed classification of the gauges is as follows:

1. Plain gauges

(a) According to their type:

(i) Standard gauges

(ii) Limit gauges

(b) According to their purpose:

(i) Workshop

(ii) Inspection

(iii) Reference, or master, or control gauges

(c) According to the form of the tested surface:

(i) Plug gauges for checking holes

(ii) Snap and ring gauges for checking shafts

(d) According to their design:

(i) Single- and double-limit gauges

(ii) Single- and double-ended gauges

(iii) Fixed and adjustable gauges

2. Adjustable-type gap gauges

3. Miscellaneous gauges

(a) Combined-limit gauges

(b) Taper gauges

(c) Position gauges

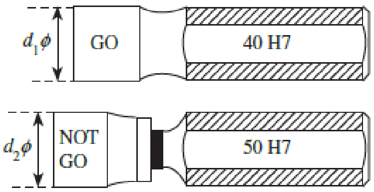
(d) Receiver gauges

(e) Contour gauges

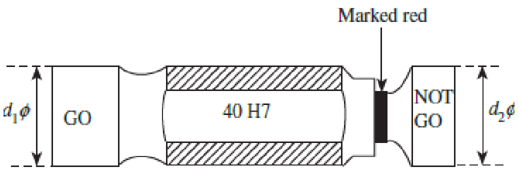
(f) Profile gauges

2.8.1 Plug Gauge

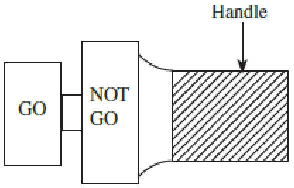
A plug gauge is a cylindrical type of gauge, used to check the accuracy of holes. The plug gauge checks whether the whole diameter is within specified tolerance or not. The 'Go' plug gauge is the size of the low limit of the hole while the 'Not-Go' plug gauge corresponds to the high limit of the hole.



Single-ended GO and NOT GO plug gauges



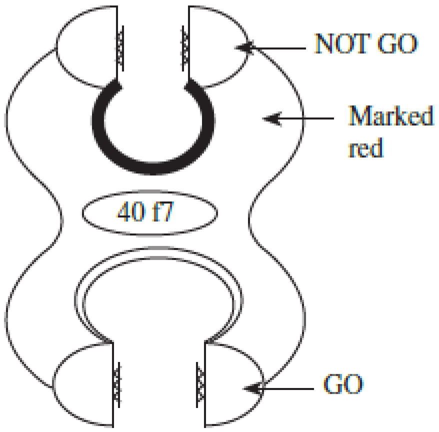
Double-ended plug gauges



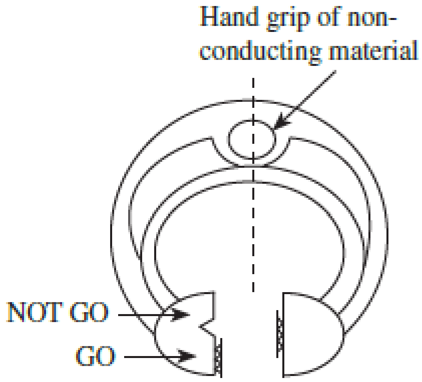
Progressive plug gauges

2.8.2 Snap Gauge

A snap gauge is a U-Shaped frame having jaws, used to check the accuracy of shafts and male members. The snap gauge checks whether the shaft diameter is within specified tolerances or not. The 'Go' snap gauge is the size of the high (maximum) limit of the shaft while the 'Not-Go' snap gauge corresponds to the low (minimum) limit of the shaft.



Double-ended snap gauge



Progressive snap gauge

2.9 TAYLOR'S PRINCIPLE OF GAUGING

Taylor's principle states that the GO gauge is designed to check maximum metal conditions, that is, LLH and HLS. It should also simultaneously check as many related dimensions, such as roundness, size, and location, as possible.

The NOT GO gauge is designed to check minimum metal conditions, that is, HLH and LLS. It should check only one dimension at a time. Thus, a separate NOT GO gauge is required for each individual dimension. During inspection, the GO side of the gauge should enter the hole or just pass over the shaft under the weight of the gauge without using undue force. The NOT GO side should not enter or pass. The basic or nominal size of the GO side of the gauge conforms to the LLH or HLS, since it is designed to check maximum metal conditions. In contrast, the basic or nominal size of the NOT GO gauge corresponds to HLH or LLS, as it is designed to check minimum metal conditions.

It can be seen from Fig. A that the size of the GO plug gauge corresponds to the LLH and the NOT GO plug gauge to the HLH. Conversely, it can be observed from Fig. B that the GO snap gauge represents the HLS, whereas the NOT GO snap gauge represents the LLS.

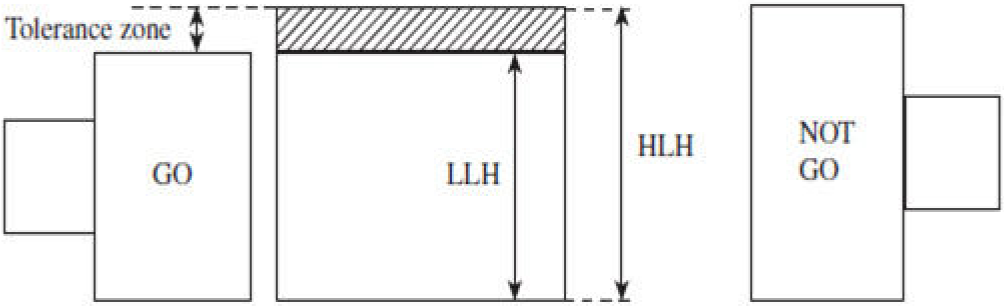


Fig. A GO and NOT GO limits of plug gauge

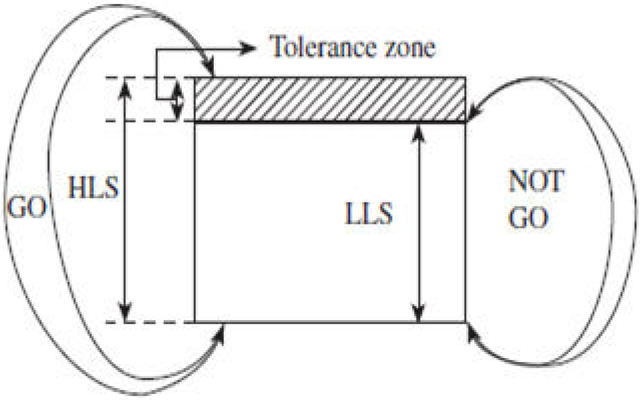


Fig. B GO and NOT GO limits of snap gauge

2.10 GAUGE TOLERANCE (GAUGE MAKER'S TOLERANCE)

Gauges, like any other component, cannot be manufactured to their exact size or dimensions. In order to accommodate these dimensional variations, which arise due to the limitations of the manufacturing process, skill of the operator, etc., some tolerance must be allowed in the manufacture of gauges. Thus, the tolerance that is allowed in the manufacture of gauges is termed gauge maker's tolerance or simply gauge tolerance.

Logically, gauge tolerance should be kept as minimum as possible; however, this increases the gauge manufacturing cost. There is no universally accepted policy for deciding the amount of tolerance to be provided on gauges. The normal practice is to take gauge tolerance as 10% of the work tolerance.

2.11 WEAR ALLOWANCE

According to Taylor's principle, during inspection the NOT GO side should not enter or pass. The NOT GO gauge seldom engages fully with the work and therefore does not undergo any wear. Hence, there is no need to provide an allowance for wear Taylor's principle also states that the GO side of the gauge should enter the hole or just pass over the shaft under the weight of the gauge without using undue force. During inspection, the measuring surfaces of the gauge constantly rub against the mating surfaces of the work piece.

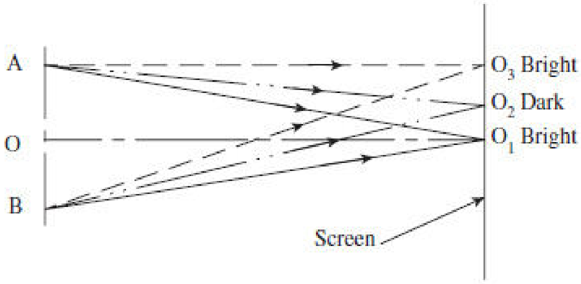
Therefore, the GO gauges suffer wear on the measuring surfaces and thus lose their initial dimension. Hence, wear allowance is provided for GO gauges to extend their service life. As a consequence of this wear, the size of the GO plug gauge decreases while that of the ring or gap gauge increases. The wear allowance provided for the GO gauges are added in a direction opposite to wear. This allowance is added in for a plug gauge while subtracted for a ring or gap gauge. A wear allowance of 10% of gauge tolerance is widely accepted in industries. If the work tolerance of a component is less than 0.1 mm, no wear allowance on gauges is provided for that component, since a wear allowance of less than 0.001 mm will not have any practical effect on the gauges.

2.15 OPTICAL MEASUREMENT

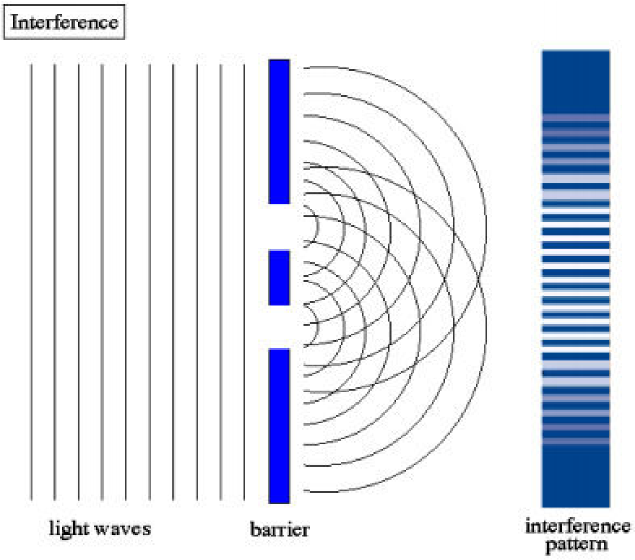
Optical measurement provides a simple, easy, accurate and reliable means for carrying out inspection and measurements in the industry .The projected image should be clear, sharp and dimensionally accurate. Application of interference of light is extreme interest in metrology. Lasers are also being increasingly used in interferometers for precision measurement. Optical magnification is one of the most widely used techniques in metrology. The primary requirement is visual magnification of small objects to a high degree with the additional provision for taking measurement.

2. 15.1 PRINCIPLE OF INTERFERENCE

When two light waves interact with each other, the wave effect leads to the phenomenon called interference of light. The instruments designed to measure with interference are known as interferometers. Let us consider two monochromatic light rays from the same light source, but originating from two point sources A and B. The distances AO_1 and BO_1 are equal, the two rays are in phase, and results in maximum illumination at point O_1. On the other hand, at point O_2, the distance BO_2 is longer than the distance AO_2.Therefore, by the time the two rays arrive at the point O_2, they are out of phase Suppose the phase difference $\delta = \lambda / 2$, where λ is the wave length of light, then it leads to complete interference and formation of a dark spot. This process repeats on either side of O_1 on the screen, resulting in the formation of alternate dark and bright areas.



Formation of fringes

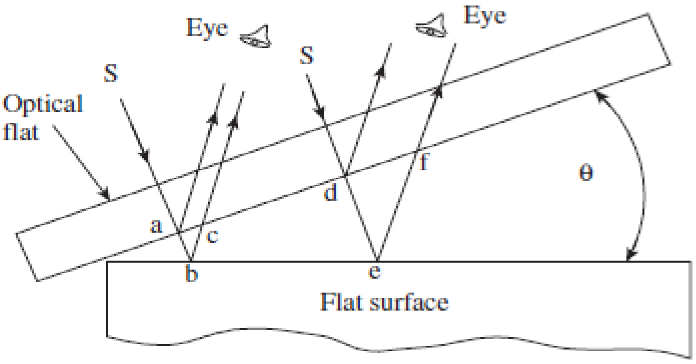


The phenomenon of interference is made use of for carrying out precise measurements of very small linear dimensions, and the measurement technique is popularly known as interferometry. This technique is used in a variety of metrological applications such as inspection of machine parts for straightness, parallelism, flatness, measurement of very small diameters, and so on. The instrument used for making measurements using interferometry technique is called an interferometer.

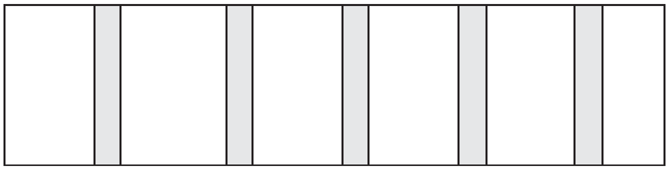
2.16 OPTICAL FLATS

An optical flat is a disk of high-quality glass or quartz. The surface of the disk is ground and lapped to a high degree of flatness. Sizes of optical flats vary from 25 to 300 mm in diameter, with a thickness ranging from 25 to 50 mm. When an optical flat is laid over a flat reflecting surface, it orients at a small angle θ, due to the presence of an air cushion between the two surfaces. Consider a ray of light from a monochromatic light source falling on the upper surface of the optical flat at an angle. This light ray is partially reflected at point 'a'. The remaining part of the light ray passes through the transparent glass material across the air gap and is reflected at point 'b' on the flat work surface. The two reflected components of the light ray are collected and recombined by the eye, having travelled two different paths whose length differs by an amount 'abc'. If 'abc' = $\lambda/2$, where λ is the wavelength of the monochromatic light source, then the condition for complete interference has been satisfied.

Next, consider another light ray from the same source falling on the optical flat at a small distance from the first one. This ray gets reflected at points'd' and 'e'. If the length 'def' equals $3\lambda/2$, then total interference occurs again and a similar fringe is seen by the observer. However, at an intermediate point between the two fringes, the path difference between two reflected portions of the light ray will be an even number of half wavelengths. Thus, the two components of light will be in phase, and a light band will be seen at this point. When light from a monochromatic light source is made to fall on an optical flat, which is oriented at a very small angle with respect to a flat reflecting surface, a band of alternate light and dark patches is seen by the eye. In case of a perfectly flat surface, the fringe pattern is regular, parallel, and uniformly spaced. Any deviation from this pattern is a measure of error in the flatness of the surface being measured.



Fringe formation in an optical flat



Interference fringes

2.16.1 Comparative Measurement with Optical Flats

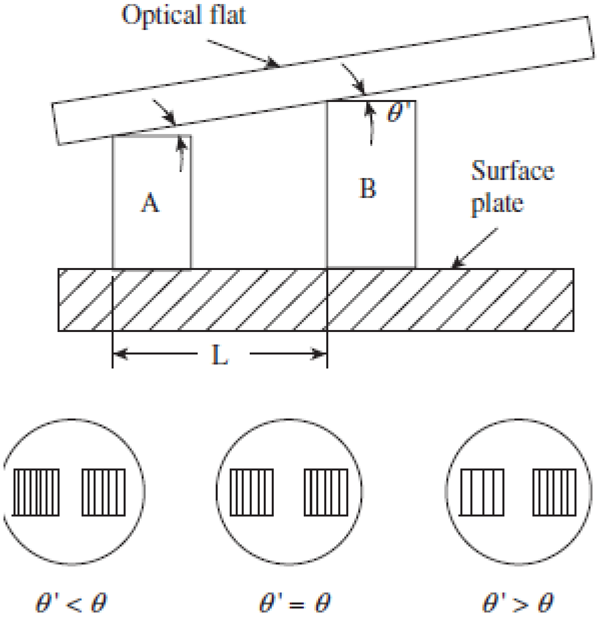
One of the obvious uses of an optical flat is to check the heights of slip gauge blocks. The slip gauge that is to be checked is kept alongside the reference gauge on a flat table. An optical flat is then placed on top of both gauges, A monochromatic light source is used and the fringe patterns are observed with the help of a magnifying glass. It can be seen from the figure that the optical flat makes inclinations of θ and θ' with the top surfaces of the two slip gauges. Ideally, the two angles should be the same.

However, in most cases, the angles are different by virtue of wear and tear of the surface of the slip gauge that is being inspected. This can easily be seen by looking at the fringe pattern that is formed on the two gauges, as seen from the magnified images. The fringes seen on both the gauges are parallel and same in number if both the surfaces are perfectly flat; otherwise, the number of fringes formed on the two gauges differs, based on the relationship between θ and θ'.

Now, let the number of fringes on the reference block be N over a width of l mm. If the distance between the two slip gauges is L and λ is the wavelength of the monochromatic light source, then the difference in height h is given by the following relation:

$h = \pi LN/2l$

This simple procedure can be employed to measure very small height differences in the range of 0.01–0.1 mm. The accuracy of this method depends on the accuracy of the surface plate and condition of the surfaces of the specimen on which the optical flat is resting.



Height measurement using an optical flat

2.17 INTERFEROMETERS

Interferometers are optical instruments that are used for very small linear measurements. They are used for verifying the accuracy of slip gauges and measuring flatness errors

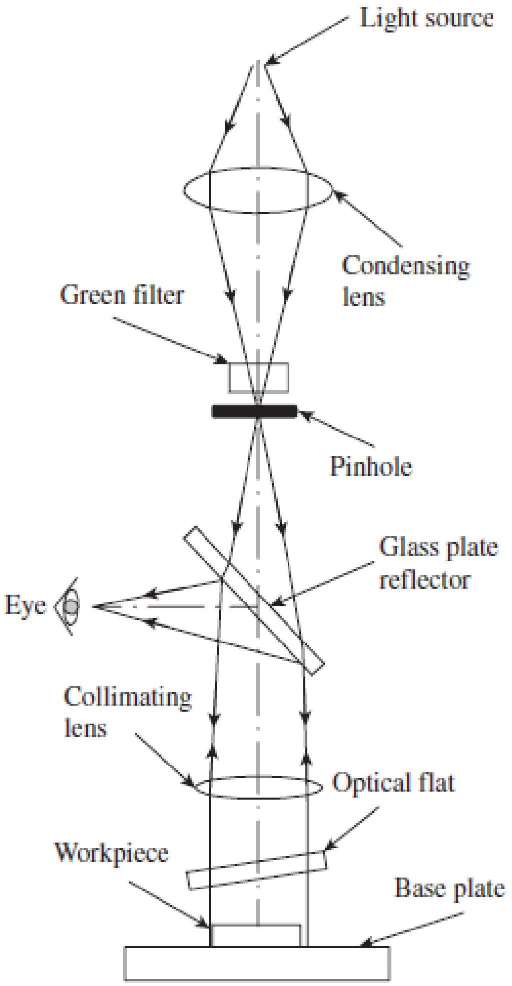
2.17.1 NPL Flatness Interferometer

This interferometer was designed and developed by the National Physical Laboratory of the United Kingdom. It comprises a simple optical system, which provides a sharp image of the fringes so that it is convenient for the user to view them. The light from a mercury vapour lam is condensed and passed through a green filter, resulting in a green monochromatic light source. The light will now pass through a pinhole, giving an intense point source of monochromatic light. The pinhole is positioned such that it is in the focal plane of a collimating lens. Therefore, the collimating lens projects a parallel beam of light onto the face of the gauge to be tested via an optical flat. This results in the formation of interference fringes. The light beam, which carries an image of the fringes, is reflected back and directed by 90° using a glass plate reflector.

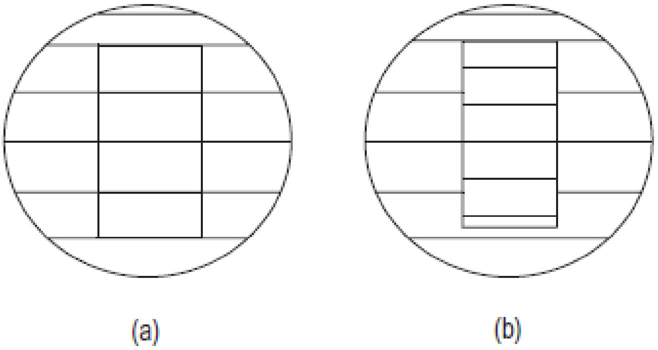
The entire optical system is enclosed in a metal or fiber glass body. It is provided with adjustments to vary the angle of the optical flat, which is mounted on an adjustable tripod. In addition, the base plate is designed to be rotated so that the fringes can be oriented to the best advantage.

Figure.(a), illustrates the fringe pattern that is typically observed on the gauge surface as well as the base plate. In Fig. (a), the fringes are parallel and equal in number on the two surfaces. That is, the two surfaces are parallel, which means that the gauge surface is perfectly flat. On the other hand, in Fig. (b), the number of fringes is unequal and, since the base plate surface is ensured to be perfectly flat, the work piece surface has a flatness error.

Due to the flatness error, the optical flat makes unequal angles with the work piece and the base plate, resulting in an unequal number of fringes. Most of the times fringes will not be parallel lines, but will curve out in a particular fashion depending on the extent of wear and tear of the upper surface of the work piece. In such cases, the fringe pattern gives a clue about the nature and direction of wear.



Optical system of an NPL flatness interferometer



Example of fringe patterns (a) Equal fringes on parallel surfaces (b) Unequal fringes due to flatness error

2.17.2 Pitter–NPL Gauge Interferometer

This interferometer is used for determining actual lengths of slip gauges. Since the measurement calls for a high degree of accuracy and precision, the instrument should be used under highly controlled physical conditions. It is recommended that the system be maintained at an ambient temperature of 20 °C, and a barometric pressure of 760 mmHg with a water vapour pressure of 7 mm, and contain 0.33% by volume of carbon dioxide.

The optical system of the Pitter–NPL interferometer is shown in Figure. Light from a monochromatic source (the preferred light source is a cadmium lamp) is condensed by a condensing lens and focused onto an illuminating aperture. This provides a concentrated light source at the focal point of a collimating lens. Thus, a parallel beam of light falls on a constant deviation prism. This prism splits the incident light into light rays of different wavelengths and hence different colours. The user can select a desired colour by varying the angle of the reflecting faces of the prism relative to the plane of the base plate. The prism turns the light by 90° and directs it onto the optical flat. The optical flat can be positioned at a desired angle by means of a simple arrangement. The slip gauge that is to be checked is kept right below the optical flat on top of the highly flat surface of the base plate. The lower portion of the optical flat is coated with a film of aluminium, which transmits and reflects equal proportions of the incident light. The light is reflected from three surfaces, namely the surface of the optical flat, the upper surface of the slip gauge, and the surface of the base plate.

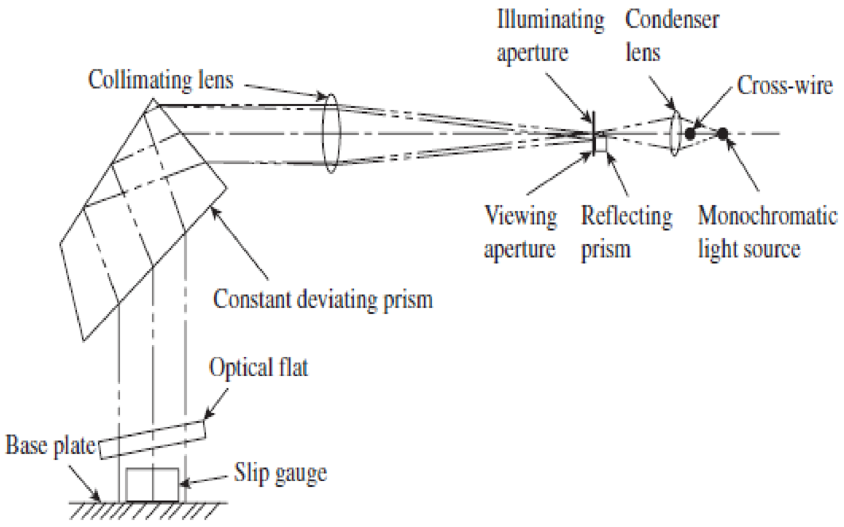
Light rays reflected from all the three surfaces pass through the optical system again; however, the axis is slightly deviated due to the inclination of the optical flat. This slightly shifted light is captured by another prism and turned by 90°, so that the fringe pattern can be observed and recorded by the user.

The typical fringe pattern observed is also shown in Figure. It can be seen that the two sets of fringes are displaced by an amount a with respect to each other. The value of 'a' varies depending on the colour of the incident light. The displacement 'a' is expressed as a fraction of the fringe spacing b, which is as follows:

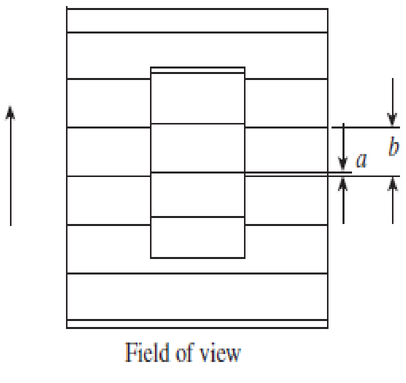
$$f = a/b$$

The height of the slip gauge will be equal to a whole number of half wavelengths, n, plus the fraction a/b of the half wavelengths of the radiation in which the fringes are observed.

Therefore, the height of the slip gauge, $H = n(\lambda/2) + (a/b) \times (\lambda/2)$, where n is the number of fringes on the slip gauge surface, λ is the wavelength of light, and a/b is the observed fraction.



Optical system of the Pitter–NPL gauge interferometer



Field of view of fringe pattern

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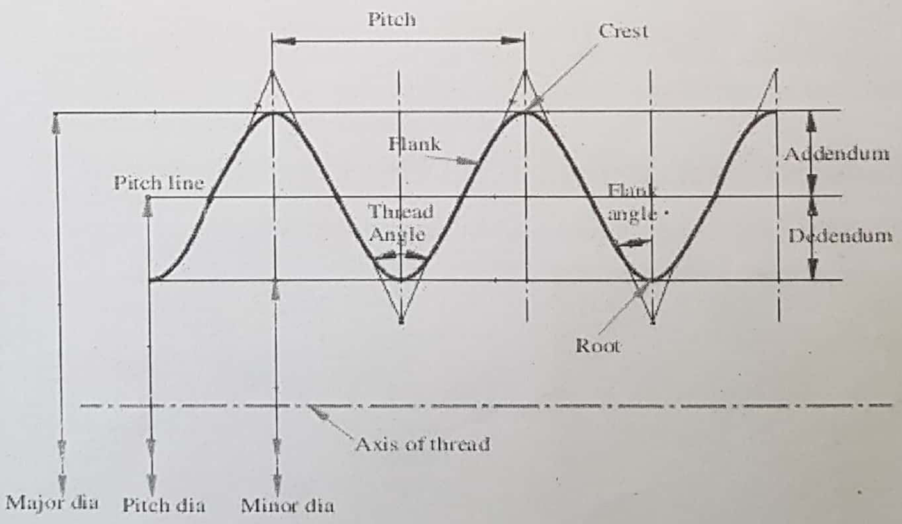
MODULE III

1. Screw thread measurement
    - Screw thread terminology
    - Measurement of major diameter – external and internal threads
    - Measurement of minor diameter – external and internal threads
    - Measurement of effective diameter – two and three wire method
    - Measurement of pitch
    - Measurement of flank angle and form – Tool maker's microscope and profile projector
2. Measurement of surface texture
    - Types of irregularities – First , second, third and fourth order
    - Roughness v/s waviness
    - Lay
    - Analysis of surface traces – Peak to valley height, RMS and CLA values
    - R_a, R_z and R_t values
    - Assessment length, evaluation length, sampling length, roughness width cut-off
    - Measurement by stylus probe, Tomlinson surface meter and Taylor Hobson Talysurf
    - Interference method for measuring surface roughness (discussed in Module I)
    - Autocollimator – principle, construction and application

SCREW THREAD TERMINOLOGIES



Axis of a thread: This is an imaginary line running longitudinally through the centre of the screw.

Crest: Crest of the thread is the top most surface joining the two sides.

Root: Root of the thread is the bottom of the groove between the two flanks.
Flank: Flank of thread are straight edges which connect the crest with the root of the thread.

Pitch: Pitch of a thread is the distance measured parallel to the axis from a point on a thread to the corresponding points on adjacent thread forms in the same axial plane and on the same side of the axis.

Depth of thread: Depth of a thread is the distance between the crest and root of the thread.

Major diameter: It is an imaginary largest diameter of the thread which would touch the crests of an internal or external thread.

Minor diameter: It is an imaginary smallest diameter of the thread which would touch the roots of an external thread.

Pitch/ Effective diameter: It is a theoretical diameter between the major and minor diameter of screw threads.

Flank angle: Flank angle is the angle made by the flank of a thread with the perpendicular to the axis of a thread.

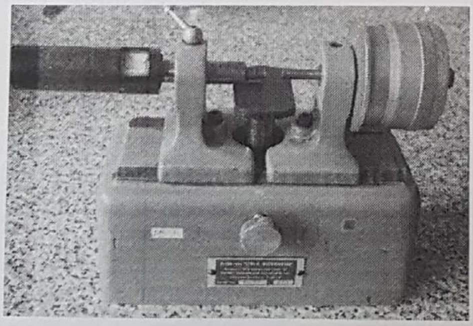
Thread angle: Thread angle is the angle between the flanks or slope of the thread measured in an axial plane.

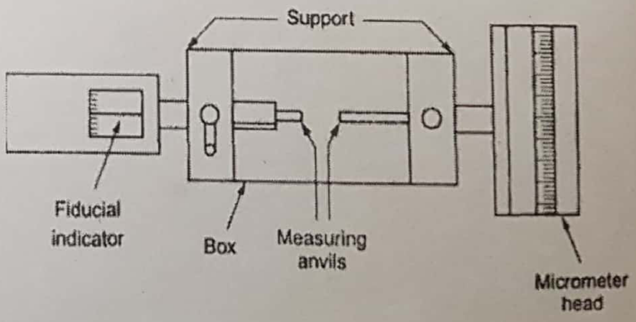
Lead: It is the distance the screw moves parallel to the screw axis when the screw is given one complete rotation.

Form of thread. This is the shape of the contour of one complete thread as seen in axial section.

MEASUREMENT OF MAJOR DIAMETER OF EXTERNAL THREAD

The major diameter of a screw thread can be determined by a bench micrometer.





A bench micrometer consists of two anvils, one is connected to fiducial indicator and another is connected to micrometer head. The fiducial indicator confirms the application of uniform and light pressure while adjusting the screw in between the two anvils. The micrometer gives the desired reading. Generally for finding the major diameter of a screw, a setting cylinder is used which a standard piece equal to the major diameter. It is used to avoid pitch and zero errors in a micrometer screw if any.

First, micrometer reading is taken for setting cylinder and the reading is assumed as R_1. Next, the micrometer reading is taken for required screw and the reading is assumed as R_2. The final measurement is obtained by the following formula without any errors.

Major diameter of thread = $D + (R_2 - R_1)$

D - Setting cylinder diameter
R_1 - Micrometer reading of setting cylinder
R_2 - Micrometer reading of screw thread

MEASUREMENT OF MAJOR DIAMETER OF INTERNAL THREAD

Measurement is done by first preparing the cast of the internal thread profile and following the same procedure as for the external threads.

For preparing the cast of the internal thread, the nut is fixed in between two wooden blocks with certain gap. Through this gap molten form of plaster of paris, wax or sulphur is poured into the nut. Before pouring the molten metal, the internal thread profile should be properly cleaned and brushed from all the dust with oil. After solidification remove the metal by lifting it up and then take the measurements.

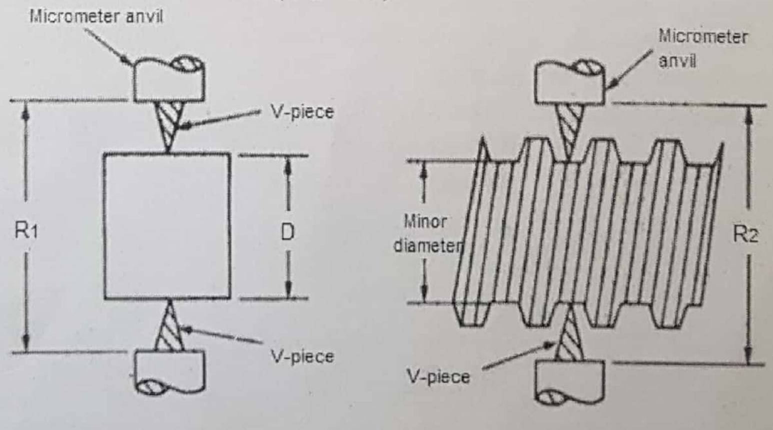
MEASUREMENT OF MINOR DIAMETER OF EXTERNAL THREAD

This is measured by a comparative process using V-pieces which make contact with the root of the thread. The included angle of V-pieces is less than the angle of the thread.

While taking readings, ensure that the micrometer be located at right angles to the axis of the screw being measured. The V-pieces are connected to the micrometer anvil and the diameter of the setting cylinder is measured by the micrometer. Next, the setting cylinder is replaced by the screw thread and the screw is adjusted in between the anvils such that the tip of V-pieces matches with the root of thread profile.

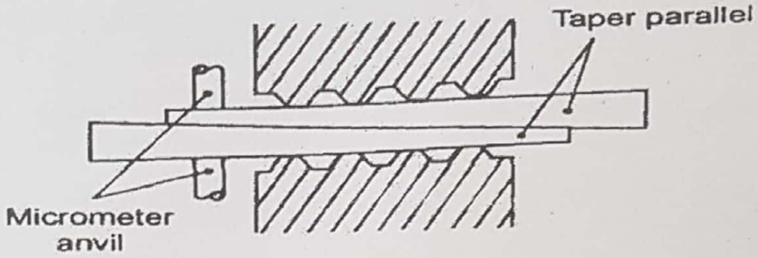
If the micrometer reading of setting cylinder with V-pieces in position is R_1 and reading of thread is R_2 and diameter of setting cylinder is D, then

Minor diameter = $D + (R_2 - R_1)$

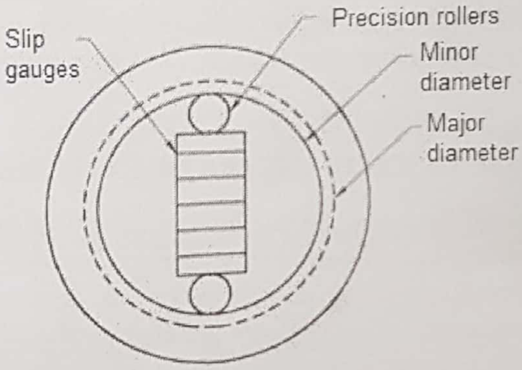


MEASUREMENT OF MINOR DIAMETER OF INTERNAL THREAD

For diameters less than 20 mm, taper parallels are used with micrometer. The taper parallels are pairs of wedges having parallel outer edges. The diameter across their outer edges can be changed by sliding them over each other. The taper parallels are inserted inside the thread and adjusted until firm contact is established with the minor diameter. The diameter over the outer edges is measured with a micrometer.



For threads bigger than 20 mm diameter, precision rollers are inserted inside the thread and proper slip gauge are inserted between the rollers so that firm contact is obtained. The minor diameter is then the length of slip gauges plus twice the diameter of rollers.



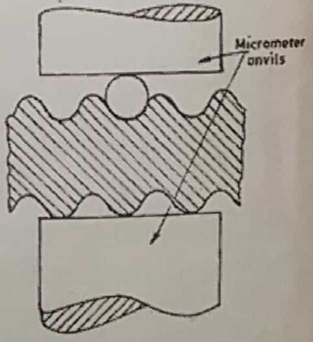
MEASUREMENT OF EFFECTIVE DIAMETER

a) One wire method – Only one wire is used. The wire is placed between two threads at one side and the anvil of the measuring micrometer contacts the crests on the other side. If D is the setting cylinder diameter, R_1 is the micrometer reading of setting cylinder and R_2 is the micrometer reading of screw thread, then

Effective diameter = $D \pm (R_1 - R_2)$

If $R_2 > R_1$, use +ve sign and

$R_2 < R_1$, use –ve sign



b) Two wire method – Two wires of same diameter are used. The wires are placed between two threads on both sides and the anvil of the measuring micrometer contacts the wire.

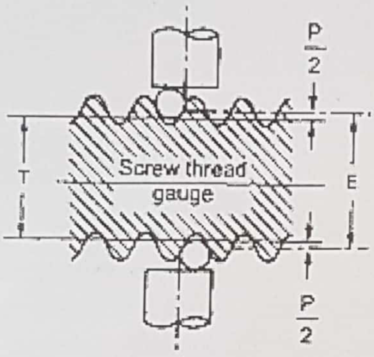
If S is the setting cylinder diameter, R_1 is the micrometer reading of setting cylinder and R_2 is the micrometer reading of screw thread, then

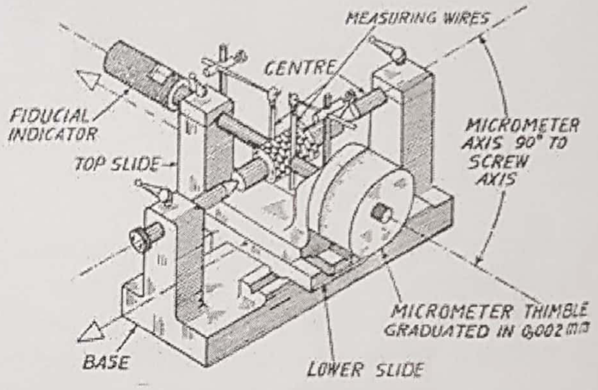
Diameter under the wires, $T = S - (R_1 - R_2)$

and, Effective diameter of the screw, $E = T + P$

where, P is a constant calculated for different threads depending upon diameter of the wire (d) and pitch of the thread (p).

For Whithworth threads, $P = 0.9605\,p - 1.1657\,d$ and Metric threads, $P = 0.866\,p - d$





For high accuracy measurement over wires by micrometer is not satisfactory, for which floating carriage machine is used. The machine ensures the axis of the micrometer is maintained at 90° to the axis of the screw under test. The lower slide moves parallel with the thread axis and top slide moves at 90° to the thread axis.

c) Three wire method – Three wires of same diameter are used. The wires are placed between two threads: one on one side and two on other side. This method ensures the alignment of micrometer anvil faced parallel to the thread axis.

The effective diameter of the screw can be calculated by the following elements:

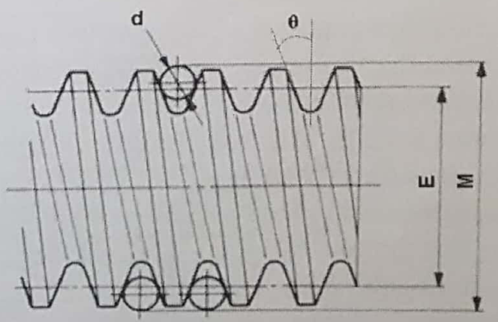
- Reading of the micrometer over the wire, M

  $M = E + Q$ (E – effective diameter; Q – constant depending upon wire diameter, d and flank angle, θ)

  $Q = d\,(1 + \operatorname{cosec}\theta) - p/2 \cot\theta$ (p – pitch of thread)

- Wire diameter, d
- Flank angle, θ

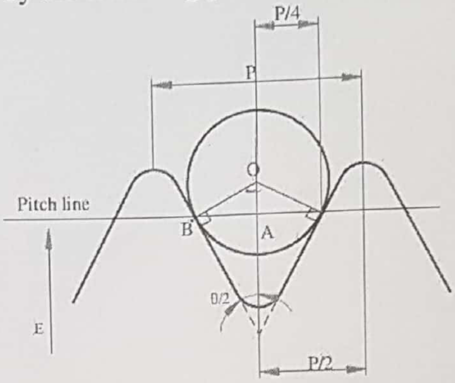
Therefore, effective diameter, $E = M - Q$



Determination of best wire diameter

Best wire size corresponds to that diameter of wire which makes contact with the flanks of the thread on the pitch line. For each pitch there is a best wire size.

Consider the wire makes contact with the flanks of the thread on the pitch line. The best diameter (D_b) is determined by the following procedure.



$$\text{In the triangle OAB, } \sin\left(B\hat{O}A\right)=\frac{AB}{OB}, \text{ or } \sin\left(90-\frac{\theta}{2}\right)=\frac{AB}{OB}$$

$$\therefore OB=\frac{AB}{\sin\left(90-\frac{\theta}{2}\right)}=\frac{AB}{\cos\frac{\theta}{2}}=AB\sec\frac{\theta}{2}.$$

$$\text{But } OB=\text{radius of wire}=\frac{1}{2}\times\text{dia of best size wire }(D_b)$$

$$\text{i.e. } D_b=2\times OB=2\times AB\sec\frac{\theta}{2}. \text{ Also since AB lies on the pitch line, } AB=\frac{P}{4}$$

where P is the pitch of the thread.

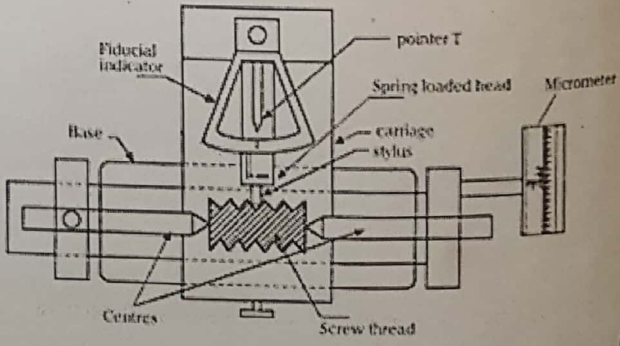
$$\therefore D_b=2\frac{P}{4}\sec\frac{\theta}{2}=\frac{P}{2}\sec\frac{\theta}{2}$$

MEASUREMENT OF PITCH

a) Pitch measuring machine (External thread)

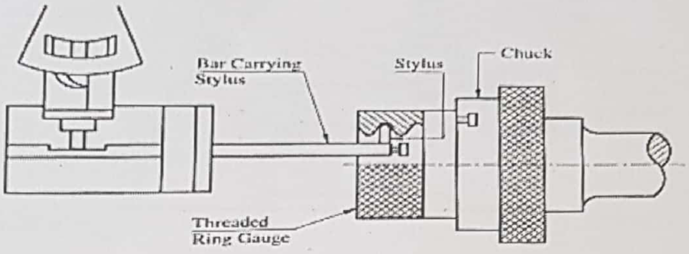
The threaded component is mounted between the centres of the pitch measuring machine. Then a stylus, of a size such that it contacts the thread flanks at points near the pitch line is inserted in the indicator frame. The stylus is moved along the screw parallel to the axis from one space to the next, which is measured on a micrometer. The stylus which is mounted on a leaf spring, moves up and down on each thread. The pointer of the indicator reads zero (it is adjusted to read zero in the first groove) when this stylus is in a central position in each successive thread. The micrometer reading is taken each time the indicator reads zero.

Accurate positioning of the stylus between the two flanks is obtained by ensuring that the pointer, T is always opposite to its index mark when reading is taken.



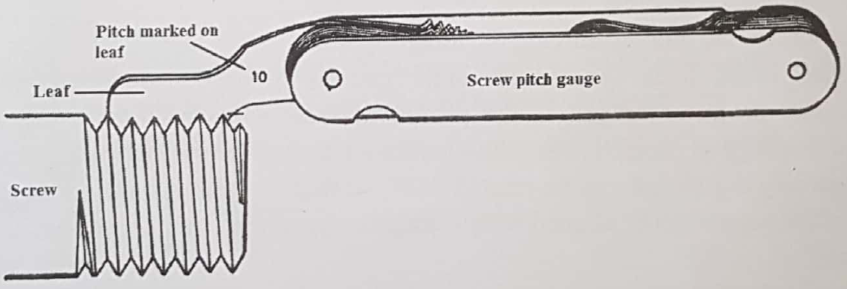
b) Pitch measuring machine (Internal thread)

A pitch measuring machine with an adaptor is used for measuring the pitch of internal threads. The adaptor carries a bar which can be inserted into the threaded hole. The stylus engages with the thread of the internal threaded component which is mounted on a face plate or chuck on the head stock of the machine.



c) Screw pitch gauge

To use the screw pitch gauge, first match the type of thread to the gauge. For example, attempting to measure metric threads with an imperial gauge will not return accurate results. Once the correct gauge is determined, extend one of the leaves of the gauge and press it against the threaded portion of the screw. If the teeth (cut into the leaf) match the spacing of the thread, read the thread pitch stamped on the leaf. If the fit is not good, try a different leaf.

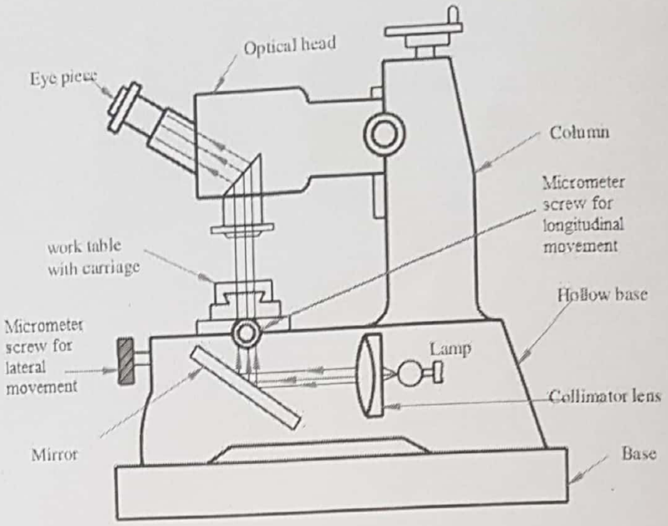


MEASUREMENT OF FLANK ANGLE AND FORM

a) Tool maker's microscope

The work piece is loaded on a glass plate on a table, which has a provision for translatory motion in two principal directions in the horizontal plane. Micrometers are provided for both X and Y axes to facilitate linear measurement to a high degree of accuracy. The entire optical system is housed in the optical head. The optical head can be moved up and down along a vertical supporting column and the image can be focused using the focusing knob. An angle dial built into the eyepiece portion allows easy angle measurement. A surface illuminator provides the required illumination of the object, so that a sharp and clear image can be obtained.

A horizontal beam of light from a light source is reflected from a mirror 90° towards the table. The light passes through the glass plate on which the screw is kept. A shadow image of the contour of the thread is obtained on the glass screen. Observations are taken through the eyepiece of the optical head.

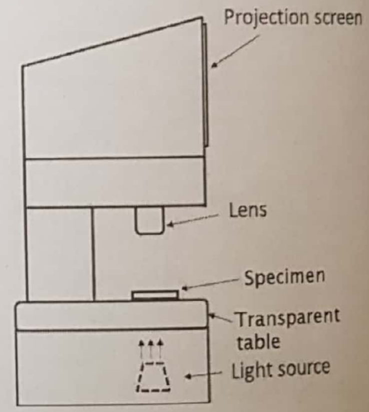


For measuring the thread angle, the screen is rotated until a line on the screen coincides with one flank of the thread profile. The angle of the screen is noted, and the screen is further rotated till the same line coincides with the adjacent flank. The difference in the angular readings gives the thread angle. Half of the thread angle equals the flank angle.

a) Profile projector

The image of the screw thread is obtained on the round glass screen and then by moving the image against the reference cross lines the thread angle can be measured. The projector magnifies the profile of the thread, and displays on projection screen. On this screen there is typically a grid that can be rotated 360°, so the X-Y axis of the screen can be aligned with a straight edge of the thread.

The flank of the thread is lined up with the grid on the screen. Angular measurements are taken directly by rotating the grid such that the adjacent edge of the flank is in line with the grid.



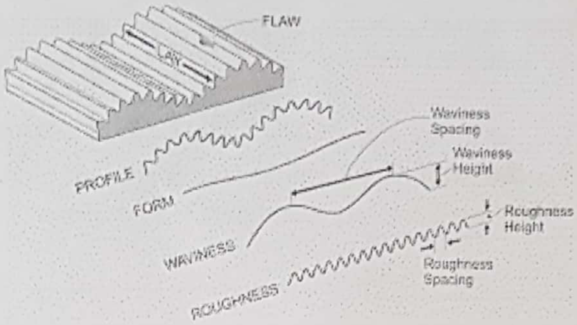
SURFACE TEXTURE

Repetitive and random deviations from the nominal surface which form the patterns on surface. It includes roughness, waviness and lay.

TYPES OF SURFACE IRREGULARITIES

- First Order - Arising due to inaccuracies in the machine itself such as lack of straightness of guideways, deformation of work under cutting forces, misalignments.
- Second order - Due to vibrations and chatter marks.
- Third order - Due to feed marks left by cutting tool.
- Fourth order - Due to rupture of the material during separation of the chip.

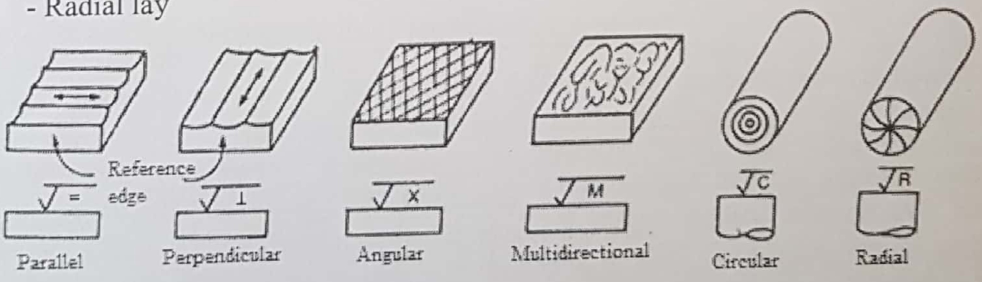
All the irregularities are grouped under two categories: Roughness and Waviness



Roughness	Waviness
Irregularities of small wavelengths	Irregularities of larger wavelengths
Caused by direct action of cutting element on material or by friction, wear and corrosion	Caused from mechanical disturbances and is periodic in character
Irregularities of third and fourth order belong to this category	Irregularities of first and second order belong to this category
Roughness width by height ratio < 50	Waviness width by height ratio <\> 50
E.g. – due to cutting tool shape, tool feed rate, feed marks	E.g. – wear of guides, inaccuracies in slides, misalignment of centres, vibrations

LAY - Direction of the predominant surface pattern produced by tool marks or scratches.

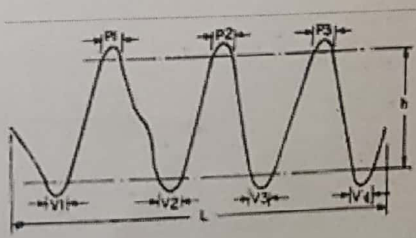
| | - Parallel lay (parallel shaping, end view of turning, slotting)
⊥ - Perpendicular lay (end view of shaping, longitudinal view of turning)
X - Angular lay (traversed end mill)
M - Multidirectional lay (lapping, honing, filing)
C - Circular lay (facing)
R - Radial lay



ANALYSIS OF SURFACE TRACES

a) Maximum peak to valley (PV) height

It is defined as the distance between a pair of lines running parallel to the general lay of the trace positioned such that the length lying within the peaks is 5% of the trace length, and that within the valleys is 10% of the trace length.

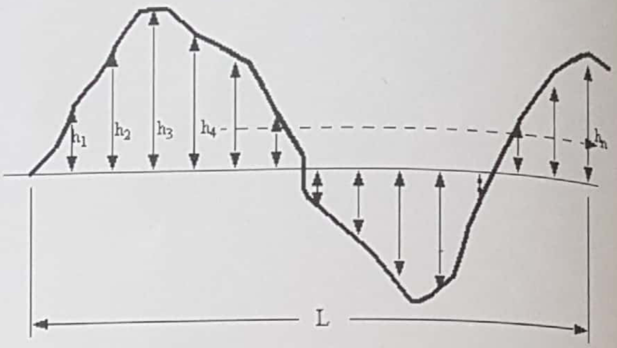


b) Root Mean Square (RMS) value

Defined as the square root of the means of the squares of the ordinates of the surface measured from a mean line.

If $h_1, h_2, h_3, \ldots\ldots, h_n$ are the heights of the ordinates within a sampling length (L), then,

$$\text{RMS value} = \sqrt{\frac{h_1^2 + h_2^2 + h_3^2 + \ldots\ldots + h_n^2}{n}}$$



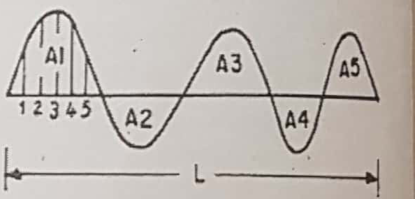
c) Centre Line Average (CLA) value

Defined as the average values of the ordinates from the mean line, regardless of the arithmetic signs of the ordinates.

$$\text{CLA value} = \frac{h_1 + h_2 + h_3 + \ldots\ldots + h_n}{n} \quad \text{(refer above figure)}$$

CLA value can also be determined by area under the profile.

$$\text{CLA value} = \frac{A_1 + A_2 + A_3 + \ldots\ldots + A_n}{L}$$

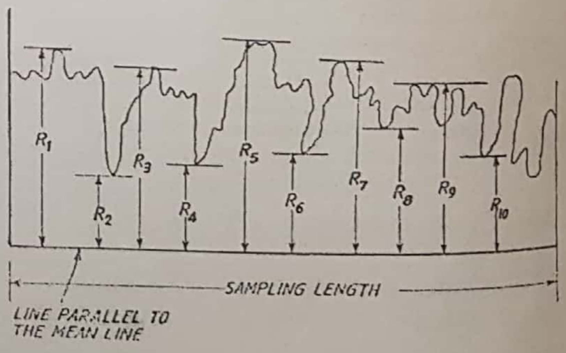


R_a, R_Z AND R_t VALUES OF SURFACE ROUGHNESS

R_a value corresponds to the arithmetical mean deviation from the mean line of the profile and is defined as the average value of the ordinates ($y_1, y_2, y_3, \ldots\ldots, y_n$) from the mean line.

$$R_a = \frac{y_1 + y_2 + y_3 + \ldots\ldots + y_n}{n} = \frac{1}{n}\int_0^l |y|\, dx \quad \text{(draw relevant figure)}$$

R_z value is defined as the average difference between the five highest peaks and the five deepest valleys within the sampling length measured from a line which is parallel to the mean line and not crossing the profile. It is called ten point height of irregularities.



$$R_z = \frac{(R_1 + R_3 + R_5 + R_7 + R_9) - (R_2 + R_4 + R_6 + R_8 + R_{10})}{5}$$

R_t value is the maximum peak to valley height within the sampling length.

ASSESSMENT LENGTH

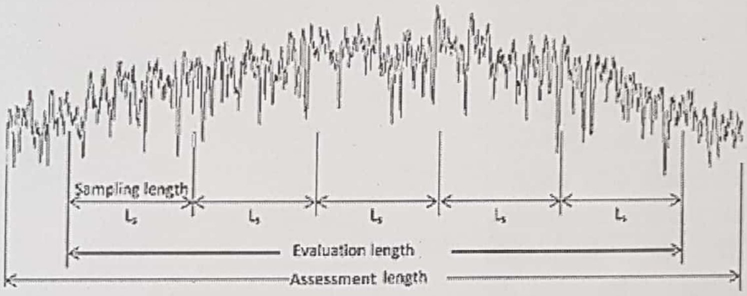
For measurement of surface roughness the whole surface texture need not be taken. The portion of the surface texture taken for surface analysis, which consists of waviness and roughness is called assessment length.

EVALUATION LENGTH

It is the length within the assessment length which is considered for the measurement of roughness parameters. It consists only roughness and not waviness.

SAMPLING LENGTH

The length of the effective profile selected for the evaluation of surface roughness within the evaluation length, without taking into account other types of irregularities. It is measured in a direction parallel to the general direction of the profile.



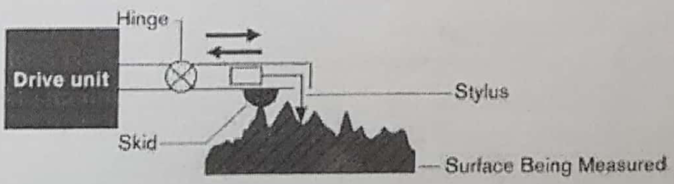
ROUGHNESS WIDTH CUTT-OFF

It is the maximum width of the surface irregularities that is included in the measurement of roughness height. Roughness heights have width above the cut-off value are neglected from the measurement.

SURFACE MEASUREMENT INSTRUMENTS

a) Stylus Probe – It consists of a stylus with a finely pointed diamond probe at its end. As the stylus is moved over the surface of the wok piece, the vertical movement of the stylus caused due to the irregularities is used to measure the surface finish of the work piece. The movement of the stylus is used to modulate a high frequency carrier current or to generate a voltage signal. The output is then amplified and recorded to produce a trace.

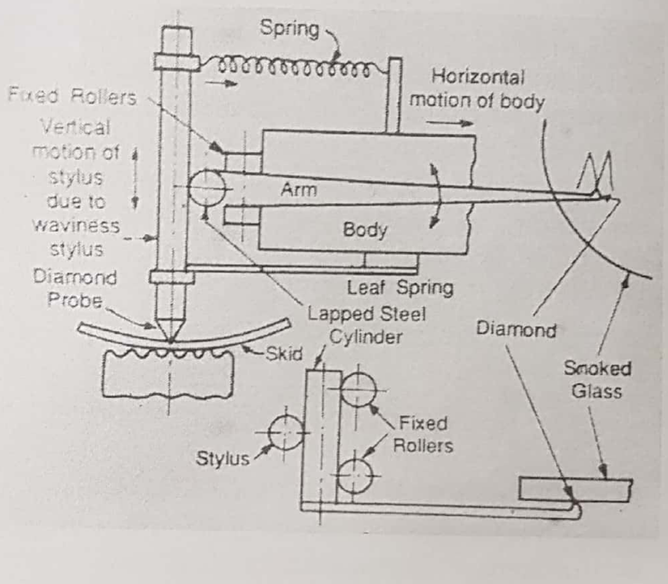
Stylus type instruments is provided with a skid or shoe which follows the general contours of the surface and provides a datum for measurement. The stylus moves over the surface with the skid.



b) Tomlinson Surface Meter

This instrument uses mechanical and optical means for magnification. The diamond stylus on the surface finish recorder is held by spring pressure against the surface of a lapped steel cylinder. The stylus is also attached to the body of the instrument by a leaf spring and its height is adjustable to enable the diamond to be positioned conveniently. The lapped cylinder is supported on one side by the stylus and on the other side by two fixed rollers. The tensile forces in these two springs keep the lapped steel cylinder in position between the stylus and a pair of fixed rollers. A light spring steel arm is attached to the horizontal lapped steel cylinder and it carries a diamond scriber at its tip which bears against a smoked glass.

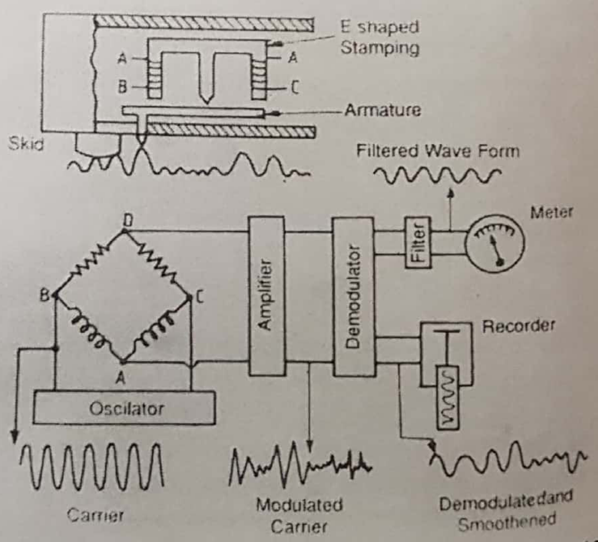
When measuring surface finish, body is moved across the surface by a synchronous motor. Any vertical movement of the stylus caused by the surface irregularities, causes the horizontal lapped steel cylinder to roll. By its rolling, the light arm attached to its end provides a magnified movement on a smoked glass plate. This vertical movement coupled with the horizontal movement produces a trace on the glass magnified in vertical direction. The smoked glass trace is then, further magnified by projecting on a screen.



c) Taylor – Hobson Talysurf

Talysurf is a stylus and skid type instrument used to measure the surface roughness by using carrier modulating principle. The measuring head consist of a sharply pointed diamond stylus of 0.002 mm tip radius. The skid is moved across the surface by means of a motorised driving unit. The stylus traces the profile of the surface and any deflections of a stylus is converted into electric current to identify the roughness measurements of the surface.

In this case the arm carrying the stylus forms an armature which pivots about the centre piece of E-shaped stamping. On two legs of the E-shaped stamping there are coils carrying an AC current. These two coils with other two resistances form an oscillator. As the armature is pivoted about the central leg, any movement of the stylus causes the air gap to vary and thus the amplitude of the original AC current flowing in the coils is



modulated. The output of the bridge thus consists of modulation only which is further demodulated so that the current is now directly proportional to the vertical displacement of the stylus. The demodulated output is caused to operate a pen recorder to produce a permanent record and a meter to give a numerical assessment directly.

AUTOCOLLIMATOR

Working principal – It is an optical instrument used to measure small angular differences. Applications include precision alignment, detection of angular movement and verification of angle standards.

It projects a beam of collimated light onto a reflector (place on the surface to be measured), which is deflected by a small angle about the vertical plane. The light reflected is magnified and focused on to an eyepiece or a photo detector. The deflection between the beam and the reflected beam is a measure of the angular tilt of the reflector. If the reflector is tilted by an angle θ, then the reflected beam deflects by an angle 2θ.

If rotation of the plane reflector by an angle θ results in the displacement of the image by an amount x, then, $x = 2f\theta$, where f is the focal length of the objective (collimator) lens.

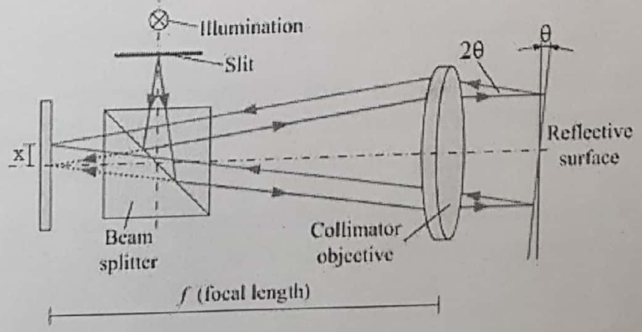
Construction and working – The main components of an autocollimator are:

- Collimator lens
- Beam splitter which contains two reticles
- Eyepiece
- Illumination device

The illuminated reticle projected over the beam splitter towards the lens is known as collimator reticle. The second reticle placed in the focus of the eyepiece is the eyepiece reticle.

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 beam of light. A flat reflector placed in front of the objective and exactly normal to the optical axis reflects the parallel beam of light back along their original paths. They are then brought to focus in the plane of the target graticule and exactly 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.

If the reflector is tilted through a small angle the reflected light will be deflected by twice the angle of tilt and will be brought to focus in the plane of the target graticule but linearly displaced from the actual target crosslines by an amount $x = 2f\theta$.



MODULE IV

1. Machine tool metrology
    - Alignment testing equipments
    - Alignment testing of lathe
    - Alignment testing of drilling machine
    - Alignment testing of milling machine

2. Laser interferometer

3. Coordinate Measuring Machine (CMM)
    - Construction and working
    - Types
    - Advantages
    - Applications
    - Types of CMM probes – contact and non-contact types

4. Machine vision
    - Steps
    - Functions
    - Advantages
    - Applications

EQUIPMENT FOR ALIGNMENT TESTING OF MACHINE TOOLS

- Dial indicator – to align work pieces in a machine and check spindle runout
- Test mandrels – for checking true running of spindles
- Straight edges and squares – for checking flatness/straightness and for testing squareness of two surfaces with each other
- Spirit level – for checking flatness and straightness
- Autocollimator – for checking deflections in horizontal, vertical or inclined planes

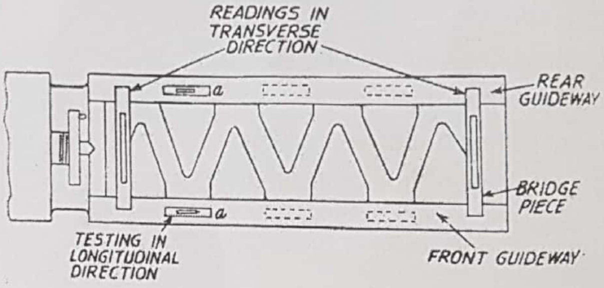
ALIGNMENT TESTING OF LATHE

a) Test for level of installation

Testing equipments – Spirit level, straight edges or autocollimator.

Purpose – If the lathe bed is not installed truly horizontal in longitudinal and transverse directions then the bed will undergo deflection and twist. Thus the movement of saddle cannot be in a straight line and true geometric cylinder cannot be generated.

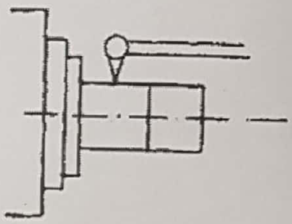
Procedure – The level of bed in longitudinal and transverse directions is tested by spirit level. The spirit level is placed on the bed in the longitudinal direction at one end and traversed along the length of the bed and readings are noted at various positions. For testing in transverse direction, the level is placed on a bridge piece to span the front and rear guideways.



b) True running of locating cylinder of main spindle

Testing equipment – Dial indicator

Purpose – To check true geometric cylindricality or roundness of spindle.

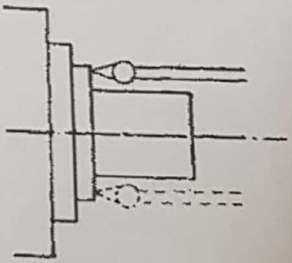


Procedure – A locating cylinder is provided to locate the chuck or face plate. The dial indicator is fixed to the carriage and the feeler of the indicator touches the locating cylinder surface. The surface is rotated on its axis and the indicator should not show any deflection of the needle.

c) Axial slip of spindle and true running of shoulder face of spindle nose

Testing equipment – Dial indicator

Purpose – To check axial slip, which is the axial spindle movement due to manufacturing errors and to check whether the face of the locating shoulder is in a plane perpendicular to the axis of rotation.

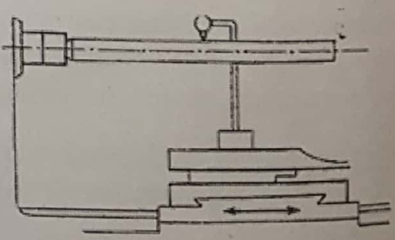


Procedure – The feeler of the dial indicator is made to touch the face of the locating spindle shoulder and the dial indicator is clamped on the bed. The locating cylinder is rotated and the change in reading is noted. The readings are taken at two diametrically opposite ends.

d) True running of taper socket in main spindle

Testing equipments – Test mandrel with taper shank and dial indicator

Purpose – If the axis of the tapered hole of the socket is not concentric with the main spindle axis, eccentric and tapered jobs will be produced.



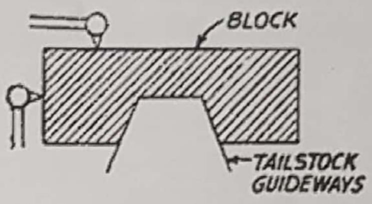
Procedure – The mandrel is held with its tapered shank in the headstock spindle socket. The dial indicator is mounted on the saddle and the feeler of the indicator is made to touch the mandrel. The saddle is then traversed along the bed and readings are taken at the two extreme ends of the mandrel.

e) Parallelism of tailstock guideways with the movement of carriage

Testing equipment – Dial indicator

Purpose – If the guideways are not parallel with the carriage movement there will be some offset of the tailstock centre which results in taper turning.

Procedure – To check the parallelism in both horizontal and vertical planes, a block is placed on the guideways and the feeler of the dial indicator is touched with the horizontal and vertical surfaces of the block. The carriage is then moved and any error is indicated by the pointer.



Other alignment tests include (refer textbook):

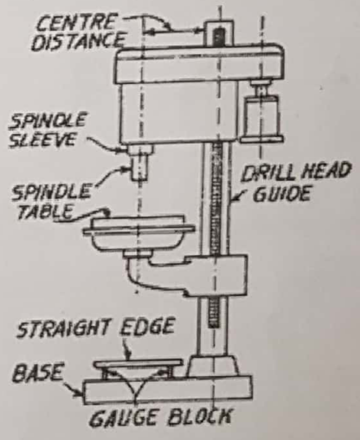
- Parallelism of the main spindle to saddle movement
- Parallelism of the tailstock sleeve to saddle movement
- True running of headstock centre
- Pitch accuracy of lead screw

ALIGNMENT TESTING OF DRILLING MACHINE

a) Flatness of clamping surface of table

Testing equipments – Straight edge, feeler gauge and gauge block (slip gauges)

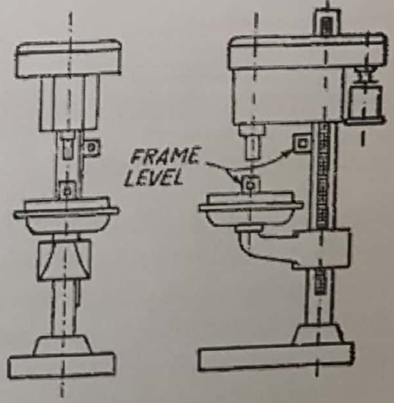
Procedure – First place the straight edge on two gauge blocks on the base in various positions and the error is noted by inserting the feeler gauge. The error should not exceed 0.1/1000 mm clamping surface.



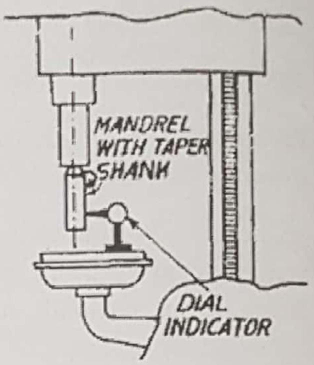
b) Perpendicularity of drill head guide with table

Testing equipments – Frame level

Procedure – Place the frame level on the guide column and table and the error is noted by noting the difference between the two readings of the levels. The error should not exceed 0.25/1000 mm guide column.



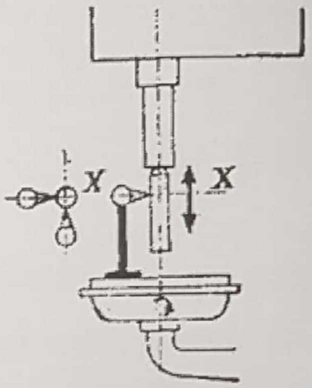
c) True running of spindle taper



Testing equipments – Mandrel and dial indicator

Procedure – The mandrel is placed in the tapered hole of the spindle. The dial indicator is mounted on the table and the feeler of the indicator is made to touch the mandrel. The spindle is rotated slowly and the readings are noted.

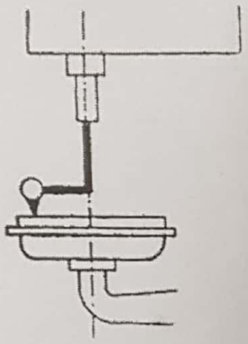
d) Parallelism of the spindle axis with its vertical movement



Testing equipments – Mandrel and dial indicator

Procedure – The test is performed at two planes right angles to each other. The mandrel is placed in the tapered hole of the spindle. The dial indicator is mounted on the table and the feeler of the indicator is made to touch the mandrel. The readings of the indicator are noted as the spindle is moved up and down from its middle position with slow vertical feed mechanism.

e) Squareness of spindle axis with table

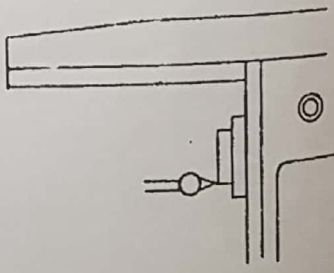


Testing equipments – Dial indicator

Procedure – The dial indicator is mounted in the tapered hole of the spindle and its feeler is made to touch the table surface. The table is slowly rotated and the readings are noted. The error should not exceed 0.05/300 mm diameter.

ALIGNMENT TESTING OF MILLING MACHINE

a) Cutter spindle axial slip

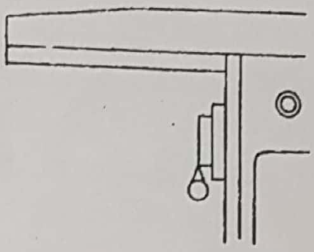


Testing equipment – Dial indicator

Procedure – Axial slip is the axial spindle movement due to manufacturing errors. The feeler of the dial indicator is made to touch the face of the locating spindle shoulder and the dial indicator is clamped on the table. The locating spindle shoulder is rotated and the change in reading is noted. The readings are taken at two diametrically opposite ends.

b) Eccentricity of external diameter

Testing equipment – Dial indicator

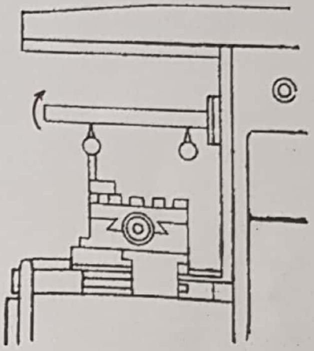


Purpose – If eccentricity is present vibrations are produced and the cutter will float sideways and cut over or under-size.

Procedure – The feeler is made to touch with the cylinder surface of the locating shoulder. The shoulder is rotated and any deviation in the reading is noted.

c) True running of internal taper

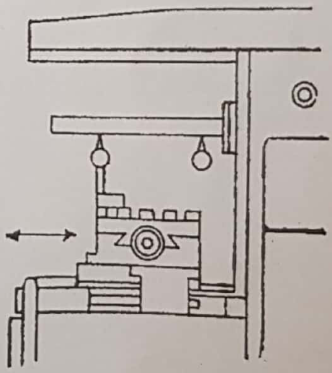
Test equipments – Mandrel and dial indicator



Procedure – The mandrel is held with its tapered shank in the spindle socket. The dial indicator is mounted on the table and the feeler of the indicator is made to touch the lower surface of mandrel. The mandrel is then turned and the indicator readings are taken at the two extreme ends of the mandrel.

d) Table surface parallel with arbor rising towards overarm

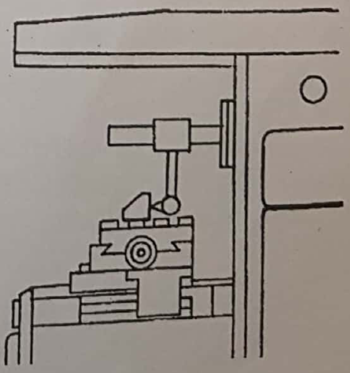
Test equipments – Mandrel and dial indicator



Procedure – The mandrel is held with its tapered shank in the spindle socket. The dial indicator is mounted on the table and the feeler of the indicator is made to touch the lower surface of mandrel. The mandrel is kept stationary and the indicator readings at the maximum travel of the table surface are observed.

e) Central T-slots parallel with longitudinal movement

Test equipments – Bracket with tennon and dial indicator



Purpose – The depth of cut will not remain constant as the job will be inclined according to the inclination of the T-slots with longitudinal movement.

Procedure – The tennon of the bracket enters the T-slot and the feeler of the dial indicator is located against the vertical face of the bracket. The dial indicator is fixed to the spindle and the table is moved longitudinally with the tennon block held stationary. The deviations in parallelism are noted from the indicator.

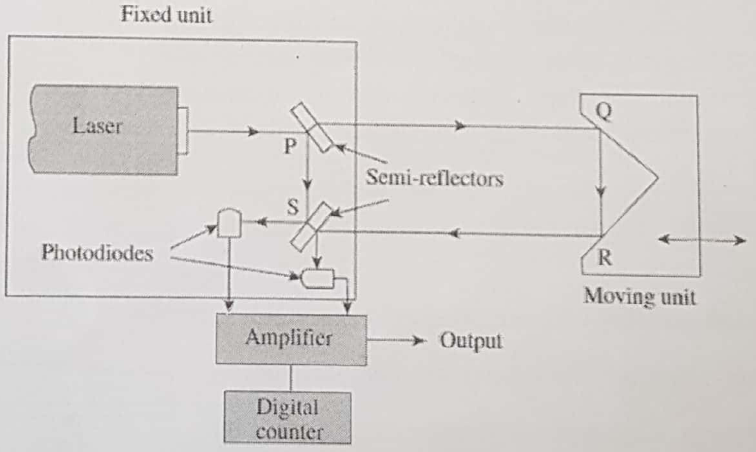
LASER INTERFEROMETER

In laser interferometry, laser light exhibits properties similar to that of a normal light. It can be represented by a sine wave whose amplitude is a measure of the intensity of the laser light. Laser interferometry can be used for measurements of small diameters as well as large displacements.

Construction – The fixed unit called the laser head consists of laser, a pair of semi-reflectors, and two photodiodes. The sliding unit has a corner cube mounted on it. The corner cube is a glass disc whose back surface has three polished faces that are mutually at right angles to each other. The corner cube will thus reflect light at an angle of 180°, regardless of the angle at which light is incident on it. The photodiodes will electronically measure the fringe intensity and provide an accurate means for measuring displacement.

Working – Laser light first falls on the semi-reflector P, is partially reflected by 90° and falls on the other reflector S. A portion of light passes through P and strikes the corner cube. Light is turned through 180° by the corner cube and recombines at the semi-reflector S. If the difference between these two paths of light (PQRS – PS) is an odd number of half wavelengths, then interference will occur at S and the diode output will be at a minimum. On the other hand, if the path difference is an even number of half wavelengths, then the photodiodes will register maximum output.

Each time the moving slide is displaced by a quarter wavelength, the path difference (i.e., PQRS – PS) becomes half a wavelength and the output from the photodiode also changes from maximum to minimum or vice versa. This sinusoidal output from the photodiode is amplified and fed to a high-speed counter, which is calibrated to give the displacement in terms of millimetres. The purpose of using a second photodiode is to sense the direction of movement of the slide.

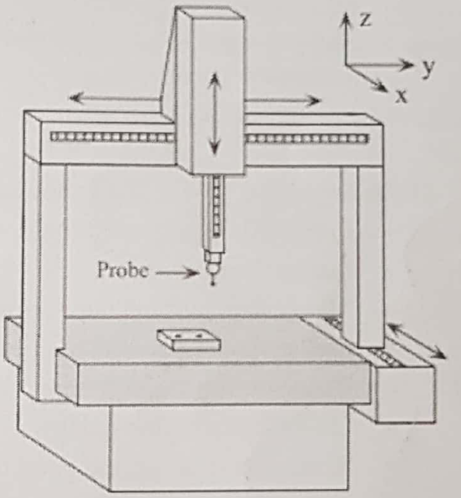


Laser interferometers are used to calibrate machine tables, slides, and axis movements of coordinate measuring machines. The equipment is portable and provides a very high degree of accuracy and precision.

COORDINATE MEASURING MACHINE (CMM)

CMM is a device that measures the geometry of work piece by sensing discrete points on the surface of the work piece with a probe. CMMs specify a probe's position in terms of its displacement from a reference position in three-dimensional Cartesian coordinate system (x-y-z axes).

Construction and working – CMM consists of three main components: the machine body, the measuring probe, and the computing system with appropriate measuring software. Each slide in the three directions is equipped with a precision linear measurement transducer. The transducer gives digital display and senses +ve and –ve directions. The measuring head incorporates probe tip, like taper tip, ball tip, etc.

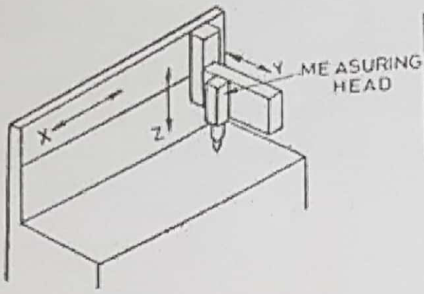


For measuring the distance between two holes, the work piece is clamped to the worktable and aligned with the slides in the three mutually perpendicular directions. The tapered probe tip is then seated in the first datum hole and the probe position is set to zero. The probe is then moved to successive holes, at each of which the reading representing the coordinates are taken with respect to the datum hole.

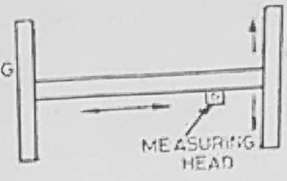
In special CMMs, both linear and rotary axes are incorporated which can measure various features of parts such as cones, cylinders and spheres.

Types of CMM –

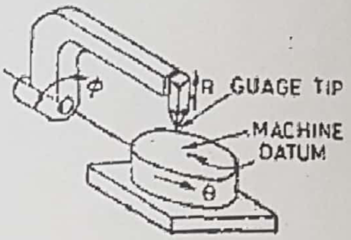
- Cantilever type - It is easiest to load and unload, but is most susceptible to mechanical error because of sag or deflection in y-axis beam.
- Bridge type – It is more difficult to load but less sensitive to mechanical errors.
- Horizontal bore mill – Best suited for large heavy work pieces.
- Vertical bore mill – Highly accurate but usually slower to operate.
- Floating bridge type – In this the complete bridge can slide in y-direction on the slides. It has the compromises of both cantilever and bridge type, and is thus fast to operate, simple in alignment, and rugged construction affords consistent accuracy.
- Spherical coordinate measuring machine – These machines have motions of their measuring head in R, θ and Ø directions and are used for inspecting parts that are basically spherical.



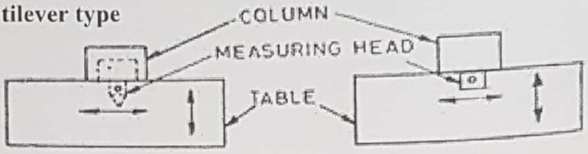
Cantilever type



Bridge type



Spherical type



Horizontal bore mill

Vertical bore mill

Advantages of CMM – The various advantages of CMM are:

- Increased inspection throughput (faster rate of production)
- Improved accuracy
- Minimisation of operator error
- Reduced operator skill requirements
- Reduced inspection fixtures and maintenance costs
- Uniform inspection quality
- Reduction of scrap and good part rejection
- No need of separate GO/NO-GO gauges for each feature
- Reduction in set-up time through automatic compensation for misalignment
- Reduction of total inspection time through use of statistical and data analysis techniques.

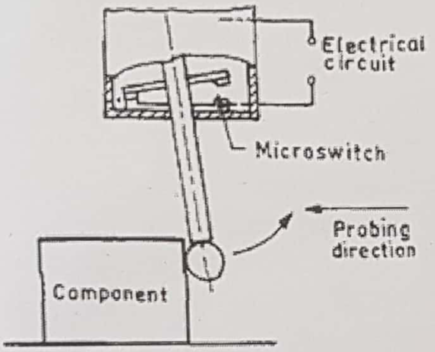
Applications of CMM – The various applications of CMM are:

- CMMs find applications in automobile, machine tool, electronics and space industries.
- CMMs are used for the development of new products and construction of prototype because of their maximum accuracy, universality and ease of operation.
- Because of high speed of inspection, precision and reproducibility, CMMs find application to check the dimensional accuracy of NC produced work piece in various steps of production.
- For safety components as for aircraft and space vehicles, inspection is carried out and documented using CMM.
- CMMs are best suited for the testing and inspection of test equipment, gauges and tools.
- CMMs are ideal for determination of shape and position, maximum metal condition, linkage of results, etc., which other conventional machines can't do.
- CMMs can also be used for sorting tasks to achieve optimum pairing of components within tolerance limits.
- CMM can replace several single purpose equipment with a low degree of utilisation like gear tester, gauge tester, length measuring machine, measuring microscope, etc.

- CMMs are also best for ensuring economic viability of NC machines by reducing their downtime for inspection results. They also help in reducing reject costs, rework costs through measurement at the appropriate time.

Types of CMM probes – CMM probes are basically classified into contact and non-contact types. Contact type include trigger type and measuring type probes, whereas non-contact type are proximity probes.

a) Trigger type probe – The buckling mechanism is a three point bearing, the contacts of which are arranged at 120° around the circumference. These contacts act as electrical micro switches. When being touched in any probing direction one or more contacts is lifted off and the current is broken, thus generating a pulse. When the circuit is opened, the current coordinate positions are read and stored. After probing, a pre-stressed spring ensures the perfect zero position of the three point bearing.

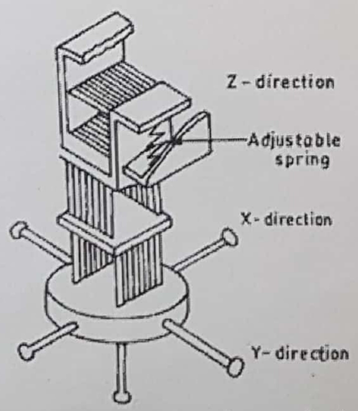


Trigger type probe head

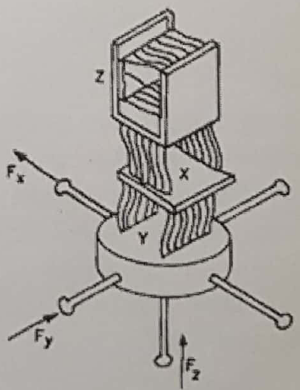
Outline of probe head

b) Measuring type probe – The buckling mechanism of this system consists of parallel guideways. At the moment of probing, the spring parallelograms are deflected from their initial position. Since the entire system is free from torsion, play and friction, a defined parallel displacement of probes as compared to their original arrangements can be measured.

In static operation, the electronic position regulating mechanism on probing of the specimen moves the slide of the probe axes till the inductive measuring systems of the probes are in their corresponding zero positions. After this, the machine coordinates are automatically transferred to the computer.



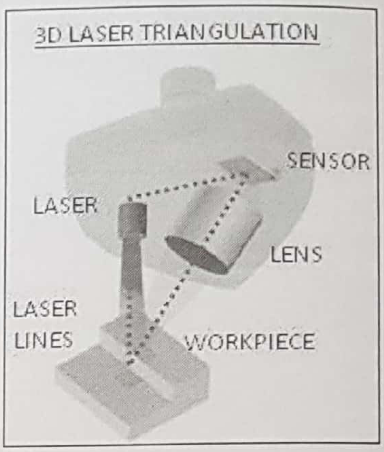
Schematic of measuring probe head



Displacement of parallelogram when probing

c) Non-contact type probes – In this type, a beam of light operating as an optical switch contacts the work piece. The non-contact probe is permanently set to a specific stand-off distance at which the light beam is triggered and measurements are taken. Because the probe never comes into contact with the work piece surface, damage is eliminated, and measurement speed is greatly improved.

Laser probes project a laser beam onto the surface of the part, the position of which is then read by triangulation through a lens in the probe receptor. Laser probe triangulation provides the actual position of the feature on the work piece being measured. When laser light is projected onto an object, the light becomes deformed by the height contours of the object. A camera senses these deformations and a computer interprets this as height information.



Vision probes are another form of non-contact sensing and are especially useful where very high-speed inspection or measurement is required. The part is not measured directly. Essentially, a picture of the part is electronically digitized, creating accurate dimensions of work piece features that are measured and evaluated.

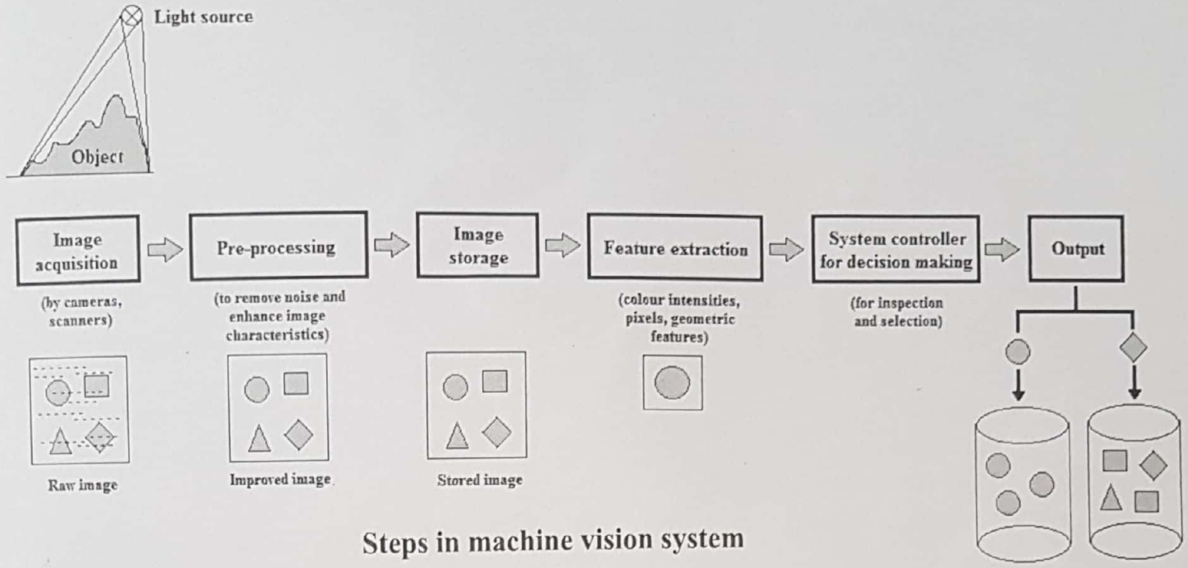
The camera used in vision systems generates a number of measurement points within a single video frame. The features of the image of the work piece are measured in comparison with various electronic models by counting the pixels of the electronic image. From this comparison, the true nature of the work piece being inspected can be inferred.

MACHINE VISION SYSTEM

It is a technique which allows a sensor to view a scene and derive a numerical decision without further human intervention. The principle is based on digital image processing using a TV camera. Machine vision is used to provide imaging-based automatic inspection in automatic inspection, process control and robot guidance.

Steps in Machine vision system –

- The first step in the automatic inspection sequence of operation is acquisition of an image, typically using cameras, lenses, and lighting. If a product is passing by a sensor, the sensor will trigger a camera to capture the image, and a light source to highlight key features.
- Next, a digitizing device takes the camera's image and translates it into digital output, which is then stored in computer memory and processed by software. In order to process an image, the image is reduced in gradation to a simple black and white format.
- The image is then analyzed by system software to identify defects and proper components based on predetermined criteria.
- After this, the product will either pass or fail inspection based on the machine vision system's findings.



Steps in machine vision system

The amount of information which can be extracted from the image depends on two factors: the number of picture elements in the grid (pixels) and intensity resolution (brightness). Various types of image acquisition systems for different resolutions include thermionic TV camera, solid state two-dimensional array camera and linear array camera.

- Thermionic TV cameras are best to distinguish small changes of tone even though they have problem of drifting under the influence of electromagnetic fields.
- Solid state cameras consist of an array of light-sensitive cells fabricated into a single silicon chip. They retain spatial relationship between pixels more accurately.
- Linear array type solid state cameras have higher resolutions and are used in high precision dimensional checking.

The various machine vision systems are binary vision, grey-scale vision and three-dimensional vision.

- Binary vision produces a black and white image and is used for location and shape analysis of flat objects. The binary image can produce a skeleton of the object which can be analysed to identify links, nodes and end points.
- In grey-scale vision, two-dimensional digital processing are used which includes contrast enhancements, edge enhancements and texture analysis.
- The three-dimensional system uses triangulation principle. When a light pattern (dots, bars or grids) is projected onto an object, the pattern becomes deformed by the height contours of the object. A camera senses these deformations and a computer interprets this as height information.

Advantages of machine vision system –

- Validation of component orientation and alignment produces high quality products and reduces the risk of failure.
- Helps to eliminate the risk of misassembled products and rejected parts through detailed inspection.
- Highly reproducible measurements can be obtained.
- Reduced amount of labour – low production costs.

- Less machine downtime and setup time – high speed production and inspection.
- Can perform assembly, test and inspection by reducing floor space.

Application of machine vision system –

- Used for checking dimensions, overall shape conformity and surface finish.
- Large-scale industries employ machine vision systems for inspection of products at various stages in the process.
- Helps in guidance, allowing a robot to locate the part or the machine to align the part such as arranging parts on or off pallets, packaging parts off a conveyor belt, finding and aligning parts for assembly or placing parts on a work shelf.
- Food and beverage industry uses machine vision systems to monitor quality.
- In the medical field, machine vision systems are applied in medical imaging as well as in examination procedures.
- A machine vision system for gauging calculates the distances between two or more points or geometrical locations on an object and determines whether these measurements meet specifications.

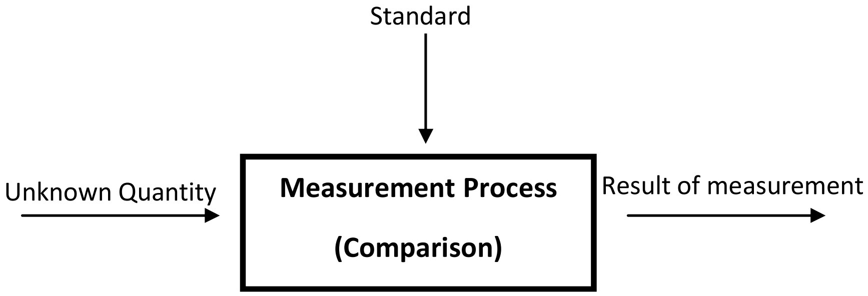
METROLOGY AND INSTRUMENTATION ME312

Module 5

- ✓ Introduction to Mechanical Measurement – significance of mechanical measurement; Fundamental methods of measurement; Classification of measuring instrument.
- ✓ Stages in generalized measuring system – Sensor-Transducer stage, Signal-Conditioning stage, Readout-Recording stage; Types of input quantities; Active and Passive transducers.
- ✓ Performance characteristic of measuring devices – Static characteristics – Accuracy, Precision, Repeatability, Sensitivity, Reproducibility, Drift, Resolution, Threshold, Hysteresis, Static calibration.
- ✓ Dynamic characteristics- different order systems and their response-, Measuring lag, Fidelity, Dynamic error; Types of errors in measurement.
- ✓ Transducers – Working, Classification of transducers.
- ✓ Motion and Dimension measurement – LVDT – Principle, applications, advantages and limitations.

Mechanical Measurement

- Measurement is the process of assigning a number to any parameter. Parameter can be any feature surrounding us, like temperature, displacement, pressure, etc.
- Measurement is defined as the quantification of a physical variable using a measuring device
- During the process of measurement, a specific value is assigned to the unknown quantity after due comparison with a predefined standard



✓ **Measurement Process**

✓ For measurement to be acceptable, the following criterions must be met:
  - ✓ The standard used for comparison must be accurately defined
  - ✓ The instrument used & method adopted must be provable
  - ✓ The numerical measure should be followed by the unit used

- Mechanical measurements come across
  - ✓ Velocity
  - ✓ Acceleration
  - ✓ Force
  - ✓ Torque
  - ✓ Flow
  - ✓ Pressure etc…

- In order to differentiate the field of measurements that pertain only to mechanical engineering we call it as mechanical measurement.

Significance of Mechanical Measurements

- Measurement is used to evaluate the performance of any plant or process. In modern power plants temperature, pressure, vibrational amplitudes, etc. must be constantly monitored by the measurement to ensure proper performance of the system
- Basis for the commercial activities such as production, pricing, sales & purchase
- Verification of physical phenomenon & theories requires an extensive experimentation of the measurement
- Establishes validity of design & it determines data for new & improves design
- Measurement id fundamental element of any automatic control system. In control system the error b/w the actual & described value of a variable is to be determined
- Provides fundamental basis for research & development

Methods of Measurement

Direct method

- This is a simple method of measurement, in which the value of the quantity to be measured is obtained directly without any calculations.
- The parameter is directly compared to a standard with help of calibrated systems.
- E.g. - measurements by using scales, vernier calipers, micrometers, bevel protector etc.
- Most widely used in production
- This method is not very accurate because it depends on human judgment.

Indirect method

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

Comparative method

- In this method the value of the quantity to be measured is compared with known value of the same quantity.
- So, in this method only the deviations from a master gauge are determined.
- E.g., dial indicators, or other comparators

Coincidence method

- It is a differential method of measurement, in which a very small difference between the value of the quantity to be measured and the reference is determined by the observation of the coincidence of certain lines or signals.
- E.g. - measurement by vernier caliper, micrometer.

Deflection method

- In this method the value of the quantity to be measured is directly indicated by a deflection of a pointer on a calibrated scale.
- E.g. – Pressure measurement using gauges

Contact method

- In this method the sensor or measuring tip of the instrument actually touches the surface to be measured.
- E.g. - measurements by micrometer, vernier caliper, dial indicators etc.

Contactless method

- In contactless method of measurement, the there is no direct contact with the surface to be measured.
- E.g. - measurement by optical instruments, such as tool makers' microscope, projection comparator.

Composite method

- The actual contour of a component to be checked is compared with its maximum and minimum tolerance limits.
- This method is very reliable to ensure interchangeability and is usually effected through the use of composite GO – NO GO gauges.

Transposition Method

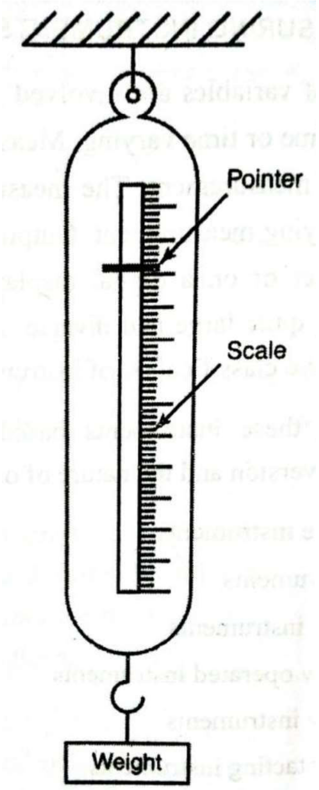
- This method involves making the measurement by direct comparison wherein the quantity to be measured (V) is initially balanced by a known value (X) of the same quantity;
- Next, X is replaced by the quantity to be measured and balanced again by another known value (Y).
- When balance indicating device gives same indication in both cases, the value of the quantity to be measured is:-

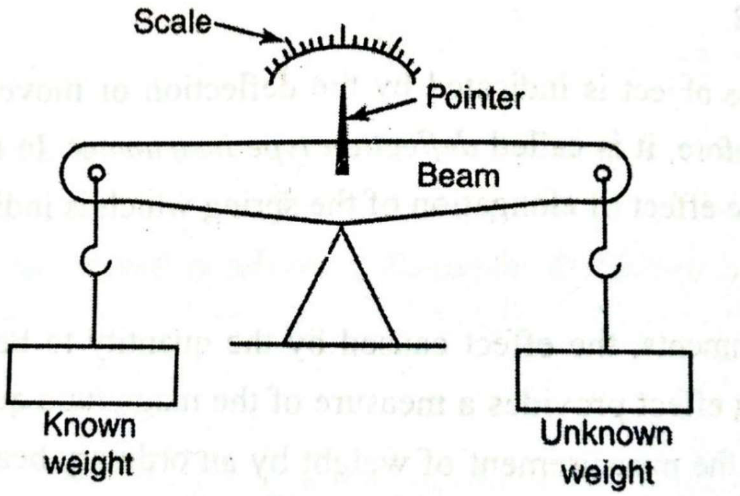
$$V = \sqrt{XY}$$

- E.g.- Determination of mass by balance & known weights

Null & deflection type

- In a deflection type instrument, the measured quantity generates some effect which can be ultimately related by the deflection of a pointer / display as a number, to its magnitude.
- E.g. - spring balance: The weight of the object is indicated by the deflection / movement of a pointer on a graduated scale. The weight of the object generates the effect of elongation of the spring which is indicated by a pointer on a scale.
- In null type instrument, the effect caused by the quantity to be measured is nullified. The required nullifying effect provides a measure of the magnitude of the quantity being measured.
- E.g. consider the measurement of weight by an ordinary beam balance.
- The unknown weight placed on one side causes the beam & pointer to deflect. Weights of known value are placed on the other side till a balanced or null condition is indicated by the pointer.
- Null type of instrument we avoid losses due to friction or movement of the parts. So they tend to be more accurate.
- But from user point of view, deflection type instruments are more convenient to use.
- If the signal is dynamic in nature it is difficult to measure with null type of instrument. Deflection type instruments are preferred.





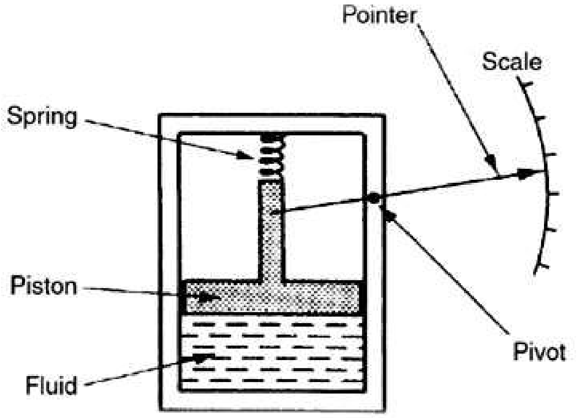
Analog & digital

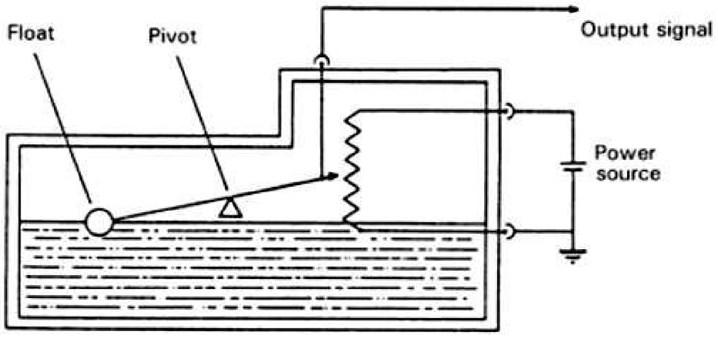
- The analog instruments give the output which varies in continuous manner
- E.g.: If voltmeter is connected to the circuit the needle of the voltmeter will continuously move & attain some position to give the voltage in the circuit.
- The digital instruments give the output which varies in discrete steps & can take only finite number of values in a given range. The output of digital instruments is generally displayed numerically as digits.
- High accuracy is given by analog type because they give continuous output
- Digital signals are important because all the data can be stored conveniently in computer system.

Active & Passive

- In passive instruments the output is produced entirely by the quantity being measured
- The act of measurement does not require external power source
  - ✓ An example of a passive instrument is the pressure measuring device
  - ✓ The pressure of the fluid is translated into a movement of a pointer against a scale.
  - ✓ The energy expended in moving the pointer is derived entirely from the change in pressure measured: there are no other energy inputs to the system.

- In active instruments the quantity being measured activates or modulates the magnitude of some external power input source which in turn produces the measurement.
- External power input source is present apart from the quantity to be measured.
  - ✓ An example of an active instrument is a float-type petrol tank level indicator
  - ✓ Here, the change in petrol level moves a potentiometer arm
  - ✓ The energy in the output signal comes from the external power source
  - ✓ Primary transducer float system modulates the value of the voltage from this external power source





Manually operated & automatic instruments

- With development of computers, PLC's and modern electronic devices there is a shift from manually operated instruments to mechanical instruments.
- But importance of manually operated instruments cannot be denied.
- Manually operated instruments require the services of a human operator.
- If some auxiliary devices are incorporated in the instrument to dispense with the human operator it is termed as automatic instruments.

Absolute & Manually Operated Instruments

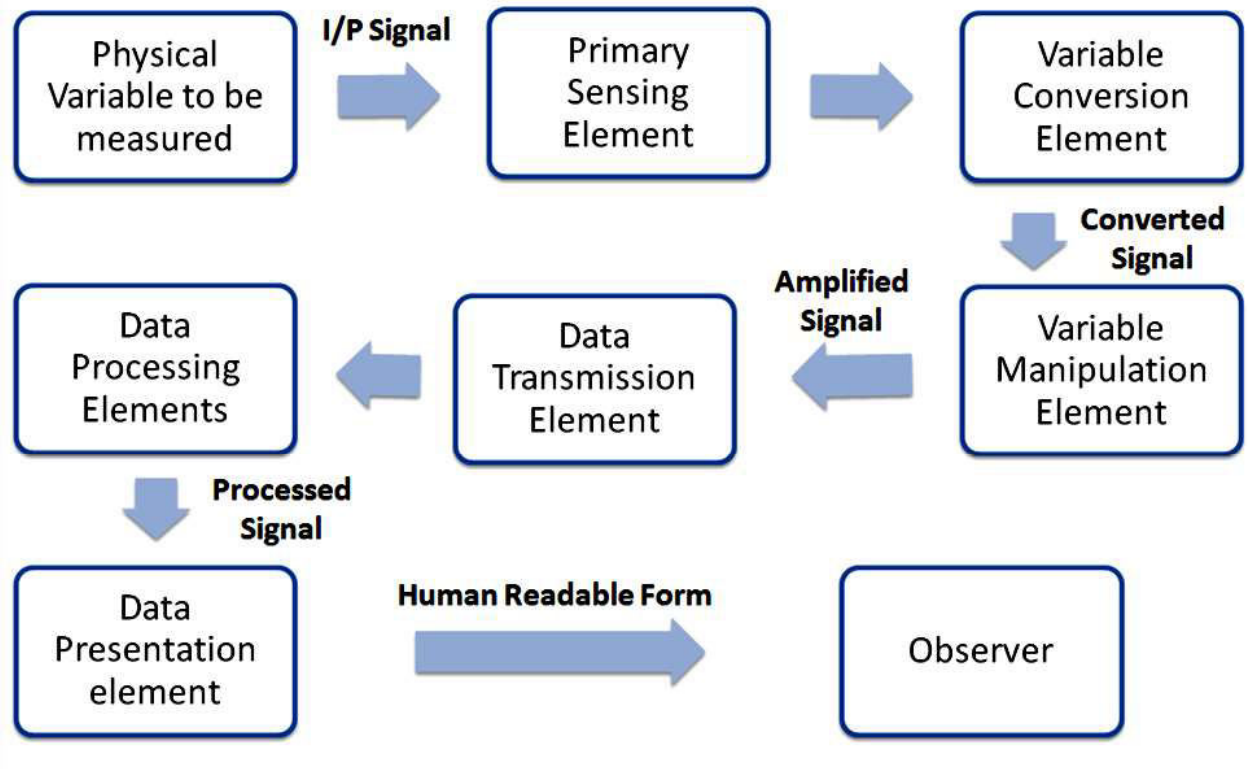
- Absolute instruments are also known as Primary Measuring Instruments.
- The measuring instruments which give the magnitude of the measuring quantity in terms of some physical constants are said to be Absolute Measuring Instruments
- E.g.: - Tangent Galvanometer, Absolute Electrometer, Raleigh Current Balance etc.
- The measuring instruments which are calibrated with absolute measuring instruments or another measuring instrument that have already been calibrated with absolute measuring instruments are said to be Secondary Measuring Instruments.
- E.g.: Ammeter, Voltmeter, Wattmeter etc.

Contacting & Non-Contacting Instruments

- In contacting instruments the primary sensing element come into physical contact with the measurand.
- E.g. – Thermometer
- In non-contacting instruments the primary sensing element does not come into physical contact with the measurand.
- E.g. – Optical Pyrometer

Elements of generalized measuring system

- The operation of a measuring instrument or a system could be described in a generalized manner in terms of **functional elements.**
- Each functional element is made up of a component or groups of components which perform required and definite steps in the measurement.
- The main functional elements of a measurement system are:
    - Primary sensing element
    - Variable conversion element
    - Variable manipulation element
    - Data transmission element
    - Data processing element
    - Data presentation element
    - Data storage element



- **Primary Sensing Element**
  - This is the element that first receives energy from the measured medium and produces an output depending in some way on the measured quantity.
  - An instrument always extracts some energy from the measured medium. The measured quantity is always disturbed by the act of measurement, which makes a perfect measurement theoretically impossible.
  - Coverts the input signals to a suitable form (electrical, mechanical…)
- **Variable Conversion Element**
  - It converts the output signal of the primary sensing element to another more suitable variable while preserving the information content of the original signal.
  - Some instruments there is no need of using a variable conversion element while some other instruments require
- **Variable Manipulation Element**
  - An instrument may require that a signal represented by some physical variable be manipulated in some way.
  - This element is used to manipulate & amplify the output of the variable conversion element
  - By manipulation we mean specifically a change in numerical value by the preservation of the physical nature of the variable.
  - Electronic voltage amplifier receives a small voltage as I/P & it produces greater magnitude of voltage as O/P.
- **Data Transmission Element**
  - When functional elements of an instrument are actually physically separated
  - It becomes necessary to transmit the data from one to another
  - Transmits the data from one element to the other element
  - E.g. Shaft & gear assembly system

- **Data Processing Element**
  - Element used to modify the data before displayed or finally recorded

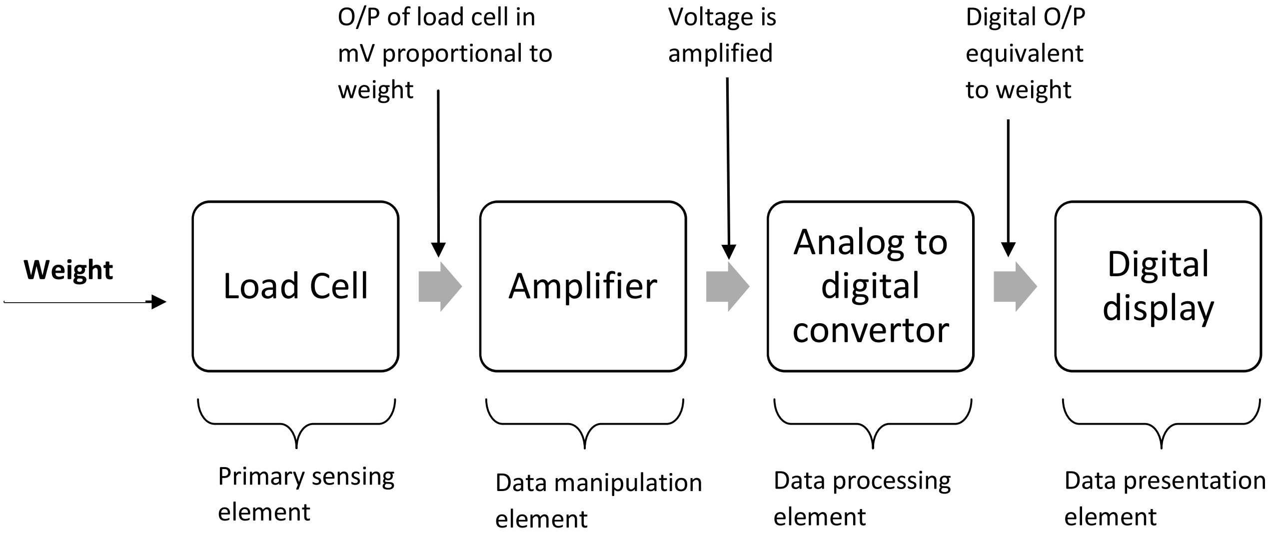
It may be used for following purposes:

- To convert the data into a useful form
- To separate the signal hidden in noise
- It may provide corrections to the measured physical variables to compensate for zero effect, temperature error, etc.

- **Data Presentation Element**
  - If the information about the measured quantity is to be communicated to a human observer for monitoring, control, or analysis purposes, it must be put into a form recognizable by one of the human senses.
  - The value of measured variables may be indicated by an analog indicator (pointer & a scale), digital indicator (ammeter, voltmeter) or by a recorder (magnetic tapes, camera…)

<u>Measurement scheme for weighing machine</u>

- Primary sensing element – Load Cell (Transducer) – Kg in to mill volts
- Data manipulation element – Amplifier – Voltage is amplified
- Data processing element – Analog to Digital converter
- Data presentation element – Digital display



Measurement scheme for Thermometer

- Primary sensing: Thermometer bulb with mercury.
- Data conversion: Temperature signal is converted into volume displacement.
- Data Manipulation: As the mercury expands it move through the capillary tube in the thermometer stem. The volume signal is thus converted into linear distance signal.
- Data presentation: Calibrated scale on the thermometer

Stages in Generalized Measurement System

- A generalized measuring system comprises of three stages:
  1. Sensor - Transducer Stage
  2. Signal Conditioning Stage
  3. Readout – Recording Stage

Sensor – Transducer Stage

- The main function of the sensor – transducer stage is to sense the input signal and transform it into its analogous signal, which can be easily measured.
- The input signal is a physical quantity such as pressure, temperature, velocity, heat, or intensity of light.
- The device used for detecting the input signal is the transducer or sensor.
- The transducer converts the sensed input signal into a detectable signal, which may be electrical, mechanical, optical, thermal, etc.
- The transducer should have the ability to detect only the input quantity to be measured and exclude all other signals

Signal Conditioning Stage

- The O/P from transducer may require some processing & modification
- Transduced signal is modified & amplified appropriately with the help of conditioning & processing devices before passing it for display
- Signal conditioning by noise reduction & filtering is performed to enhance the condition of the signal obtained in the first stage, in order to increase the signal-to-noise ratio

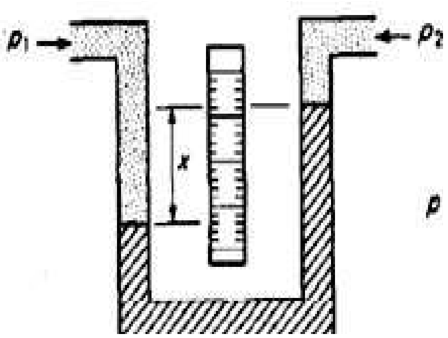
- If required, the obtained signal is further processed by means of integration, differentiation, addition, subtraction, digitization, modulation, etc
- In order to obtain an output that is analogous to the input, the characteristics of the input signals should be transformed with true fidelity.
- Also called as intermediate modifying stage

Readout – Recording Stage

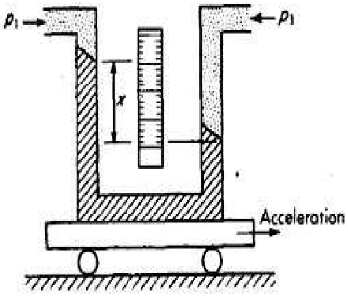
- Presents the value of the output that is analogous to the input value
- The output value is provided by either indicating or recording for subsequent evaluations by human beings or a controller, or a combination of both
- The indication may be provided by a scale and pointer, digital display, or cathode ray oscilloscope
- Recording may be in the form of an ink trace on a paper chart or a computer printout
- Other methods of recording include punched paper tapes, magnetic tapes, high speed camera, TV equipment, CRT
- For control & analysis purpose microprocessor or computers may be used
- The final stage in measurement is known as terminating stage
- Thus, measurement of physical quantities such as pressure, force, and temperature, which cannot be measured directly, can be performed by an indirect method of measurement.
- This can be achieved using a transduced signal to move the pointer on a scale or by obtaining a digital output

Types of Input Quantities

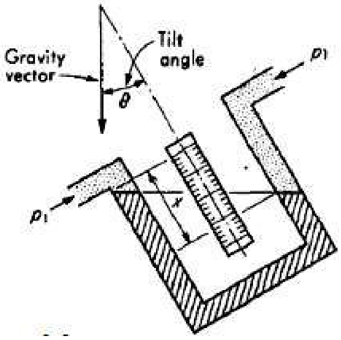
- **Desired inputs :**
  - Quantities that the instrument is specifically intended to measure.
  - The desired inputs $P_1$and P_2 whose difference causes the output x, which can be read off the calibrated scale



- **Interfering inputs :**
  - Quantities to which the instrument is unintentionally sensitive.
  - The measurement systems are not desired to respond to interfering inputs on account of their principle of working, design etc.
  - Measuring pressures under acceleration influence: an error will be engendered because of the interfering acceleration input.



- **Modifying inputs :**
  - The quantities that cause a change in the input-output relations for the desired and interfering inputs
  - If the manometer is not properly aligned with the gravity vector, it gives a modified output signal.
  - Angular disorientation, ambient temperature



Performance Characteristics of measuring devices

- Performance characteristics give a meaningful description of the quality of the device
- Measurement system characteristics are classified in to two types:

Static characteristics

- They are concerned with the measurement of quantities that are constant or vary slowly with time

Dynamic characteristics

- They are concerned with rapidly varying quantities

Static Characteristics

- Accuracy
- Precision
- Repeatability
- Sensitivity
- Reproducibility
- Drift
- Resolution
- Threshold
- Hysteresis
- Static Calibration

Accuracy

- Accuracy of the instrument is defined as the closeness with which an instrument reading approaches the true value of the quantity being measured.
- Inaccuracy is measured a ratio of the highest deviation of a value represented by the instrument to the ideal value
- Accuracy of an instrument is inversely proportional to the error
- Highly accurate instrument produces low errors

Precision

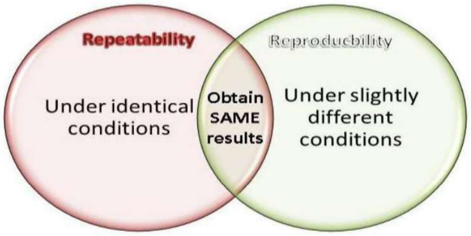
- Precision is a measure of reproducibility of the instruments
- A measure of consistency of measurement .i.e. successive reading does not differ
- Relates how carefully the final measurement can be read but not how accurate the measurement is.

Repeatability

- Repeatability is defined as the ability of the instrument to give the same output reading for the same applied input value repeatedly under the same operating conditions
- Repeatability describes the closeness of output readings when the same input is applied over a short period of time with the same measurement conditions (instrument, observer & external factors)

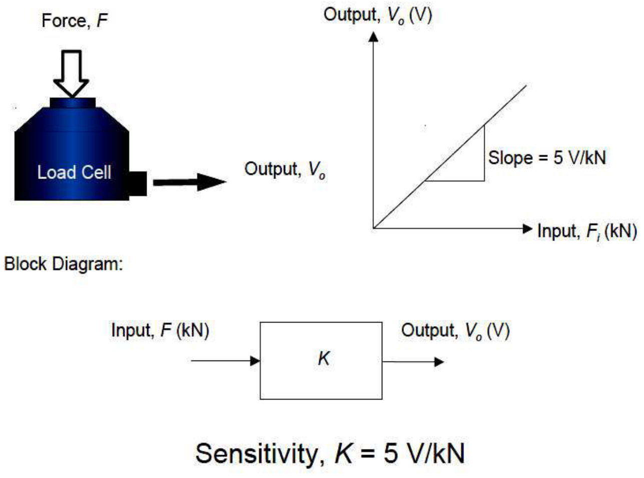
Reproducibility

- Reproducibility describes the closeness of output readings for the same input when there are changes in the methods of measurement (different instrument, observer & external factors)



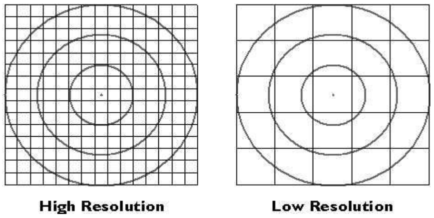
Sensitivity

- Sensitivity is an absolute quantity, the smallest absolute amount of change that can be detected by a measurement.
- This is the relationship between a change in the output reading for a given change of the input (This relationship may be linear or non-linear.)
- If the calibration curve is liner, as shown, the sensitivity of the instrument is the slope of the calibration curve.



Resolution

- Resolution is the smallest unit of measurement that can be indicated by an instrument



Drift

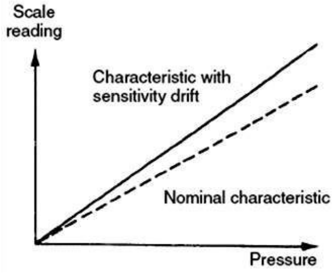
- The gradual shift in the indication or record of the instrument over an extended period of time, during which the true value of the variable does not change is referred to as drift.
  - *Zero drift*
  - *Sensitivity drift / span drift*
  - *Zonal drift*

✓ **Zero Drift**

- If the whole calibration is shifted by the same amount due to slippage or due to undue warming up of tube of electronic tube circuits, zero drift sets in
- Zero setting can prevent this

✓ **Span Drift or Sensitivity Drift:**

- If there is proportional change in the indication all along upward scale, the drift is called span drift or sensitivity drift.
- Hence higher calibrations get shifted more than lower calibrations.

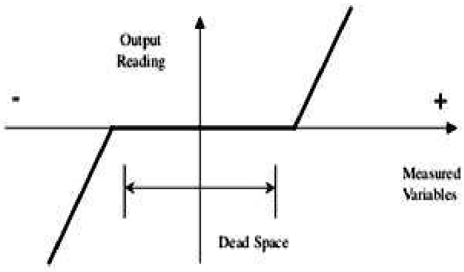


✓ **Zonal drift**

- In case the drift occurs over a portion of span of instrument, while remaining portion of the scale remains unaffected, it is called zonal drift.

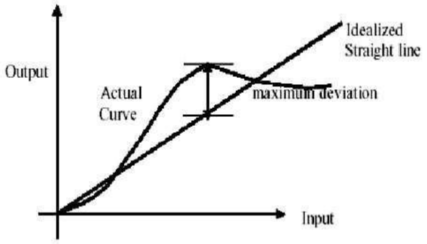
✓ **Dead zone**

- Dead zone is defined as the largest change of input quantity for which there is no output of the instrument.



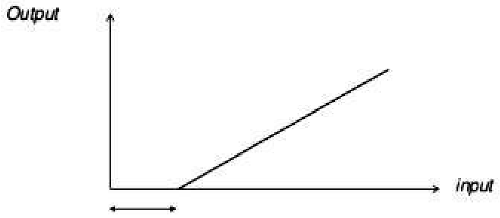
Linearity

- A measuring instrument/system is said to be linear if it uniformly responds to incremental changes.
- Linearity of a sensor refers to the O/P that is directly proportional to I/P over its entire range so that the slope of a graph of O/P vs. I/P describes a straight line.
- Non – Linearity is defined as the maximum deviation of the output of the measuring system from a specified straight line.



Threshold

- If the input to the instrument is gradually increased from zero, a minimum value of that input is required to detect the output.
- This minimum value of the input is defined as the threshold of the instrument



Hysteresis

- Hysteresis is a phenomenon which depicts different output effects when loading and unloading.
- Hysteresis is caused by energy storage/ dissipation in the system.
- Maximum input and output hysteresis are usually expressed as the percentage of the full scale input or output reading

Static Calibration

- Static calibration refers to a situation in which one of the inputs (desired, modifying and interfering) is varied and other two are kept constant.
- Static calibration gives input output relations obtained when only one I/P of the instrument is varied at a time, all other inputs being kept constant.

Dynamic Characteristics

- The dynamic characteristics of a measuring system describe its behavior between the time a input quantity changes value and when the time the instrument output attains a steady value in response.
    - Speed of response
    - Measuring lag
    - Fidelity
    - Dynamic error

Speed of Response

- Speed of Response is defined as the rapidity with which an instrument or measurement system responds to changes in measured quantity.
- The speed at which the output changes is less than the speed at which the input varies.

Measuring Lag

- An instrument does not react to a change in input immediately. The delay in the response of an instrument to a change in the measured quantity is known as measuring lag.
- *Measuring lag is of two types :*
    - **Retardation type:** In this type of measuring lag the response begins immediately after a change in measured quantity has occurred.
    - **Time delay type:** In this type of measuring lag the response of the measurement system begins after a dead zone after the application of the input.

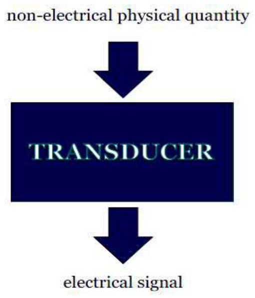
Fidelity

- Fidelity of a system is defined as the ability of the system to reproduce the output in the same form as the input.
- It is the degree to which a measurement system indicates changes in the measured quantity without any dynamic error.
- Supposing if a linearly varying quantity is applied to a system and if the output is also a linearly varying quantity the system is said to have 100 percent fidelity. Ideally a system should have 100 percent fidelity and the output should appear in the same form as that of input.

Dynamic Error

- The dynamic error is the difference between the true value of the quantity changing with time and the value indicated by the instrument if no static error is assumed.

Transducers



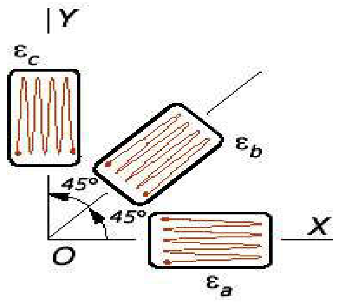
- The transduction process involves the transformation of one form of energy into another form.
- A transducer is a device that converts one form of energy into another form
- A large group of transducers used in instrumentation area convert mechanical input into electrical output

Transduction principles

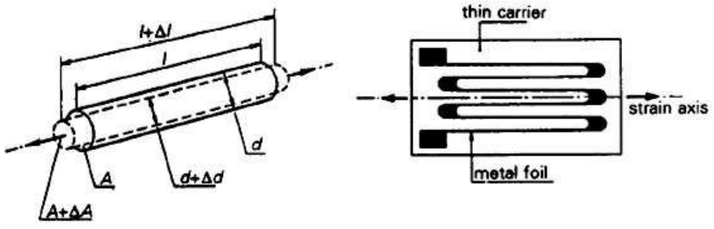
- Electro mechanical transducers
    - Resistive transducer
    - Inductive transducer
    - Capacitive transducer
    - Piezoelectric transducer
- Electromagnetic transducers
    - Eddy current transducer

Resistive transducer

- The resistance R is a function of the cross sectional area of the conductor (A), its length (L) and its resistivity (ρ).
- ***R = f (ρ,L,A)***
- If the conductor is mechanically strained or compressed, the parameters A, l, and ρ, and as a consequence R, will change. This enables one to measure very small displacements.
- If, besides the magnitude of the strain, we also wish to measure the direction of the strain, a combination of strain gauges is used, arranged in a certain geometric pattern. This arrangement is known as a strain gauge rosette.



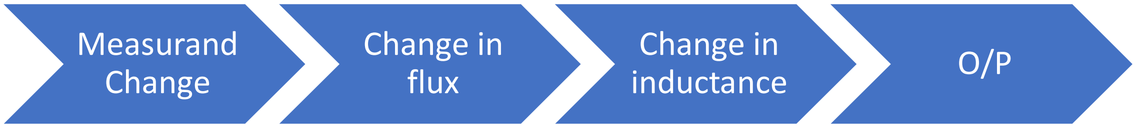
(a) Freely suspended strain wire. (b) Metal foil strain gauge.



(a) (b)

Inductive transducer

- Inductive sensors are based on electromagnetic induction or mutual inductance
- Detect the mechanical energy which is converted into a corresponding electrical signal
- Consists of :
    - Fixed iron
    - Movable armature.
    - ‘N’ no. of windings



- When the mechanical element whose displacement is to be measured, is moved
- The movement causes a change in flux generated by the circuit and a corresponding change in O/P

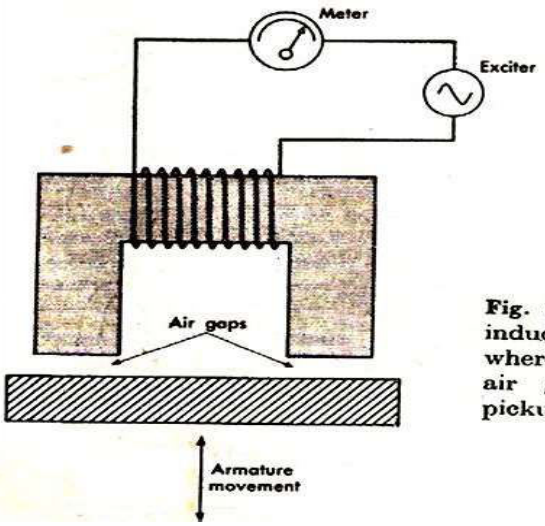


Fig. 6.7 A simple self-inductance arrangement wherein a change in the air gap changes the pickup output.

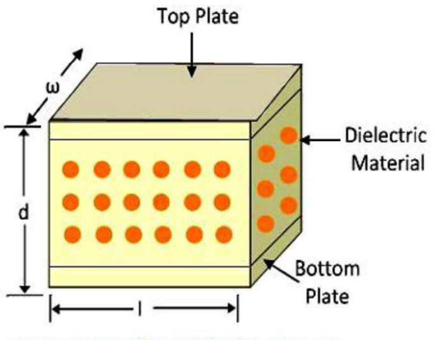
- **L** , the inductance is given by

$$L = \frac{N^2 \mu_0 A_0}{2 l_0}$$

- μ_0 - magnetic permeability
- A_0- equivalent cross-sectional area
- l_0- length of the gap

Capacitive transducer

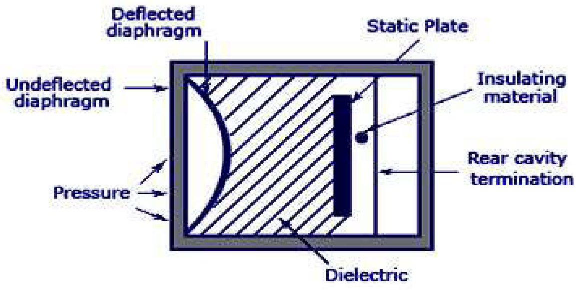
- Capacitive transducer is used for measuring displacement, pressure, etc..
- The capacitance of capacitive transducer changes : overlapping of plates, change in distance b/w the plates & dielectric constant
- The capacitive transducer contains two parallel metal plates
- These plates are separated by dielectric medium (air, metal, gas or liquid)
- In normal capacitor the distance b/w the plates are fixed
- But in capacitive transducer the distance b/w them are varied
- The input quantity causes change of capacitance which is directly measured by the capacitive transducer



Parallel Plate Capacitive Transducer

Circuit Globe

- Displacement can be measured by directly connecting the measurable devices to the movable plate of the capacitor
- The equations below express the capacitance between the plates of a capacitor



$$C = \frac{\varepsilon A}{d}$$

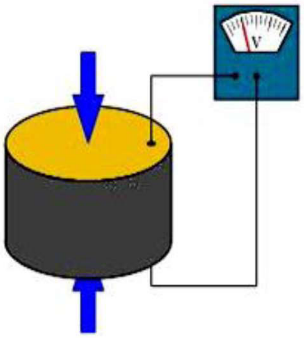
$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

– Where

A – Overlapping area of plates in m^2
d – the distance between two plates in meter
ε – permittivity of the dielectric material
ε_r – relative permittivity
ε_0 – the permittivity of free space

Piezoelectric transducer

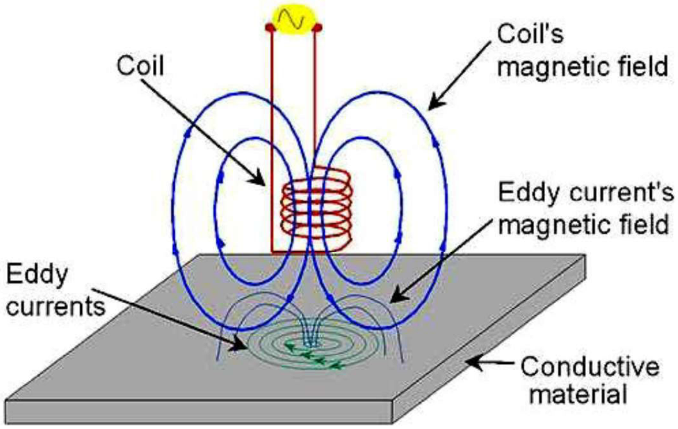
- The word "piezoelectric" literally means electricity caused by pressure
- There are certain materials that generate electric potential or voltage when mechanical strain is applied to them or conversely when the voltage is applied to them, they tend to change the dimensions along certain plane. This effect is called as the piezoelectric effect

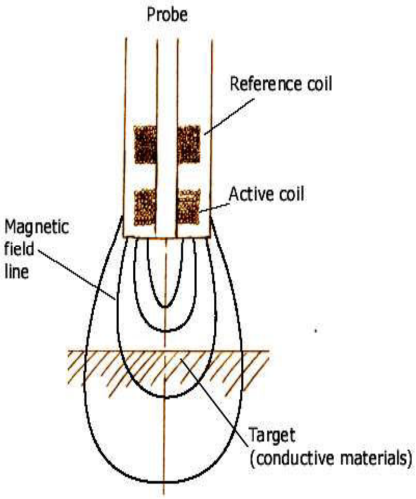


- When mechanical stress or forces are applied to some materials along certain planes, they produce electric voltage.
- This electric voltage can be measured easily by the voltage measuring instruments, which can be used to measure the stress or force.
- The voltage output obtained from these materials due to piezoelectric effect is proportional to the applied stress or force.
- The output voltage can be calibrated against the applied stress or the force so that the measured value of the output voltage directly gives the value of the applied stress or force.

Eddy current transducer

- An AC current is applied to the coil as a result a magnetic field is generated
- When the coil is placed near the conductive material eddy current will be generated in the material
- Due to the magnetic field in the coil eddy current will be generated in the conductive material
- Eddy current in the conductor generates their own magnetic field & oppose the emf produced by the coil
- Closer the probe / coil to the conductor eddy current generation & opposition will be more
- As the two fields oppose each other it will change the impedance of the coil & is detected by the circuit & produce o/p
- Uses the effect of eddy currents to sense the proximity of conductive materials.
- Contains two coils: an **active coil** (main coil) and a **balance coil**.
- The active coil senses the presence of a nearby conductive object, and balance coil is used to balance the output bridge circuit.





CLASSIFICATION OF TRANSDUCERS

- Transducers are classified as follows:
    1. Primary and secondary transducers
    2. Based on the principle of transduction
    3. Active and passive transducers
    4. Analog and digital transducers
    5. Direct and inverse transducers
    6. Null and deflection transducers

Primary and Secondary Transducers

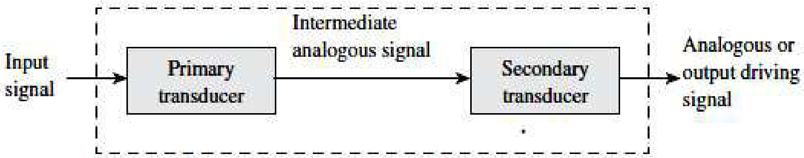
- Transducers may comprise two important components: *Sensing / detecting element & transduction element.*

Sensing or detecting element

- The function of this element is to respond to a physical phenomenon or a change in the physical phenomenon.
- Hence it is termed a primary transducer.

Transduction element

- The function of a transduction element is to transform the output obtained by the sensing element to an analogous electrical output
- Hence it is termed a secondary transducer.

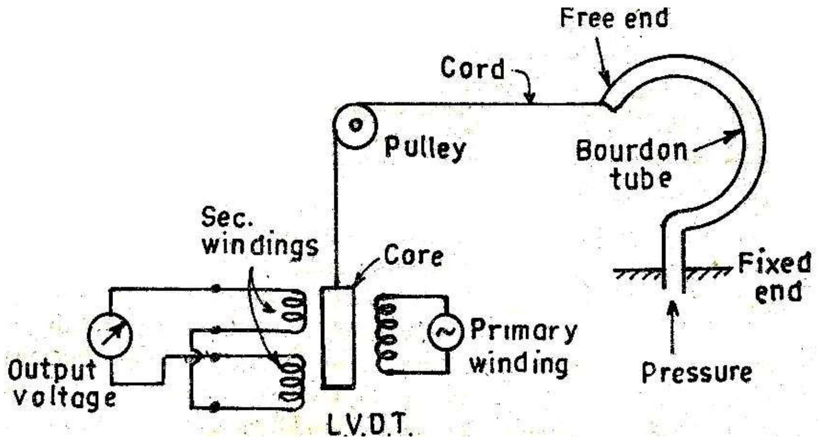


Primary detector transducer stage with primary and secondary transducers

- An example of a primary detector transducer stage comprising both these elements is the combination of the bourdon tube and the linear variable differential transformer (LVDT)

Example of a primary detector transducer stage

- The bourdon tube, which acts as a detecting element, senses pressure and gives the output in the form of displacement
- This displacement is further used to move the core of LVDT, and a voltage is obtained as output
- Thus, the pressure is converted into displacement, which in turn is transduced into an analogous voltage signal.
- Thus, the bourdon tube acts as the primary sensing element and the LVDT as the secondary transducer



Based on Principle of Transduction

- How the I/P quantity is transdused into capacitance, resistance, and inductance values
  - Capacitive
  - Resistive
  - Inductive
  - Piezoelectric
  - Thermoelectric
  - Electro kinetic
  - Optical

Active and Passive Transducers

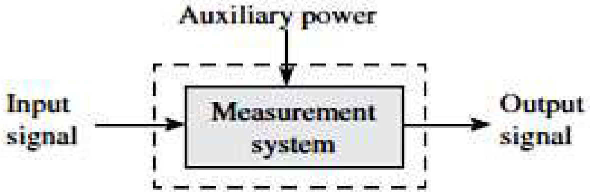
Active transducers

- Are of a self-generating type
- They develop their own voltage or current output.
- They do not need any auxiliary power source to produce the output.
- The energy required to produce the output is derived from the physical quantity being measured.

- Examples of active transducers are piezoelectric crystals, tachogenerators, thermocouples, and photovoltaic cells.

Passive transducers

- Derive the power required for transduction from an auxiliary power source.
- A part of the power required for generating the output is derived from the physical quantity being measured
- These transducers remain passive in the absence of an external power source; hence, they are called passive transducers.
- Are termed externally powered transducers
- Resistive, capacitive, and inductive transducers are some of the examples of passive transducers.



Analog and Digital Transducers

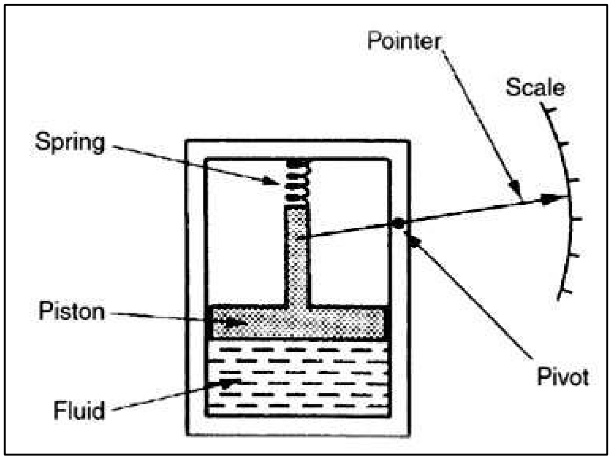
- Based on the output generated, that is, depending on whether the output generated is a continuous function of time or is in discrete form, transducers are classified as analog and digital transducers.
- Analog transducer, the input quantity is converted into an analog output, which is a continuous function of time.
- LVDT, strain gauge, thermocouple, and thermistor are some examples of analog transducers.
- If a transducer converts the input quantity into an electrical signal that is in the form of pulses, as output, called a digital transducer.
- These pulses are not continuous functions of time but are discrete in nature.
- Easier to process & transmit data as a function of two numbers 0 and 1
- E.g. Shaft encoders, linear displacement transducers using conducting or non-conducting contacts

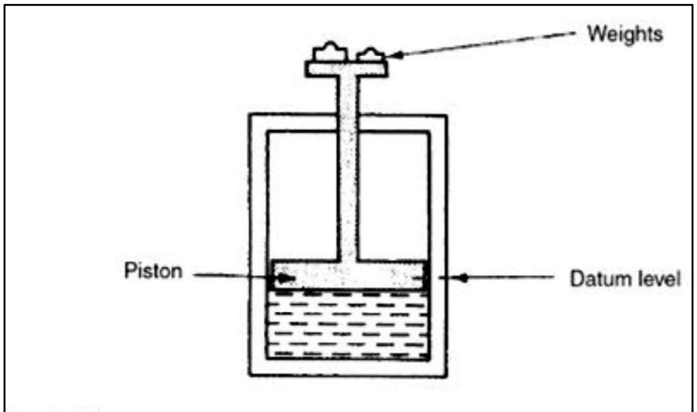
Direct and Inverse Transducers

- When a measuring device measures and transforms a non-electrical variable into an electrical variable, it is called a direct transducer.
- A thermocouple that is used to measure temperature, radiation, and heat flow is an example of a transducer
- If an electrical quantity is transformed into a non-electrical quantity, it is termed an inverse transducer.
- A piezoelectric crystal wherein a voltage is given as the input causes mechanical deformation.

Null- and Deflection-type Transducers

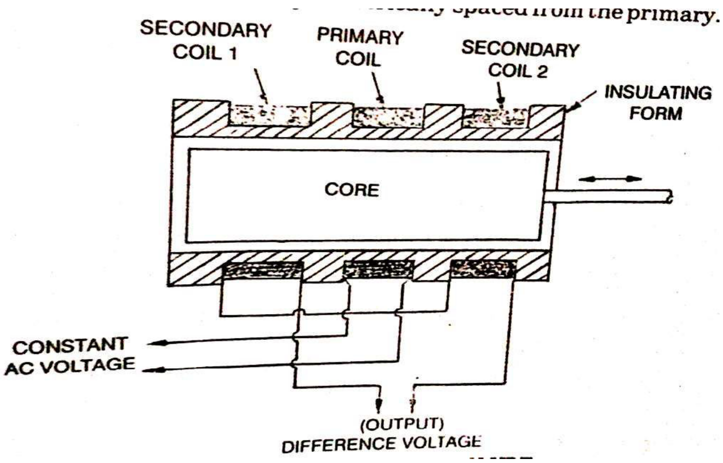
- A deflection type transducer works on the principle that the measured quantity produces a deflection of the pointer.
- The pressure measuring device is an example of a deflection type transducer.
- A null type transducer works on the principle of maintaining zero deflection by applying an appropriate known effect that opposes the one generated by the measured quantity.
- An alternative type of pressure gauge is the deadweight gauge which is a null type instrument. Here, weights are put on the top of the piston until the downward force balances the fluid pressure. Weights are added until the piston reaches a datum level, known as null point. Pressure measurement is made in terms of the value of the weights needed to reach this null position.





Deadweight pressure gauge.

Motion & Dimension Measurement by Linear Variable Differential Transformer (LVDT)



- Is a passive type sensor
- An LVDT produces an output proportional to the displacement of a movable core within the field of several coils
- As the core moves from its 'null' position, the voltage induced by the coils change, producing an output representing the difference in induced voltage
- It works on the mutual inductance principle
- It consists of a primary coil wound on an insulating form and two secondary coils symmetrically spaced from the primary
- An external AC power source is applied to the primary coil and the two secondary coils are connected together in phase opposition
- The motion of the core varies the mutual inductance of secondary coils
- This change in inductance determines the electrical voltage induced from the primary coil to the secondary coil
- If the core is centred in the middle of the two secondary windings, then the voltage induced in both the secondary coils will be equal in magnitude but opposite in phase, and the net output will be zero
- An output voltage is generated when the core moves on either side of the null position

Advantages of electrical comparators

- Highly sensitive and provides good magnification
- Insensitive to temperature changes
- Digital display minimizes the reading errors

Disadvantages of electrical comparators

- Requires external power source
- Fluctuations in supply voltage can affect the results
- The core has appreciable mass. The resulting inertial effects can lead to wrong measurements

Applications

- Used to measure the displacement, deflection, position and profile of workpiece.

Dynamic characteristics- different order systems and their response

- In general, the response of measurement instruments under dynamic conditions can be complex.
- The fundamental concepts of dynamic response can be understood by studying relatively simple mathematical models.
- Consider three mathematical models for dynamic system response:
  - Zero
  - First
  - Second order systems

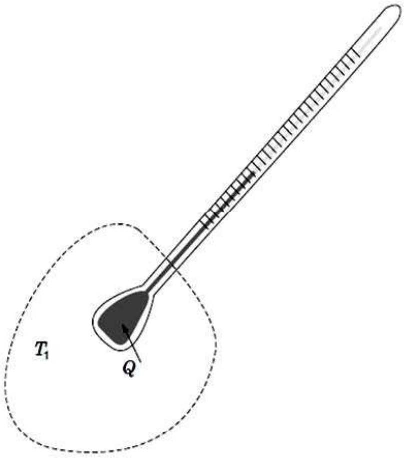
Zeroth Order Systems

- Consider a thermometer that measures the temperature in a room
- For practical purposes, the thermometer will indicate the current temperature at the location where it has been installed
- The output of the instrument follows the input “exactly” for a Zeroth order system
- Let ***f(t)*** be the input to the system as a function of time and ***y(t)*** be the output, then the relationship between them is

$$y(t) = K f(t)$$

  - f(t) : actual temperature of the room
  - y(t) : indicated temperature
  - K is a constant that multiplies the input to generate the output.
  - K is called the static sensitivity.
- The output of Zeroth order systems is not affected by the speed at which ***f(t)*** changes
- If ***y (t)*** is the temperature as displayed in a readout device and the thermometer is calibrated correctly, then K would ideally be equal to one.
- If the output of the thermometer is, for example, an electrical signal, then K would be a constant with units of Volts per degree Fahrenheit
- Results of static calibration are sufficient to characterize the response of the system.

First Order Systems



- Consider an oral thermometer used at a clinic to measure body temperature.
- Prior to use, the thermometer is at room temperature.
- When the thermometer makes contact with measurand it experiences a sudden increase in temperature
- The operator have to wait for a while before reading the temperature
- This situation cannot be represented by a zero order system
- The thermometer was originally at room temperature, $\mathbf{T_o}$
- It is then made to contact the measurand at temperature $\mathbf{T_1}$
- In order for the thermometer to work, the mercury in the bulb must be heated to $\mathbf{T_1}$
- The thermal expansion of the mercury will cause the column of mercury in the stem of the thermometer to increase in length
- Measuring this length with the scale marked in the glass gives a temperature reading **T(t)**
- It takes time for the temperature of the mercury to reach the value $\mathbf{T_1}$
- Due to conservation of energy, the rate of change of energy in the bulb with respect to time is equal to how fast heat is flowing in

$$\frac{dE}{dt} = \frac{dQ}{dt}$$

- As E increases, the temperature of the mercury, T, rises in proportion.
- How fast the temperature increases depends on mass, m, of the mercury the 'specific heat,' $\mathbf{C_v}$
- The increase in energy is related to the increase in temperature by

$$\frac{dE}{dt} = mc_v\frac{dT}{dt}$$

- How fast heat can flow through the walls of the bulb depends on a property of glass called the convection heat transfer coefficient, **h**, the surface area of the bulb, **A**, and the current temperature difference between the mercury and the measurand.
- In equation form,

$$\frac{dQ}{dt} = hA[T_1 - T]$$

$$\frac{dE}{dt} = \frac{dQ}{dt} \quad ①$$

$$\frac{dE}{dt} = mc_v\frac{dT}{dt} \quad ② \qquad\qquad \frac{dQ}{dt} = hA[T_1 - T] \quad ③$$

$$mc_v\frac{dT}{dt} = hA[T_1 - T] \quad ④$$

$$\frac{mc_v}{hA}\frac{dT}{dt} + T = T_1$$

- This is a differential equation that governs what the temperature of the mercury is at any time.
- In general, the equation of a first order system is given by

$$\tau\frac{dy}{dt} + y = Kf(t)$$

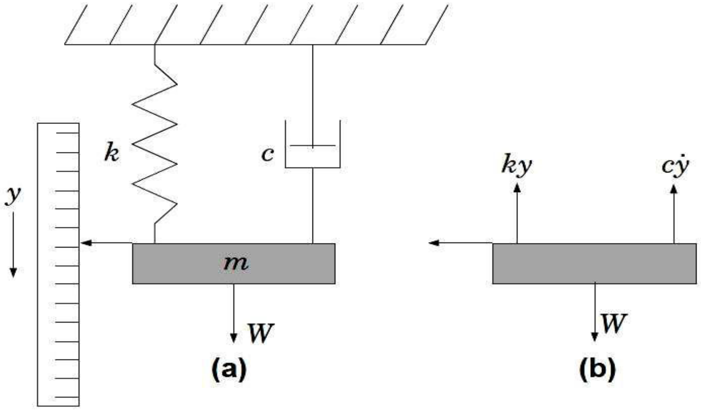
– For the above example we have,

$$y = T,\ \ f(t) = T_1,\quad \tau = \frac{mc_v}{hA} \quad K = 1.$$

- Equation governing the behaviour of a first order system is a first order differential equation

Second Order Systems

- Consider weight scales, they generally have a pointer, which indicates weight on a dial
- When loaded the pointer will oscillate a bit before settling & indicating correct weight
- Reason for the oscillation of the pointer is that the scale has mass, hence inertia
- The balance can be represented by the mass-spring-dashpot system
- To simplify, the dial has been replaced by the straight scale



(a) **(b)**

Model of weight balance. (b) Free body diagram.

- The mass m represents the object weighted so that the weight ***W*** is equal to ***mg*** where ***g*** is the acceleration of gravity.
- The spring force is proportional to the displacement ***y*** of the mass.
- If the zero value of ***y*** corresponds to the position of the spring when it is unloaded, then the force F_s required to stretch the spring a distance ***y*** is given by

$$F_s = ky$$

- The damping is provided by the dashpot
- This force-speed (Damping Force) relation can be written as

$$F_d = c\frac{dy}{dt}$$

  - where *c is called the damping coefficient*

- Applying Newton's second law we obtain the equation

$$m\frac{d^2y}{dt^2} + c\frac{dy}{dt} + ky = W,$$

$$\frac{m}{k}\frac{d^2y}{dt^2} + \frac{c}{k}\frac{dy}{dt} + y = \frac{1}{k}W.$$

- This is the differential equation that governs the motion of the scale.
- Since the weight is indicated by the displacement of the scale, the equation also governs the indicated weight
- In general, the equation for a second order system is given by

$$\frac{1}{\omega_n^2}\frac{d^2y}{dt^2} + \frac{2\zeta}{\omega_n}\frac{dy}{dt} + y = Kf(t).$$

  - In the above example we have,

$$\omega_n = \sqrt{\frac{k}{m}}, \qquad \zeta = \frac{c}{2\sqrt{km}} \qquad K = \frac{1}{k}.$$

METROLOGY AND INSTRUMENTATION ME312

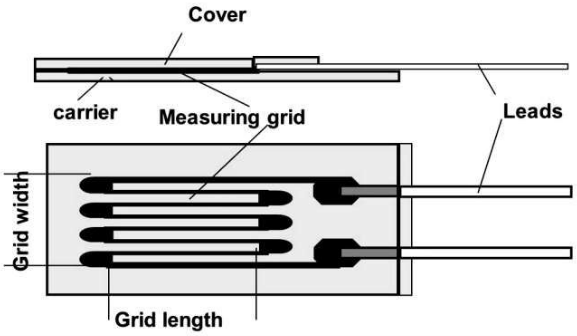
Module 6

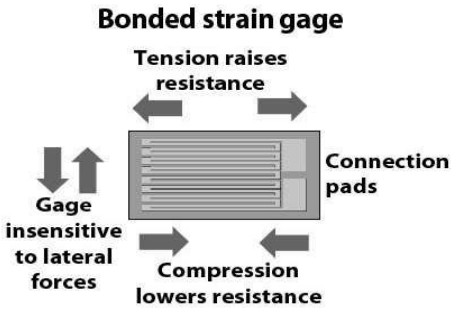
- ✓ Strain and Stress Measurement - Electrical resistance strain gauge - Principle, operation.
- ✓ Measurement of Force and Torque – Strain-Gauge Load Cells, Hydraulic and Pneumatic load cells – basic principle and three component force measurement using piezoelectric quartz crystal.
- ✓ Torque Measurement – Dynamometers – Mechanical, Hydraulic and Electrical.
- ✓ Vibration measurement – Vibrometers and Accelerometers – Basic principles and operation.
- ✓ Temperature Measurement – Use of Thermal Expansion – Liquid- in-glass thermometers, Bimetallic strip thermometer, Pressure thermometers.
- ✓ Thermocouples – Principle, application laws for Thermocouples, Thermocouple materials and construction, measurement of Thermocouple EMF.
- ✓ Resistance Temperature Detectors (RTD); Thermistors; Pyrometers (Basic Principles).

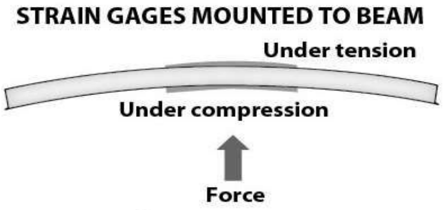
Strain & Stress Measurement

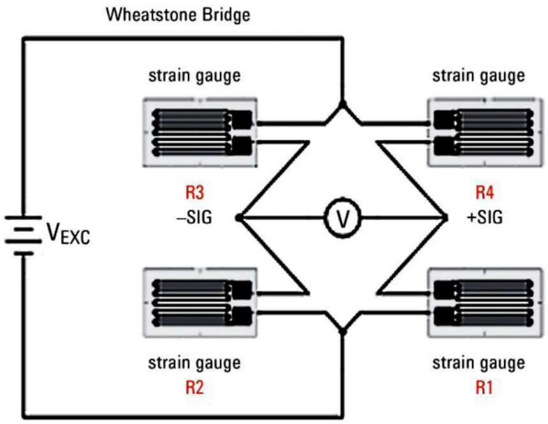
Electrical Resistance Strain Gauges

- Strain Gauge is a passive transducer that converts a mechanical displacement into change of resistance
- 1856 Lord Kelvin demonstrated that the resistances of copper wire and iron wire change when the wires are subjected to mechanical strain.
- The electrical resistance of a copper wire / iron wire changes when the wire is either stretched or compressed
- He used a Wheatstone bridge circuit with a galvanometer as the indicator.
- Electrical resistance strain gages are sensors made of thin foil or wire-type conductors that respond to variations in length with variations in electrical resistance.
- Strain gages are used to measure linear strains that occur at surface points of an object when it responds to some actuating load
- The strain gage is bonded to the surface with an adhesive
- Deformation of the surface element forces the strain gage to change its length
- The variation in length of the parallel segments of the wire-type conductor will be directly proportional to the variation in electrical resistance of the conductor.

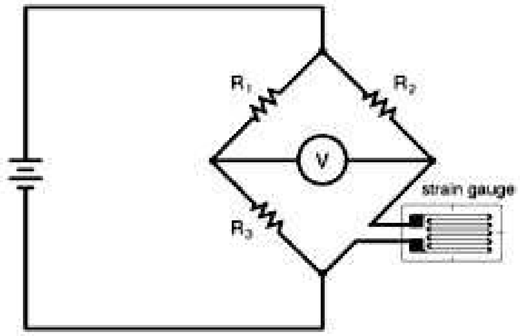






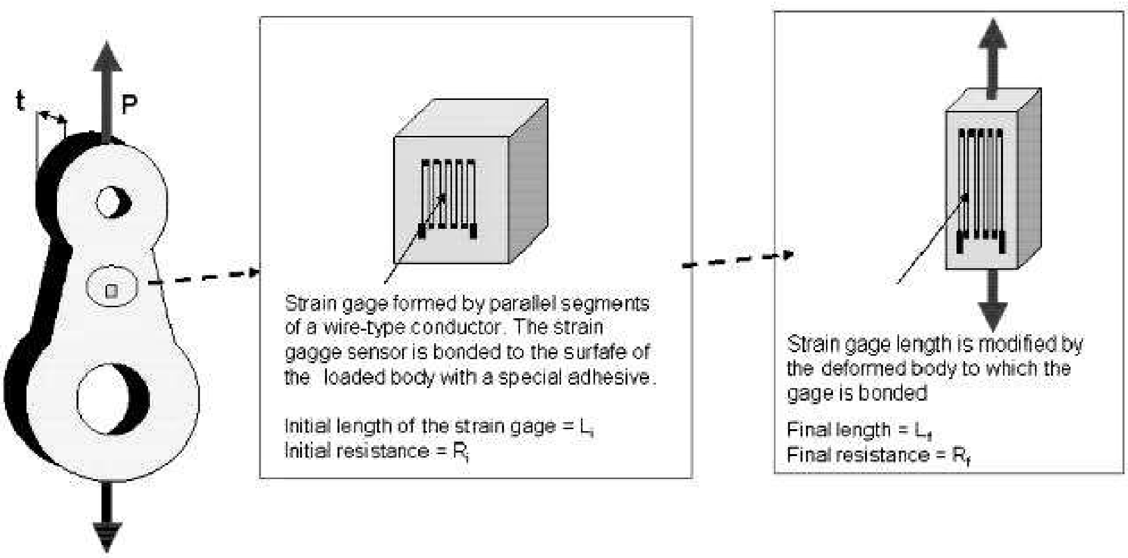


Full Bridge Strain Gauge Circuit



Quarter Bridge strain gauge circuit

- Relationship between the variation in resistance of gage ΔR and strain ε to be determined, where K is the gage factor.



Strain gage formed by parallel segments of a wire-type conductor. The strain gagge sensor is bonded to the surfafe of the loaded body with a special adhesive.

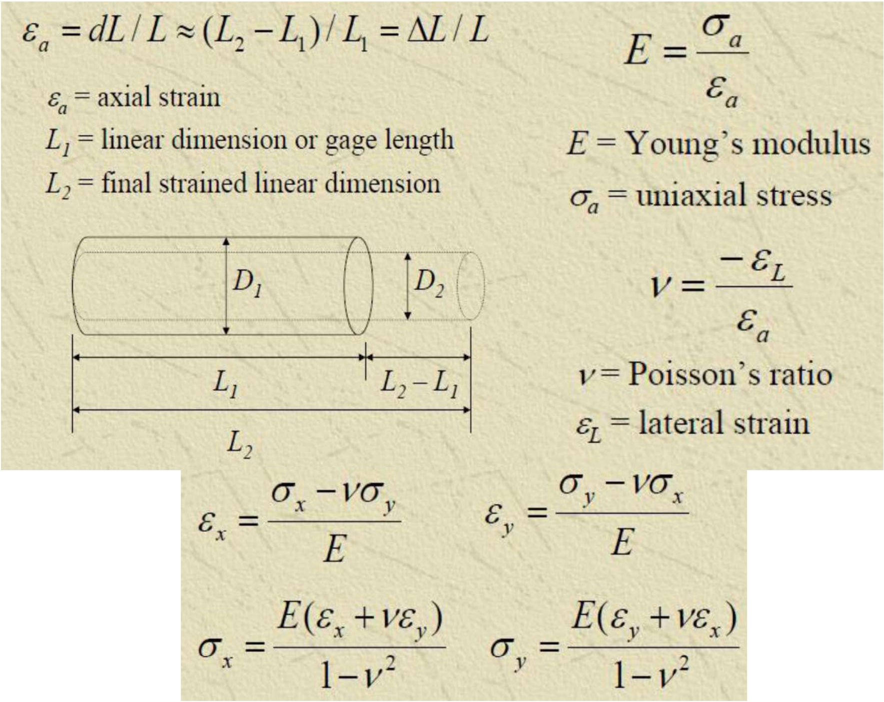
Initial length of the strain gage = L_i
Initial resistance = R_i

Strain gage length is modified by the deformed body to which the gage is bonded

Final length = L_f
Final resistance = R_f

$$\frac{R_f - R_i}{R_i} = K.\frac{L_f - L_i}{L_i}$$

$$\frac{\Delta R}{Ri} = K.\varepsilon$$



$$\varepsilon_a = dL/L \approx (L_2 - L_1)/L_1 = \Delta L/L$$

ε_a = axial strain
L_1 = linear dimension or gage length
L_2 = final strained linear dimension

$$E = \frac{\sigma_a}{\varepsilon_a}$$

E = Young's modulus
σ_a = uniaxial stress

$$\nu = \frac{-\varepsilon_L}{\varepsilon_a}$$

ν = Poisson's ratio
ε_L = lateral strain

$$\varepsilon_x = \frac{\sigma_x - \nu\sigma_y}{E} \qquad \varepsilon_y = \frac{\sigma_y - \nu\sigma_x}{E}$$

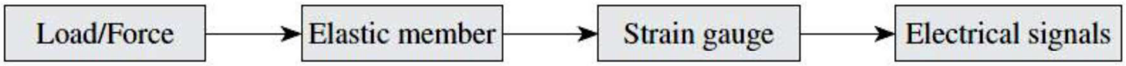
$$\sigma_x = \frac{E(\varepsilon_x + \nu\varepsilon_y)}{1-\nu^2} \qquad \sigma_y = \frac{E(\varepsilon_y + \nu\varepsilon_x)}{1-\nu^2}$$

Force and torque measurement

- The force transducer is also known as **a load cell**.
  - Strain gauge load cells
  - Hydraulic load cell
  - Pneumatic load cell
  - *Multi-component piezoelectric force transducers*

Elastic members

- Force-measuring transducers employ various mechanical elastic members
- Application of a load or force on these members causes an analogous deflection
- This deflection, which is usually linear, is measured either directly or indirectly by employing secondary transducers.



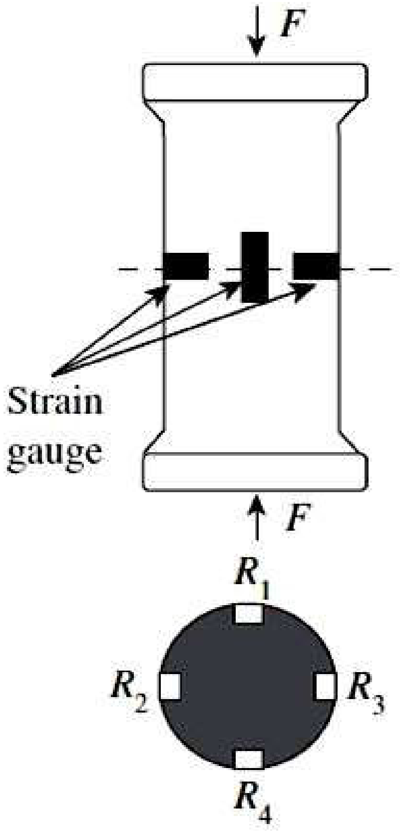
Use of a strain gauge for force determination

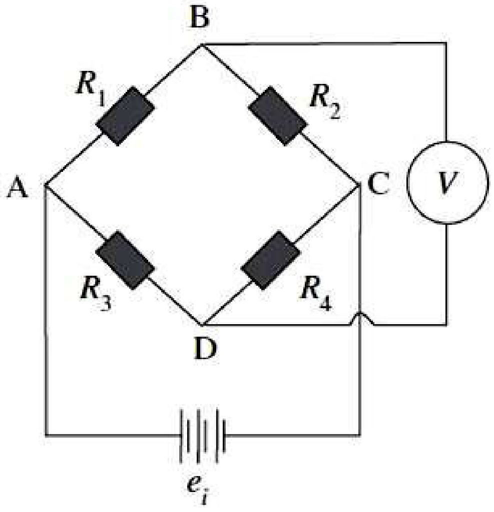
- This displacement is then converted into an electrical signal by the secondary transducers.
- The strain gauge is the most popular secondary transducer employed for the measurement of force
- Load cells employ strain gauges for force measurement

Strain Gauge Load Cells

- When an elastic member is combined with a strain gauge and used for the measurement of force, it is termed as a load cell
- In load cells, elastic members act as primary transducers and strain gauges as secondary transducers
- A load cell is used in an indirect method of force measurement where force or weight is converted into an electrical signal
- Load cells are used extensively for the measurement of force.
- A load cell comprises four strain gauges
- Two of these are used for measuring the longitudinal strain while the other two for measuring the transverse strain.
- The four strain gauges are mounted at 90° to each other

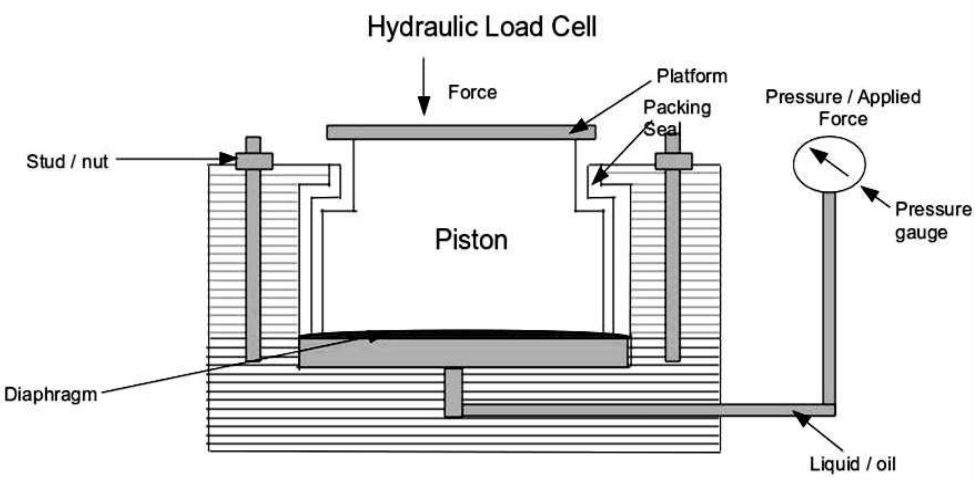
- Two gauges experience tensile stresses while the other two are subjected to compressive stresses
- At the no-load condition, resistance in all the four gauges will be same.
- The potential across the two terminals B and D are same
- The Wheatstone bridge is now balanced and hence output voltage is zero
- When specimen is stressed due to the applied force, the strain induced is measured by the gauges.
- Gauges R1 and R4 measure the longitudinal (compressive) strain
- Gauges R2 and R3 measure the transverse (tensile) strain
- In this case, voltages across the terminals B and D will be different, causing the output voltage to vary, which becomes a measure of the applied force upon calibration.





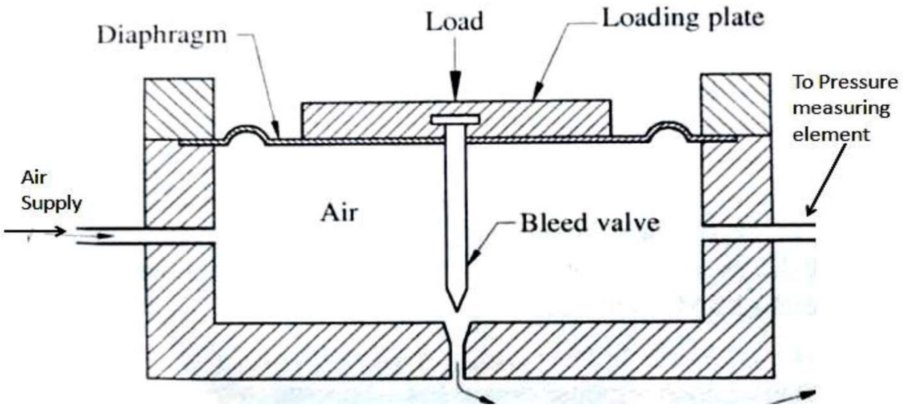
Hydraulic Load Cell

- When a force is applied on a liquid medium contained in a confined space, the pressure of the liquid increases.
- This increase in pressure of the liquid is proportional to the applied force.
- Hence a measure of the increase in pressure of the liquid becomes a measure of the applied force when calibrated



- The main parts of a hydraulic load cell are as follows
  - A diaphragm
  - A piston with a loading platform placed on top of the diaphragm.
  - A liquid medium which is under a pre-loaded pressure is on the other side of the diaphragm.
  - A pressure gauge (bourdon tube type) connected to the liquid medium
- The force to be measured is applied to the piston
- The applied force moves the piston downwards and deflects the diaphragm and this deflection of the diaphragm increases the pressure in the liquid medium (oil)
- This increase in pressure of the liquid medium is proportional to the applied force.
- The increase in pressure is measured by the pressure gauge which is connected to the liquid medium.
- The pressure is calibrated in force units and hence the indication in the pressure gauge becomes a measure of the force applied on the piston

Pneumatic load cell

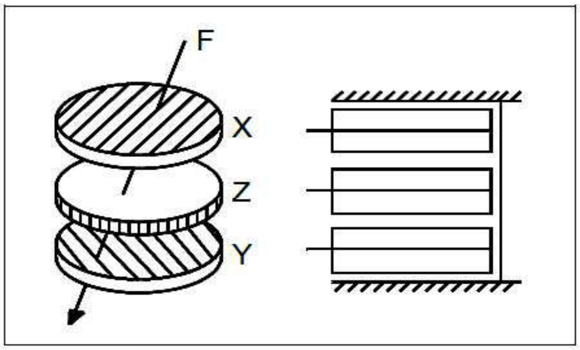


- Force-balance device whose operation relies on the pressure exerted by the force or weight on a volume of air in a confined space. Consists of :
- An Elastic Diaphragm: This is made of a flexible material or can also be a corrugated diaphragm just like that of a hydraulic load cell.
- A Loading Platform: This is where the force is applied or weight to be quantified is placed. It is usually a steel piston with the diaphragm attached to its base.
- Air Supply Regulator: This is located at the bottom of the device or at its side below the diaphragm. It is basically an opening that is regulated by a valve.
- An Outlet Nozzle: This is also an opening but not directly regulated by any valve.
- The Flapper/Bleed Valve: This is attached to the body of the diaphragm. Its upward/downward movement opens/closes the outlet nozzle.
- A Pressure Gauge or Manometer: Indicates the pressure as a measure of the weight or applied force.
- Sensitive to pressure changes, the load cell should be adjusted to zero setting before using it to measure force
- The force is applied to the loading platform to which a diaphragm and a flapper is attached.
- This applied load deflects the diaphragm and as a result, causes the flapper to move downwards and shut off the outlet nozzle.
- While this is happening, a back pressure is also acting on the diaphragm thereby producing a counteractive upward force
- Air pressure is regulated until the diaphragm returns to the pre-loaded position
- This is indicated by the air which comes out of the nozzle. At this stage, the corresponding pressure indicated by the pressure gauge gives a measure of the applied force when calibrated

Multi component piezoelectric force transducers

(Three component force measurement using piezoelectric quartz crystal)

- They measure the forces in three orthogonal axes.
- Force F acts upon the transducer and is transmitted to each of three discs with the same magnitude and direction.
- Each piezoelectric crystal ring has been cut along a specific axis
- The orientation of the sensitive axis coincides with the axis of the force component to be measured
- Each then produces a charge proportional to the force component specific to that disc.
- The charge is collected via the electrodes inserted into the stack

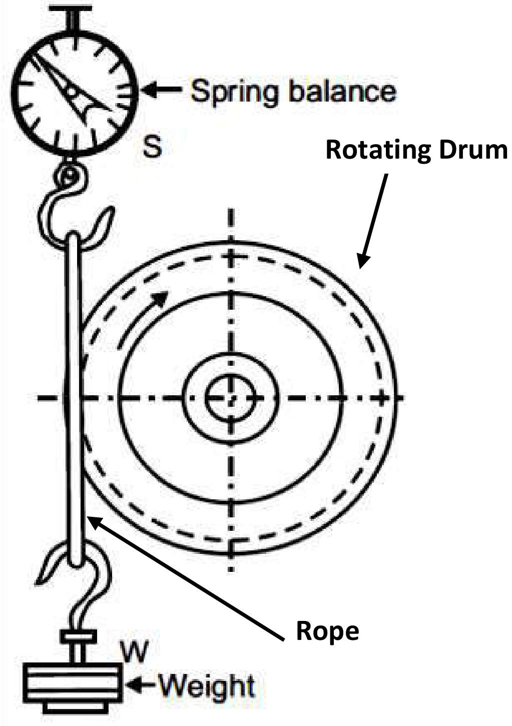


Multi-component crystal force sensor

Torque measurement

- Dynamometers
  - Mechanical
  - Hydraulic
  - Electrical
- The dynamometer is a device which absorbs the power and transforms it into heat energy.

Rope brake (mechanical) dynamometer



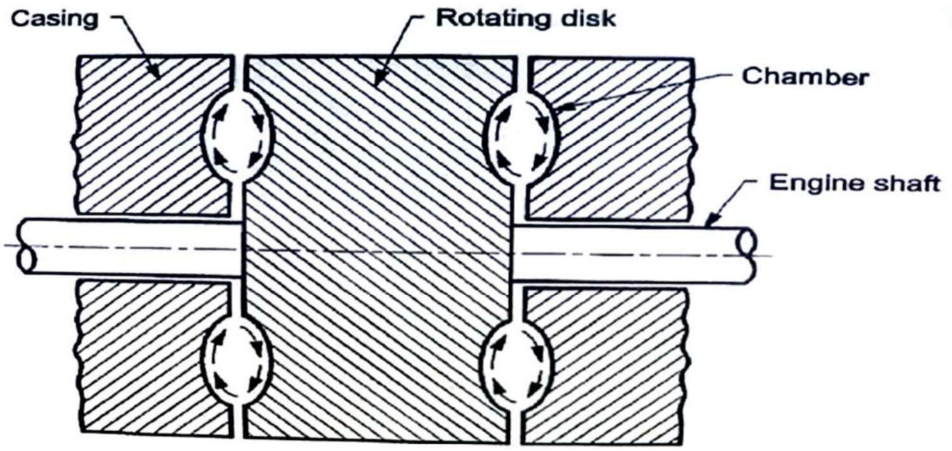
- The rope brake dynamometer consists of some turns of rope wound around the rotating drum attached to the output shaft.
- One side of the rope is connected to spring balance and the other side to a loading device.
- The power is absorbed in friction between the rope and the drum. Therefore drum in rope brake requires cooling.
- In the operation of the brake, the engine is made to run at a constant speed.
- The frictional Torque, due to the rope, must be equal to the torque being transmitted by the engine.
- Brake power can't be measured accurately because of change in the friction coefficient of the rope with a change in temperature.

$$\text{Braking Torque, } T_b = (W-s) * r$$

$$\text{The power absorbed by the engine} = \frac{2\pi N\,(W-S)}{60*1000}\ (\text{KW})$$

Hydraulic dynamometer

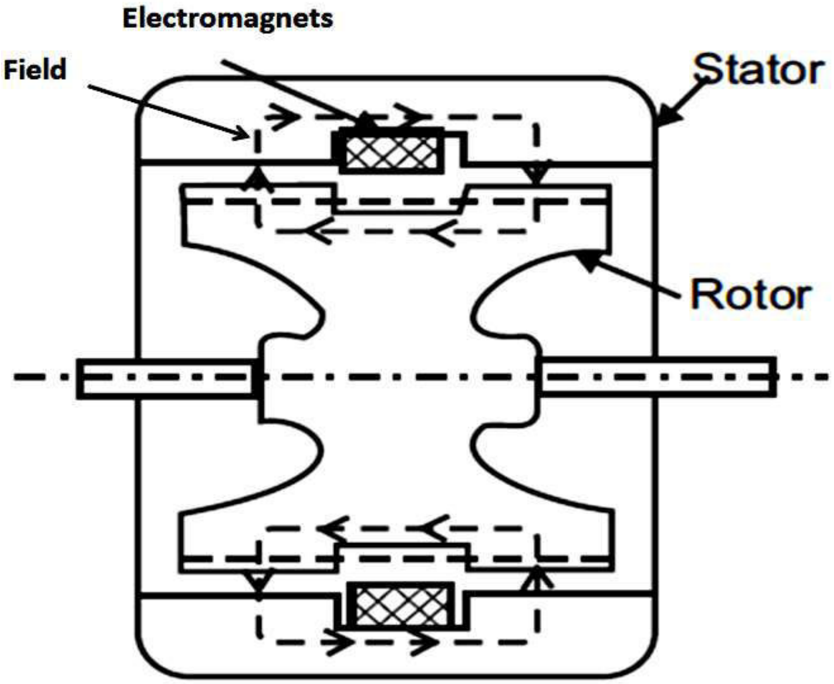
- It works on the principal of dissipating energy in fluid friction rather than dry friction.
- Water or oil is used
- A rotating disc connected to a shaft whose power to be measured
- Rotating disc is mounted inside the casing
- Casing is mounted on antifriction bearing & has a brake arm & a balance system attached to it
- The casing is in the form of two halves
- One of them is mounted on the either side of the rotating disc
- The semi elliptical grooves placed in the casing match with the corresponding grooves inside the rotating disc to form vortex inside the chamber



- When the shaft is rotating the water drives into the grooves
- It tries to rotate the casing as well
- But the rotation of casing is resisted by the braking arm & the balance system measures the torque
- The frictional force developed between the rotor and the fluid is carried away through continuous supply of working fluid.

Eddy current (electrical) dynamometer

- Eddy current dynamometer consists of a stator which are fitted with electromagnets
- A rotor made of conductive material which is coupled to the output shaft of the engine.
- When the rotor rotates , eddy currents are induced in the stator
- Due to the magnetic flux set up by the passage of current in the electromagnets.



- The eddy currents produced will resist any change in the magnetic field.
- Therefore the rotor obtains a reverse force & attempts to reduce the rotational speed of the rotor
- But the torque supplied by engine maintains the rpm.
- The torque will be measured with the help of a moment arm.
- In mechanical dynamometers friction was involved
- Since no contact b/w the rotor & stator hence no friction
- Fast in operation & lighter in weight
- But requires external power & chances of eddy current losses

Vibration measurement

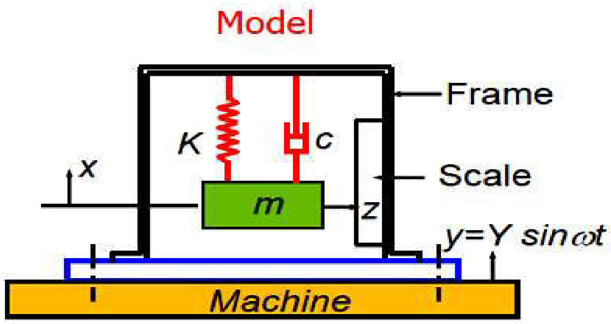
Components of Vibration

- The components of vibration measurement are
  - Acceleration
  - Velocity
  - Displacement
- Spring force $\propto$ displacement
- Damping force $\propto$ velocity
- Inertia force $\propto$ acceleration
- Vibration measurement is necessary to know the response of a structure / a system
- In vibration analysis of a mechanical system, it is required to measure the displacement, velocity and acceleration components of a system.
- An instrument, which is used to measure these parameters, is referred as vibration measuring instrument or seismic instrument or vibration pick up .
- Two types of seismic transducers known as vibrometer and accelerometer are widely used.
- Vibrometer or a seismometer is a device to measure the displacement of a vibrating body.
- Accelerometer is an instrument to measure the acceleration of a vibrating body.
- Vibrometer is designed with low natural frequency and accelerometer with high natural frequency.

- So vibrometer is known as low frequency transducer and accelerometer as high frequency transducer.

Vibrometer

- Consists of a mass – spring damper system mounted on the vibrating body
- The vibratory motion is measured by finding the displacement of mass relative to the base on which it is mounted



m-seismic mass
c-damping coefficient of seismic unit
K-stiffness of spring used in seismic unit
x-absolute displacement of seismic mass
y-base excitation (assume SHM)
z=(x-y) displacement of seismic mass relative to frame

Equation of motion of the seismic mass:

$$m(\ddot{x}-\ddot{y})+c(\dot{x}-\dot{y})+K(x-y)= \; m\ddot{y} \;\ldots\ldots\ldots\ldots\ldots(1)$$

Let, relative displacement of seismic mass is *z=(x-y)*

$$m\ddot{z}+c\dot{z}+Kz = \; m\ddot{y} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

consider base excitation to be Simple Harmonic Motion

$$y(t) = Y \sin \omega t \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$m\ddot{z}+c\dot{z}+Kz = -m\omega^2 Y \sin \omega t \;\ldots\ldots\ldots\ldots\ldots(4)$$

The above equation represents a equation of motion of a forced vibration with $m\omega^2 Y = F$

- On solving the above differential equation , the steady-state solution is given by

$$z(t) = Z \sin(\omega t - \phi)$$

Magnification Factor = $\frac{Z}{Y} = \frac{r^2}{\sqrt{(1-r^2)^2 + (2\xi r)^2}}$ $\qquad r = \frac{\omega}{\omega_n}$

ξ is damping Ratio

r is frequency Ratio $\qquad \zeta = \frac{c}{2m\omega_n}$

- So the relative amplitude Z is shown equal to the amplitude of vibrating body Y on the screen.
- Though Z and Y are not in the same phase but Y being in simple harmonic, will result in the output signal as true reproduction of input quantity.

Laser Doppler vibrometer

- Laser Doppler Vibrometer (LDV) is a Laser based non-contact vibration measurement system.
- The system works on the principle of Doppler Effect and interferometry for vibration measurement

Doppler Effect

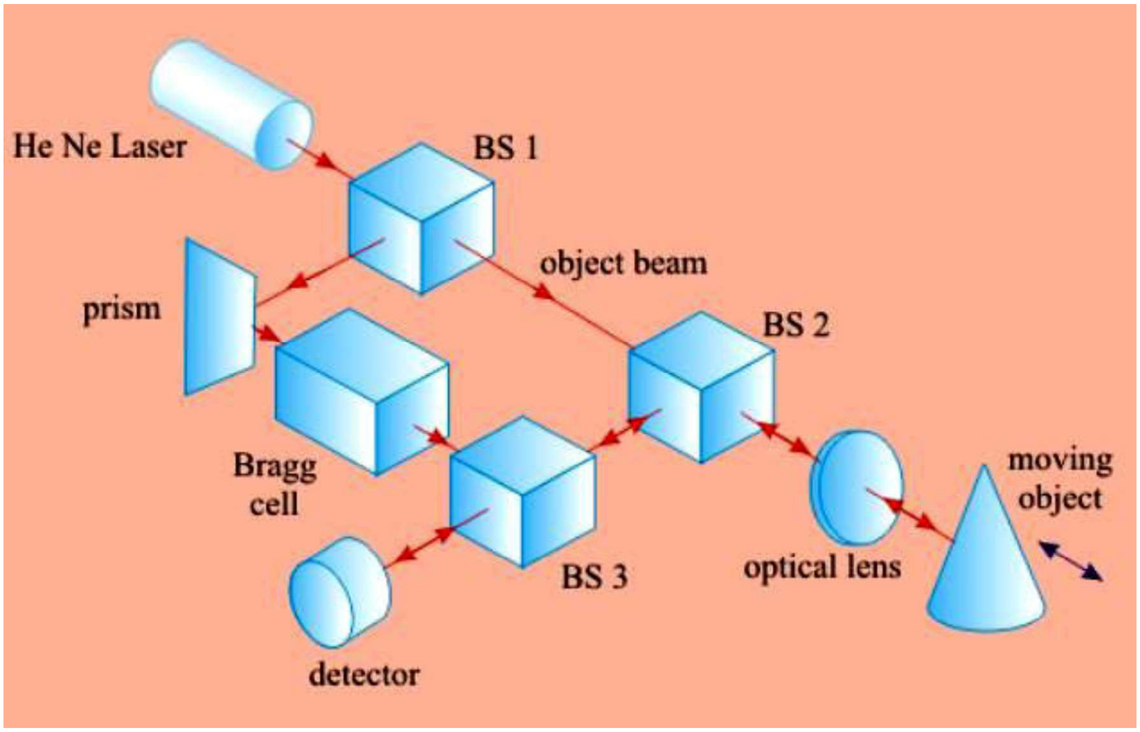
- If a wave is reflected by a moving object and detected by an instrument the measured frequency shift of the wave can be described as:

$$f_D = 2 \cdot v/\lambda$$

  - v is the object's velocity
  - λ is the wavelength of the emitted wave.
- To be able to conversely determine the velocity of an object, the (Doppler) frequency shift has to be measured at a known wavelength. This is done in the LDV by using a laser interferometer.

Interferometry

- The Laser Doppler Vibrometer works on the basis of optical interference requiring two coherent light beams.
- The interference term relates to the path difference between both the beams.
- If the path difference b/w the interfering beams is integral multiplier of Laser wavelength, constructive interference occur
- If the path difference is odd multiplier of half the wave length, destructive interference occurs where the overall intensity becomes zero.
- The interference phenomenon is exploited technically in Laser Doppler Vibrometer as shown in the Figure



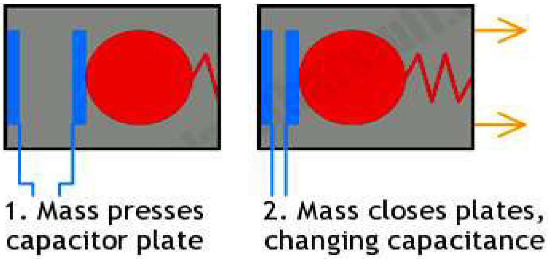
- A laser-Doppler Vibrometer detects the Doppler shift of laser light, that is reflected from the test object
- A laser beam is divided by beam splitter BS1 into a measurement beam and reference beam
- Reference beam propagates & is projected to the photo detector
- After passing through the beam splitter BS2 the measurement beam is focussed onto the sample
- Measurement beam is incident on the test object where the light is scattered by the moving object
- Depending on the velocity & displacement the back scattered light is changed in frequency & phase
- The characteristics of motion are completely contained in the backscattered light
- The superposition of this light with the reference beam creates a modulated detector o/p signal revealing the Doppler shift in frequency
- Signal processing & analysis provides the vibrational displacement of the test object

Accelerometer

- An accelerometer is a sensor that measures the physical acceleration experienced by an object due to inertial forces or due to mechanical excitation.
- An ability of an accelerometer to sense acceleration can be put to use to measure a variety of things like tilt, vibration, rotation, collision, gravity, etc.
- Applications – Vibration measurement, Mobile phones, Aircrafts, Airbags, Washing machines

Capacitive Accelerometers

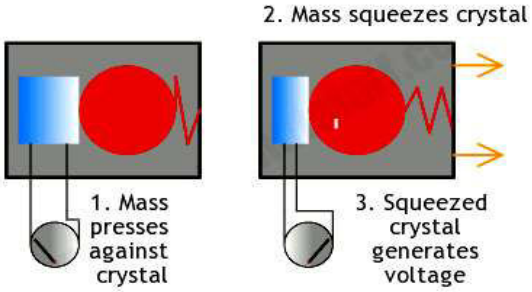
- Capacitors can also be used in accelerometers to measure force.
- If a moving mass alters the distance between two metal plates, measuring the change in their capacitance gives a measurement of the force that's acting.



- As the accelerometer(grey) moves to the right, the mass (red) is left behind and pushes the metal plates (blue) closer together, changing their capacitance in a measurable way.

Piezoelectric Accelerometers

- When the accelerometer moves, the mass squeezes the crystal and generates a electric voltage
- The voltage will be proportional to the accelerative force
- The basic concept of a piezoelectric accelerometer: as the accelerometer box moves right, the mass squeezes the piezoelectric crystal, which generates a voltage. The bigger the acceleration, the bigger the force, and the greater the current that flows

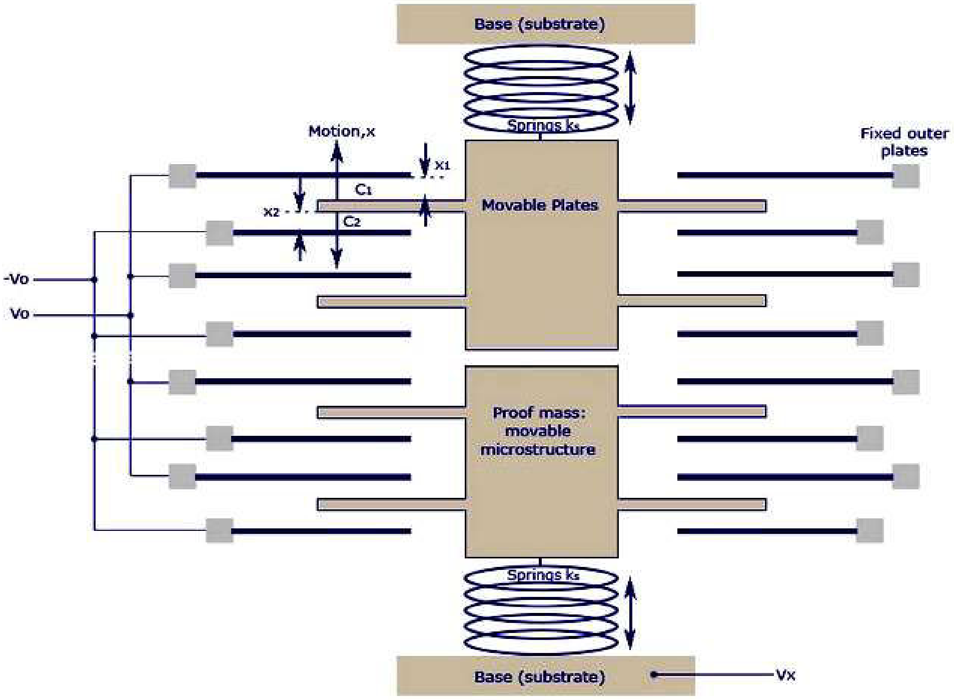


MEMS accelerometer

- An accelerometer is an electromechanical device that is used to measure acceleration and the force producing it.
- Piezoelectric accelerometer are bulky and cannot be used for all operations, a smaller and highly functional device like the MEMS accelerometer was developed.
- MEMS (micro electromechanical systems) accelerometers are manufactured through micro fabrication process
- One of the most commonly used MEMS accelerometer is the capacitive type
- The capacitive MEMS accelerometer is famous for its high sensitivity and its accuracy at high temperatures
- The device does not change values depending on the base materials used
- Depends only on the capacitive value that occurs due to the change in distance between the plates.
- If two plates are kept parallel to each other and are separated by a *distance 'd'*, and if *'ε'* is the *permittivity* of the separating material, then *capacitance* produced can be written as

$$C_0 = \epsilon_0 \epsilon \frac{A}{d} = \epsilon_A \frac{1}{d},$$

- A – is the area of the electrodes
- A change in the values of ε, A or d will cause a change capacitance
- Accelerometer values mainly depend on the change of values of d or A



- MEMS transducer mainly consists of a movable microstructure or a proof mass that is connected to a mechanical suspension system and thus on to a reference frame
- The movable plates and the fixed outer plates act as the capacitor plates.
- When acceleration is applied, the proof mass moves accordingly.
- The deflection of proof mass is measured using the capacitance difference
- The free-space (air) capacitances between the movable plate and two stationary outer plates C1 and C2 are functions of the corresponding displacements x1 and x2

$$C_1 = \epsilon_A \frac{1}{x_1} = \epsilon_A \frac{1}{d+x} = C_0 - \Delta C, \qquad C_2 = \epsilon_A \frac{1}{x_2} = \epsilon_A \frac{1}{d-x} = C_0 + \Delta C.$$

- If the acceleration is zero, the capacitances C1 and C2 are equal because x1 = x2
- The proof mass displacement x results due to acceleration.
- If x ǂ 0, the capacitance difference is found to be

$$C_2 - C_1 = 2\Delta C = 2\epsilon_A \frac{x}{d^2 - x^2}.$$

- By measuring ΔC ,we can calculate the displacement x
- The displacement will be proportional to the capacitance difference
- MEMS accelerometers are used in mobile phones , gaming devices , digital cameras , laptops etc

Temperature Measurement

Use of thermal expansion

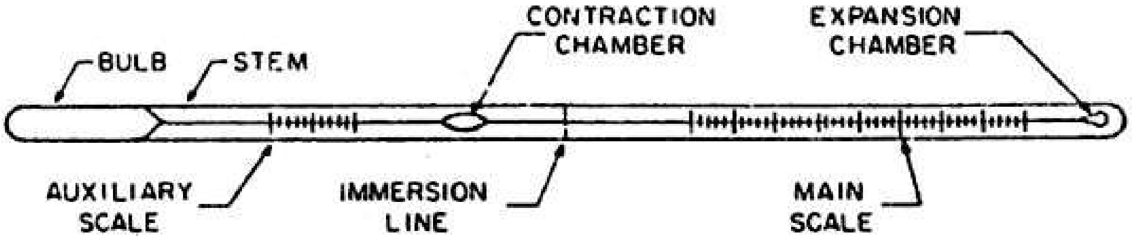
- Thermal expansion is the tendency of matter to change its volume in response to change in temperature
- When a substance is heated, the kinetic energy of the molecules increases
- Molecules begin to vibrate / move more and thus maintain a greater average separation
- Temperature measuring / monitoring systems use the principle of expansion / contraction of liquids, gases or solids when it is exposed to temperature changes
- When liquid confined in a tube, as the temperature increases, the molecules of the liquid move faster, and the liquid expands. The amount of expansion is related to the increase in temperature.

Liquid - in - Glass Thermometer

- The liquid in glass thermometer, is the most commonly used device to measure temperature and it is inexpensive to make and easy to use.
- The components of a typical liquid-in-glass thermometer are:
  - Bulb
  - Stem
  - Auxiliary scale
  - Contraction chamber
  - Immersion line
  - Main Scale
  - Expansion chamber

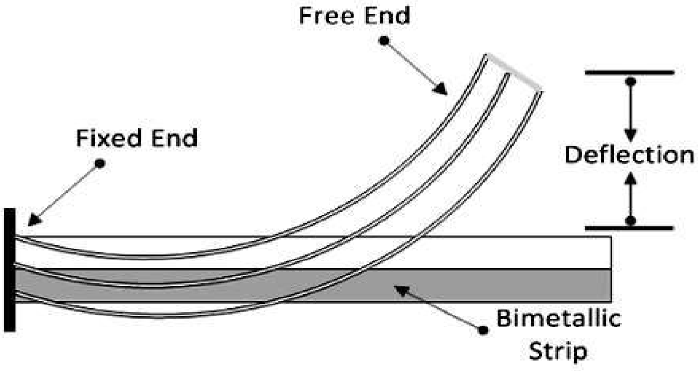
- Bulb: The reservoir for containing most of the thermometric liquid.
- Stem: The glass tube having a capillary bore along which the liquid moves with changes in temperature.
- Auxiliary Scale: A narrow-temperature-range scale for reading a reference temperature (usually the ice point). If the main scale range includes the reference temperature no auxiliary scale is supplied.

- Contraction Chamber: An enlargement of the capillary bore between the auxiliary and main scales, or between the reservoir and the main scale, to limit the length of the capillary (and hence the thermometer).
- Immersion Line: A line marking the depth to which a partial-immersion thermometer should be immersed
- Main Scale: An engraved, etched, or otherwise permanently attached scale with well-defined, narrow graduation lines against which the height of the liquid in the capillary is measured
- There may be a coloured backing material for better visibility of the lines. The main scale is graduated in fractions or multiples of degrees Celsius. If its range incorporates the reference temperature, it is the only scale.
- Expansion Chamber: Enlargement at the top of the capillary into which the liquid can flow if the thermometer temperature exceeds the scale limit.
- It is undesirable for liquid to enter the expansion chamber, however, so it is much better to ensure that there is no overheating of the thermometer.
- The expansion chamber also prevents excessive gas pressure when the thermometer is used near the top of its range, especially in high-temperature pressurized thermometers.



Bimetallic Strip Thermometer

- Are mechanical thermometers
- These thermometers use the following two principles:
  - All metals expand or contract when there is a change in temperature.
  - The rate at which this expansion or contraction takes place depend on the temperature co-efficient of expansion of the metal. Temperature coefficient of expansion is different for different metals. Hence the difference in thermal expansion rates is used to produce deflections which are proportional to temperature changes.



Bimetallic Strip fixed at one end

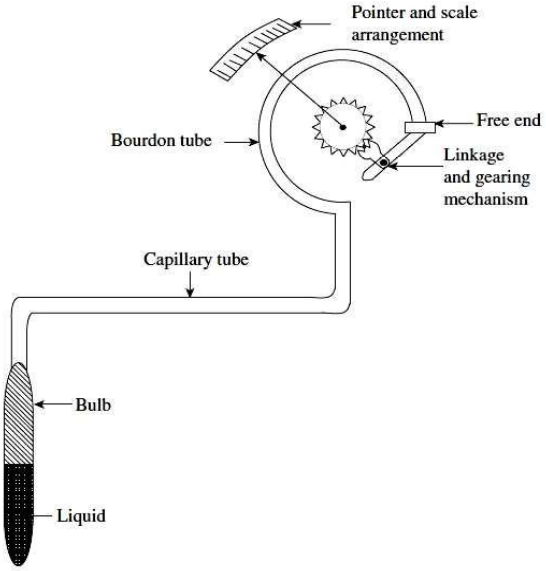
- The bimetallic thermometer consists of a bimetallic strip.
- A bimetallic strip is made of two thin strips of metals which have different coefficients of expansion.
- The two metal strips are joined together by brazing, welding or riveting so that the relative motion between them is arrested.
- The bimetallic strip is in the form of a cantilever beam. An increase in temperature will result in the deflection of the free end of the strip
- Side with a higher coefficient expand more than the side that is less responsive to temperature changes. As a result, the bimetallic strip will bend to one side.
- This deflection is linear and can be related to temperature changes.

Thermostats

- In a thermostat the main component is a bimetallic strip
- With change in temperature the the side with a higher coefficient of expansion expand more than the side with lower coefficient of expansion.
- As a result, the bimetallic strip will bend to one side
- When the strip bend it will close an electrical circuit and the air conditioner go into action
- By adjusting the thermostat, one varies the distance that the bimetallic strip must be bent in order to close the circuit
- Once the air in the room reaches the desired temperature, the high-coefficient metal will begin to contract, and the bimetallic strip will straighten. This will cause an opening of the electrical circuit, disengaging the air conditioner.

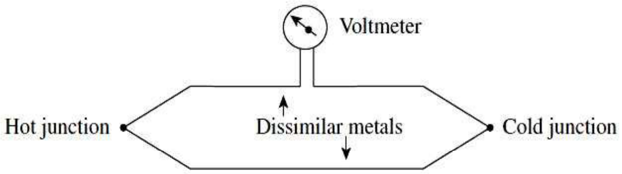
Pressure Thermometer

- The change in temperature can be measured using pressure thermometers.
- Work on the principle of thermal expansion
- Temperature change can be determined using these thermometers, which rely on pressure measurement.
- Depending on the filling medium, pressure thermometers can be classified as liquid, gas, or a combination of liquid and its vapour.
- Pressure thermometers comprise the following components:
  - ✓ A bulb filled with a liquid, vapour, or gas
  - ✓ A flexible capillary tube;
  - ✓ A bourdon tube
- Due to variation in temperature, the pressure and volume of the system change and the fluid either expands or contracts.
- This causes the bourdon tube to move or uncoil, which actuates the needle on the scale, thus providing a measure of the temperature



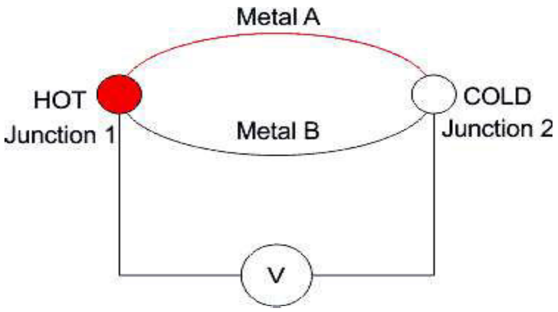
Thermocouple

- Thermocouples are active sensors employed for the measurement of temperature.
- The thermoelectric effect is the direct conversion of temperature differences to an electric voltage.
- When two dissimilar metals are joined together to form two junctions such that one junction (hot junction / measured junction) is at a higher temperature than the other junction (cold junction / reference junction), a net emf is generated.



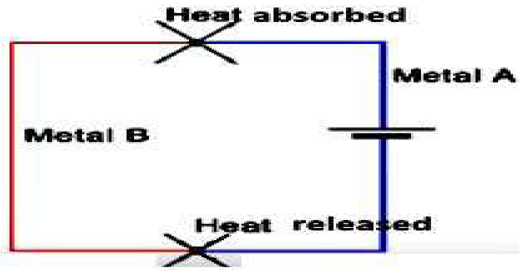
Principle of operation: Seebeck effect

- If two junctions of thermo-couple are placed at different temperature, then an emf will be produced in thermo-couple which will be proportional to the temperature difference



Peltier Effect

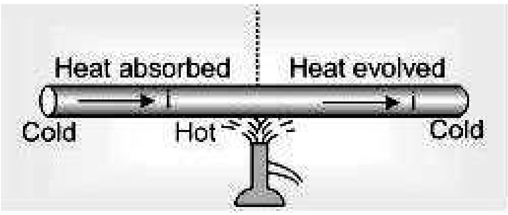
- It is reverse of Seebeck effect.
- According to this, when an electric current is passed through thermo-couple, heat is evolved at one junction and absorbed at the other end i.e. one end become hot while other become cold.



Peltier effect

Thomson Effect

- If a conductor is placed in varying temperature along its length and current is passed through it then it will absorb or evolve heat.

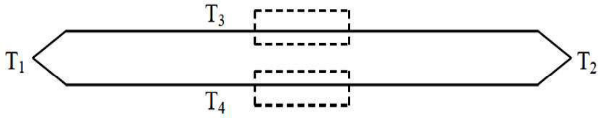


Laws of Thermocouples

- Apart from the Peltier and Thomson effects, which form the basis of thermoelectric emf generation
- Three laws of thermocouples that govern this phenomenon are required to be studied in order to understand their theory and applicability
- Provide some useful information on the measurement of temperature.

Law of homogeneous Circuits

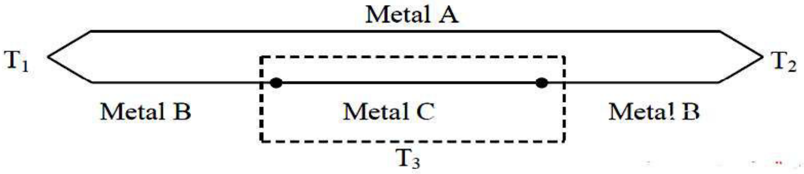
- Thermoelectric current cannot be sustained in a circuit of a single homogenous material, regardless of the variation in its cross section and by the application of heat alone.
- This law suggests that two dissimilar materials are required for the formation of any thermocouple circuit.
- If two thermocouple junctions are at T_1 and T_2 , then the thermal emf generated is independent and unaffected by any temperature distribution along the wires
- The emf generated is a function of temperature gradient (T_1-T_2)
  α – Seebeck coefficient



$$V = \alpha(T_1 - T_2)$$

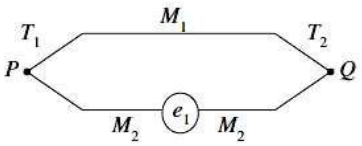
Law of intermediate metals

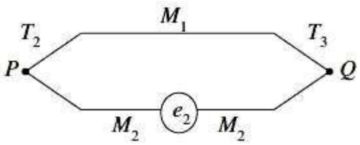
- Law of intermediate metals states that a third metal may be inserted in to a thermocouple system if and only if the junctions with the third metal are kept at same temperature.

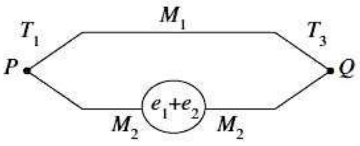


Law of intermediate temperatures

- If a thermocouple circuit generates an emf e1 when its two junctions are at temperatures T1 and T2, and e2 when the two junctions are at temperatures T2 and T3, then the thermocouple will generate an emf of e1 + e2 when its junction temperatures are maintained at T1 andT3.

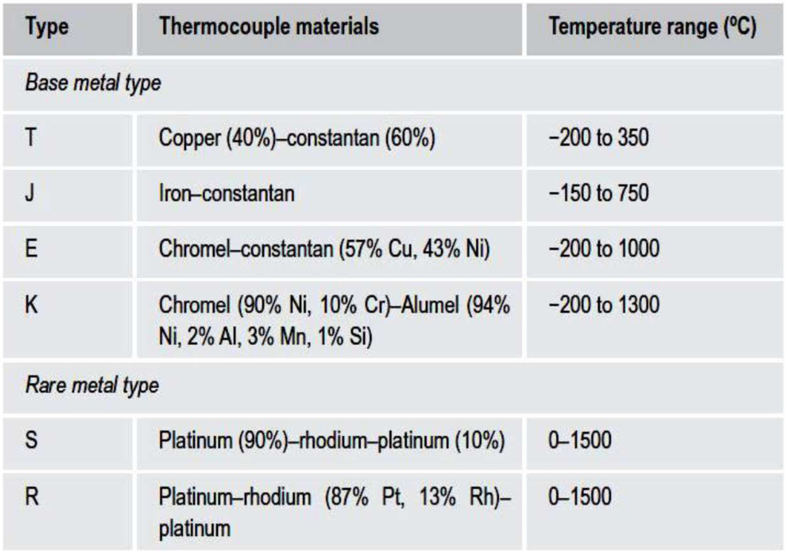






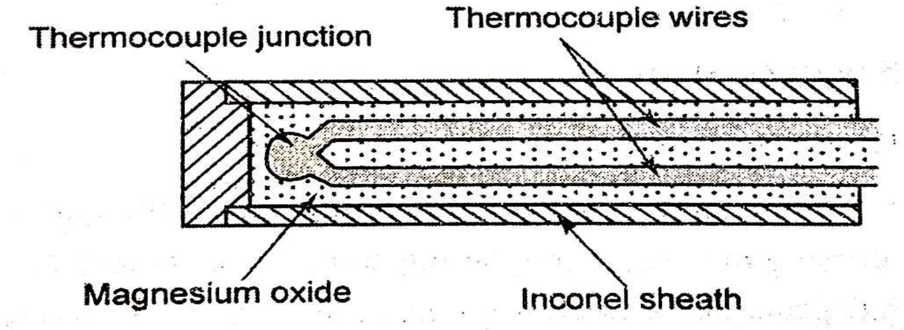
Thermocouple materials

- Any two different materials can be used to form a thermocouple
- However, only a few are suitable for temperature measurement applications
- Thermocouple materials are divided into base metal type and rare, noble, or precious metal type
- Platinum (platinum–rhodium) thermocouples are called noble thermocouples, and all other thermocouples belong to the base metal type.



Type	Thermocouple materials	Temperature range (ºC)
Base metal type		
T	Copper (40%)–constantan (60%)	−200 to 350
J	Iron–constantan	−150 to 750
E	Chromel–constantan (57% Cu, 43% Ni)	−200 to 1000
K	Chromel (90% Ni, 10% Cr)–Alumel (94% Ni, 2% Al, 3% Mn, 1% Si)	−200 to 1300
Rare metal type		
S	Platinum (90%)–rhodium–platinum (10%)	0–1500
R	Platinum–rhodium (87% Pt, 13% Rh)–platinum	0–1500

Construction of Thermocouple

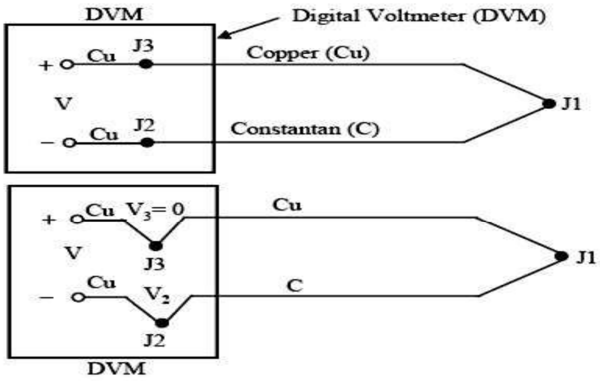


- Leads of the thermocouple are encased in a rigid metal sheath
- The measuring junction is at the bottom of the thermocouple housing
- Magnesium oxide surrounds the thermocouple wires

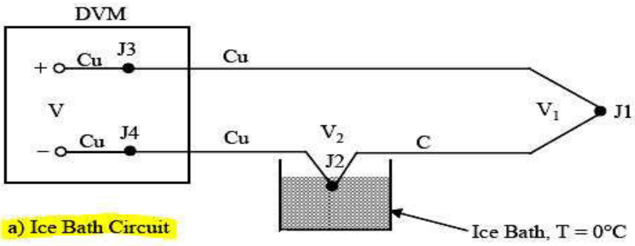
- Prevent vibration that could damage the fine wires & to enhance heat transfer b/w the measuring junction & the medium surrounding the thermocouple
- A voltmeter cannot be directly connected to a thermocouple because the voltmeter leads themselves create a new thermoelectric circuit.
- The voltage across the thermocouple is measured by physically putting one junction in to ice bath.

Measurement of thermocouple emf

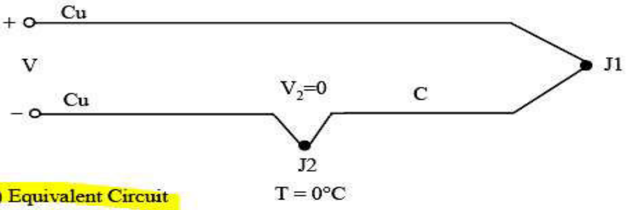
- Consider a digital voltmeter (DVM) that is connected across a copper-constantan thermocouple.
- We need to measure the output voltage V1 at junction J1
- But the addition of voltmeter created two more metallic junctions : J2 and J3
- Since J3 is a copper-to-copper junction, it creates no thermal voltage



- However, J2 is a copper-to-constantan junction, which will add a voltage V_2 in opposition to V_1.
- The resultant voltmeter reading *V* will be proportional to the temperature difference between J1 and J2. (T1 & T2 may change)
- One way to determine the temperature of J2 is to physically put the junction into an ice bath.
- This forces its temperature to be 0°C and establishes J2 as the "reference junction".
- Now both voltmeter terminal junctions are now copper-copper, they create no thermal voltage, and the reading "*V*" on the voltmeter is proportional to the temperature difference between J1 and J2.



a) Ice Bath Circuit



b) Equivalent Circuit

$$V = V_1 - V_2 = \alpha(T_{J1} - T_{J2}) = \alpha(T_{J1} - 0) = \alpha T_{J1}$$

α - Seebeck coefficient

Resistance Temperature Detectors (RTDs)

- RTDs are also known as resistance thermometers
- When a metal wire is heated, the resistance increases
- So temperature can be measured using the resistance of a wire
- An RTD is a temperature sensor that works on the principle that the resistance of electrically conductive materials is proportional to the temperature to which they are exposed.
- Resistance of a metal increases with an increase in temperature. So, metals can be classified as per their positive temperature coefficient (PTC)
- RTDs converts the temperature to voltage signals by measurement of resistance
- RTD elements are constructed of platinum, copper, nickel or nickel – iron alloys
    - Because of *Linear resistance – temperature characteristics, high coefficient of resistance & ability to withstand repeated temperature cycles*
- The linear relationship of resistance – temperature is given by:

$$\mathbf{R = R_0 (1 + \alpha T)}$$

Where,

R is the resistance at a temperature T ^{o}C

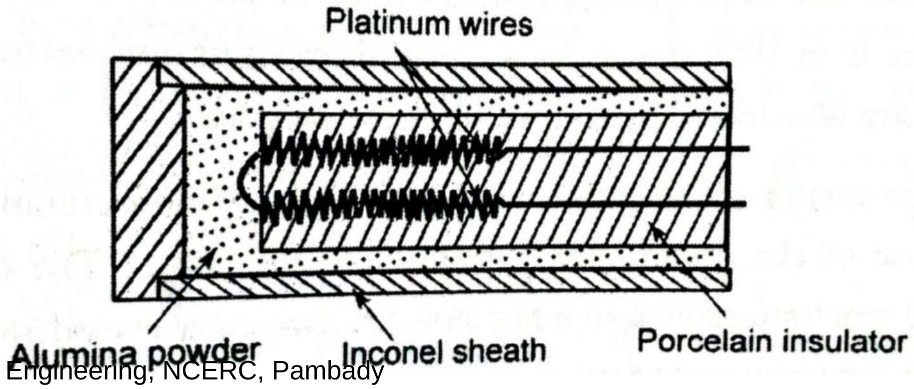
R_0 is the resistance at temperature at 0 ^{o}C

α is the temperature coefficient of resistance

- The RTD temperature coefficient represents the sensors' sensitivity to temperature change
- The larger the temperature coefficient (α), the larger the resistance change (ΔR) in response to an ambient temperature change (ΔT)

Construction of RTD

- The material used must be capable of being drawn into fine wire so that the element can be easily constructed
- RTD elements are long, spring like wires surrounded by an insulator & enclosed in a sheath of metal for protection.



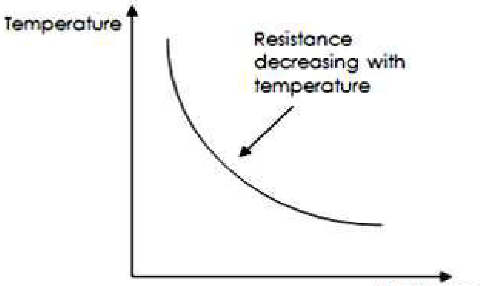
- Platinum is used as RTD element that is surrounded by a porcelain insulator
- Insulator prevents a short circuit b/w wire & metal sheath
- Inconel is normally used in manufacturing of RTD sheath because of its inherent corrosion resistance
- When it is placed in a liquid or gas medium, the Inconel sheath quickly reaches the temperature of the medium
- The change in temperature will cause the platinum wire to heat or cool
- Thereby resulting a proportional change in resistance
- Measured by a resistance measuring device calibrated to give proper temperature reading

- **Advantages :**
  - Suitable for measuring high temperatures
  - High accuracy, good stability & repeatability
  - Low drift
  - Wide operating range
  - Suitability for precision applications

- **Disadvantages :**
  - Size is more than thermocouple
  - Power supply is required
  - Resistance element is more expensive than thermocouple
  - Chances of error due to self heating & thermoelectric effect of resistive element

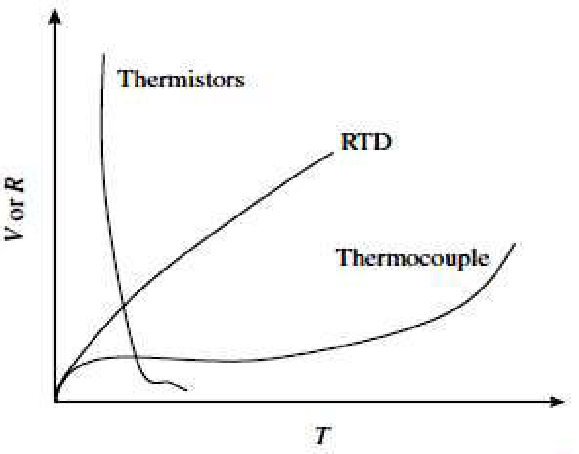
Thermistors

- A thermistor is a resistance thermometer or a resistor whose resistance is dependent on temperature
- A thermistor is similar to an RTD, but a semiconductor material is used instead of a metal
- The name comes from a combination of the words "resistor" & "thermal"
- Resistance can change by more than 1000 times.
- Thermistors sense minute changes in temperature undetected by RTDs & thermocouples
- There are two types:
- *PTC (Positive Temperature Coefficient of Resistance).* Resistance increases with increase in temperature. Used in electric current control devices
- *NTC (Negative Temperature Coefficient of Resistance)*- Resistance decreases with increase in temperature
- The most common type of Thermistors are those in which resistance decreases as the temperature increases (NTC)



- The relationship between temperature and resistance is given by the following equation

$$R = R_R e^{\beta\left(\frac{1}{T}-\frac{1}{T_R}\right)}$$



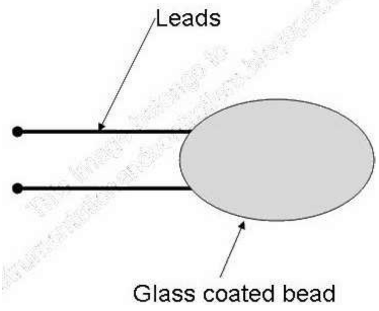
Comparison of temperature characteristics

Here, R is the resistance at temperature T

R_R is the resistance at the reference temperature T_R

β is a constant

- Thermistor are composed of sintered mixture of metallic oxides such as manganese, nickel cobalt, copper, iron and uranium
- Ground to fine powder, compressed & subjected to high heat.
- They are available in variety of sizes and shapes
- Thermistors may be in the form of beads, probes, rods and discs

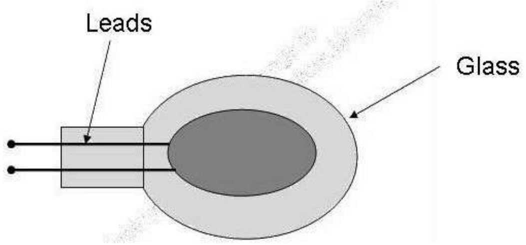


Bead Thermistors

- Smallest Thermistors are in the form of heads with a diameter of 0.15mm to 1.25mm. This is the most familiar type of Thermistor usually glass coated.

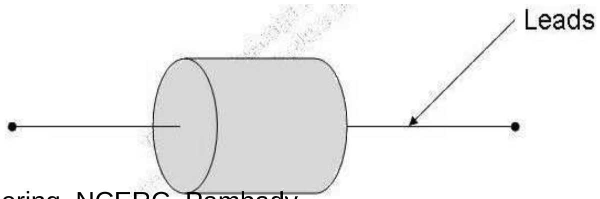
Probe Thermistors

- Beads may be sealed in the tips of solid glass rods to form probes Glass probe have a diameter of about 2.5mm.
- The probes are used for measuring temperature of liquids.



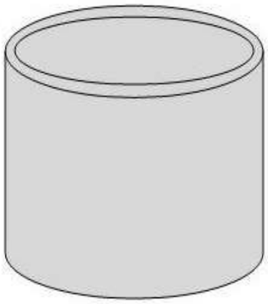
Disc Thermistors

Discs are made by pressing material under high pressure into cylindrical flat shapes with a diameters ranging from 2.5mm to 25mm. they are mainly used for temperature control.



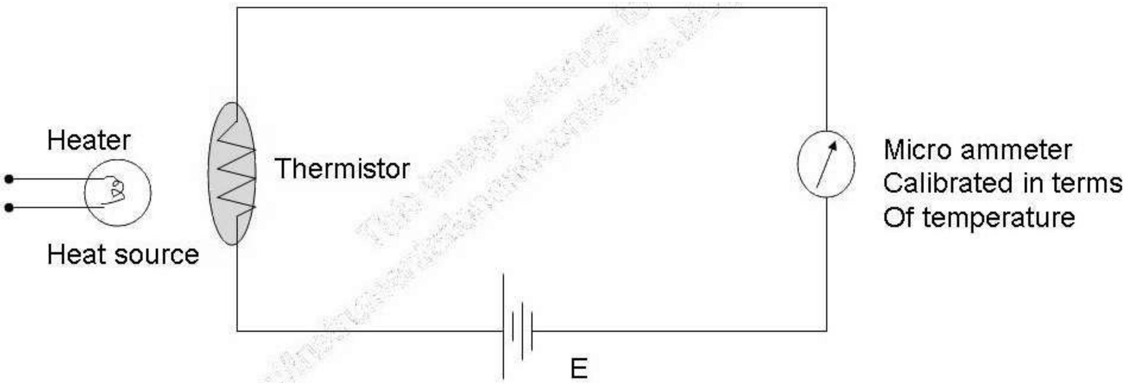
Washer Type Thermistors

- Washer type is usually long cylindrical units
- Leads are attached to the ends of the rods
- The advantage of this type is, it produce high resistance under moderate power



Temperature measurement using Thermistors

- Thermistor is placed in the environment whose temperature is to be measured.
- Thermistor is connected in a circuit consisting of battery and micro-ammeter
- Any change in temperature causes a change in resistance of Thermistor.
- Hence, corresponding change in circuit current.
- By directly calibrating micro ammeter in terms of temperature, we can measure temperature



Advantages of using RTDs

- Possess very high sensitivity, than that of RTDs & thermocouples
- Manufactured in any shape & size
- Withstand mechanical & electrical stresses
- Response is fast
- Inexpensive
- High degree of accuracy

Limitations

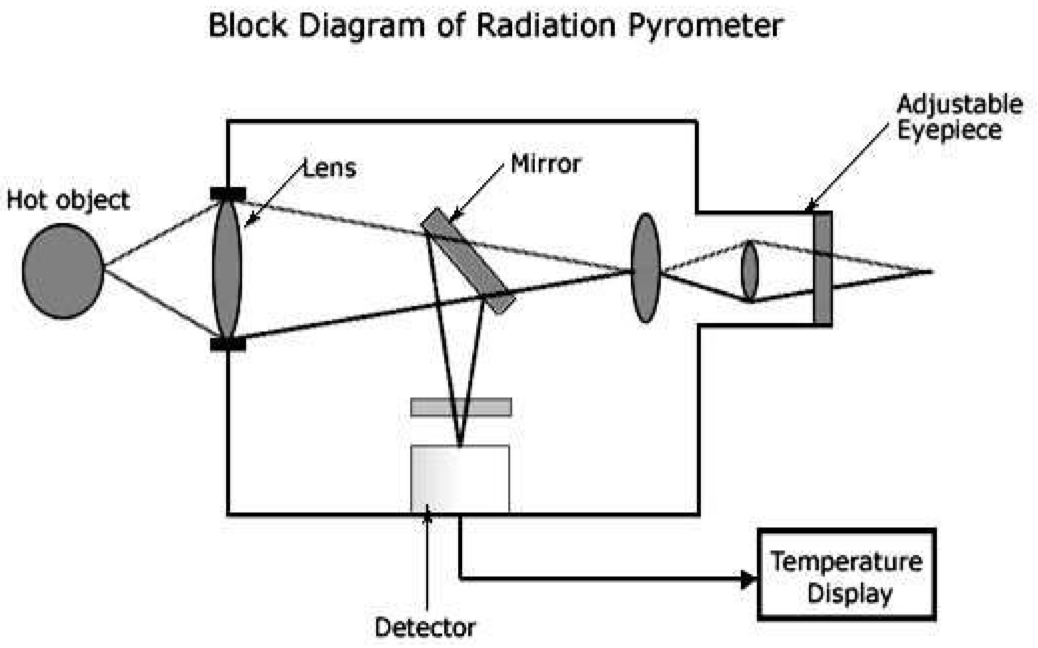
- Limited measuring range
- Poor performance at higher temperatures
- Self heating errors may occur

Pyrometers

- Pyrometers are non- contact type temperature measurement instruments.
- A pyrometer is a device that is used for the temperature measurement of an object.
- Pyrometers are used in temperature measurement through a measurement of thermal radiation emitted by the body or based on the change in intensity & colour of radiation
    - Radiation Pyrometer
    - Optical Pyrometer
    - IR Pyrometer
- Unlike a RTD, thermocouple, there is no direct contact between the pyrometer and the object whose temperature is to be found out

Radiation Pyrometer

- This device is used in places where physical contact temperature sensors like Thermocouple, RTD, & Thermistors would fail because of the high temperature of the source
- The main theory behind a radiation pyrometer is that the temperature is measured through the naturally emitted heat radiation by the body.
- This heat is known to be a function of its temperature
- The radiation pyrometer has an optical system, including a lens, a mirror and an adjustable eye piece.
- The heat energy emitted from the hot body is passed on to the optical lens, which collects it and is focused on to the detector with the help of the mirror and eye piece arrangement

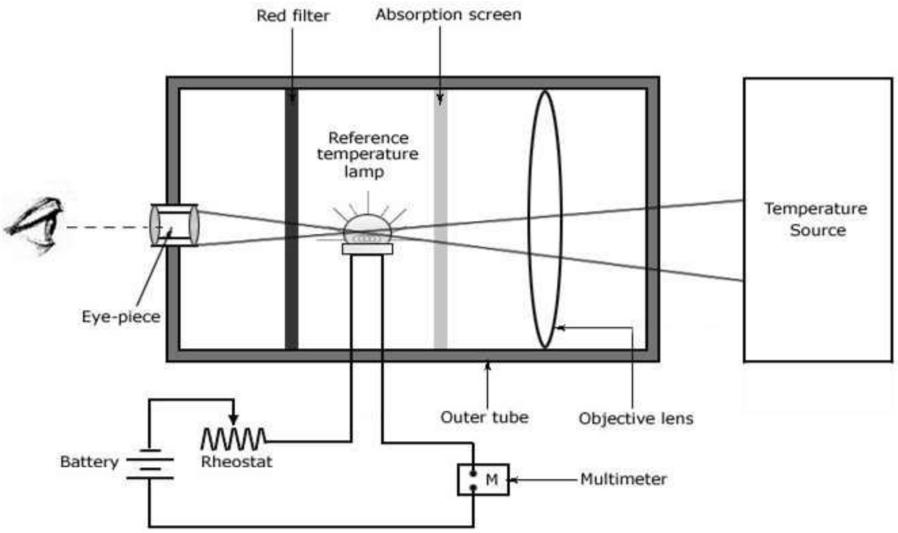


- The detector may either be a thermistor or photomultiplier tubes
- The latter is known for faster detection of fast moving objects, the former may be used for small scale applications
- Thus the heat energy is converted to its corresponding electrical signal by the detector and is sent to the output temperature display device

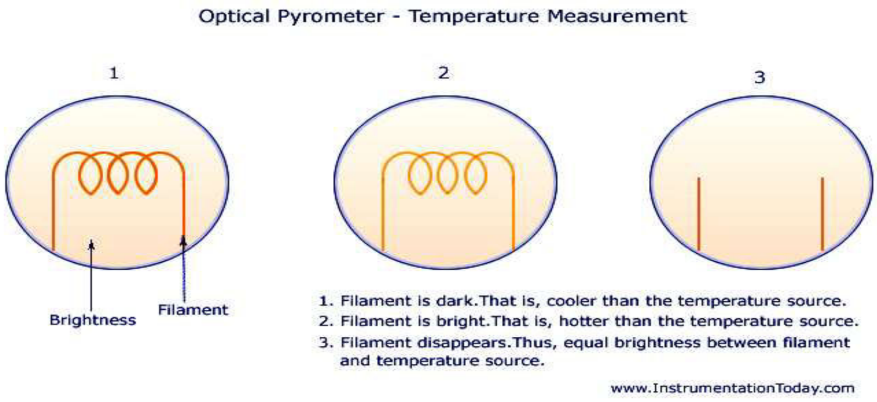
- **Advantages:**
  - It is a non-contact-type device.
  - It gives a very quick response.
  - High-temperature measurement can be accomplished.
- **Disadvantages:**
  - Errors in temperature measurement are possible due to emission of radiations to the atmosphere.
  - Emissivity errors affect measurements.

Optical Pyrometer

- In an optical pyrometer, a brightness comparison is made to measure the temperature
- Compares the brightness produced by the radiation of the object whose temperature is to be measured, with that of a reference temperature
- The reference temperature is produced by a lamp
- The brightness of the lamp can be adjusted till its intensity becomes equal to the brightness of the source object
- For an object, its light intensity always depends on the temperature of the object, whatever may be its wavelength.
- After adjusting the intensity, the current passing through it is measured using a multimeter, as its value will be proportional to the temperature of the source when calibrated
- *An optical pyrometer has following components*
  - An eye piece at the left side and an optical lens on the right.
  - A reference lamp, which is powered with the help of a battery.
  - A rheostat to change the current and hence the brightness intensity.
  - Absorption screen is fitted between the optical lens and the reference bulb to increase the temperature range
  - A red filter placed between the eye piece and the reference bulb helps in narrowing the band of wavelength.



- The radiation from the source is focussed by objective lens on to the reference bulb.
- The eyepiece is adjusted such that the filament of the reference lamp is in a sharp focus and the filament is super-imposed on the temperature source image.
- Controlling the rheostat values the current in the reference lamp changes
- This in turn, changes its intensity. This change in current can be observed in three different ways.



1. Filament is dark.That is, cooler than the temperature source.
2. Filament is bright.That is, hotter than the temperature source.
3. Filament disappears.Thus, equal brightness between filament and temperature source.

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1. <u>The filament is dark:</u> That is, cooler than the temperature source.
2. <u>Filament is bright:</u> That is, hotter than the temperature source.
3. <u>Filament disappears:</u> Thus, there is equal brightness between the filament and temperature source.
    - At this time, the current that flows in the reference lamp is measured, as its value is a measure of the temperature of the radiated light in the temperature source, when calibrated.

- **Advantages**
  - Simple assembling of the device enables easy use of it.
  - Provides a very high accuracy with +/- 5 degree Celsius.
  - There is no need of any direct body contact
  - Relatively inexpensive
  - Does not depend on surface properties of material

- **Disadvantages**
  - Not suitable for low temperature measurement. Temperature more than 700 degree Celsius can only be measured, as the measurement is based on the light intensity.
  - Adjustment of standard lamp temperature is done manually. So it may cause some error

- **Applications**
  - Used to measure temperatures of liquid metals or highly heated materials.
  - Can be used to measure furnace temperatures.