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

DEPARTMENT OF MECHATRONICS ENGINEERING

COURSE MATERIALS

MR 205 SCIENCE OF MEASUREMENTS

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: 2013
- Course offered: B.Tech Mechatronics 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

To develop professionally ethical and socially responsible Mechatronics engineers to serve the humanity through quality professional education.

DEPARTMENT MISSION

1) The department is committed to impart the right blend of knowledge and quality education to create professionally ethical and socially responsible graduates.
2) The department is committed to impart the awareness to meet the current challenges in technology.
3) Establish state-of-the-art laboratories to promote practical knowledge of mechatronics to meet the needs of the society

PROGRAMME EDUCATIONAL OBJECTIVES

I. Graduates shall have the ability to work in multidisciplinary environment with good professional and commitment.
II. Graduates shall have the ability to solve the complex engineering problems by applying electrical, mechanical, electronics and computer knowledge and engage in lifelong learning in their profession.
III. Graduates shall have the ability to lead and contribute in a team with entrepreneur skills, professional, social and ethical responsibilities.
IV. Graduates shall have ability to acquire scientific and engineering fundamentals necessary for higher studies and research.

PROGRAM OUTCOME (PO'S)

Engineering Graduates will be able to:

PO 1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO 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.

PO 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.

PO 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.

PO 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.

PO 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.

PO 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.

PO 8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO 9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 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.

PO 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.

PO 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 OUTCOME(PSO'S)

PSO 1: Design and develop Mechatronics systems to solve the complex engineering problem by integrating electronics, mechanical and control systems.

PSO 2: Apply the engineering knowledge to conduct investigations of complex engineering problem related to instrumentation, control, automation, robotics and provide solutions.

COURSE OUTCOME

After the completion of the course the student will be able to

CO 1	Describe measurement system and the types of errors in measurement
CO 2	Understand various parameters of measurement systems
CO 3	Acquire knowledge about various sensors and transducers
CO 4	Gain Knowledge about the working of various measurement instruments
CO 5	Understand the concept of linear and angular measurements
CO 6	Recognize various measurement methods.

CO VS PO'S AND PSO'S MAPPING

CO	PO1	PO 2	PO3	PO 4	PO5	PO6	PO7	PO8	PO9	PO 10	PO 11	PO 12	PS0 1	PSO 2
CO 1	2	2	1	-	-	1	-	-	-	1	-	1	2	2
CO 2	3	2	2	-	-	2	-	-	-	1	-	2	2	2
CO 3	3	2	2	-	-	3	-	-	-	1	-	3	3	3
CO 4	3	2	2	-	-	2	-	-	-	1	-	3	3	3
CO 5	3	3	3	-	-	2	-	-	-	1	-	3	2	2
CO 6	3	3	3	-	-	2	-	-	-	1	-	3	3	2

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
MR205	Science of Measurements	3-0-0-3	2016

Prerequisites : Nil

Course Objectives

- To understand the basic principles of measurements.
- To learn about various methods of measuring instruments

Syllabus

Mechanical measurement- direct comparison and indirect comparison-the generalized measurement system- types of input quantities'- calibration- uncertainty- systematic and random errors-common type of errors- terms used in rating instrument performance- propagation of uncertainty- Kline and Mclintock approach-Zero, First and Second order instruments- input output configuration of generalized measurement system-Sensors – primary and secondary transducers – active and passive transducers - Measurement of temperature – expansion thermometers-resistance thermometers– thermo electric thermometers-Pyrometers – optical, total radiation and photo electric pyrometers- Measurement of flow -Measurement of low pressure- measurement of high pressure – Linear and angular measurement- Measurement of surface roughness - Measurement of screw thread profiles – gear tooth measurement

Expected outcome.

- The students will pick up familiarity with basics of measurements, methods of measuring various parameters and dimensions in engineering applications.

Text Book:

1.Ernest O Doebelin, Measurement Systems Application and Design, Mc Graw- Hill Publishing Company
2. Jain R.K., "Engineering Metrology", Khanna Publishers.
3. Beckwith, Marangoni, Lienhard, "Mechanical Measurements", Pearson Education.

References:

1. Gupta S.C, "Engineering Metrology", Dhanpat rai Publications, 2005
2. Jayal A.K, "Instrumentation and Mechanical Measurements", Galgotia Publications 2000
3. A.K Sawhney "A course in Mechanical Measurements and Instrumentation & Control"
4. Donald Deckman, "Industrial Instrumentation", Wiley Eastern, 1985.
5. Alan S. Morris, "The Essence of Measurement", Prentice Hall of India, 1997

Course Plan

Module	Contents	Hours	Sem. Exam Marks
I	Mechanical measurement- direct comparison and indirect comparison-the generalized measurement system- types of input quantities- calibration- uncertainty- systematic and random errors-common - type of errors- classification of errors- terms used in rating instrument performance- introduction to uncertainty analysis-propagation of uncertainty- Kline and Mclintock approach .	7	15%
II	Zero, First and Second order instruments –input output configuration of generalized measurement system-methods for correcting for spurious inputs- inherent insensitivity-high gain feedback-signal filtering and opposing input	7	15%
FIRST INTERNAL EXAMINATION			

III	Sensors – primary and secondary transducers – active and passive transducers - linear variable differential transformer – construction and characteristics– capacitance transducers – piezo electric transducers – photoelectric sensors – Hall Effect transducers – Resistance wire strain gauges-gauge factor-measuring circuits-calibration	7	15%
IV	Expansion thermometers – liquid in glass thermometer – partial and total immersion thermometers – resistance thermometers–thermistors – Thermo electric thermometers – laws of thermocouples –Pyrometers – optical, total radiation and photo electric pyrometers Measurement of flow – rotameter -magnetic flow meters – hotwire anemometers – Measurement of low pressure – McLeod gauge – thermal conductivity gauge – measurement of high pressure – bulk modulus gauge	7	15%
SECOND INTERNAL EXAMINATION			
V	Linear and angular measurement: slip gauges - Measurement of angles – sine bar – sine center – angle gauges – optical instruments for angular measurement- auto collimator – applications – straightness and squareness –angle dekkor – Measurement of surface roughness – surface texture – methods of measuring surface finish -the Talysurf instrument – the profilograph – Tomlinson surface meter – Tracer type profilograph	7	20%
VI	Measurement of screw thread profiles – errors in pitch–microscopic method – measurement of internal thread – measurement of effective diameter – two wire and three wire method – measurement of root diameter – gear tooth measurement – measurement of gear profile – tooth thickness – tooth spacing – pitch circle diameter – Parkinson s gear tester.	7	20%
END SEMESTER EXAM			

QUESTION PAPER PATTERN

Maximum Marks : 100 Exam Duration:3 hours

PART A: FIVE MARK QUESTIONS

8 compulsory questions –1 question each from first four modules and 2 questions each from last two modules (8 x 5= 40 marks)

PART B: 10 MARK QUESTIONS

5 questions uniformly covering the first four modules. Each question can have maximum of three sub questions, if needed. Student has to answer any 3 questions

(3 x10 = 30 marks)

PART C: 15 MARK QUESTIONS

4 questions uniformly covering the last two modules. Each question can have maximum of four sub questions, if needed. Student has to answer any two questions

(2 x15 = 30 marks)

QUESTION BANK

Q:NO:	QUESTIONS	CO	KL	PAGE NO:
MODULE I				
1	Explain the needs of inspection	CO1	**K2**	12
2	What are the objective of metrology?	CO1	**K1**	14
3	What are the sub divisions of standards?	CO1	**K2**	19
4	Explain the methods of measurements.	CO1	**K2**	25
5	Define precision and accuracy.	CO1	**K2**	27
6	What is error? What are the classification of errors?	CO1	**K1**	30
7	Compare systematic and random errors?	CO1	**K3**	33
8	What is standardization? Explain briefly about standard organization.	CO1	**K2**	42
MODULE II				
1	Define zero order system.	CO2	K2	48
2	Compare first and second order system.	CO2	K3	48
3	Explain input-output configuration of instruments.	CO2	K2	49
4	What are the methods to correcting interfering input?	CO2	K2	51
5	Explain inherent insensitivity.	CO2	K2	52
6	Explain signal filtering.	CO2	K2	54
7	Explain methods of opposing inputs.	CO2	K2	56
MODULE III				
1	Explain primary and secondary transducer	CO3	K2	62

2	Explain active and passive transducers.	CO3	K2	62
3	Explain working of LVDT with neat fig.	CO3	K2	69
4	What is capacitive transducer? Explain with neat fig.	CO3	K2	77
5	Explain piezo electric transducer with neat fig.	CO3	K2	73
6	Explain the working of Hall effect transducer with neat fig.	CO3	K2	71
MODULE IV				
1	How to measure temperature? List out the devices used for measuring temperature.	CO4	K4	83
2	Explain working of liquid-glass thermo meter	CO4	K2	94
3	What is resistance thermometer? explain with neat fig.	CO4	K2	87
4	What is the principle of thermocouple? Explain working of thermocouple with neat fig.	CO4	K2	102
5	Explain Mcleod gauge with neat figure.	CO4	K2	89
6	What is a thermistor? Explain with neat fig.	CO4	K2	100
MODULE V				
1	Explain working of slip gauge.	CO5	K2	126
2	How to measure angles?	CO5	K2	129
3	Explain the working of vernier caliper.	CO5	K2	115
4	Explain the working of vernier height gauge.	CO5	K2	118
5	Explain the working of micrometer.	CO5	K2	121
MODULE 6				
1	Explain screw thread terminology.	CO6	K	139
2	List out screw thread measuring device.	CO6	K	142
3	Explain screw thread micrometer.	CO6	K	144
4	Explain screw pitch gauge.	CO6	K	145
5	Explain three wire method.	CO6	K	146

6	How to measure minor diameter?	CO6	K	147
7	How to measure minor diameter?	CO6	K	148

APPENDIX 1

CONTENT BEYOND THE SYLLABUS

MODULE 1

Mechanical Measurement & Metrology

Course Contents

1.1 Introduction

- Metrology is a science of measurement. Metrology may be divided depending upon the quantity under consideration into: metrology of length, metrology of time etc. Depending upon the field of application it is divided into industrial metrology, medical metrology etc.
- Engineering metrology is restricted to the measurement of length, angles and other quantities which are expressed in linear or angular terms.
- For every kind of quantity measured, there must be a unit to measure it. This will enable the quantity to be measured in number of that unit. Further, in order that this unit is followed by all; there must be a universal standard and the various units for various parameters of importance must be standardized.
- It is also necessary to see whether the result is given with sufficient correctness and accuracy for a particular need or not. This will depend on the method of measurement, measuring devices used etc.
- Thus, in a broader sense metrology is not limited to length and angle measurement but also concerned with numerous problems theoretical as well as practical related with measurement such as:

1. Units of measurement and their standards, which is concerned with the establishment, reproduction, conservation and transfer of units of measurement and their standards.
2. Methods of measurement based on agreed units and standards.
3. Errors of measurement.
4. Measuring instruments and devices.
5. Accuracy of measuring instruments and their care.
6. Industrial inspection and its various techniques.
7. Design, manufacturing and testing of gauges of all kinds.

1.2 Need of Inspection

- Inspection means checking of all materials, products or component parts at various stages during manufacturing. It is the act of comparing materials, products or components with some established standard.

- In old days the production was on a small scale, different component parts were made and assembled by the same craftsman. If the parts did not fit properly at the time of assembly, he used to make the necessary adjustments in either of the mating parts so that each assembly functioned properly.
- Therefore, it was not necessary to make similar parts exactly alike or with same accuracy as there was no need of inspection.
- Due to technological development new production techniques have been developed. The products are being manufactured on a large scale due to low cost methods of mass production. So, hand fit method cannot serve the purpose any more. The modern industrial mass production system is based on interchangeable manufacture, when the articles are to be produced on a large scale.
- In mass production the production of complete article is broken up into various component parts. Thus the production of each component part becomes an independent process. The different component parts are made in large quantities in different shops. Some parts are purchased from other factories also and then assembled together at one place. Therefore, it becomes essential that any part chosen at random should fit properly with any other mating parts that too selected at random. This is possible only when the dimensions of the component parts are made with close dimensional tolerances. This is only possible when the parts are inspected at various stages during manufacturing.
- When large number of identical parts are manufactured on the basis of interchangeability if their dimensions are actually measured every time lot of time will be required. Hence, to save the time gauges are used, which can tell whether the part manufactured is within the prescribed limits or not.

Thus, the need of inspection can be summarized as:

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

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

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

1.3 Objectives of Metrology

While the basic objective of a measurement is to provide the required accuracy at minimum cost, metrology would have further objective in a modern engineering plant with different shops like Tool Room, Machine Shop, Press Shop, Plastic Shop, Pressure Die Casting Shop, Electroplating and Painting Shop, and Assembly Shop; as also Research, Development and Engineering Department. In such an engineering organization, the further objectives would be as follows:

1. Thorough evaluation of newly developed products, to ensure that components designed is within the process and measuring instrument capabilities available in the plant.
2. To determine the process capabilities and ensure that these are better than the relevant component tolerance.
3. To determine the measuring instrument capabilities and ensure that these are adequate for their respective measurements.
4. To minimize the cost of inspection by effective and efficient use of available facilities and to reduce the cost of rejects and rework through application of Statistical Quality Control Techniques
5. Standardization of measuring methods. This is achieved by laying down inspection methods for any product right at the time when production technology is prepared.
6. Maintenance of the accuracies of measurement. This is achieved by periodical calibration of the metrological instruments used in the plant.
7. Arbitration and solution of problems arising on the shop floor regarding methods of measurement.

8. Preparation of designs for all gauges and special inspection fixtures.

Development of Material Standard

– The need for establishing standard of length was raised primarily for determining agricultural land areas and for the erection of buildings and monuments. The earliest standard of length was established in terms of parts of human body. The Egyptian unit was called a cubit. It was equal to the length of the forearm (from the elbow to the tip of the middle figure).

– Rapid advancement made in engineering during nineteenth century was due to improved materials available and more accurate measuring techniques developed. It was not until 1855 that first accurate standard was made in England. It was known as imperial standard yard. This was followed by International Prototype meter made in France in the year 1872. These two standards of lengths were made of material (metal alloys) and hence they are called as material standards in contrast to wavelength standard adopted as length standard later on.

Imperial Standard Yard

– The imperial standard yard is made of 1 inch square cross-section bronze bar (82% copper, 13% tin, 5% zinc) 38 inches long. The bar has two 1/2 inch diameter X 1/2 inch deep holes. Each hole is fitted with 1/10th inch diameter gold plug. The top surface of these plugs lie on the neutral axis of the bronze bar.

The purpose of keeping the gold plug lines at neutral axis has the following advantages.

- Due to bending of beam the neutral axis remains unaffected
- The plug remains protected from accidental damage.

The top surface of the gold plugs is highly polished and contains three lines engraved transversely and two lines longitudinally.

The yard is defined as the distance between two central transverse lines on the plugs when,

1. The temperature of the bar is constant at 62°F and,
2. The bar is supported on rollers in a specified manner to prevent flexure.

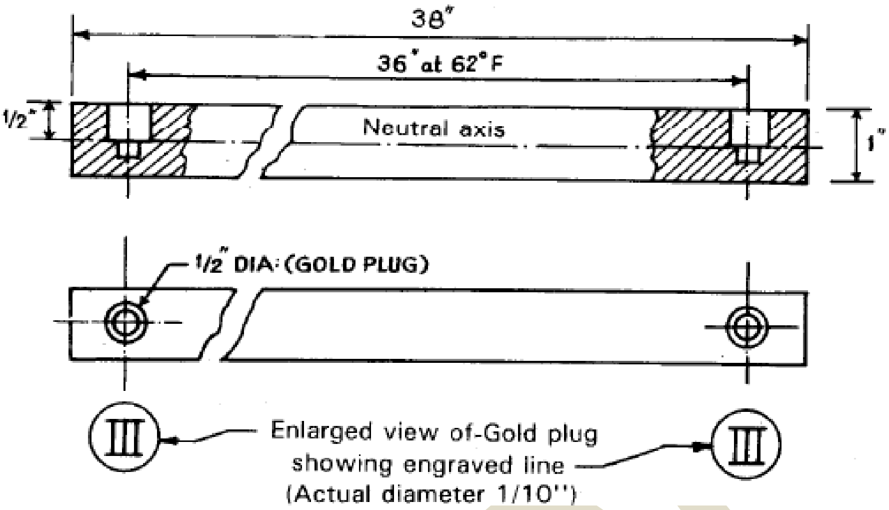


Figure 1.1 Imperial Standard Yards

International StandardMeter (Prototype)

- This standard was established originally by International Bureau of Weights and Measures in the year 1875. The prototype meter is made of platinum-iridium alloy (90% platinum and 10% iridium) having a cross-section as shown in Fig. 1.2.
- The upper surface of the web is highly polished and has two fine lines engraved over it. It is in-oxidisable and can have a good finish required for ruling good quality of lines. The bar is kept at 0°C and under normal atmospheric pressure. It is supported by two rollers of at least one cm diameter symmetrically situated in the same horizontal plane. The distance between the rollers is kept 589 mm so as to give minimum deflection. The web section chosen gives maximum rigidity and economy of costly material. The distance between the centers portions of two lines engraved on the polished surface of this bar of platinum-iridium alloy is taken as one meter.
- According to this standard, the length of the meter is defined as the straight line distance, at 0°C between the centre portions of pure platinum-iridium alloy (90% platinum, 10% iridium) of 102 cm total length and having a web cross-section as shown in Fig. 1.2.

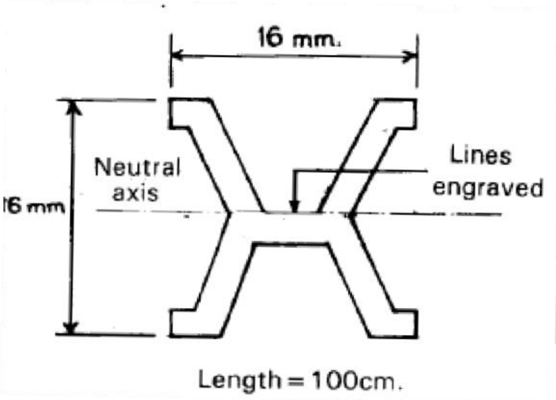


Figure 1.2 International Prototype Meter Cross-sections

- The metric standard when in use is supported at two points which are 58.9 cm apart as calculated from Airy's formula, according to which the best distance between the supporting points is given by

$$\sqrt{\ }$$

  Where, L = total length of bar (assumed uniform), b = distance between points, n = number is supports

- For prototype meter,

$$\sqrt{\ }$$

- This reference was designated as International Prototype Meter M in 1899. It is preserved by (BIPM) at Sevres in France. The BIPM is controlled by the International Committee of Weights and Measure.
- The imperial standard yard was found to be decreasing in length at the rate of one- millionth of an inch for the past 50 years when compared with internal standard meter. The prototype meter is quite stable. There-fore, yard relationship had to be defined in terms of meter as 1 yard = 0.9144 meter, or inch = 25.4 mm.

  Disadvantages of Material Standard

1. The material standards are influenced by effects of variation of environmental conditions like temperature, pressure, humidity and ageing etc., and it thus changes in length.
2. These standards are required to be preserved or stored under security to prevent their damage or destruction.
3. The replica of these standards was not available for use somewhere else.

4. These are not easily reproducible.
5. Conversion factor was to be used for changing over to metric working.
6. Considerable difficulty is experienced while comparing and verifying the sizes of gauges.

Wavelength Standard

- The major drawback with the metallic standards meter and yard is that their length changes slightly with time. Secondly, considerable difficulty is experienced while comparing and verifying the sizes of gauges by using material standards. This may lead to errors of unacceptable order of magnitude. It therefore became necessary to have a standard of length which will be accurate and invariable. Jacques Babinet a French philosopher suggested that wavelength of monochromatic light can be used as natural and invariable unit of length.
- In 1907 the International Angstrom (A) unit was defined in terms of wavelength of red cadmium in dry air at 15°C (6438.4696 A = 1 wavelength of red cadmium). Seventh General Conference of Weights and Measures approved in 1927, the definition of standard of length relative to the meter in terms of wavelength of the red cadmium as an alternative to International Prototype meter.
- Orange radiation of isotope krypton-86 was chosen for new definition of length in 1960, by the Eleventh General Conference of Weights and Measures. The committee decided to recommend that Krypton-86 was the most suitable element and that it should be used in a hot-cathode discharge lamp maintained at a temperature of 63° Kelvin. According to this standard meter was defined as equal to 1650763.73 wavelengths of the red orange radiation of Krypton isotope 86 gases.
- The standard as now defined can be reproduced to an accuracy of about 1 part in 10^9. The meter and yard were redefined in terms of wave length of orange Kr-86 radiation as,

  1 meter = 1650763.73 wavelengths, and

  1 yard = 0.9144 meter

  = 0.9144 x 1650763.73 wavelengths

  = 1509458.3 wavelengths.

Meter as of Today

- Although Krypton-86 standard served well, technologically increasing demands more accurate standards. It was through that a definition based on the speed of light would be technically feasible and practically advantageous. Seventeenth General Conference of Weights and Measure. Agreed to a fundamental change in the definition of the meter on 20th October 1983.
- Accordingly, meter is defined as the length of the path travelled by light in vacuum in 1/299792458 seconds. This can be realized in practice through the use of an iodine- stabilized helium-neon laser.
- The reproducibility is 3 parts in 1011, which may be compared to measuring the earth's mean circumference to an accuracy of about 1 mm. With this new definition of meter, one standard yard will be the length of the path travelled by light travelled in 0.9144 x 1/299792458 sec. I. e., in 3×10^{-9} sec.

The advantages of wavelength standard are:

1. It is not a material standard and hence it is not influenced by effects of variation of environmental conditions like temperature, pressure, humidity and ageing.
2. It need not be preserved or stored under security and thus there is no fear of being destroyed as in case of meter and yard.
3. It is not subjected to destruction by wear and tear.
4. It gives a unit of length which can be produced consistently at all the times in all the circumstances, at all the places. In other words it is easily reproducible and thus identical standards are available with all.
5. This standard is easily available to all standardizing laboratories and industries.
6. There is no problem of transferring this standard to other standards meter and yard.
7. It can be used for making comparative measurements of very high accuracy. The error of reproduction is only of the order of 3 parts in 10^{11}

Subdivision of standards

The international standard yard and the international prototype meter cannot be used for general purposes. For practical measurement there is a hierarchy of working standards. Thus depending upon their importance of accuracy required, for the work the standards are subdivided into four grades;

1. Primary standards
2. Secondary standards

3. Territory standards 4. Working standards.

1. Primary Standards

For precise definition of the unit, there shall be one, and only one material standard, which is to be preserved under most careful conditions. It is called as primary standard. International yard and International meter are the examples of primary standards. Primary standard is used only at rare intervals (say after 10 to 20 years) solely for comparison with secondary standards. It has no direct application to a measuring problem encountered in engineering.

2. Secondary Standards

Secondary standards are made as nearly as possible exactly similar to primary standards as regards design, material and length. They are compared with primary standards after long intervals and the records of deviation are noted. These standards are kept at number of places for safe custody. They are used for occasional comparison with tertiary standards whenever required.

3. Tertiary Standards

The primary and secondary standards are applicable only as ultimate control. Tertiary standards are the first standard to be used for reference purposes in laboratories and workshops. They are made as true copy of the secondary standards. They are used for comparison at intervals with working standards.

4. Working Standards

Working standards are used more frequently in laboratories and workshops. They are usually made of low grade of material as compared to primary, secondary and tertiary standards, for the sake of economy. They are derived from fundamental standards. Both line and end working standards are used. Line standards are made from H-cross-sectional form.

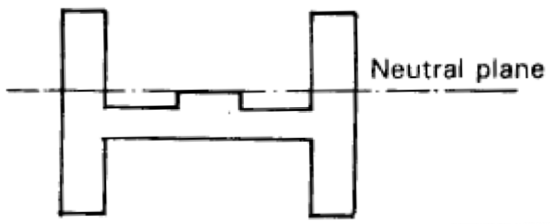


Figure 1.3 Working Line Standards

Most of the precision measurement involves the distance between two surfaces and not with the length between two lines. End standards are suitable for this purpose. For shorter lengths up to 125 mm slip gauges are used and for longer lengths end bars of circular cross- section are used. The distance between the end faces of slip gauges or end bars is controlled to ensure a high degree of accuracy.

Sometimes the standards are also classified as:

1. Reference standards- Used for reference purposes.
2. Calibration standards - Used for calibration of inspection and working standards.
3. Inspection standards - Used by inspectors.
4. Working standards - Used by operators, during working.

Line and End Measurements

A length may be measured as the distance between two lines or as the distance between two parallel faces. So, the instruments for direct measurement of linear dimensions fall into two categories.

1. Line standards.
2. End standards.

Line Standards

When the length is measured as the distance between centers of two engraved lines, it is called line standard. Both material standards yard and meter are line standards. The most common example of line measurements is the rule with divisions shown as lines marked on it.

Characteristics of Line Standards

1. Scales can be accurately engraved but the engraved lines themselves possess thickness and it is not possible to take measurements with high accuracy.
2. A scale is a quick and easy to use over a wide range.
3. The scale markings are not subjected to wear. However, the leading ends are subjected to wear and this may lead to undersize measurements.
4. A scale does not possess a "built in" datum. Therefore it is not possible to align the scale with the axis of measurement.
5. Scales are subjected to parallax error.
6. Also, the assistance of magnifying glass or microscope is required if sufficient accuracy is to be achieved.

End standards

When length is expressed as the distance between two flat parallel faces, it is known as end standard. Examples: Measurement by slip gauges, end bars, ends of micrometer anvils, vernier calipers etc. The end faces are hardened, lapped flat and parallel to a very high degree of accuracy.

Characteristics of End Standards

1. These standards are highly accurate and used for measurement of close tolerances in precision engineering as well as in standard laboratories, tool rooms, inspection departments etc.
2. They require more time for measurements and measure only one dimension at a time.
3. They are subjected to wear on their measuring faces.
4. Group of slips can be "wrung" together to build up a given size; faulty wringing and careless use may lead to inaccurate results.
5. End standards have built in datum since their measuring faces are f l at and parallel and can be positively locked on datum surface.
6. They are not subjected to parallax effect as their use depends on feel.

Comparison between Line Standards and End Standards:

Sr. No.	**Characteristic**	**Line Standard**	**End Standard**
1.	Principle	Length is expressed as the distance between two lines	Length is expressed as the distance between two flat parallel faces
2.	Accuracy	Limited to ± 0.2 mm for high accuracy, scales have to be used in conjunction with magnifying glass or microscope	Highly accurate for measurement of close tolerances up to ± 0.001 mm.
3.	Ease and time & measurement	Measurement is quick and easy	Use of end standard requires skill and is time consuming.
4.	Effect of wear	Scale markings are not subject to wear. However, significant wear may occur on leading ends. Thus it may be difficult to assume zero of scale as datum.	These are subjected to wear on their measuring surfaces.
5.	Alignment	Cannot be easily aligned with the	Can be easily aligned

		axis of measurement.	with the axis of measurement.
6.	Manufacture and cost	Simple to manufacture at low cost.	Manufacturing process is complex and cost is high.
7.	Parallax effect	They ate subjected to parallax error	They ate not subjected to parallax error
8.	Examples	Scale (yard, meter etc.)	Slip gauges, end bars, V-caliper, micrometers etc.

The accuracy of both these standards is affected by temperature change and both are originally calibrated at 20 ± 0.5°C. It is also necessary to take utmost case in their manufacture to ensure that the change of shape with time, secular change is reduced to negligible.

Classification of Standards and Traceability

- In order to maintain accuracy and interchangeability in the items manufactured by various industries in the country, it is essential that the standards of units and measurements followed by them must be traceable to a single source, i.e., the National Standards of the country. Further, the National Standards must also be linked with International Standard to maintain accuracy and interchangeability in the items manufactured by the various countries.
- The national laboratories of well-developed countries maintain close tolerance with International Bureau of Weights and Measures, there is assurance that the items manufactured to identical dimensions in different countries will be compatible.

Application of precise measurement has increased to such an extent that it is not practicable for a single national laboratory to perform directly all the calibrations and standardizations required by a large country. It has therefore become necessary that the process of traceability technique needs to be followed in stages, that is, National laboratories, standardizing laboratories, etc. need to be established for country, states, and industries but all must be traceable to a single source as shown in Fig. 1.4 below.

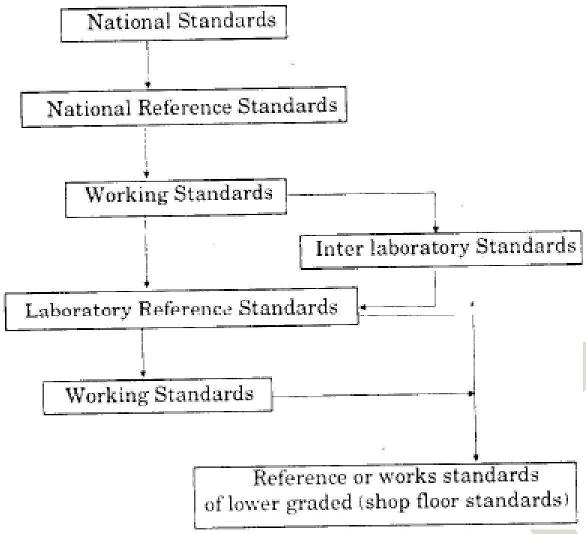


Figure 1.4 Classifications of Standards in Order

Clearly, there is degradation of accuracy in passing from the defining standards to the standard in use. The accuracy of a particular standard depends on a combination of the number of times it has been compared with a standard of higher order, the recentness of such comparisons, the care with which it was done, and the stability of the particular standard itself

Measuring system element

A measuring system is made of five basic elements. These are:

1. Standard
2. Work piece
3. Instrument
4. Person
5. Environment.

The most basic element of measurement is a standard without which no measurement is possible. Once the standard is chosen a measuring instrument incorporations this standard is should be obtained. This instrument is then used to measure the job parameters, in terms of units of standard contained in it. The measurement should be performed under standard environment. And, lastly, there must be some person or mechanism (if automatic) to carry out the measurement.

Methods of Measurement

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

The methods of measurement can be classified as:

1. Direct method
2. Indirect method
3. Absolute/Fundamental method
4. Comparative method
5. Transposition method
6. Coincidence method
7. Deflection method
8. Complementary method
9. Contact method
10. Contactless method etc.

1. Direct method of measurement.

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

2. Indirect method of measurement.

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

3. Absolute or Fundamental method.

It is based on the measurement of the base quantities used to define the quantity. For example, measuring a quantity directly in accordance with the definition of that quantity, or measuring a quantity indirectly by direct measurement of the quantities linked with the definition of the quantity to be measured.

4. Comparative method.

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

5. Transposition method.

It is a method of measurement by direct comparison in which the value of the quantity measured is first balanced by an initial known value A of the same quantity, and then the value of the quantity measured is put in place of this known value and is balanced again by another known value B. If the position of the element indicating equilibrium is the same in both cases, the value of the quantity to be measured is. For example, determination of a mass by means of a balance and known weights, using the Gauss double weighing method.

6. **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. For example, measurement by vernier caliper micrometer.

7. **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.

8. **Complementary method.**

   In this method the value of the quantity to be measured is combined with a known value of the same quantity. The combination is so adjusted that the sum of these two values is equal to predetermined comparison value. For example, determination of the volume of a solid by liquid displacement.

9. **Method of measurement by substitution.**

   It is a method of direct comparison in which the value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same.

10. **Method of null measurement.**

    It is a method of differential measurement. In this method the difference between the value of the quantity to be measured and the known value of the same quantity with which it is compared is brought to zero.

11. **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. In such cases arrangement for constant contact pressure should be provided to prevent errors due to excessive contact pressure.

12. 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 etc.

1.4 Precision and Accuracy

Precision

– The terms precision and accuracy are used in connection with the performance of the instrument. Precision is the repeatability of the measuring process.

– It refers to the group of measurements for the same characteristics taken under identical conditions. It indicates to what extent the identically performed measurements agree with each other. If the instrument is not precise it will give different (widely varying) results for the same dimension when measured again and again. The set of observations will scatter about the mean. The scatter of these measurements is designated as 0, the standard deviation. It is used as an index of precision. The less the scattering more precise is the instrument. Thus, lower, the value of 0, the more precise is the instrument.

Accuracy

– Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement.

– It is practically difficult to measure exactly the true value and therefore a set of observations is made whose mean value is taken as the true value of the quality measured.

Distinction between Precision and Accuracy

– Accuracy is very often confused with precision though much different. The distinction between the precision and accuracy will become clear by the following example. Several measurements are made on a component by different types of instruments (A, B and C respectively) and the results are plotted.

– In any set of measurements, the individual measurements are scattered about the mean, and the precision signifies how well the various measurements performed by same instrument on the same quality characteristic agree with each other.

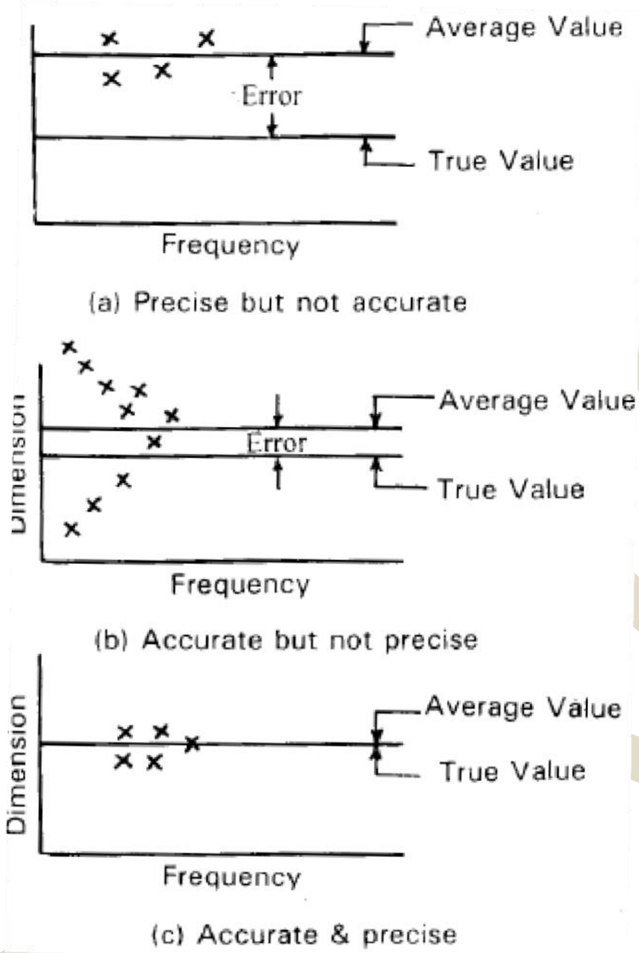


Figure 1.5 Precision And Accuracy

- The difference between the mean of set of readings on the same quality characteristic and the true value is called as error. Less the error more accurate is the instrument. Figure 1.5 shows that the instrument A is precise since the results of number of measurements are close to the average value. However, there is a large difference (error) between the true value and the average value hence it is not accurate.
- The readings taken by the instruments are scattered much from the average value and hence it is not precise but accurate as there is a small difference between the average value and true value. Fig. 1.5 (c) shows that the instrument is accurate as well as precise.

1.5 Errors in Measurement

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

– Error in measurement = Measured value - True value. The error in measurement may be expressed or evaluated either as an absolute error or as a relative error.

Absolute Error

– True absolute error. It is the algebraic difference between the result of measurement and the conventional true value of the quantity measured.

– Apparent absolute error. If the series of measurement are made then the algebraic difference between one of the results of measurement and the arithmetical mean is known as apparent absolute error.

Relative Error

– It is the quotient of the absolute error and the value of comparison used for calculation of that absolute error. This value of comparison may be the true value, the conventional true value or the arithmetic mean for series of measurement.

The accuracy of measurement, and hence the error depends upon so many factors, such as:

- Calibration standard
- Work piece
- Instrument
- Person
- Environment etc. as already described.

No matter, how modern is the measuring instrument, how skillful is the operator, how accurate the measurement process, there would always be some error. It is therefore attempted to minimize the error. To minimize the error, usually a number of observations are made and their average is taken as the value of that measurement.

– If these observations are made under identical conditions i.e., same observer, same instrument and similar working conditions excepting for time, then, it is called as Single Sample Test'.

– If however, repeated measurements of a given property using alternate test conditions, such as different observer and/or different instrument are made, the procedure is called as `Multi-Sample Test'. The multi-sample test avoids many controllable errors e.g., personal error, instrument zero error etc. The multi-sample test is costlier than the single sample test and hence the later is in wide use.

– In practice good numbers of observations are made under single sample test and statistical techniques are applied to get results which could be approximate to those obtainable from multi-sample test.

Types of Error

During measurement several types of error may arise, these are

1. Static errors which includes
   - Reading errors
   - Characteristic errors
   - Environmental errors.
2. Instrument loading errors.
3. Dynamic errors.

Static errors

These errors result from the physical nature of the various components of measuring system. There are three basic sources of static errors. The static error divided by the measurement range (difference between the upper and lower limits of measurement) gives the measurement precision.

Reading errors

Reading errors apply exclusively to the read-out device. These do not have any direct relationship with other types of errors within the measuring system.

Reading errors include: Parallax error, Interpolation error.

Attempts have been made to reduce or eliminate reading errors by relatively simple techniques. For example, the use of mirror behind the readout pointer or indicator virtually eliminates occurrence of parallax error.

<u>Interpolation error.</u>

It is the reading error resulting from the inexact evaluation of the position of index with regards to two adjacent graduation marks between which the index is located. How accurately can a scale be readthis depends upon the thickness of the graduation marks, the spacing of the scale division and the thickness of the pointer used to give the reading Interpolation error can be tackled by increasing; using magnifier over the scale in the viscinity of pointer or by using a digital read out system.

Characteristic Errors

It is defined as the deviation of the output of the measuring system from the theoretical predicted performance or from nominal performance specifications.

Linearity errors, repeatability, hysteresis and resolution errors are part of characteristic errors if the theoretical output is a straight line. Calibration error is also included in characteristic error.

Loading Errors

Loading errors results from the change in measurand itself when it is being measured, (i.e., after the measuring system or instrument is connected for measurement). Instrument loading error is the difference between the value of the measurand before and after the measuring system is connected/contacted for measurement. For example, soft or delicate components are subjected to deformation during measurement due to the contact pressure of the instrument and cause a loading error. The effect of instrument loading errors is unavoidable. Therefore, measuring system or instrument should be selected such that this sensing element will minimize instrument loading error in a particular measurement involved.

Environmental Errors

These errors result from the effect of surrounding such as temperature, pressure, humidity etc. on measuring system.

External influences like magnetic or electric fields, nuclear radiations, vibrations or shocks etc. also lead to environmental errors.

Environmental errors of each component of the measuring system make a separate contribution to the static error. It can be reduced by controlling the atmosphere according to the specific requirements.

Dynamic Errors

Dynamic error is the error caused by time variations in the measurand. It results from the inability of the system to respond faithfully to a time varying measurement. It is caused by inertia, damping, friction or other physical constraints in the sensing or readout or display system.

For statistical study and the study of accumulation of errors, these errors can be broadly classified into two categories

1. Systematic or controllable errors, and
2. Random errors.

Systematic Errors

Systematic errors are regularly repetitive in nature. They are of constant and similar form. They result from improper conditions or procedures that are consistent in action. Out of the systematic errors all except the personal error varies from individual to individual depending on the personality of observer. Other systematic errors can be controlled in magnitude as well as in sense. If properly analyzed they can be determined and reduced. Hence, these are also called as controllable errors.

Systematic errors include:

1. Calibration Errors. These are caused due to the variation in the calibrated scale from its normal value. The actual length of standards such as slip gauge and engraved scales will vary from the nominal value by a small amount. This will cause an error in measurement of constant magnitude. Sometimes the instrument inertia and hysteresis effect do not allow the instrument to transit the measurement accurately. Drop in voltage along the wires of an electric meter may include an error (called single transmission error) in measurement.

2. Ambient or Atmospheric conditions (Environmental Errors). Variation in atmospheric condition (i.e., temperature, pressure, and moisture content) at the place of measurement from that of internationally agreed standard values (20° temp. and 760 mm of Hg pressure) can give rise to error in the measured size of the component. Instruments are calibrated at these standard conditions; therefore error may creep into the given result if the atmosphere conditions are different at the place of measurement. Out of these temperatures is the most significant factor which causes error in, measurement due to expansion or contraction of component being measured or of the instrument used for measurement.

3. Stylus Pressure. Another common source of error is the pressure with which the work piece is pressed while measuring. Though the pressure involved is generally small but this is sufficient enough to cause appreciable deformation of both the stylus and the work piece.

In ideal case, the stylus should have simply touched the work piece. Besides the deformation effect the stylus pressure can bring deflection in the work piece also.

Variations in force applied by the anvils of micrometer on the work to be measured results in the difference in its readings. In this case error is caused by the distortion of both micrometer frame and work-piece.

4. Avoidable Errors. These errors may occur due to parallax, non-alignment of work piece centers, improper location of measuring instruments such as placing a thermometer in

sunlight while measuring temperature. The error due to misalignment is caused when the centre line of work piece is not normal to the centre line of the measuring instrument.

5. Random Errors. Random errors are non-consistent. They occur randomly and are accidental in nature. Such errors are inherent in the measuring system. It is difficult to eliminate such errors. Their specific cause, magnitudes and source cannot be determined from the knowledge of measuring system or conditions of measurement.

The possible sources of such errors are:

1. Small variations in the position of setting standard and work piece.
2. Slight displacement of lever joints of measuring instruments.
3. Operator error in scale reading.
4. Fluctuations in the friction of measuring instrument etc.

Comparison between Systematic Errors and Random Errors

Systematic Errors	**Random Errors**
These errors are repetitive in nature and are of constant and similar form	These are non-consistent. The sources giving rise to such errors are random.
These errors result from improper conditions or procedures that are consistent in action.	Such errors are inherent in the measuring system or measuring instruments.
Except personal errors, all other systematic errors can be controlled in magnitude and sense.	Specific causes, magnitudes and sense of these errors cannot be determined from the knowledge of measuring system or condition.
If properly analyzed these can be determined and reduced or eliminated.	These errors cannot be eliminated, but the results obtained can be corrected.
These include calibration errors, variation in contact pressure, variation in atmospheric conditions, parallax errors, misalignment errors etc.	These include errors caused due to variation in position of setting standard and work-piece, errors due to displacement of lever joints of instruments, errors resulting from backlash, friction etc.

Errors likely to creep in Precision Measurements

The standard temperature for measurement is 20°C and all instruments are calibrated at this temperature. If the measurements are carried out at temperature other than the standard temperature, an error will be introduced due to expansion or contraction of instrument or part to be measured. But if the instrument and the work piece to be measured are of same material, accuracy of measurement will not be affected even if the standard temperature is not maintained. Since both will expand and contract by the same amount.

The difference between the temperature of instrument and the work piece will also introduce an error in the measurement, especially when the material of the work piece or instrument has higher coefficient of expansion. To avoid such errors, instrument and the work piece to be measured should be allowed to attain the same temperature before use and should be handled as little as possible. For example, after wringing together several slip gauges to form a stock for checking a gauge, they should be left with the gauge for an hour, if possible preferably on the table of the comparator which is to be used for performing the comparison.

To attain accurate results, high grade reference gauges should be used only in rooms where the temperature is maintained very close to the standard temperature.

Handling of gauges changes its temperature, so they should be allowed to stabilize.

There are two situations to be considered in connection with the effect of temperature, these are:

(a) Direct measurement. Let us consider a gauge block being measured directly by interferometry. Here, the effect of using a non-standard temperature produces a proportional error, $E = l \alpha (t - t_s)$, where

- L = nominal length
- α = coefficient of expansion
- $(t - t_s)$ = deviation from standard temperature
- t = temperature during measurement
- t_s = standard temperature

(b) Comparative measurement. If we consider two gauges whose expansion coefficients are respectively α_1 and α_2, then the error due to nonstandard temperature will be, Error, $E = l (\alpha_1 - \alpha_2)(t - t_s)$

As the expansion coefficients are small numbers, the error will be very small as long as both parts are at the same temperature. Thus, in comparative measurement it is important that all components in the measuring system are at the same temperature rather than necessarily at the standard temperature.

Other ambient conditions may affect the result of measurement. For example, if a gauge block is being measured by interferometry, then relative humidity, atmospheric pressure and CO_2 of the air affects the refractive index of the atmosphere. These conditions should all be recorded during the measurement and the necessary correction made.

Internationally accepted temperature for measurement is 20°C and all instruments are calibrated at this temperature. To maintain such controlled temperature, the laboratory should be air-conditioned.

Effect of supports

When long measuring bars, straight edges are supported as beam, they are defected or deformed. This elastic deformation occurs because a long bar, supported at to ends sags under their own weight. This problem was considered by Sir G.B. Airy, who showed that the position of the supports can be arranged to give minimum error. The amount of deflection depends upon the positions of the supports.

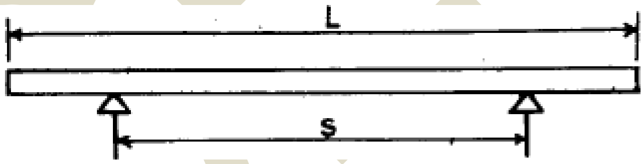
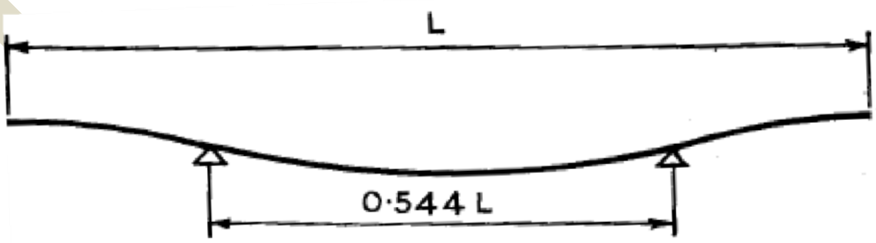


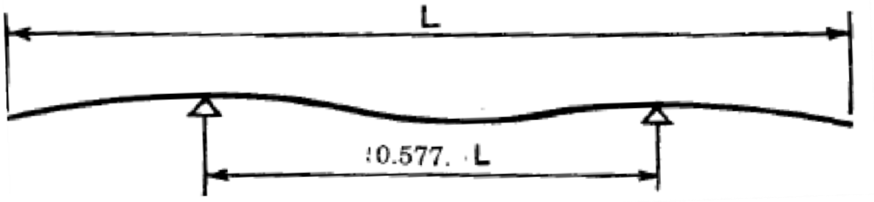
Figure 1.6 Effect of support

Two conditions are considered, as shown in Fig. 1.7,

(1) A bar of length L supported, equidistant from the centre. In this case the slope at the ends of the bar is zero. For minimum deflection, the distance between the supports should be 0.554 times the length of the bar S = 0.544 L or S/L = 0.544



(a) Line standard and End bars (slope at ends zero)



(b) Straight edges (deflection at ends equals' deflection).

Figure 1.7 Support Positions for Different Conditions of Measurement

(2) A straight edge of length L supported, equidistant from the centre. The straight edges are used to check the straightness and flatness of the parts. They are maker of H section.

In this case the deflection at the ends is equal to the deflection at the centre. For minimum deflection the distance between the supports should be 0.577 times the length i.e. for any points

–

Effect of alignment

Abbe's alignment principle: It states that "the axis or line of measurement should coincide with the axis of measuring instrument or line of the measuring scale."

If while measuring the length of a work piece the measuring scale is inclined to the true line of the dimension being measured there will be an error in the measurement.

The length recorded will be more than the true length. This error is called "Cosine error". In many cases the angle 0 is very small and the error will be negligible.

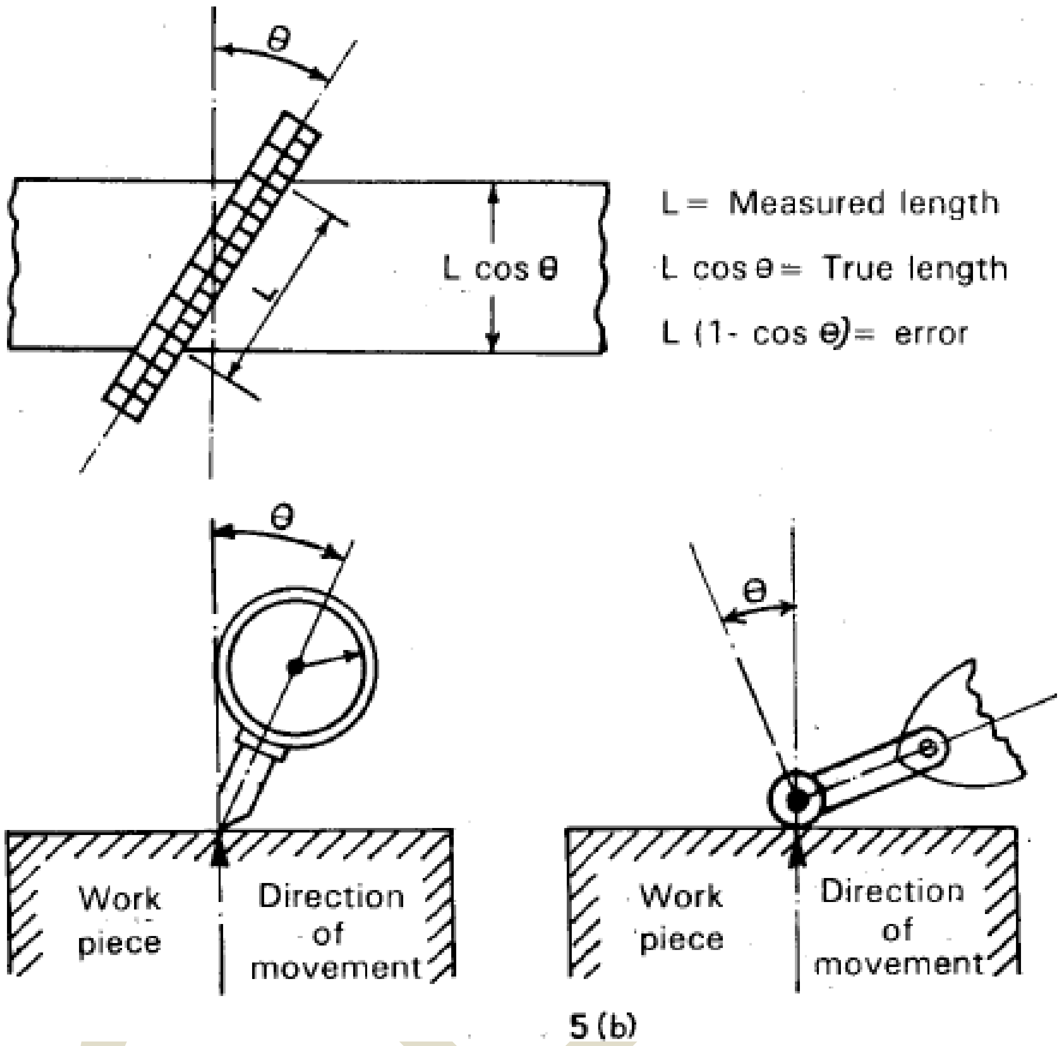


Figure 1.8 (A) And (B) Effect of Misalignment

The cosine error may also, occur while using dial gauge, if the axis of the pointer is not along the direction of measurement of work. Also, when in indicator is fitted with a ball-end stylus form, the arm should be so set that the direction of movement of the work is tangential to the arc along which the ball moves, otherwise cosine error will be introduced.

The combined cosine and sine error will occur if the micrometer axis is not truly perpendicular to the axis of the work piece (Refer Fig. 1.9). The same error occurs while measuring the length of the end gauge in a horizontal comparator if the gauge is not supported so that its axis is parallel to the axis of the measuring or anvils or if its ends, though parallel to each other are not square with ends.

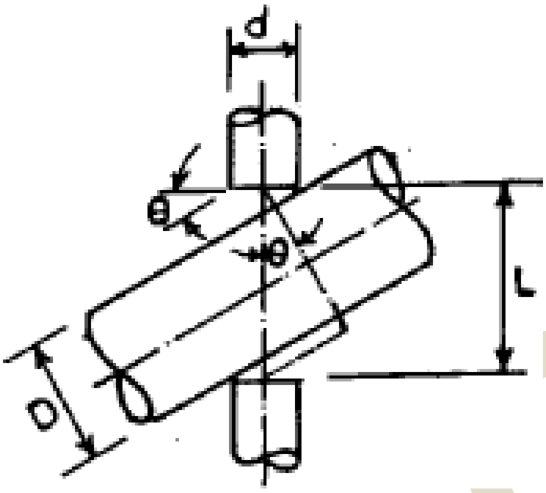


Figure 1.9 Combined Sines and Cosine Error

Referring Fig.1.9, if D = true diameter, L =apparent length, d = micrometer anvil diameter Then D = (L cos θ) - d sin θ = L cos θ – d sin θ

And error, = L – D = L – (L cos θ – d sin θ) = L (1- cos θ) + d sin θ

The errors of above nature are avoided by using with spherical ends.

Contact pressure

The variation in the contact pressure between the anvils of the instrument and the work being measured produce considerable difference in reading. Though the pressure involved is generally small, but it is sufficient enough to came appreciable deformation of both the anvil (and stylus) and the work piece. The deformation of the work piece and the anvils of instrument depend -upon the contact pressure and the shape of the contact surfaces. When there is a surface contact between the instrument anvils and work piece, there is very little deformation, but when there is a point contact the deformation is appreciable.

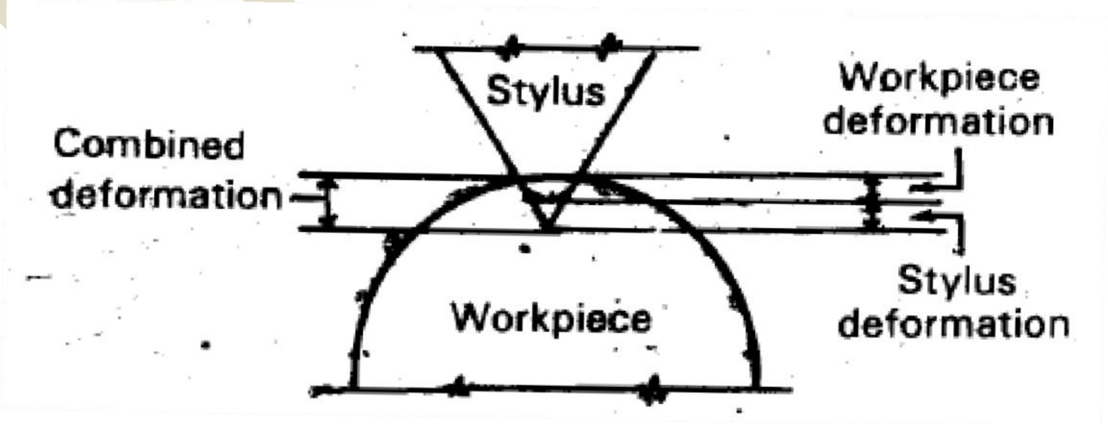


Figure 1.10 Effect of Contact Pressure on Measurement

Fig. 1.10 shows the error caused by combined deformation of the stylus and the work piece.

To minimize this error the development of correct feel is one of the skills to be acquired by the inspector. To avoid this effect of contact pressure the micrometer is fitted with a ratchet mechanism to apply the correct pressure during measurement. The ratchet slips when the applied pressure exceeds the minimum required operating pressure.

Parallax Error

A very common error that may occur in an instrument while taking the readings is parallax error.

Parallax error occurs when:

- The line of vision is not directly in line with the measuring scale
- The scale and the pointer are separated from each other (hot in the same plane). Refer

Fig. 1.11

Let d = separation of scale and pointer

D = distance between the pointer and eye of the observer

Θ = angle which the line of sight makes with the normal to scale.

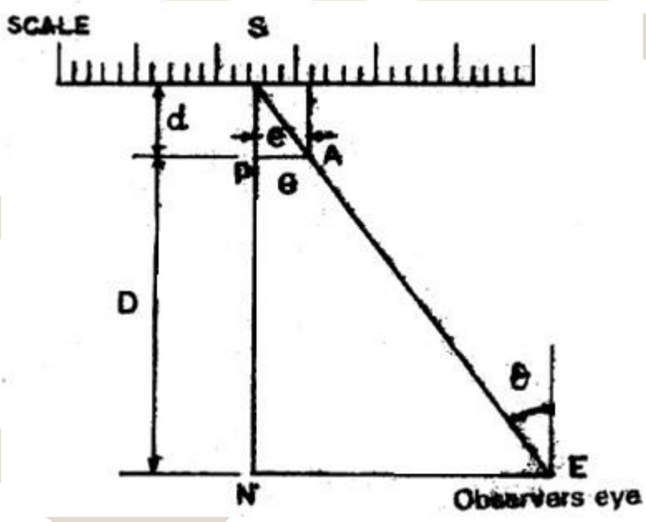


Figure 1.11 Parallax Errors

Now generally, Θ is small therefore, tan Θ = Θ and error e = dΘ.

For least error d should be minimum possible, value of Θ can be reduced to zero by placing mirror behind the pointer which ensures normal reading of scale.

Dust

The dust present in the atmosphere may change the reading by a fraction of micron, where accuracy of the order of micron is desired such as while using slip gauges the effect of dust can be prevented by

1. Incorporating electrostatic precipitators in laboratory or in the air ducts in addition to air filters.
2. The work pieces and masters should be cleaned by clean chamois or by a soft brush.
3. Gauges should never be touched with moist fingers.
4. The contact surfaces should be sprayed with suitable filtered clean solvent.

Errors due to vibrations

Vibrations may affect the accuracy of measurement. The instrument anvil will not give consistent and repetitive reading if it is subjected to vibration.

For eliminating or reducing effect of vibration on measurement, the following precautions should be taken:

1. The laboratory should be located away from the sources of vibration.
2. Slipping cork, felt, rubber pads should be used under the gauge.
3. Putting a gauge on a surface plate resting in turn on a heavy plate also reduces the effect of vibrations.
4. Precision measurement -should be carried out away from shop floor.
5. Errors due to location

The part to be measured is located on a table or a surface plate which forms the datum for comparison with the standard. The reading taken by the comparator is thus the indication of the displacement of the upper surface of the measured part from the datum. If the datum surface is not flat, or if the foreign matter such as dirt, chips etc. are present between the datum and the Work piece surface then error will be introduced in the reading taken.

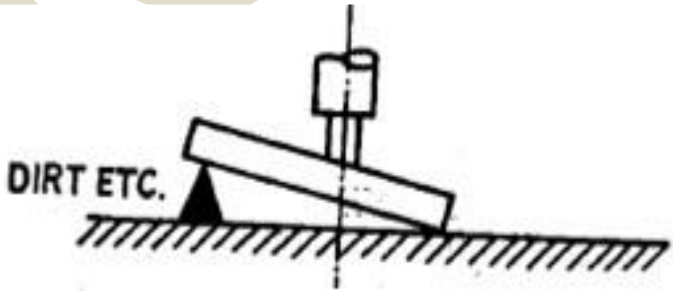


Figure1.12 Surface Displacements

Error due to poor contact

Fig. 1.13 shows how the poor contact between the working gauge or instrument and the work piece causes an error. Although, everything feels all right, yet the error is bound to occur. To avoid this type of error the gauge with wide area of contact should not be used while measuring irregular or curved surface and correct pressure should be applied while making the contact.

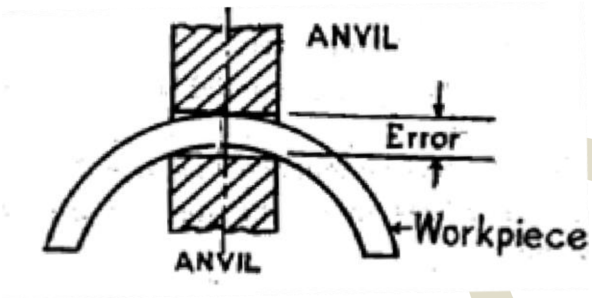


Figure 1.13 Errors Due To Poor Contact

Error due to wear in gauges

The measuring surfaces of instrument such as the anvils of the micrometer are subjected to wear due to repeated use. The internal instrument error such as threads of the micrometer spindle can also lead to error in measurement.

Wear can be minimized by keeping gauge, masters and work pieces clean and away from dust. Gauge, anvils and such other part s of the instrument which are subjected to wear should be properly hardened. Chrome plated parts are more resistant to wear.

The lack of parallelism due to wear of anvils can be checked by optical flats; and, the-wear on spherical contacts of the instrument by means of microscope.

1.6 General Care of Metrological Equipment

- The equipment (apparatus) used for precision measurements is designed to fine limits of accuracy and is easily liable to be damaged by even-slight mishandling and such damage may not be noticeable. A great deal of careful handling is, therefore, required.
- As far as possible, the highly finished surfaces should not be touched by hand because the natural acids on the skin are likely to corrode the finished surface and also the temperature of body may upset the dimensions of the precision instruments.
- In order to overcome this many standard metrology laboratories recommend washing of hands thoroughly and coating them with a thin fily; of pure petroleum jelly before handling the instruments.
- Further very precise equipment like slip gauges is allowed to be handled only by using a piece of chamois leather or tongs made from a strip of "Perspex".

- When the equipment is not in use, it should be protected from atmospheric corrosion. For this purpose the highly finished surfaces are first wiped with a solvent to remove any finger mark and then coated with mixture of heated petroleum jelly and petrol.
- This mixture spreads much more easily and is applied with cloth or with fingers. Brushing is not recommended as it is liable to ti air which, with the moisture it contains, may cause rusting.
- As the standard temperature for measurement is 20°C, for very precise measurement the instruments and work pieces should be allowed to attain this temperature before use and the handling should be as little as possible.

1.7 Standardization and Standardizing Organization

- For overall higher economy, efficiency and productivity in a factory and country, it is essential that diversity be minimized and interchangeability among parts encouraged. All this is possible with standardization. Standardization is done at various levels, viz. International, National, association, company.
- Realizing the role of standardization in the development of industry, organizations to handle the complexities of standardization have been evolved in each of the chief industrial countries. In India, Bureau of Indian Standards (BIS) is responsible for evolving standards on metrological instruments, etc.
- There are several sectional committees, each dealing with various main branches of industry, in BIS. The detailed work of drawing up specifications is done by more specialized technical committees who prepare a draft standard based on practice in other countries and the needs of the country, and circulate it to relevant industries, government and service departments, research and teaching organizations, and others likely to be interested.
- Comments are invited both from producer and user to consider all aspects; meetings help to discuss the matters in depth and final standards issued. The technical committees also keep on revising the existing standards from time to time.
- The Bureau of Indian Standards is the National body for standardization in India. The functions of the Bureau are:

1. Formulation, publication and promotion of Indian Standards
2. Inspection of articles or process under Certification Scheme;
3. Establishment, maintenance and recognition of laboratories;

4. Formulate, implement and coordinate activities relating to quality maintenance and improvement in products and processes;
5. Promote harmonious development in standardization, quality systems and certification and matters connected therewith both within the country and at international level;
6. Provide information, documentation and other services to consumers and recognized consumer organizations on such terms and conditions as may be mutually agreed upon;
7. Give recognition to quality assurance systems in manufacturing or processing units on such terms and conditions as mutually agreed upon;
8. Bring out handbooks, guides and other special publications; and for conformity to any other standard if so authorized.

Thus, the main functions of the Bureau can be grouped under standards formulation, certification marking and laboratory testing, promotional and international activities.

Bureau of Indian Standards has under the Mechanical Engineering Division Council, EDC, a separate Engineering Metrology Sectional Committee. This Committee was set up in 1958 and its main task is to formulate standards for the various aspects of dimensional metrological measuring instruments and accessories used in the mechanical engineering field. A large number of Indian Standards in the field of engineering metrology have been formulated.

- In Great Britain, British Standards Institution plays similar role to BIS.
- In Europe, the International Federation of National Standardizing Association, known as I.S.A., coordinates the work of the continental countries. Before Second World War, U.K. and U.S.A. did not take any part in it, but after war, the countries like. U.K., U.S.A. and Russia have taken part in its works. In 1946, the I.S.A., was re-formed as the International Organization for Standardization, I.S.O. In fact, for engineering matters, the foremost standards organization at international level is I.S.O. The national standards organisations of individual countries are the members of I.S.O. The I.S.O. recommendations are used as basis for national and company standards. Lot of co-operative discussions in the field of standardization has also been carried out in three countries-America, Britain and Canada known was ABC conference. The International Electro-technical Commission (IEC) deals with electrical engineering standards. Both ISO and IEC have published recommendations on some aspects of engineering metrology.
- National Physical Laboratories (NPL) carry out lot of research work in various fields; responsible for defining standards, and also issue certification marks for quality instruments.

International organization of Weights and Measurements

It was established in 1975 under the "International meter convention" in Paris with the object of maintaining uniformity of measurements throughout the world. It comprises of:

1. The General Conference of Weights and Measures
2. The International Committee of Weights and Measures.
3. The International Organization of Legal Metrology.

General Conference of Weights and Measures

Its objects are:

- To draw up and promote the decisions necessary for the propagation and perfection of an international system of units and standards of measurement.
- To approve the results of new fundamental metrological determinations and the various scientific resolutions in the field of metrology which are of international interest.

International Committee of Weights and Measures

This Committee is placed under the authority of the General Conference of Weights and Measures and is responsible for promoting the decisions taken by the latter. Its objects are:

- To direct and supervise the work of the International Bureau of Weights and Measures.
- To establish co-operation among national laboratories of metrology for executing the metrological work which the General Conference of Weights and Measures decides to execute jointly by the member states of the organization.
- To direct such work and co-ordinate the results and to look after the conservation of the International Standards.

Principal Global Organizations involved in Metrology

<u>BIPM (Bureau International des PoidsetMeasures):</u> It is created under the Meter convention for measurement standard activities. It provides leadership in ensuring collaboration on metrological matters and the maintenance of an efficient worldwide measurement system. It serves as the technical focal point to guarantee the equivalence of national standards. BIPM with its laboratories and offices at Serves act as a permanent international centre for Metrology under the supervision of the CIPM.

<u>ILAC (International Laboratory Accreditation Conference):</u> It is engaged in international laboratory accreditation and the standards writing bodies. It has demonstrated competence in calibration and testing.

IEC (International Electro technical Commission): A voluntary sector to prescribe standards. CIPM (Committee International des Poidset Measures): Most of the activities of CIPM are performed under the supervision of CIPM. Several (CCs) consultative committees have been set up by the CIPM.

CGPM (Conference General des Poidset Measures).

ISO (International Organization for Standardization): A voluntary sector to specify standards. NMI (National Metrology Institute). A national laboratory responsible for the development and maintenance of measurement standards for the dissemination of the SI units, their multiples and sub multiples, and capable of making accurate measurements available to all users.

International Organization of Legal Metrology (OIML); It was established in 1955 under the "International Convention of Legal Metrology" Paris to unify the metrological practices. Its objects are

International organization of legal Metrology: It was established in 1955 under the "International convention of legal metrology" Paris to unity the metrological practices. Its objects are:

- To determine the general principles of Legal Metrology. Legal Metrology is concerned with the statutory technical and legal requirement of units of measurements, methods of measurements and measuring instruments with a view to assure public guarantee in respect of the security and the appropriate accuracy of measurements.
- To study with the object of unification, statutory and regulatory problems of legal metrology the solution of which is of international interest.
- To establish the draft of a model law and regulation on measuring instruments and their use.
- To prepare a plan for the physical organization of a model service for the verification and control of measuring instruments and to establish the necessary and adequate characteristics and qualities which measuring instruments should possess in order that they may be approved by the member states and their use recommended on international basis. This organization comprises of the International Conference of Legal Metrology, the International Committee of Legal Metrology and the International Bureau of Legal Metrology.

OIML has made a number of international recommendations. They have also published a "Vocabulary of Legal Metrology-Fundamental Terms" the English translation of which is published in India by the Directorate of Weights and Measures, Ministry of Industry.

The functions of the Directorate of Weights and Measures are:

- To ensure the conservation of national standards and to guarantee their accuracy by comparison with international standards.
- To guarantee and impart proper accuracy to the secondary standards by comparison with national standards.
- To carry out scientific and technical work in all fields of metrology and methods of measurements.
- To take part in the work of other national organizations interested in metrology.
- To draw up draft laws relating to legal metrology and to promulgate the corresponding regulations.
- To regulate and advise on, supervise and control the manufacture and repair of measuring instruments.
- To inspect the use of instruments and the measurement operations when such use and such operations are covered under public guarantee.
- To detect frauds in measurement or sale of goods and to book offender for trials where necessary.
- To coordinate the activities of authorities exercising metrological supervision.
- To cooperate with all to ensure respect for the regulations of legal metrology.
- To organize training in legal metrology
- To represent the country in international activities regarding legal metrology.

National Service of Legal Metrology: The National Service of Legal Metrology has following organizations to assist it in discharge of its duties:

- National Bureau of Legal Metrology. (It is the directing organization)
- National Institute of Legal Metrology. (It is entrusted with the performance of scientific and research work)
- National Bureau of Verification.

There are regional bureau of verification, local bureau of verification, mobile bureau of verification, and verification centers to assist national bureau of verification in ensuring appropriate accuracy of the standards, carrying out metrological supervision, verifying measuring instruments.

- Verification agents (Authorized to exercise the functions of verification)

MODULE 2

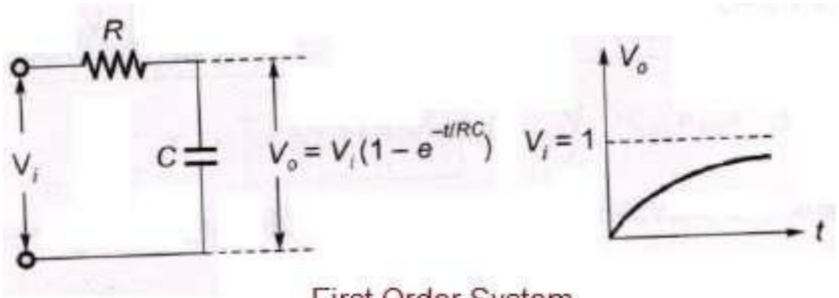
Zero Order System

In the system in which as input changes, output also changes immediately is called zero order system.

Example:

➡Resistor

First Order System



First Order System

Definition:

• In the system in which as input changes, output also changes but not immediately is called first order system.

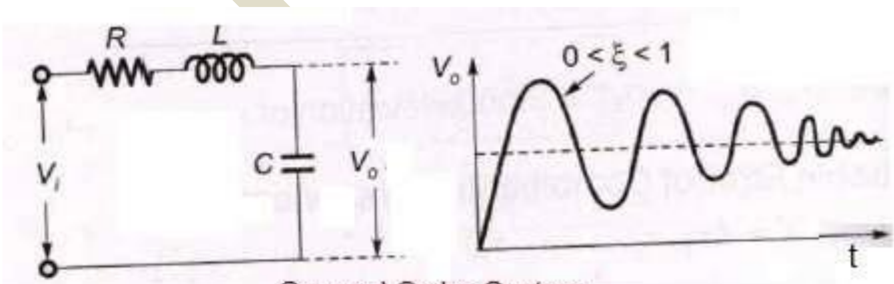
• This system takes some delay but without oscillation.

• The figure-1 depicts circuit diagram of one such first order system.

Example:

➡Heater

Second Order System



Second Order System

Definition:

• In the system in which as input changes, output also changes but with some delay and oscillation is called second order system.

• The figure-2 depicts circuit diagram of one such second order system.

• Analog instruments are second order instrument which has damping factor (ξ) between 0.6 to 0.8. It is an underdamped system.

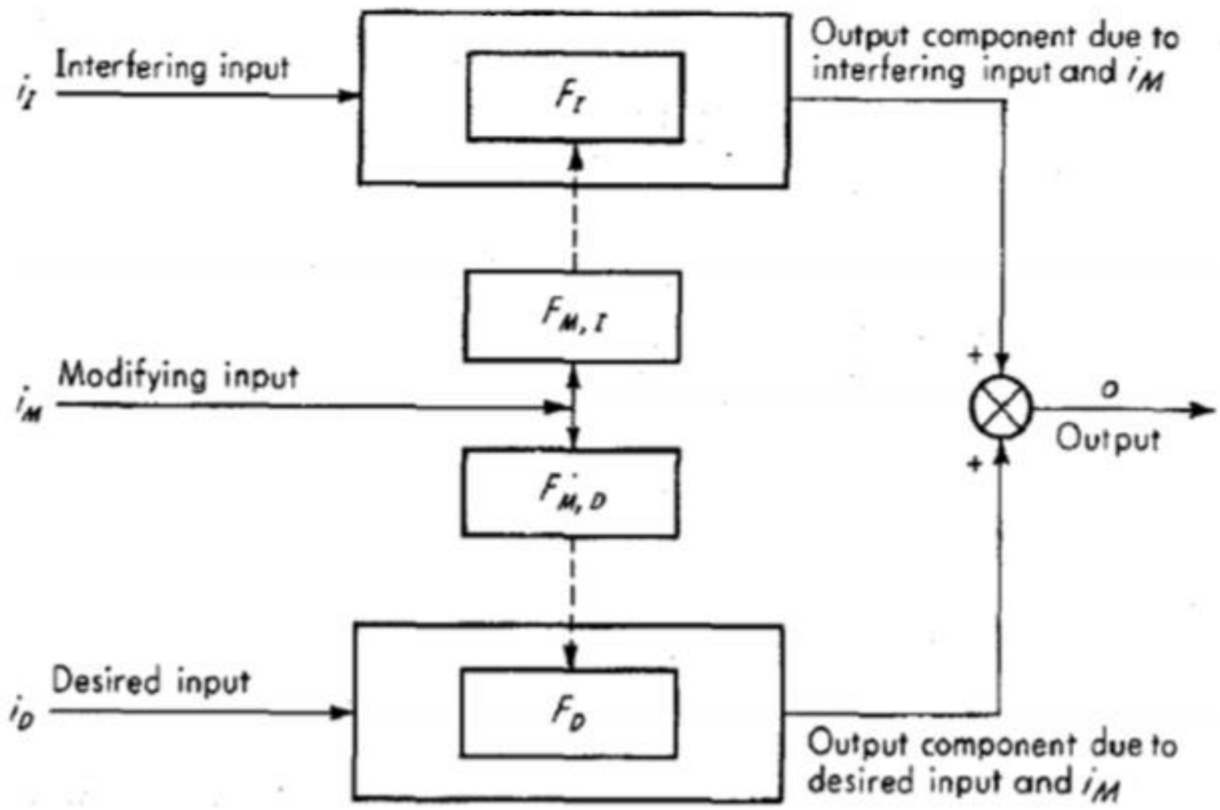
INPUT-OUTPUT CONFIGURATION OF INSTRUMENTS AND MEASUREMENT SYSTEMS

• A generalized configuration containing the significant input -output relationships present in all measuring apparatus, ▫ A scheme suggested by Draper, McKay, and Lees

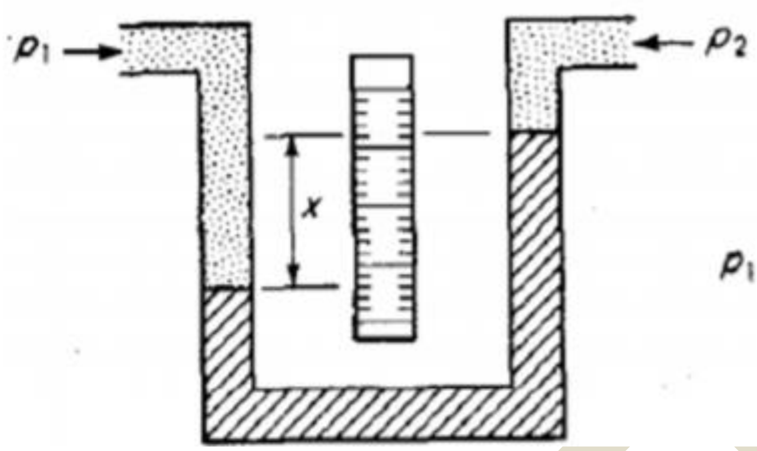
• Desired inputs : quantities that the instrument is specifically intended to measure.

• Interfering inputs :quantities to which the instrument is unintentionally sensitive.

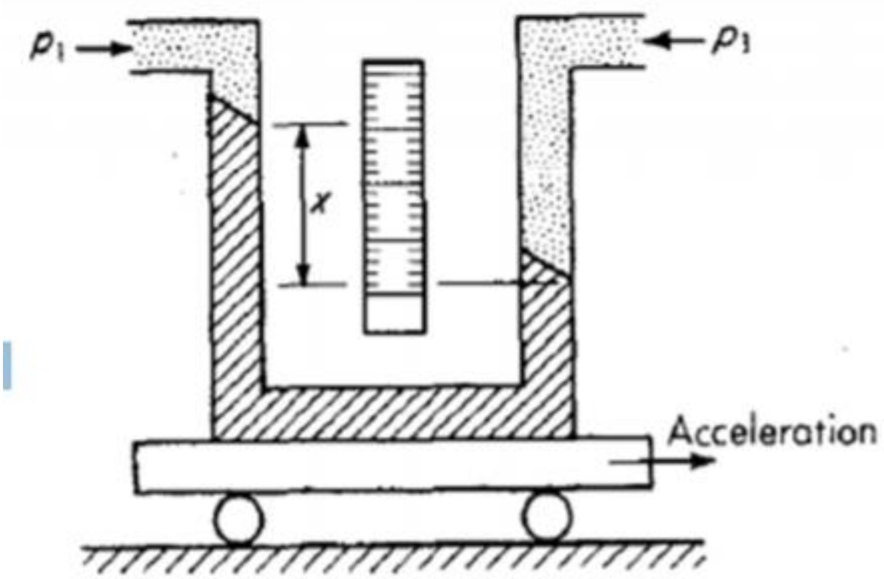
• Modifying inputs are the quantities that cause a change in the input-output relations for the desired and interfering inputs



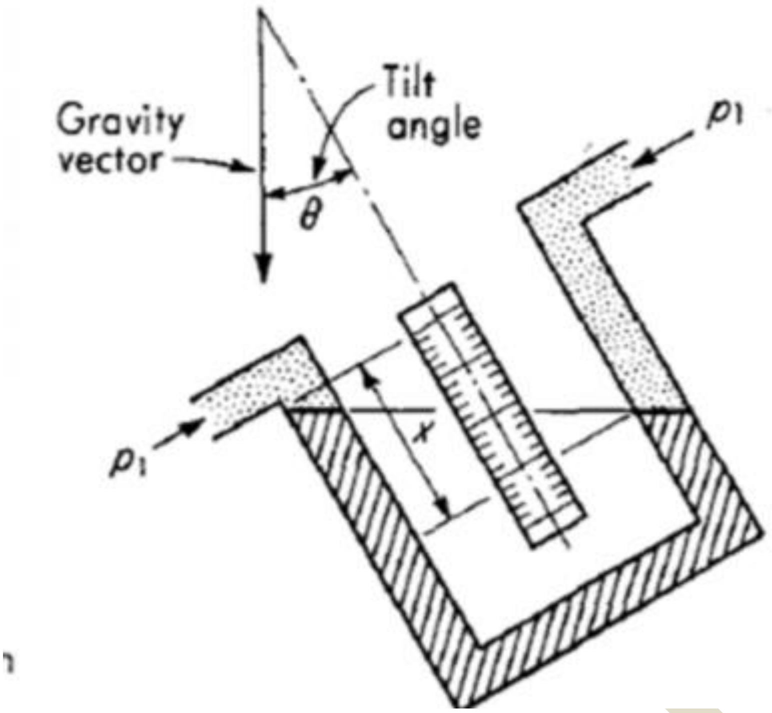
Examples: Interfering/Modifying inputs The desired inputs p1 and p 2 whose difference causes the output x, which can be read off the calibrated scale



Measuring pressures under acceleration influence; an error will be engendered because of the interfering acceleration input.



If the manometer is not properly aligned with the gravity vector, it give an interfering output signal (also a modifying input).



Modifying inputs: ambient temperature and gravitational force.
Both the desired and the interfering inputs may be altered by the modifying inputs

Methods of Correction for Interfering and Modifying Inputs

• A number of methods for nullifying/reducing the effects of spurious inputs are available:

▫ The method of inherent insensitivity
▫ The method of high-gain feedback
▫ The method of calculated output corrections
▫ The method of signal filtering
▫ The method of opposing inputs

The method of inherent insensitivity

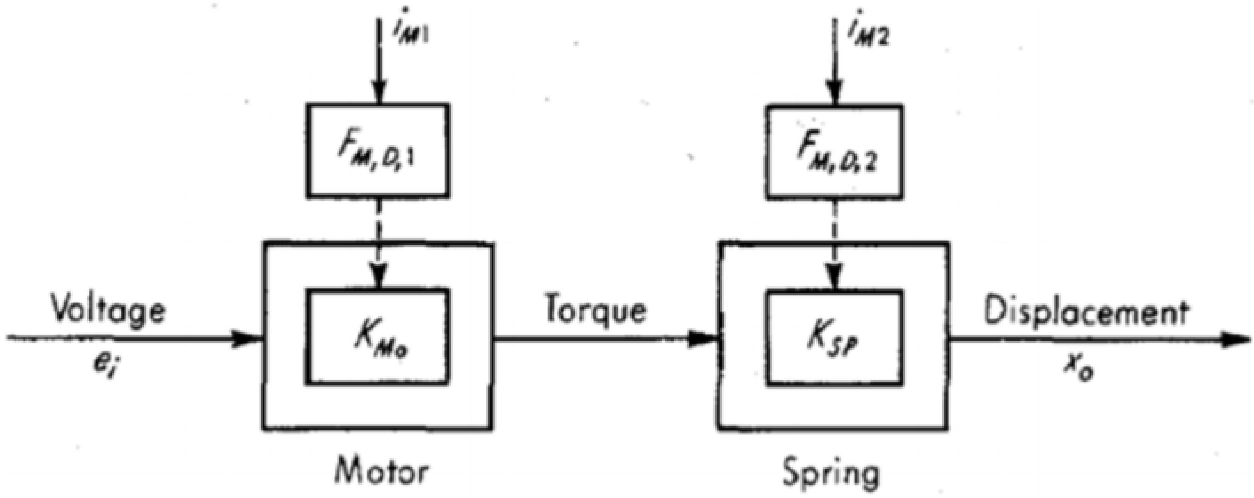
• The elements of the instrument should inherently be sensitive to only the desired inputs:

▫ Choosing gage material that exhibits an extremely low temperature coefficient of resistance while retaining its sensitivity to strain.

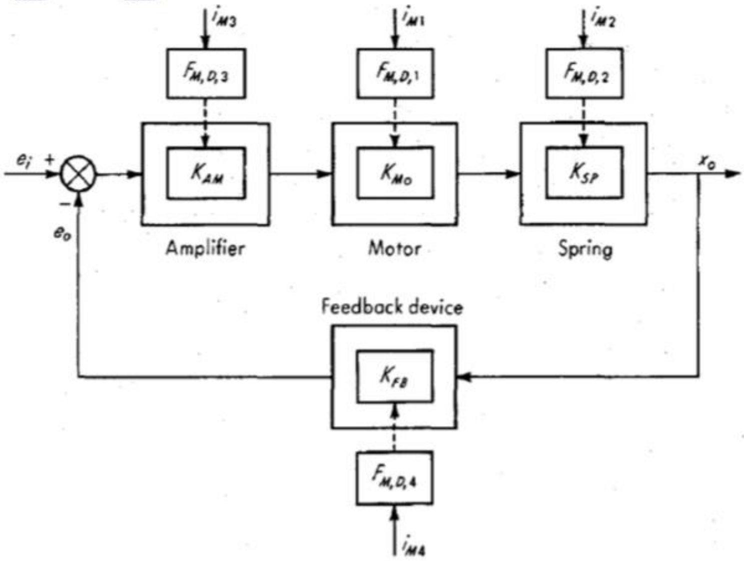
▫ In mechanical apparatus that must maintain accurate dimensions in the face of ambienttemperature changes, the use of a material of very small temperature coefficient of expansion may be helpful.

The method of high-gain feedback • E.g.: Measuring a voltage e i by applying it to a motor whose torque acts on a spring, causing a displacement x 0

$$x_o = (K_{Mo} K_{SP}) e_i$$



Open-loop system



- The output x_o is measured by the feedback device, which produces a voltage e_o proportional to x_o

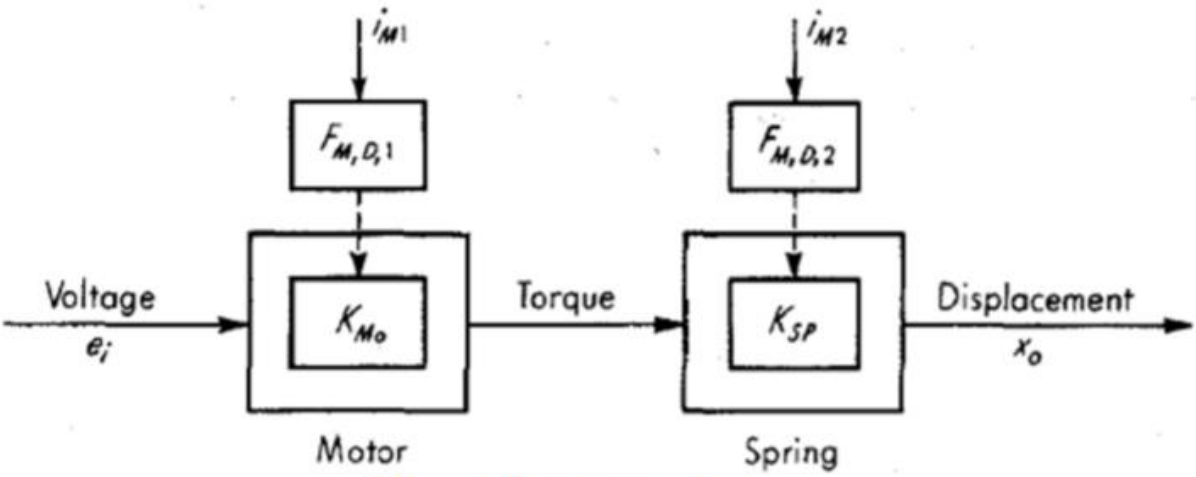
- *We now require K_{FB} stay constant (unaffected by i_{M4})*

$$x_o = \frac{K_{AM} K_{Mo} K_{SP}}{1 + K_{AM} K_{Mo} K_{SP} K_{FB}} e_i$$

K_{AM} to be very large ("high-gain")

$$K_{AM} K_{Mo} K_{SP} K_{FB} \gg 1 \longrightarrow x_o \approx \frac{1}{K_{FB}} e_i$$

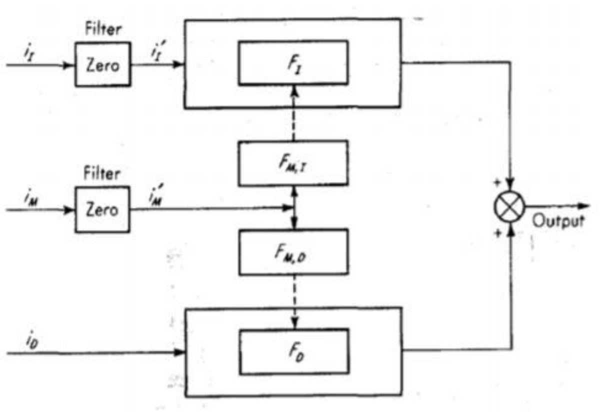
$$x_o = (K_{Mo}K_{SP})e_i$$



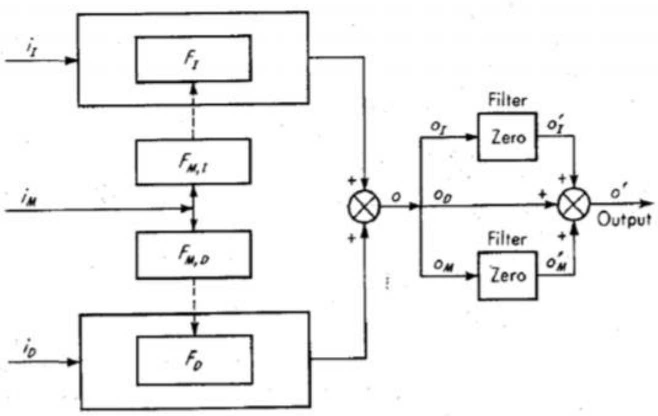
Open-loop system

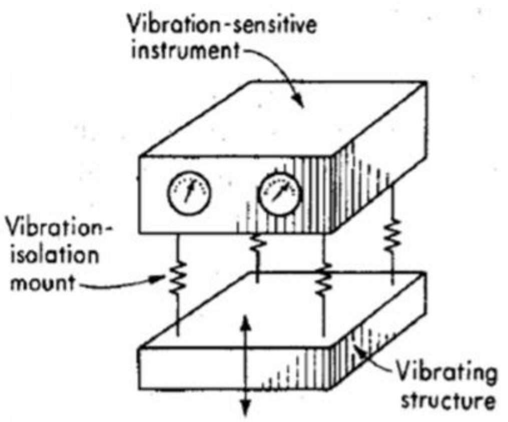
The method of signal filtering

Input filtering

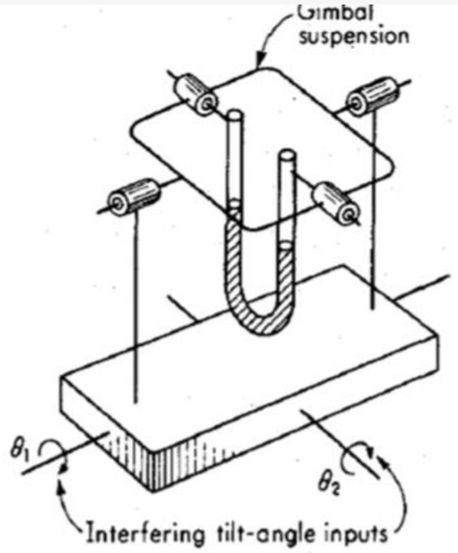


Output filtering

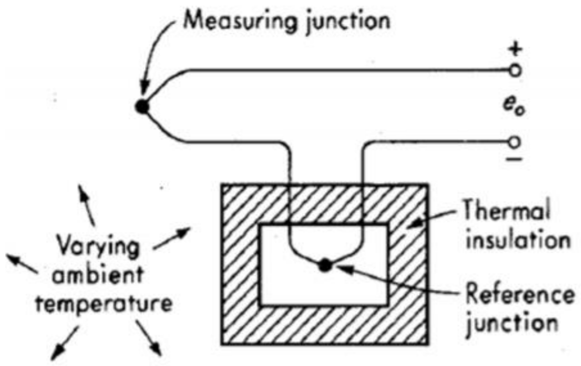




- Electromechanical devices for navigation and control of aircraft or missiles,
  - The interfering vibration input may be filtered out by use of suitable spring mounts.

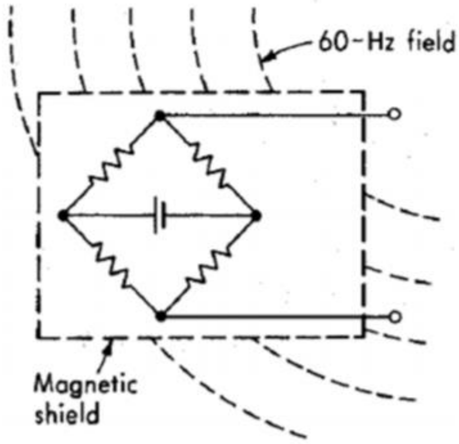


- The interfering tilt-angle input to the manometer may be effectively filtered out by means of the gimbal-mounting

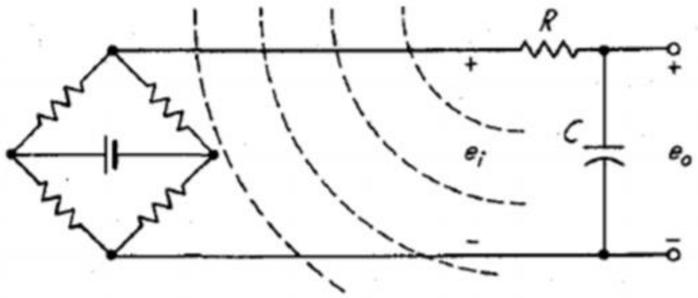


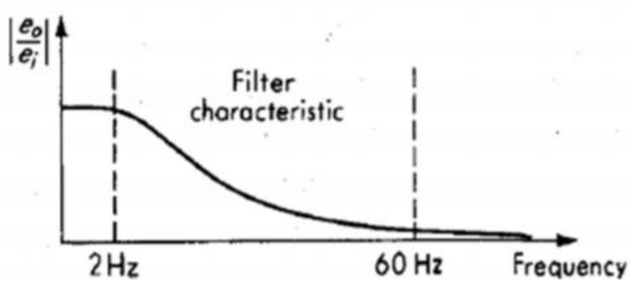
- The thermocouple reference junction is shielded from ambient temperature fluctuations.
- Such an arrangement acts as a filter for temperature or heat-flow inputs

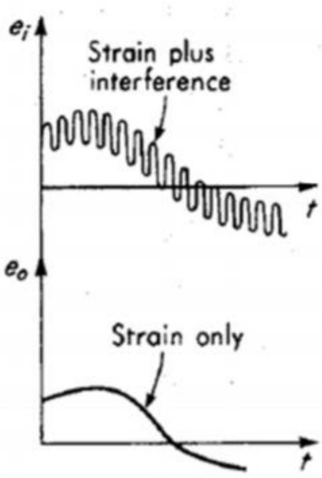
- The strain-gage circuit is shielded from the interfering 60-Hz field



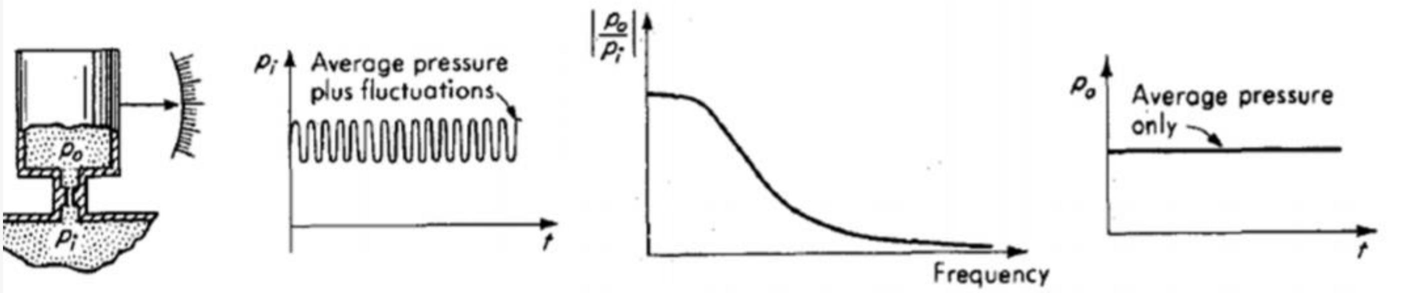
- The strains to be measured are mainly steady and never vary more rapidly than 2 Hz.
- It is possible to insert a simple *RC filter that will pass the desired* signals but almost completely block the 60-Hz interference.

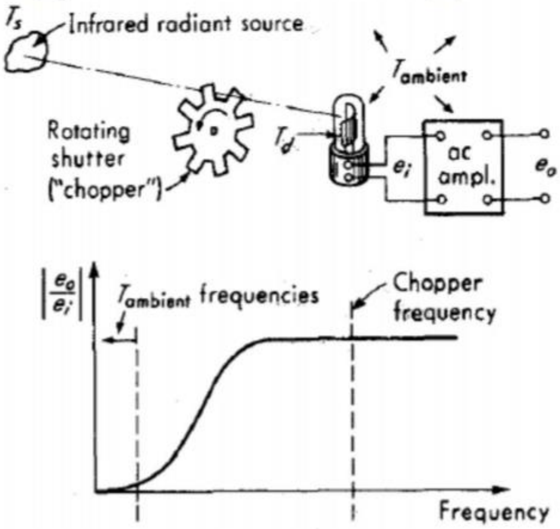




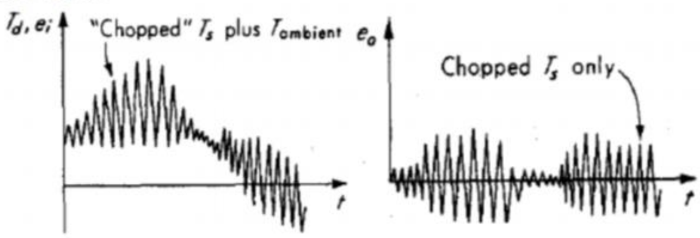


- The pressure gage modified by the insertion of a flow restriction between the source of pressure and the piston chamber,
  - The pulsations in the air pressure may be smoothed by the pneumatic filtering effect of the flow restriction and associated volume.

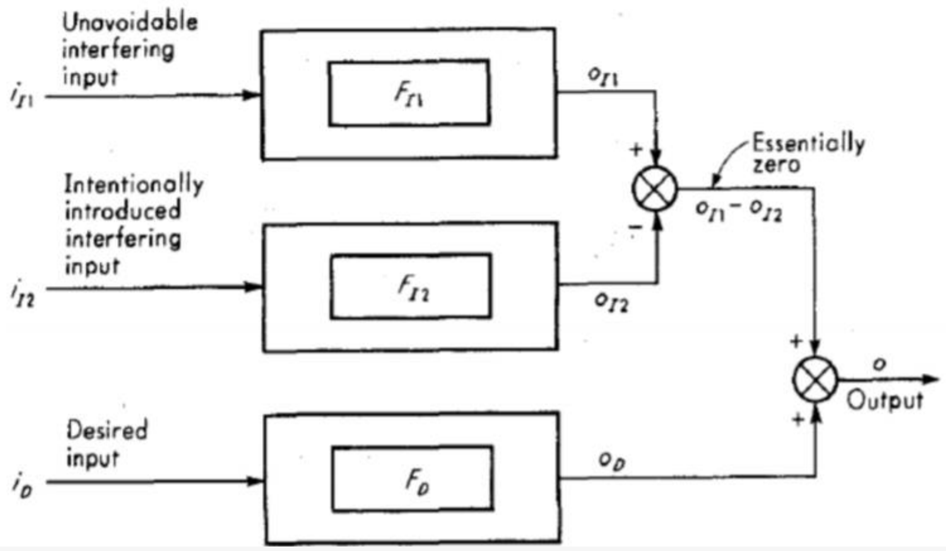




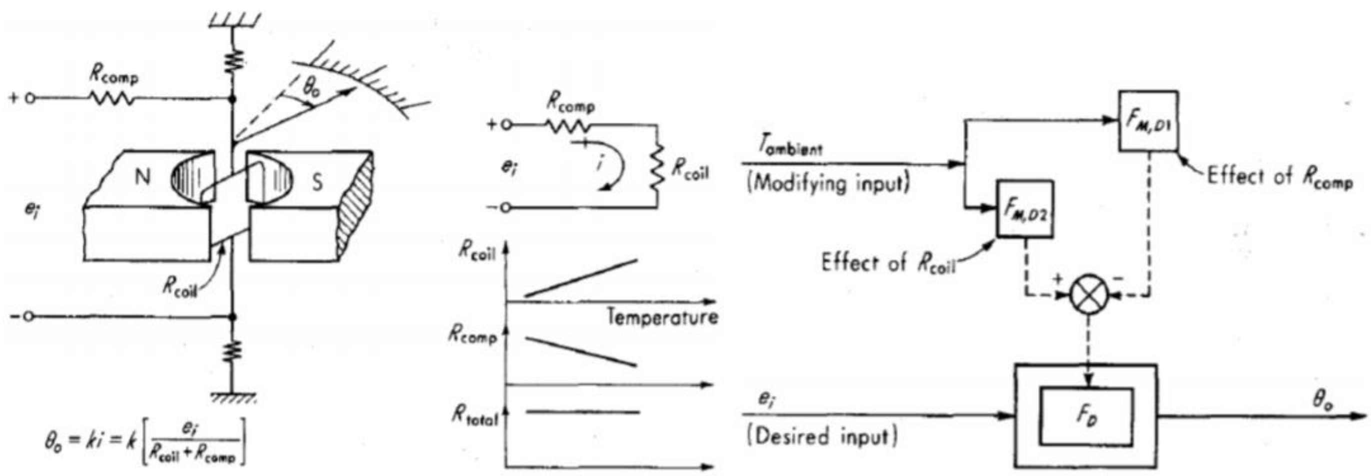
- A "chopped" radiometer senses the temperature T_s in terms of the infrared radiant energy emitted.
- The difficulty is that the ambient temperature, as well as T_s, affects T_d.
- Interposing a rotating shutter between the radiant source and the detector, so that the desired input is "chopped," or modulated, at a known frequency.



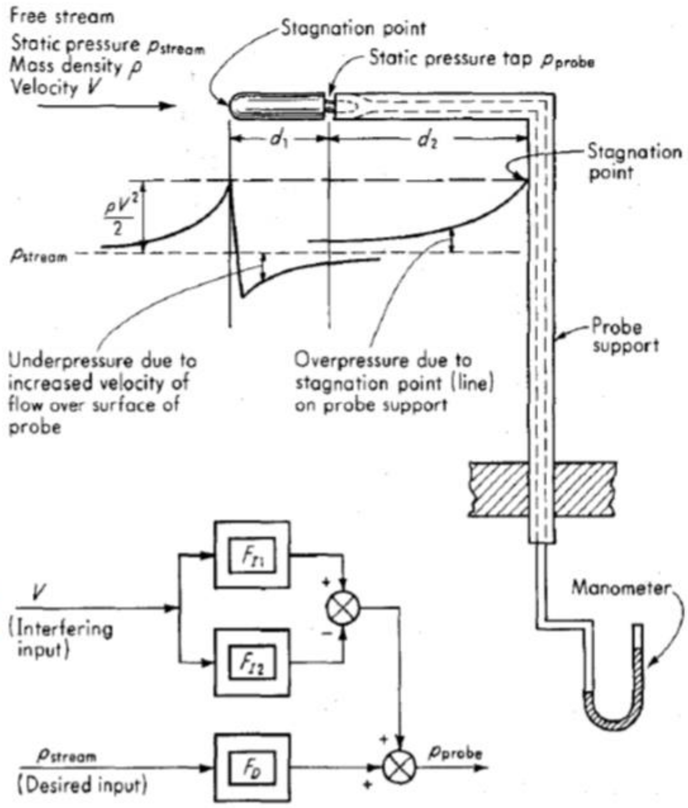
- Intentionally introducing into the instrument interfering and/or modifying inputs that tend to cancel the bad effects of the unavoidable spurious inputs.



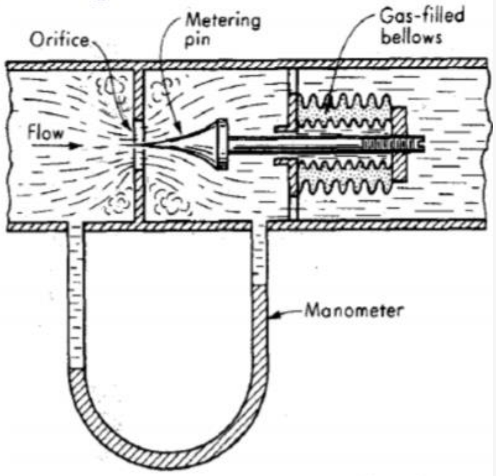
- A millivoltmeter is basically a current-sensitive device.
- However, as long as the total circuit resistance is constant, its scale can be calibrated in voltage, since voltage and current are proportional.

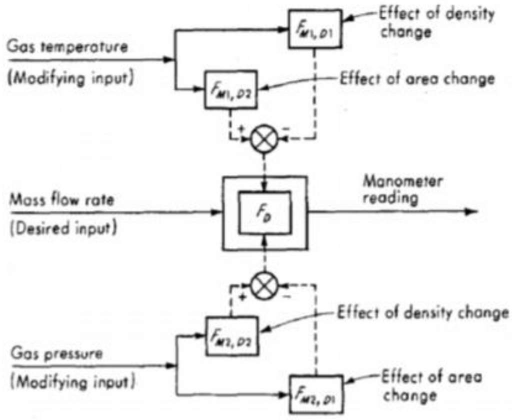


- This velocity increase due to change in streamline causes a drop in static pressure.
- By properly choosing distances d_1 and d_2 two under/overpressure effects can be made exactly to cancel, giving a true static-pressure value at the tap.

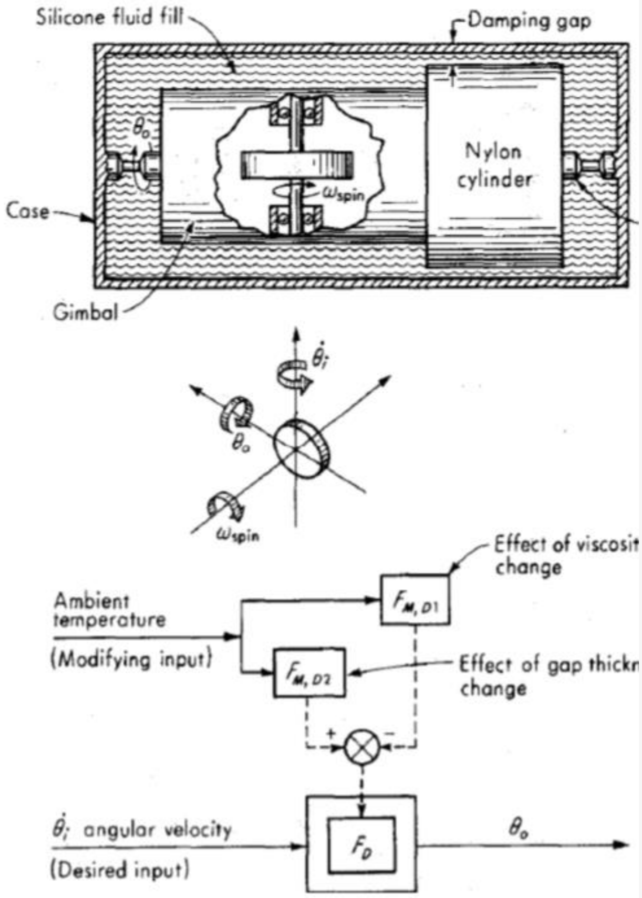


- The mass flow rate of gas through an orifice may be found by measuring the pressure drop across the orifice.
- Variations in gas temperature and pressure yield different mass flow rates for the same orifice pressure drop.
- Opposing input is accomplished by attaching the specially shaped metering pin to a gas-filled bellows, enabling the flow area to be varied in just the right way.





- The action of the device is that a vehicle rotation at angular velocity $\dot{\theta}_i$ causes a proportional displacement θ_o of the gimbal relative to the case.
- When the temperature increases, viscosity drops, causing a loss of damping.
- Simultaneously, the nylon cylinder expands, narrowing the damping gap and thus restoring the damping to its proper value.



MODULE 3

SENSORS

Sensors have played a role in manufacturing for years, but until recently they have been largely constrained by issues such as system noise, signal attenuation, and response dynamics. Today, integration of local computing power and the Internet of Things (IoT) has transformed ordinary sensors into smart sensors, enabling them to carry out complex calculations on measured data locally within a sensor module. Along with their increased capabilities, sensors have also become remarkably small (some are no larger than a pencil eraser) and extremely flexible, allowing them to be attached to difficult-to-reach and potentially dangerous equipment, turning bulky machines into high-tech intel. This fusion of sensing and signal-processing functions is redefining the sensor landscape.

Smart Sensors Defined

For a proper definition, we turned to an expert. Tom Griffiths, Product Manager at Honeywell Industrial, which produces smart sensors, defines the technology this way:

"Smart sensors ... are microprocessor driven and include features such as communication capability and on-board diagnostics that provide information to a monitoring system and/or operator to increase operational efficiency and reduce maintenance costs."

Five additional characteristics of a smart sensor include:

1. Signaling conditioning that preserves integrity and ensures isolation in harsh industrial environments
2. Using the local computing power to process and interpret data locally; make decisions based on the physical parameters measured; and communicate accordingly
3. Creating boundary conditions without a human operator
4. Enabling in-fault alarms and processing efficiency
5. Complying with a variety of communication standards such as Wi-Fi, Bluetooth, and ZigBee

Three Main Benefits of Smart Sensors

Aside from the aforementioned size, which allows smart sensors to be placed just about anywhere imaginable, what really gets manufacturers excited is the prospect of greater profitability, happier customers, wider market-share, and more productive assets. Smart sensors offer three key benefits that help achieve these goals:

1. Equipment and environmental conditions

Which parts need replacement? Which need maintenance? In the past, this could be a guessing game that resulted in major inefficiencies and loss of productivity. But, it was better than the alternative: waiting until a machine overheated or broke down, which could really throw production schedules off course and even lead to potential accident and injury. With smart sensors, this is all in the past. Applied throughout the supply chain and constantly collecting data, smart sensors monitor the conditions of equipment and its utilization rate in real time, giving workers a 360-degree view of all activities. With the aid of smart sensors, manufacturing employees can view machine performance and receive advance notice of potential problems or anomalies so they can be addressed proactively. Smart sensors monitor the following conditions and more:

- Temperature
- Speed
- Weight
- Operational failures
- Changes in operations
- Object movement (target too close/too far)
- Valve status (open/closed)

A smart sensor is also able to report oxygen levels and the heart rate of employees to make the workplace a safer place.

2. Improving and automating logistics and asset management

Outfitting with GPS, smart sensors can track location of assets, vehicles, inventory, or even people. The data is utilized by manufacturers to see at what point in its journey a shipment is at, the whereabouts of a fleet truck, and more. Manufacturers can also use sensor data to predict and confirm when assets arrive and when they leave warehouses, distribution centers, and retail stores. Notifications that an asset is not where it should be alert manufacturers to a potential problem in the supply chain that needs to be addressed, and they could also be an indicator of potential inventory theft. Another sensor benefit? They help keep shelves stocked by notifying automated storage and retrieval systems of needed inventory. Smart sensors monitor the following conditions and more:

- Asset location
- Asset presence in shelf
- Asset temperature
- Inventory control

3. Controlling energy costs and meeting specific regulatory requirements of each industry

We've come a long way from "The Clapper". While motion sensors in homes and offices have been saving energy costs for years by turning on and off lights based on activity, smart sensors are a giant leap forward, giving manufacturers the ability to view and control temperatures and activity on the factory floor and in distribution centers; they can now control energy usage on a large scale. The benefits are twofold: they help manufacturers combat the increasing cost of energy use, and enable them to meet the strict energy use regulations imposed upon the manufacturing sector.

Managing Smart Sensor Data

All sensors have the ability to collect, store, and monitor data. Smart sensors take it a step further, offering a 360-degree view of each of the following:

- **Context.** In order to use the data, you need to know something about the contributing factors. Time stamps, GPS coordinates, weather, and relevant machine/asset/vehicle are the most common variables which provide valuable context for the manufacturer.
- **Relevance** - How is the data being collected relate to company goals? Does it impact the bottom line, or indicate risk to customer satisfaction? Relevance is subjective, but data needs to point to a significant end result that benefits the business in some way.
- **Communication** - Data must be conveyed to another machine (typically the internet or an intranet) that can record, store, and organize data. Security surrounding the data is also critical if it is sensitive information.

- **Analysis** - Raw data is often useless; once captured, it needs to be aggregated and analyzed to recognize anomalies, or the data points which indicate that something isn't operating properly and needs attention.
- **Action** - At last, the ROI! Some data points can trigger predetermined actions, saving both time and resources. They also ensure the proper response is initiated without human intervention.

Smart sensors, especially when combined with IoT, are changing the way manufacturers collect data and communicate. They are helping to created better products, and produce them faster. Rapid adoption of smart sensors has also resulted in falling prices (small smart sensors go for less than 50 cents) enabling manufacturers of every size to get in the game

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A smart sensor is also able to report oxygen levels and the heart rate of employees to make the workplace a safer place.

2. Improving and automating logistics and asset management

Outfitting with GPS, smart sensors can track location of assets, vehicles, inventory, or even people. The data is utilized by manufacturers to see at what point in its journey a shipment is at, the whereabouts of a fleet truck, and more. Manufacturers can also use sensor data to predict and confirm when assets arrive and when they leave warehouses, distribution centers, and retail stores. Notifications that an asset is not where it should be alert manufacturers to a potential problem in the supply chain that needs to be addressed, and they could also be an indicator of potential inventory theft. Another sensor benefit? They help keep shelves stocked by notifying automated storage and retrieval systems of needed inventory. Smart sensors monitor the following conditions and more:

- Asset location
- Asset presence in shelf
- Asset temperature
- Inventory control

3. Controlling energy costs and meeting specific regulatory requirements of each industry

We've come a long way from "The Clapper". While motion sensors in homes and offices have been saving energy costs for years by turning on and off lights based on activity, smart sensors are a giant leap forward, giving manufacturers the ability to view and control temperatures and activity on the factory floor and in distribution centers; they can now control energy usage on a large scale. The benefits are twofold: they help manufacturers combat the increasing cost of energy use, and enable them to meet the strict energy use regulations imposed upon the manufacturing sector.

Managing Smart Sensor Data

All sensors have the ability to collect, store, and monitor data. Smart sensors take it a step further, offering a 360-degree view of each of the following:

- **Context.** In order to use the data, you need to know something about the contributing factors. Time stamps, GPS coordinates, weather, and relevant machine/asset/vehicle are the most common variables which provide valuable context for the manufacturer.
- **Relevance** - How is the data being collected relate to company goals? Does it impact the bottom line, or indicate risk to customer satisfaction? Relevance is subjective, but data needs to point to a significant end result that benefits the business in some way.

- **Communication** - Data must be conveyed to another machine (typically the internet or an intranet) that can record, store, and organize data. Security surrounding the data is also critical if it is sensitive information.
- **Analysis** - Raw data is often useless; once captured, it needs to be aggregated and analyzed to recognize anomalies, or the data points which indicate that something isn't operating properly and needs attention.
- **Action** - At last, the ROI! Some data points can trigger predetermined actions, saving both time and resources. They also ensure the proper response is initiated without human intervention.

Smart sensors, especially when combined with IoT, are changing the way manufacturers collect data and communicate. They are helping to created better products, and produce them faster. Rapid adoption of smart sensors has also resulted in falling prices (small smart sensors go for less than 50 cents) enabling manufacturers of every size to get in the game

LIGHT SENSORS

A light sensor is a photoelectric device that converts light energy (photons) detected to electrical energy (electrons).

Candela

- Originated from the term candles, candela refers to luminous intensity; how strong is the light to a naked eye
- The higher the luminous intensity, the higher the sensitivity it is to our eyes

Lumen

- Measures the total amount of visible light from a light source through the relationship between luminous intensity and the angle that a light beam fills
- Commonly used to rate the brightness of a lightbulb
- To simply put it Lumen = Total amount of light emitted in all directions

Lux

- Used to measure illuminance, the area where the luminous flux is spread
- It's similar to Lumen but it takes into account the surface area
- To simply put it, Lux = total amount of light that falls on a parrticular surface

What are the types of light sensor

There are different types of light sensors available; mainly Photoresistor, Photodiodes, and Phototransistors. Sounds technical? I'll break it down with the explanations below!

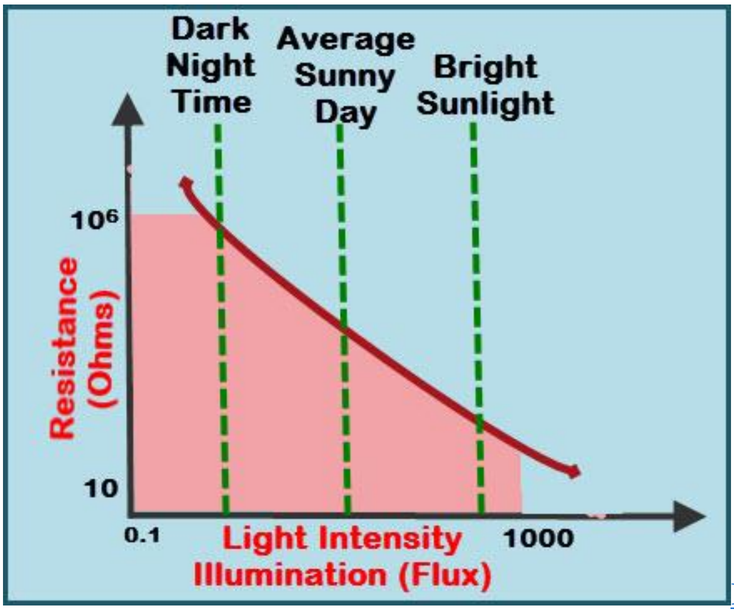
1. Photoresistors (LDR)

The most common light sensor type that's used in a light sensor circuit are photoresistors, also known as a light-dependent resistor (LDR). Photoresistors are used to simply detect whether a light is on or off and compare relative light levels throughout a day.

What are photoresistors made of?

- A high resistance Semiconductor material called cadmium sulfide cells, highly sensitive to visible and near-infrared light

How photoresistors work?



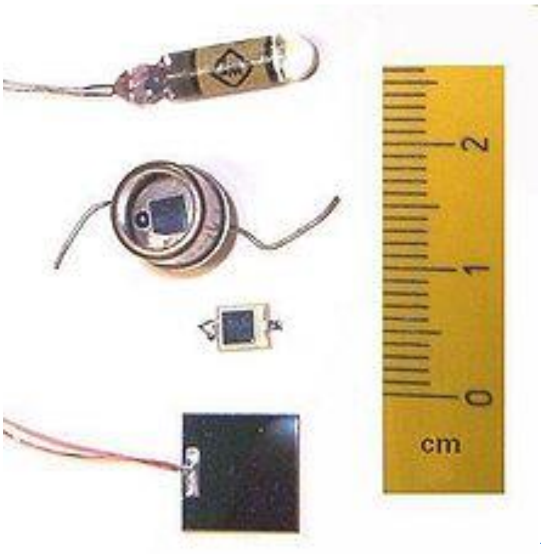
[Photoresistor Working Principle]

As its name suggests, photoresistors work similarly to your regular resistors, but instead resistance change is dependent on the amount of light it's exposed to.

- High intensity of light causes a lower resistance between the cadmium sulfide cell
- The low intensity of light results in a higher resistance between the cadmium sulfide cells

This working principle can be seen in applications such as street lamps, wherein the day, the higher light intensity results in lower resistance and no light produced.

2. Photodiodes



How photodiodes look like

Photodiodes are another type of light sensor. But instead of using the change in resistance like LDR, it's more complex to light, easily changing light into a flow of electric currents.

Also known as a photodetector, photo sensor

What are photodiodes made of?

- Photodiodes are mainly made from silicon and germanium materials and comprise of optical filters, built-in lenses and surface areas

How photodiodes work?

Photodiodes work on the working principle called the inner photoelectric effect. To simply put it, when a beam of light hits, electrons are loosened, causing electron-holes which results in electrical current to flow through.

- The brighter the light present, the stronger the electrical current will be

Photodiode light sensor applications

Since current generated by photodiodes are directly proportional to the intensity of light, it makes it favourable for light sensing that requires fast light response changes.

Since photodiodes are responsive to infrared light, it's applicable for more usages as well.

Here are some of the applications of photodiode:

- Consumer electronics ranging from compact disc players to smoke detectors and even remote control devices
- Medical applications such as equipment/instruments used for measuring and analysis purposes
- Solar energy systems such as solar panels

3. Phototransistors

The last light sensor type we'll be exploring today is the phototransistor. The phototransistor light sensor can be described as a photodiode + amplifier. With the added amplification, light sensitivity is far better on the phototransistors.

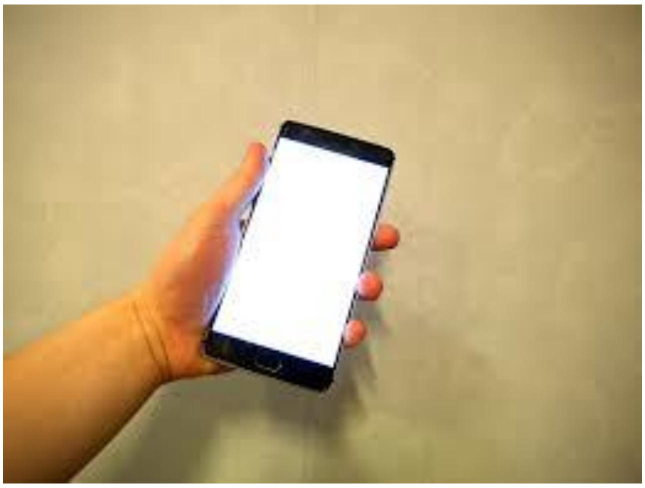
- However, it doesn't fair better in low light level detection as compared to photodiodes.

Since both light sensor types share a similar working principle, do refer to the previous explanation

What is a light sensor used for? Applications

Despite the different types of light sensors, it can still be used in a variety of applications as seen below:

Consumer electronics



Ever wonder what's behind your smartphone and tablets that allow for auto screen brightness adjustments? Yes, it's an ambient light sensor! It measures the ambient light level of your surroundings and determines the suitable brightness of your screen!

Automobiles

Similarly to how light sensor works on your smartphones, it is used in automobiles to support the drivers' field of vision. The present light sensor detects surrounding ambient light, and if it's getting too dark, it'll automatically turn on light systems!

Agricultural Usages


Image Reference: Trusty Joe

We all know crops need mainly two things for growth; Sunlight and water. This is where a light sensor comes to play, helping farmers keep their crops hydrated yet not over-hydrating it. Here's how:

- A light sensor is connected to a sprinkler system, detecting levels of sunlight and only activating it when the sun isn't at its brightest
- It is used alongside other temperature sensors to help gather informative data as well

Security applications

Commonly used in circuits for shipment cargos, light sensors are connected to circuits and placed inside as it can detect whenever a container is open due to the change in light exposure. This helps in better processing of lost goods and tracking of personnel.

- As such, photoresistors are commonly used due to its suitability

Light sensors available at Seeed

Since photoresistors, photodiodes, and phototransistors offer versatility at affordable pricing, you can collect illuminance data using Arduino or Raspberry Pi through our selection of light sensors available at Seeed!

LINEAR VOLTAGE DIFFERENTIAL TRANSFORMER

Linear Variable Differential Transformer commonly known by its acronym, LVDT is an electromechanical transducer which converts rectilinear motion of an object into a corresponding electrical signal. It is used for measuring movements ranging from microns upto several inches.

LVDT consists of a primary winding and a pair secondary windings. Primary winding is sandwiched between the secondary windings. Secondary windings are symmetrically spaced about the primary and are identically wound. The coils are wound on a hollow form of glass reinforced polymer and then secured in a cylindrical stainless steel housing. The windings form the stationary part of the sensor.

The moving element of an LVDT is called the core made of highly permeable magnetic material; the core moves freely axially in the coil's hollow bore. The core is mechanically coupled to the object whose displacement is to be measured.

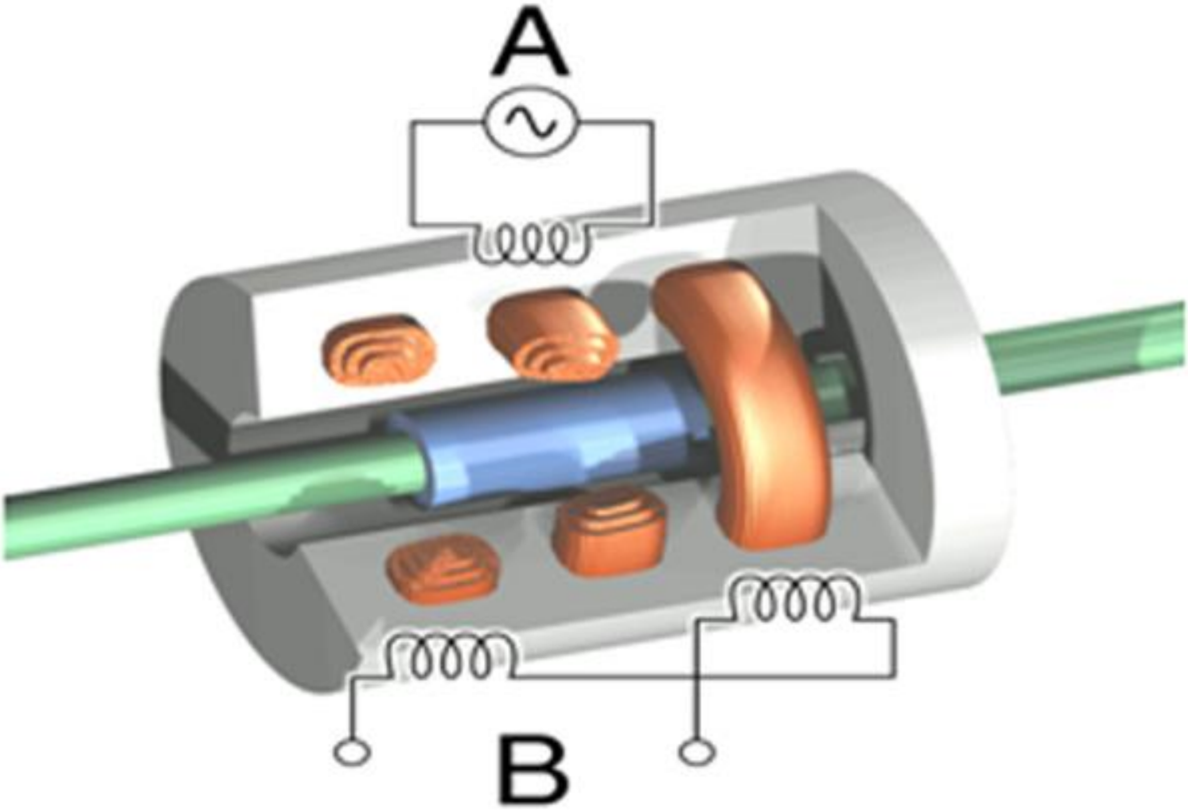


Fig. 4: Graphical Image Showing Insides of a Typical Linear Voltage Differential Transformer

When the primary winding of LVDT is energized by alternating current of suitable amplitude and frequency, AC voltage is induced in the secondary. The output of the LVDT is the differential voltage between the two secondary windings; the differential voltage varies with the position of the core. Often, differential AC output voltage is converted into DC voltage for use in measurement systems.

When primary winding is excited, the voltage induced in the secondary depends upon the coupling of the magnetic flux by the core to the secondary windings. When the core is at the centre, equal flux is coupled to the two secondary windings and hence, the differential voltage output is zero. However, when the core is at off-centre, unequal flux is induced in the secondary windings and the amount of flux in the two windings and hence the differential voltage between the two wingings depend upon the position of the core.

LVDTs offer various advantages like Friction-Free Operation, very high resolution, unlimited mechanical life, high reliability, no cross sensitivity, environmentally rugged, and so on.

For measuring angular motions, a variant of LVDT, i.e, Rotary Voltage Differential Transformer is used. RVDT is exactly similar to LVDT in terms of operation; difference is in their construction

HEBM & Fiber-Optic Position Sensor

Hall Effect based Magnetic Position Sensors

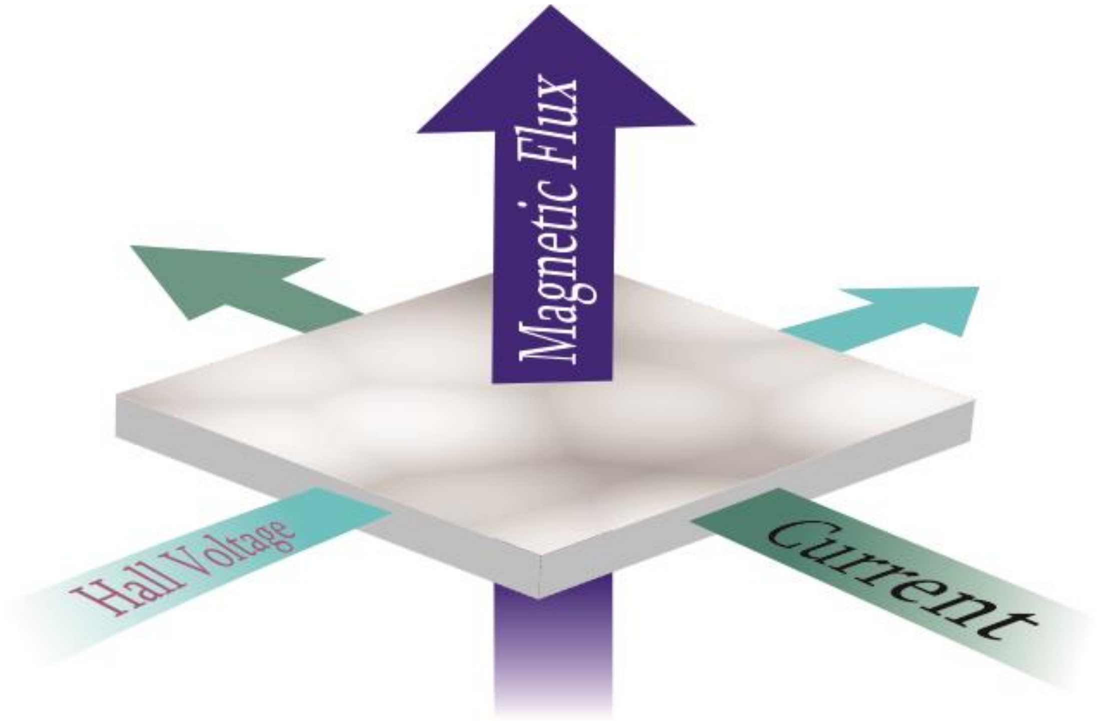


Fig. 12: Representational Image Explaining Working of Hall Effect Based Magnetic Position Sensors

The Hall Effect principle states that when a current carrying conductor is placed in a magnetic field, a voltage will be generated perpendicular to the direction of the field and the flow of current.
When a constant current is passed through a thin sheet of semiconducting material, there is no potential difference at the output contacts if the magnetic field is zero. However, when a perpendicular magnetic field is present, the current flow is distorted. The uneven distribution of electron density creates a potential difference across the output terminals. This voltage is called the Hall voltage. If the input current is held constant the Hall voltage will be directly proportional to the strength of the magnetic field.

Fig. 13: Image Shoiwng Hall Effect Based Magnetic Sensor

In position sensors which use hall efffect, the moving part is connected to a magnet.Thus, the sensor consists of a Hall element and a magnet housed within the sensor shaft. With the movement of the body or its part the magnet also moves and therefore, the magnetic field across the Hall element and so the Hall voltage. Thus Hall voltage becomes a function of the position of the moving part.

Commercially available Hall elements are made of Bulk Indium Arsenide (InAs), Thin Film InAs, Gallium Arsenide (GaAs), Indium Antimonide (InSb).

Fiber-Optic Position Sensor

Optical fibers offer distinct advantages of their immunity to EMI, inability to generate sparks in potentially explosive environment. Position sensors based on optical fibers can be used for measurement ranging from few centimeters to few meters where very high resolution is not of paramount importance.

Fluorescence followed by absorption is at the heart of this sensor. Pump source is connected to the body or its part whose motion is to be sensed. The fiber is fluorescent, and at the ends of the fiber are placed two photo-detectors.

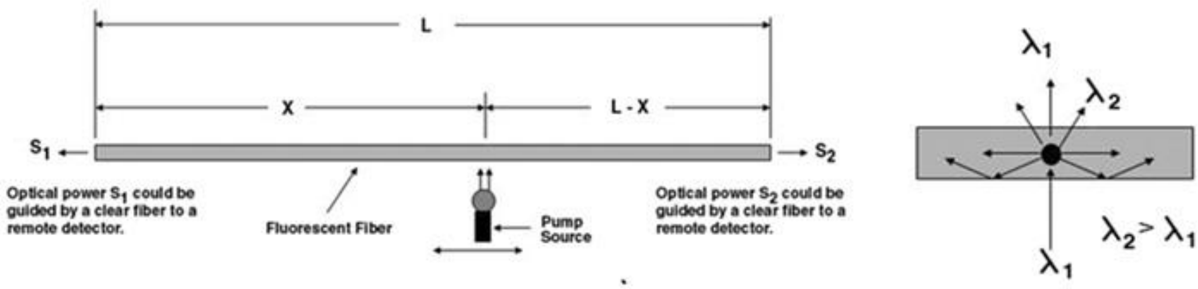


Fig. 14: Diagram Showing Working of a Optical Fiber Based Position Sensor

The logarithm of the ratio of the two signals S1 and S2 is linear in x and independent of the strength of the pump source.

OPTICAL POSITION SENSOR

Optical sensors are based one of the two mechanisms. In first type, light is transmitted from one end and received at the other. Change in one of the characteristics- intensity, wavelength, polarization or phase- by the physical parameter is monitored. In second type, transmitted light is reflected from the object and light returned towards the source is monitored.

First type of optical sensors are used in optical encoders commonly used to provide feedback to provide position feedback for actuators. Optical encoders consists of a glass or plastic disc that rotates between a light source(LED) and light receiver(photodetector). The disc is encoded with alternate light and dark sectors so that pulses are generated as the disc rotates. Based on the count of the pulses, speed of the disc and hence the angular position is computed. To identify the direction of movement, two photodetectors are used. Absolute optical encoders have a unique code that can be detected for every angular position.

An example of second types of sensors is found on machine tools measure the position of the work table is measured and displayed.

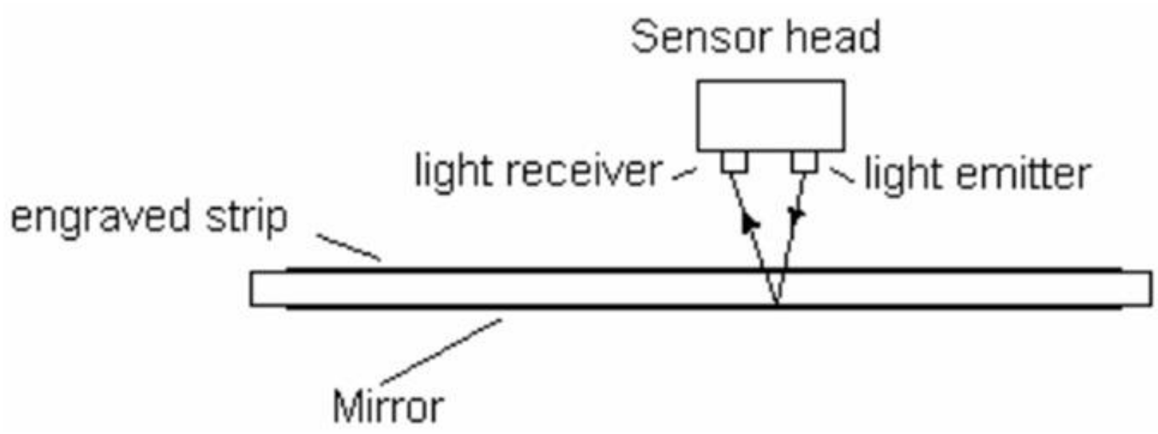


Fig. 15: Image Showing an Application of Position Sensor used in Machine Tools

The strip or disc has very fine lines engraved on it which interrupt the beam. The number of interruptions is counted electronically and this represents the position or angle

Piezoelectric Transducer

Definition:

A transducer utilizing piezoelectric element to convert mechanical motion into electrical signal is called a piezoelectric transducer. This transducer works on the principle of ***Piezoelectric Effect.*** It is an active transducer.

Piezoelectric Material and Piezoelectric Effect:

A piezoelectric transducer uses a piezoelectric material as a transduction element. A piezoelectric material is one in which an electrical potential difference appears across a certain surface of a crystal if the dimension of the crystal is changed by the application of force. This potential difference appears due to displacement of charge. The process is reversible which means if potential difference across some specified surface is changed, the dimension of the piezoelectric material will also change. This effect is known is ***Piezoelectric Effect***. Elements exhibiting qualities are known as electro-resistive elements.

Rochelle Salt, Ammonium Dihydrogen Phosphate, Lithium Suphate, dipotassium tartarate, quartz and ceramic are some common example of piezoelectric material. Basically, there are two types of piezoelectric materials: Natural and Synthetic.

A natural piezoelectric material is one which occurs in nature and can be used as such. However, synthetic piezoelectric materials are those materials in which piezoelectric properties are not found in their original state but these properties are produced using special techniques such as polarizing treatment.

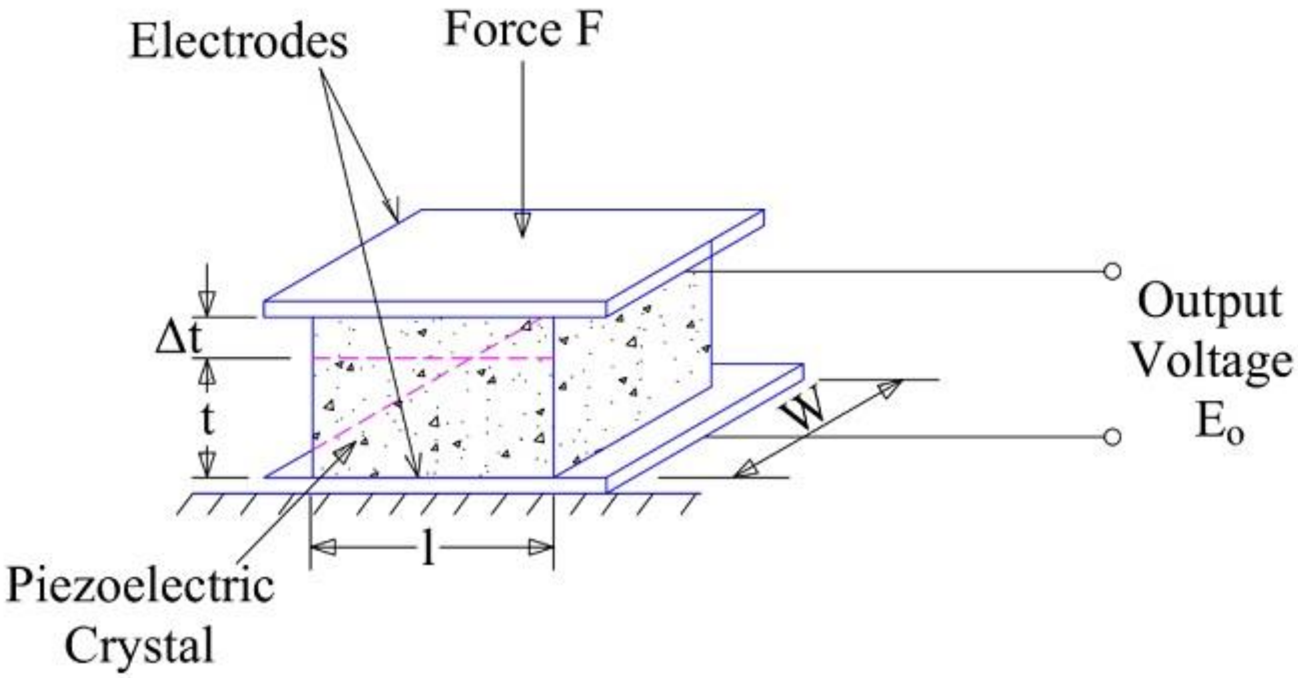
Quartz and Ceramic are examples of natural piezoelectric material whereas materials like lithium sulphate, ethylene diamine tartarate belong to the synthetic group.

Working Principle of Piezoelectric Transducer:

The working principle of a Piezoelectric Transducer is based on the fact that when a mechanical force is applied on a piezoelectric crystal, a voltage is produced across its faces. Thus, mechanical phenomena is converted into electrical signal. No external supply is required for this transducer to work and hence it is an active transducer.

Piezoelectric Tansducer responds to the mechanical force / deformation and generate voltage. There may be various modes of deformation to which these transducers can respond. The modes can be: thickness expansion, transverse expansion, thickness shear and face shear.

In a piezoelectric transducer, a piezoelectric crystal is sandwiched between the two electrodes. When a mechanical deformation takes place, it generates charge and hence it acts as a capacitor. A voltage is developed across the electrodes of the transducer which can be measured and calibrated with the deforming force to directly measure the mechanical deforming force. Figure below shows a simple piezoelectric transducer.



It should be noted that, piezoelectric effect is direction sensitive. This means that, the polarity of charge will not be same for a tensile and compressive force. The polarity of voltage induced due to a tensile force will be opposite to the polarity of voltage produced due to a compressive force.

The magnitude and polarity of induced charge on the electrodes are directly proportional to the applied force and its direction. Let the applied force be F, then the charge induced will be given as

Q = kF ……….(1)

where k is constant of proportionality. This constant is nothing but the charge sensitivity of the piezoelectric material. It is constant for a given material and defined as the charge generated per unit applied force. Its unit is (Columb / Newton)

Assuming the surface area of electrode, separation between the electrodes be A and d respectively, the charge generated on each of the electrode of piezoelectric transducer is given as below.

Q = CV

where C is capacitance formed by the electrodes and the piezoelectric material

C = ƐA / d

Therefore,

Q = ƐAV / d ………….(2)

From (1) and (2),

kF = ƐAV / d

F = (ƐAV) / (dk)

Carefully observe the above expression; Ɛ, A, d and k are constant for a given piezoelectric transducer. This essentially means that, magnitude of applied force is directly proportional to the output voltage across the electrodes.

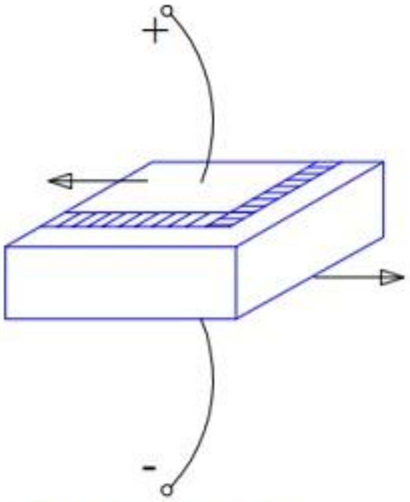
Thus, by measuring the value of voltage across the electrodes of piezoelectric transducer, we can find the value of mechanical force. Hence, mechanical force converted into electrical signal which is the whole & sole requirement of any transducer.

Modes of Operation of Piezoelectric Crystal:

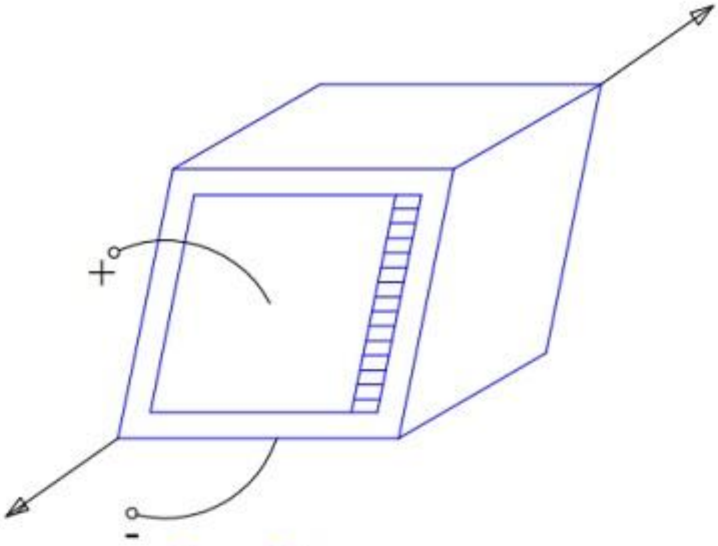
Piezoelectric crystal can be used in many modes. There modes are:

- Thickness shear
- Face Shear
- Thickness Expansion
- Transverse Expansion

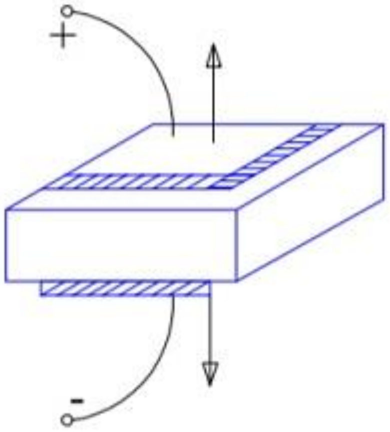
These modes are shown in figure below.



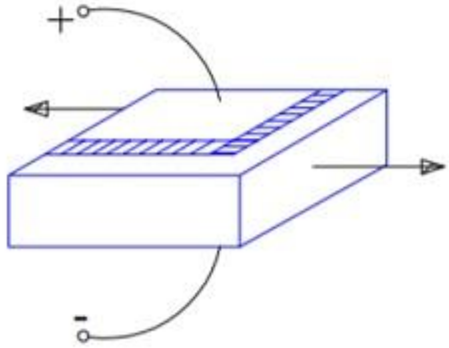
Thickness Shear



Face Shear



Thickness Expansion



Transverse Expansion

Each of the above mode can be converted into electrical signal by using piezoelectric transducer. By cementing two crystals together so that their electrical axes are perpendicular, “Benders” or “Twisters” can be produced. This means that a bending motion applied to a bender produces an output voltage. Similarly, a twisting motion applied to a twister produces a voltage output

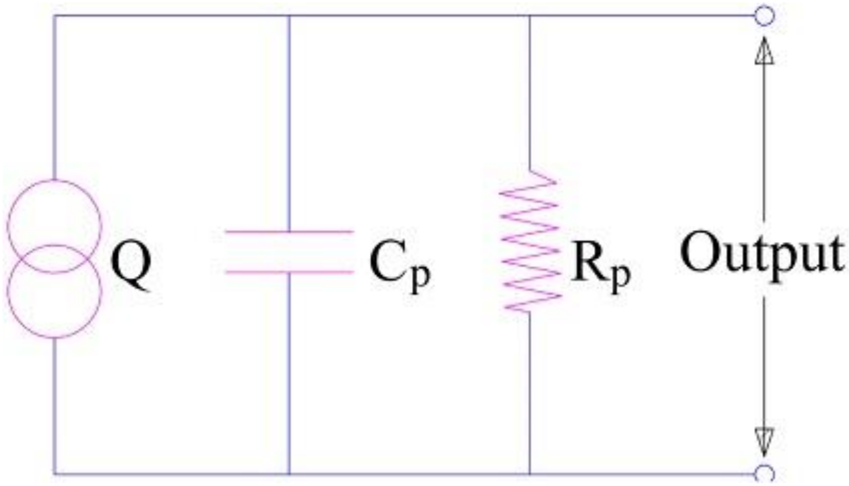
Properties of Piezoelectric Crystal:

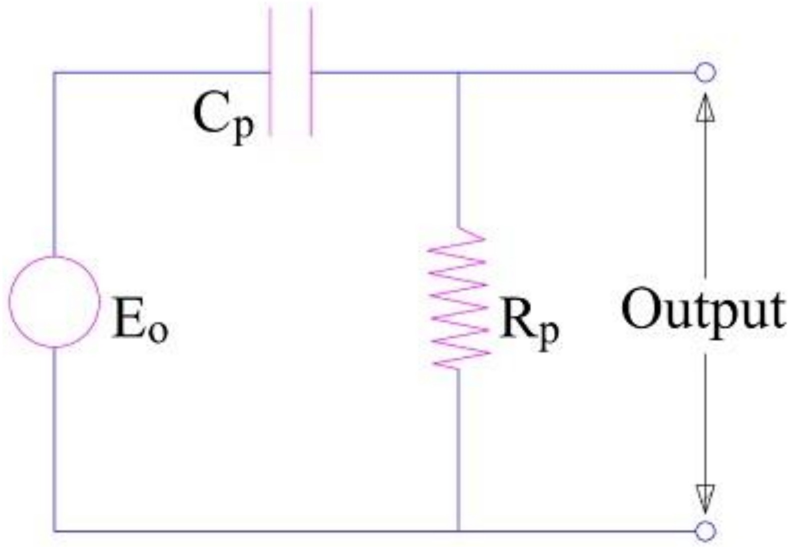
The main properties of piezoelectric material for its suitability for use in piezoelectric transducer are stability, output insensitivity to temperature & humidity and ability to be formed in most desirable shape. Quartz is the most stable piezoelectric crystal. However, its output is very small. On the other hand, Rochelle Salt provides highest output but its main drawback is that it can only be used over a limited temperature range (up to 45°C only) and it has to be protected from moisture.

Barium Tartarate has the advantage that it can be formed into various shapes and sizes. Its dielectric constant is also high (hence Capacitance C will be high which will result in higher output voltage). Natural crystal posses the advantage that they have higher mechanical and thermal stability, can withstand higher stresses. The synthetic material has generally higher voltage sensitivity.

Equivalent Circuit of Piezoelectric Transducer:

The basic electrical equivalent circuit of a piezoelectric transducer is shown in figure below.





Following points may be noted from the equivalent circuit of piezoelectric transducer:

- Source is a charge generator whose value is equal to dF.
- The charge generated is across the capacitance C_p of the crystal and leakage resistance R_p.
- The charge generator can be replaced by an equivalent voltage source having a voltage of $E_o = Q/C_p = dF/C_p$

Application / Usages of Piezoelectric Material and Transducer:

The application or usages of piezoelectric material and transducer are listed below:

- Quartz is commonly used for stabilizing electronic oscillators due to its high stability.
- Piezoelectric Transducer is mainly used in dynamic measurements. The voltage developed by application of strain is not held under static condition. Therefore, these transducers are used in the measurement of quantities such as Surface Roughness, acceleration (called accelerometer) and vibrations.
- Ultrasonic generator also uses Barium titanate which is a piezoelectric material. Such materials are used in industrial cleansing apparatus and also in underwater detection system known as ***sonar***.

CAPACITIVE TRANSDUCER

Definition:

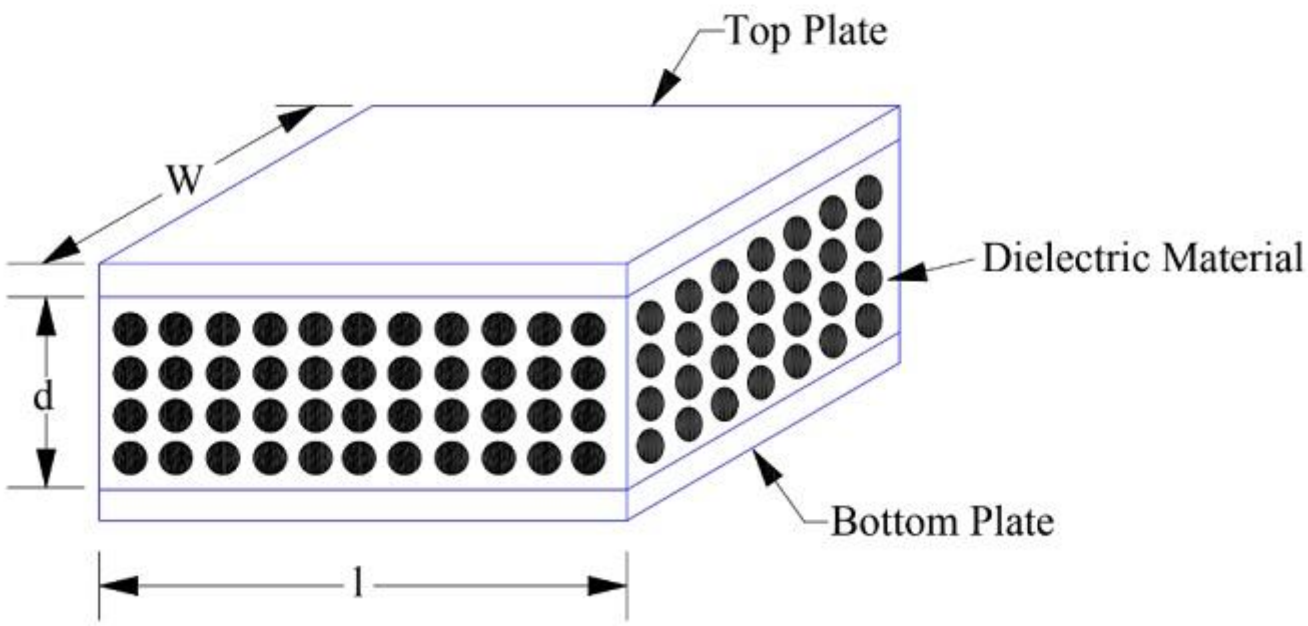
Capacitive Transducer is a device which changes its capacitance with change in the physical phenomena to be measured. It is a passive transducer which required external source of supply to function.
The transduction element of capacitive transducer is a capacitor which may be a parallel plate, cylindrical or angular capacitor. It is commonly used for the measurement of linear displacement.

Working Principle of Capacitive Transducer:

The working principle of capacitive transducer is based on the capacitance of parallel plate capacitor. The capacitance (C) of a parallel plate capacitor with plate area A separated by distance d is given as below.

$C = \varepsilon_o \varepsilon_r A / d$ ………….(1)

Where ε_o and ε_r are the permittivity of free space and the relative permittivity of the dielectric material of capacitor.
A typical parallel plate capacitor with a dielectric material in between the plate is shown in the figure below.



The capacitive transduce works on the principle that the capacitance can be varied by varying the following:

- Area of plate
- Separation between the plates
- Changing the dielectric material between the plates.

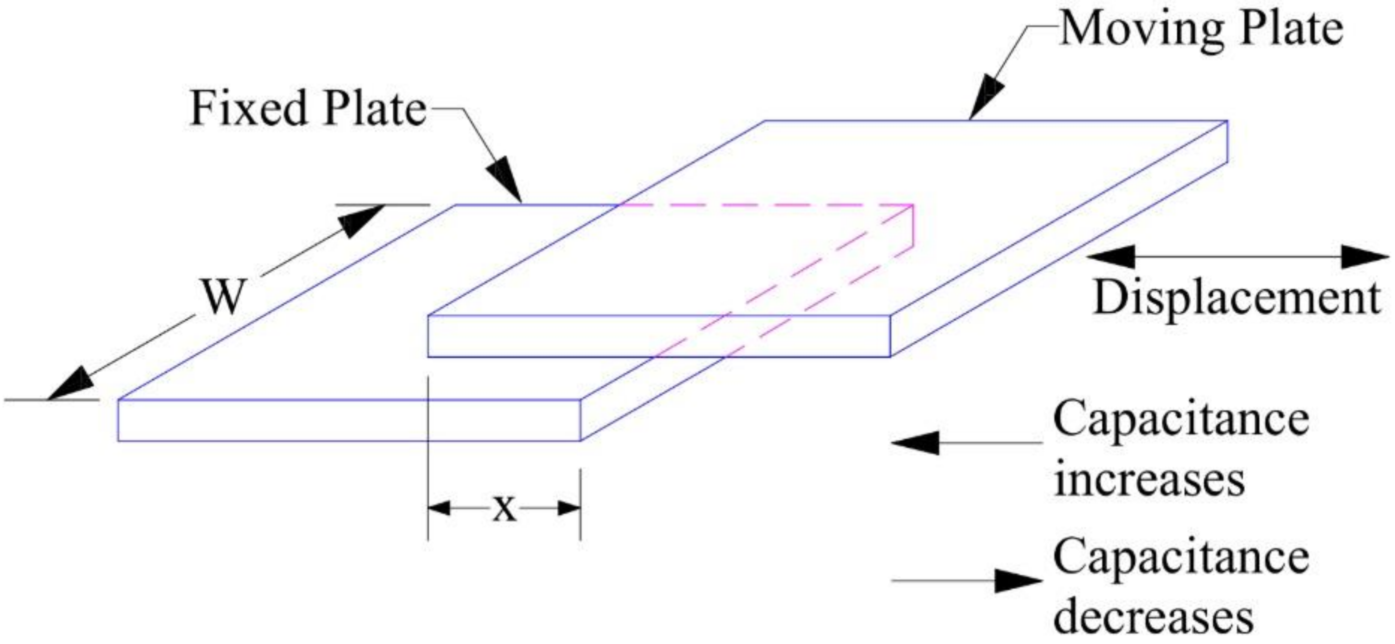
In capacitive transducer, the above changes are caused by physical variables like linear displacement, angular displacement, force, pressure and level of liquid. Notice that when the liquid level changes through the capacitor, the dielectric medium is changed and hence the capacitance will change.
The change in capacitance may be measured by bridge circuit. The output impedance of capacitive transducer is given as $X_c = (1/2\pi fC)$ where f is supply frequency and C is capacitance. Assuming frequency if supply to be constant, the output impedance is a function of capacitance and hence change in physical variable results in corresponding change in X_c.
The capacitive transducer is mostly used for the measurement of linear displacement. For this purpose, following effects are utilized:

- Change in capacitance due to change in overlapping area of plate
- Change in capacitance due to change in separation between the plates.

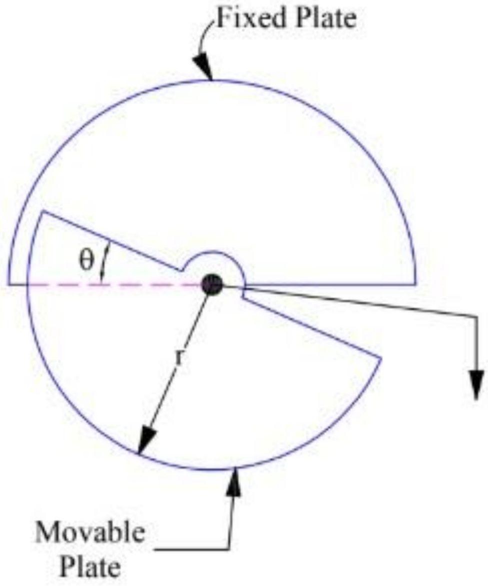
Transducer using change in Area of Plate:

As we know that, capacitance of parallel plate capacitor is directly proportional to the area of plate, therefore, this property can be employed to measure the displacement. Above all, the response of such type

of transducer will be linear which simply means that physical change will have a linear relation with the measured capacitance.
For the measurement of displacement using capacitive transducer, one plate of parallel plate capacitor is kept fixed while the other plate is allowed to displace. An elementary diagram of this transducer is shown in figure below.



Let us assume that the width of plate is W and the length at any time t is X. Thus, the area of plates of parallel plate capacitor so formed at time t will be (WX). Therefore, the capacitance at any time t is given as below.
$C = [\varepsilon_o \varepsilon_r (WX) / d]$
From the above expression, it is clear that the displacement X is directly proportional to capacitance C. Hence, measurement of capacitance will directly tell us the magnitude of displacement. Thus, physical quantity displacement is converted into electrical quantity capacitance which is the required function of a transducer.
Sensitivity of a device is the rate of change of output with respect to input. Thus, the sensitivity of capacitive transducer will be the rate of change of capacitance (C) with respect to displacement (X). Let us now find this sensitivity (S).
$S = dC / dX$
$= \varepsilon_o \varepsilon_r W / d$
From the above expression, it may be stated that the sensitivity of a capacitive transducer is constant and depends on the width & separation between the plates. This is a great feature of capacitive transducer and exploited for measurement of linear displacement ranging from 1 mm to 10 mm. The accuracy is as high as 0.005%.
The principle of change of capacitance with change in area is also employed for the measurement of angular displacement. Figure below shows a two-plate capacitor in which one plate is fixed and the other can rotate.

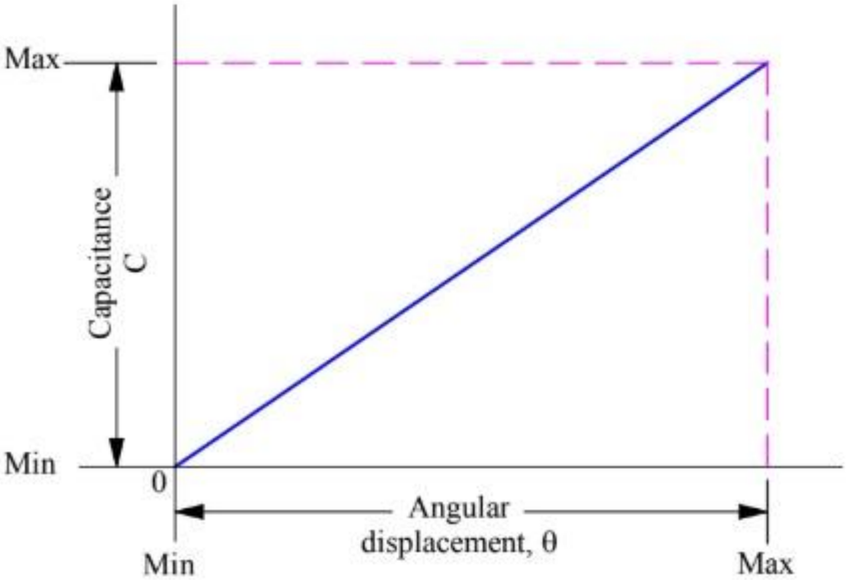


The angular displacement changes the effective area between the plates and hence, a corresponding change in capacitance. Let, at any time t, the angular overlapping position is ϴ. Since the area of entire plate is ($\pi r^2/2$) for angular overlapping of π radian, therefore, the area (A) of plate for angular overlapping of ϴ radian will be

$A = (\pi r^2/2\pi)\Theta$ = $\boldsymbol{\Theta r^2/2}$

Capacitance = $[\varepsilon_o \varepsilon_r \Theta r^2/ (2d)]$

From the above expression, it is obvious that the capacitance is directly proportional to the angular movement. Hence, measurement of capacitance is a direct indication of angular movement. The graph between the capacitance and angular position is a straight line and shown below.

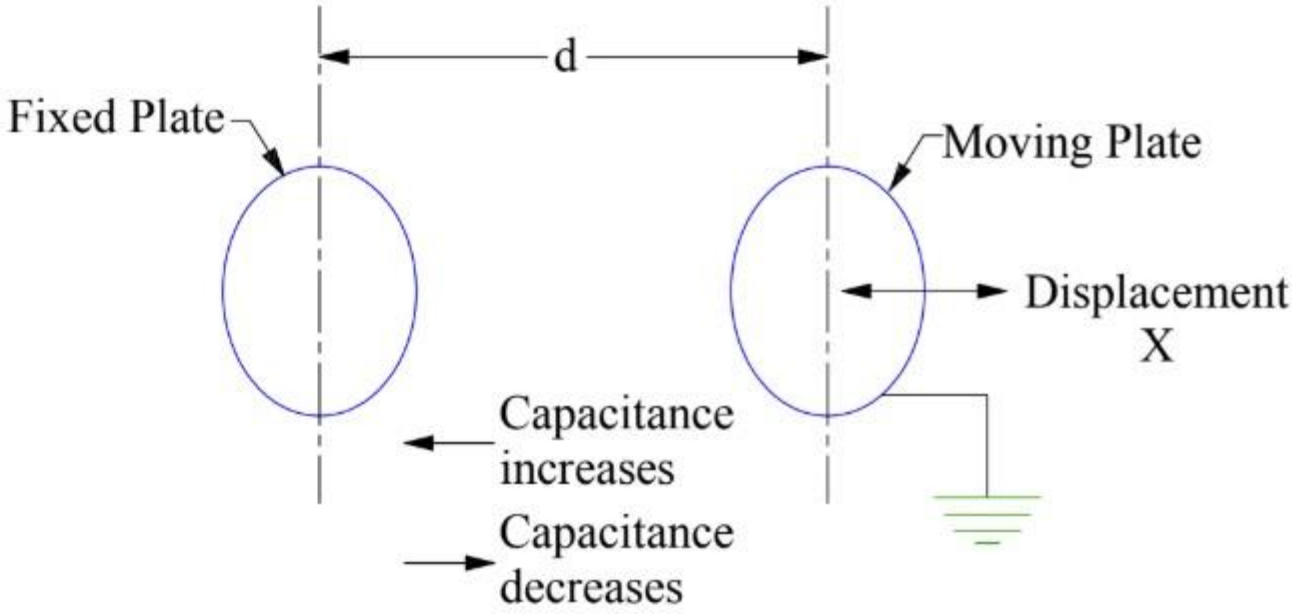


It should be bear in mind that, above mentioned capacitive transducer can only be used for measuring angular position from 0 to 180°.

Transducers Using Change in Distance between the Plates:

A Capacitive Transducer can also be designed to respond to linear displacement by attaching one of the plates of capacitor to the moving object and keeping the other plate fixed. When the object moves, the distance between the plate changes and hence the capacitance changes. The variation of capacitance with separation between the plates is evident from (1). It can easily be seen from (1) that capacitance is inversely proportional to the distance between the plates.

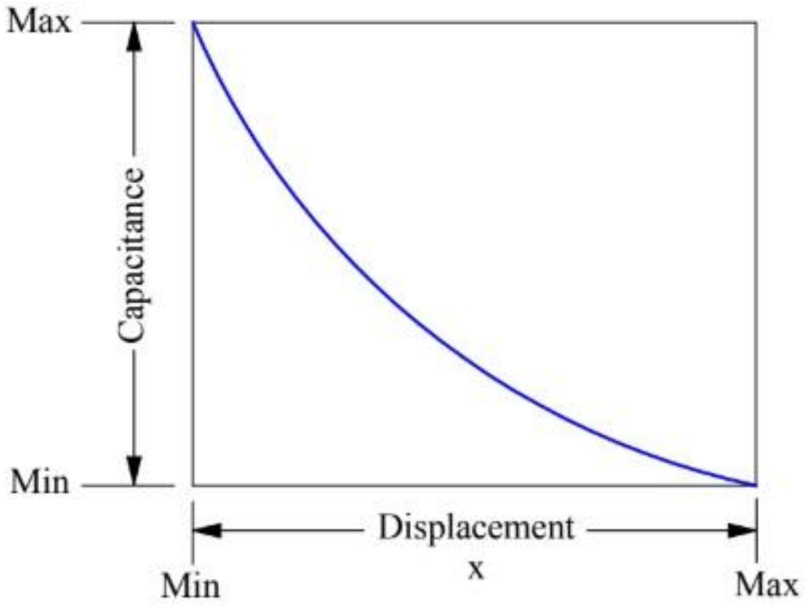
An elementary diagram of a capacitive transducer utilizing principle of change of capacitance with change in distance between the plates is shown in figure below.



The separation between the plate is x at any time t. Hence, capacitance is given as

$C = \varepsilon A/x$

The characteristics of this transducer is, thus, non-linear. Actually, it is hyperbolic as shown below.



The sensitivity of this transducer is calculated as below.

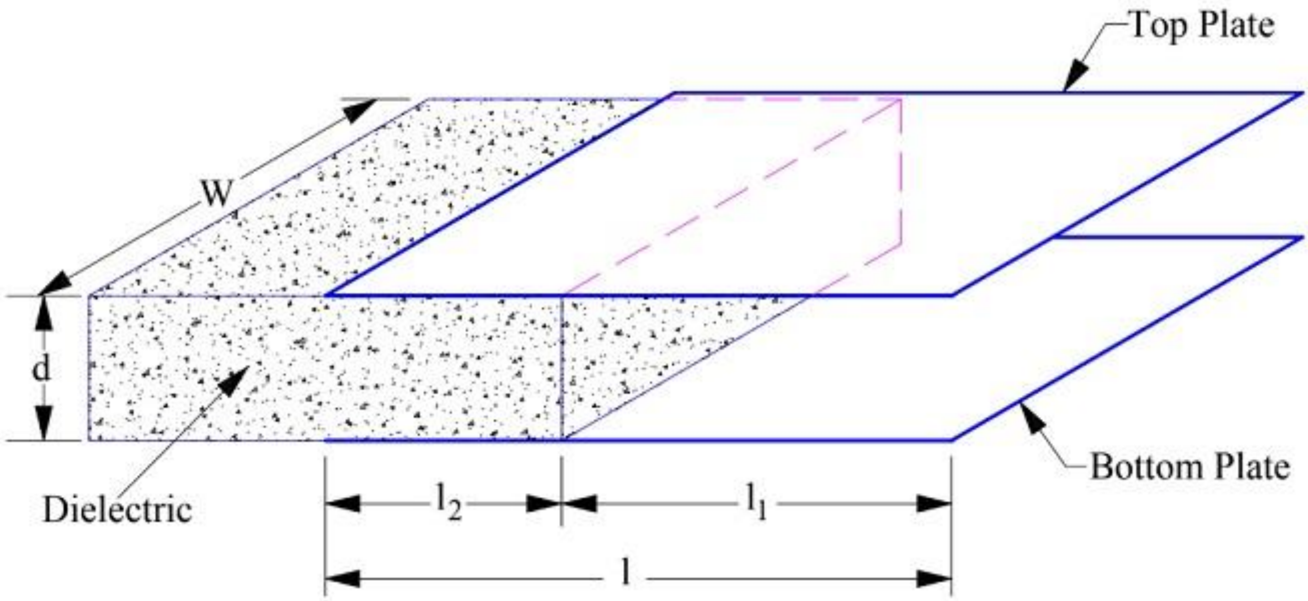
$S = dC/dx$

$= -\varepsilon A/x^2$

The sensitivity of this transducer is not constant rather it varies with the separation between the plates. In fact, the lesser the distance x, the more is the sensitivity. This means that, the device will respond for lower value of displacement. It will not respond to higher value of displacement. This is the reason; this type of capacitive transducer is used for applications requiring measurement of extremely small displacement.
You might think that this is a disadvantage. But actually, it is not so. Just compare the sensitivity of capacitive transducer utilizing change in area and change is distance between the plate. The sensitivity is constant for the former while the same is higher for extremely small displacement. This means, if we want to measure very very small displacement, transducer utilizing change in separation between plates will be more responsive i.e. change in capacitance will be more for an extremely small change in displacement between the plates. This is advantageous for measurement of small displacement. Any doubt? Please write in comment box.

Transducer using change in Dielectric Constant:

A capacitive transducer may use the principle of change in dielectric constant to achieve variable capacitance. This is quite obvious if you refer (1). The capacitance of parallel plate capacitor is directly proportional to dielectric constant (Ɛ) for a given plate area and separation. This principle is also utilized in capacitive transducer for the measurement of linear displacement.
An elementary diagram using change in capacitance due to change in dielectric constant is shown in figure below.



The plates of capacitor are fixed. However, a moving object having some dielectric constant ε_r is moving into the plates. We want to measure the displacement of the object. At any intermediate stage, let the l_2 length of object is inside the plates. Therefore, up to l_2 length, the capacitor is filled up with dielectric having dielectric constant ε_r whereas l_1 length have air. The capacitance in this combination can be found as shown below.

$$C = \frac{\varepsilon_0 W}{d}[l_1 + \varepsilon_r l_2]$$

From the above expression, it is clear that, as the object moves into the capacitor, the value of l_2 increases and hence the capacitance C increases. By measuring this capacitance, the linear displacement can be predicted.

Advantage and Disadvantage of Capacitive Transducer:

Advantage:

The major advantages of capacitive transducer are listed below:

- This transducer requires very small force to operate and hence utilized in small systems.
- They are very sensitive. The accuracy is as good as 0.005%.
- The loading effect is minimum in this transducer due to high input impedance.
- A resolution of the order of 2.5×10^{-3} can easily be obtained using these transducers.
- Measurement of Inductive Transducer is affected by the stray magnetic field whereas a capacitive transducer is not affected.
- The power requirement of capacitive transducer is less as they require less force to operate.

Disadvantage:

The principle disadvantages of a capacitive transducer are mentioned below:

- Capacitive Transducer requires its metallic part to be insulated from each other. If they get short, the value of capacitance will become zero. Above all, to avoid the effect of stray capacitance on the measurement, the frame of this transducer must be earthed.
- The Capacitive Transducer shows non-linear behavior may a times because of the effect of edges. Guard rings are used to eliminate this effect.
- The cable connecting to the transducer is also a source of error when measuring small physical changes. The cable may be source of loading resulting in loss of sensitivity. Also loading makes the low frequency response poor.
- The capacitance may change due to dust, moisture etc.
- They are temperature sensitive and therefore, any change in temperature adversely affects their performance.
- The instrumentation circuitry used with capacitive transducer is quite complex.
- The output impedance ($1/2\pi fC$) of capacitive transducer is quite high due to lower value of capacitance. This leads to loading effect. The output impedance depends on the frequency of signal used for the measurement of capacitance. For capacitance lying between 10-500 pF, the frequency used are such that they give an output impedance in the range of 1 kΩ to 10 MΩ. This high value of output impedance means that the insulation resistance must be kept high to avoid the shunting of capacitance unduly and reducing the sensitivity.

Application of Capacitive Transducer:

The major applications of a capacitive Transducer are listed below.

- Capacitive Transducer is mostly used for the measurement of linear and angular displacement. They are very sensitive and can measure extremely small displacement of the order of 10^{-6} mm.
- They are also used for the measurement of force and pressure. Force and pressure are first converted into linear displacement and then the displacement is measured by capacitive transducer.
- Capacitive Transducer can be directly used for pressure measurement where change in pressure results in corresponding change in dielectric constant of medium between the plates of capacitor.
- Dielectric constant of gases changes with humidity. Therefore, a capacitive transducer can measure the humidity in gases by employing the change in capacitance due to change in dielectric constant principle.
- It can also be used to measure liquid level, volume, density etc. However, a mechanical modifier is required for the measurement of these parameters.

MODULE 4

THE MEASUREMENT OF TEMPERATURE

A change in temperature of a substance can often result in a change in one or more of its physical properties. Thus, although temperature cannot be measured directly, its effects can be measured. Some properties of substances used to determine changes in temperature include changes in dimensions, electrical resistance, state, type and volume of radiation and colour.

Temperature measuring devices available are many and varied. Those described in this chapter are those most often used in science and industry.

At the end of this chapter you should be able to:

• describe the construction, principle of operation and practical applications of the following temperature measuring devices:

(a) liquid-in-glass thermometer (including ad- vantages of mercury, and sources of error)

(b) thermocouples (including advantages and sources of error)

(c) resistance thermometer (including limita- tions and advantages of platinum coil)

(d) thermistors

(e) pyrometers (total radiation and optical types, including advantages and disadvantages)

• describe the principle of operation of

(a) temperature indicating paints and crayons

(b) bimetallic thermometers

(c) mercury-in-steel thermometer

(d) gas thermometer

• select the appropriate temperature measuring device for a particular application.

Liquid-in-glass thermometer

A **liquid-in-glass thermometer** uses the expansion of a liquid with increase in temperature as its principle of operation.

Construction

A typical liquid-in-glass thermometer is shown in Figure 25.1 and consists of a sealed stem of uniform small-bore tubing, called a capillary tube, made of glass, with a cylindrical glass bulb formed at one end. The bulb and part of the stem are filled with a liquid such as mercury or alcohol and the remaining part of the tube is evacuated. A temperature scale is formed by etching graduations on the stem. A safety reservoir is usually provided, into which the liquid can expand without bursting the glass if the temperature is raised beyond the upper limit of the scale.

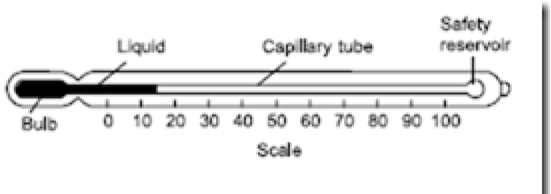


Figure 25.1

Principle of operation

The operation of a liquid-in-glass thermometer depends on the liquid expanding with increase in temperature and contracting with decrease in temperature. The position of the end of the column of liquid in the tube is a measure of the temperature of the liquid in thebulb – shown as 15°C in Figure 25.1, which is about room temperature. Two fixed points are needed to calibrate the thermometer, with the interval between these points being divided into 'degrees'. In the first thermometer, made by Celsius, the fixed points chosen were the temperature of melting ice (0°C) and that of boiling water at standard atmospheric pressure (100°C), in each case the blank stem being marked at the liquid level. The distance between these two points, called the fundamental interval, was divided into 100 equal parts, each equivalent to 1°C, thus forming the scale.

The **clinical thermometer**, with a limited scale around body temperature, the **maximum and/or minimum thermometer**, recording the maximum day temperature and minimum night temperature, and the **Beckman thermometer**, which is used only in accurate measurement of temperature change, and has no fixed points, are particular types of liquid-in-glass thermometer which all operate on the same principle.

Advantages

The liquid-in-glass thermometer is simple in construc- tion, relatively inexpensive, easy to use and portable, and is the most widely used method of temperature measurement having industrial, chemical, clinical and meteorological applications.

Disadvantages

Liquid-in-glass thermometers tend to be fragile and hence easily broken, can only be used where the liquid column is visible, cannot be used for surface temperature measurements, cannot be read from a distance and are unsuitable for high temperature measurements.

Advantages of mercury

The use of mercury in a thermometer has many advantages, for mercury:

(i) is clearly visible,

(ii) has a fairly uniform rate of expansion,

(iii) is readily obtainable in the pure state,

(iv) does not 'wet' the glass,

(v) is a good conductor of heat.

Mercury has a freezing point of –39°C and can- not be used in a thermometer below this temperature. Its boiling point is 357°C but before this temperature is reached some distillation of the mercury occurs if the space above the mercury is a vacuum. To prevent this, and to extend the upper temperature limits to over 500°C, an inert gas such as nitrogen under pressure is used to fill the remainder of the capillary tube. Alcohol, often dyed red to be seen in the capillary tube, is considerably cheaper than mercury and has a freezing point of –113°C, which is considerably lower than for mercury. However it has a low boiling point at about 79°C.

Errors

Typical errors in liquid-in-glass thermometers may oc- cur due to:

(i) the slow cooling rate of glass

(ii) incorrect positioning of the thermometer

(iii) a delay in the thermometer becoming steady (i.e. slow response time)

(iv) non-uniformity of the bore of the capillary tube, which means that equal intervals marked on the stem do not correspond to equal temperature intervals.

Thermocouples

Thermocouples use the e.m.f. set up when the junction of two dissimilar metals is heated.

Principle of operation At the junction between two different metals, say, cop- per and constantan, there exists a difference in electrical potential, which varies with the temperature of the junction. This is known as the 'thermo-electric effect'. If the circuit is completed with a second junction at a different temperature, a current will flow round the circuit. This principle is used in the thermocouple. Two different metal conductors having their ends twisted together are shown in Figure 25.2. If the two junctions are at different temperatures, a current *I* flows round the circuit.

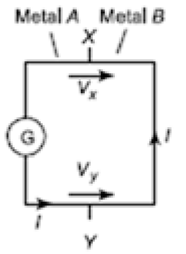


Figure 25.2

The deflection on the galvanometer *G* depends on the difference in temperature between junctions *X* and *Y* and is caused by the difference between voltages *Vx* and *Vy*. The higher temperature junction is usually called the 'hot junction' and the lower temperature junction the 'cold junction'. If the cold junction is kept at a constant known temperature, the galvanometer can be calibrated to indicate the temperature of the hot junction directly. The cold junction is then known as the reference junction.

In many instrumentation situations, the measuring instrument needs to be located far from the point at which the measurements are to be made. Extension leads are then used, usually made of the same material as the thermocouple but of smaller gauge. The reference junction is then effectively moved to their ends. The thermocouple is used by positioning the hot junction where the temperature is required. The meter will indicate the temperature of the hot junction only if the reference junction is at 0°C for:

(temperature of hot junction) = (temperature of the cold junction) + (temperature difference)

In a laboratory the reference junction is often placed in melting ice, but in industry it is often positioned in a thermostatically controlled oven or buried under- ground where the temperature is constant.

Construction

Thermocouple junctions are made by twisting together the ends of two wires of dissimilar metals before welding them. The construction of a typical copper- constantan thermocouple for industrial use is shown in Figure 25.3. Apart from the actual junction the two conductors used must be insulated electrically from each other with appropriate insulation and is shown in Figure 25.3 as twin-holed tubing. The wires and insulation are usually inserted into a sheath for protection from environments in which they might be damaged or corroded.

Applications

A copper-constantan thermocouple can measure temperature from –250°C up to about 400°C, and is used typically with boiler flue gases, food processing and with sub-zero temperature measurement. An iron-constantan thermocouple can measure temperature from –200°C to about 850°C, and is used typically in paper and pulp mills, re-heat and annealing furnaces and in chemical reactors. A chromel-alumel thermo-couple can measure temperatures from –200°C to about 1100°C and is used typically with blast furnace gases, brick kilns and in glass manufacture.

For the measurement of temperatures above 1100°C radiation pyrometers are normally used. However, thermocouples are available made of platinum- platinum/rhodium, capable of measuring temperatures up to 1400°C, or tungsten-molybdenum which can measure up to 2600°C.

Advantages

A thermocouple:

(i) has a very simple, relatively inexpensive con- struction

(ii) can be made very small and compact

(iii) is robust

(iv) is easily replaced if damaged

(v) has a small response time

(vi) can be used at a distance from the actual mea- suring instrument and is thus ideal for use with automatic and remote-control systems.

Sources of error

Sources of error in the thermocouple, which are difficult to overcome, include:

(i) voltage drops in leads and junctions

(ii) possible variations in the temperature of the cold junction

(iii) stray thermoelectric effects, which are caused by the addition of further metals into the ‘ideal’ two-metal thermocouple circuit.

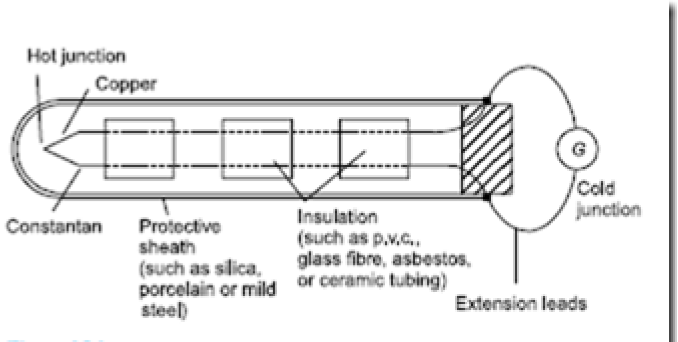


Figure 25.3

Additional leads are frequently necessary for extension leads or voltmeter terminal connections.

A thermocouple may be used with a battery- or mains-operated electronic thermometer instead of a millivoltmeter. These devices amplify the small e.m.f.'s from the thermocouple before feeding them to a multi-range voltmeter calibrated directly with tem- perature scales. These devices have great accuracy and are almost unaffected by voltage drops in the leads and junctions.

Problem 1. A chromel-alumel thermocouple generates an e.m.f. of 5 mV. Determine the temperature of the hot junction if the cold junction is at a temperature of 15°C and the sensitivity of the thermocouple is 0.04 mV/°C.

Temperature difference for 5 m $V = \frac{5\,\text{mV}}{0.04\,\text{mV/°C}}$

$= 125°\text{C}.$

Temperature at hot junction = temperature of cold junction + temperature difference

$= 15°\text{C} + 125°\text{C} = 140°\text{C}$

Practise Exercise 137 Further problem on the thermocouple

1. A platinum–platinum/rhodium thermocouple generates an e.m.f. of 7.5 mV. If the cold junction is at a temperature of 20°C, deter- mine the temperature of the hot junction. Assume the sensitivity of the thermocouple to be 6 μV/°C [1270°C]

Resistance thermometers

Resistance thermometers use the change in electrical resistance caused by temperature change.

Construction

Resistance thermometers are made in a variety of sizes, shapes and forms depending on the application for which they are designed. A typical resistance thermometer is shown diagrammatically in Figure 25.4. The most common metal used for the coil in such thermometers is platinum even though its sensitivity is not as high as other metals such as copper and nickel. However, platinum is a very stable metal and provides reproducible results in a resistance thermometer. A platinum resistance thermometer is often used as a calibrating device. Since platinum is expensive, connecting leads of another metal, usually copper, are used with the thermometer to connect it to a measuring circuit.

The platinum and the connecting leads are shown joined at *A* and *B* in Figure 25.4, although sometimes this junction may be made outside of the sheath. How- ever, these leads often come into close contact with the heat source which can introduce errors into the measurements. These may be eliminated by including a pair of identical leads, called dummy leads, which experience the same temperature change as the extension leads.

Principle of operation

With most metals a rise in temperature causes an increase in electrical resistance, and since resistance can be measured accurately this property can be used to measure temperature. If the resistance of a length of wire at 0°C is $R0$, and its resistance at θ°C is $R\theta$, then $R\theta = R0\ (1 + \alpha\theta)$, where a is the temperature coefficient of resistance of the material.

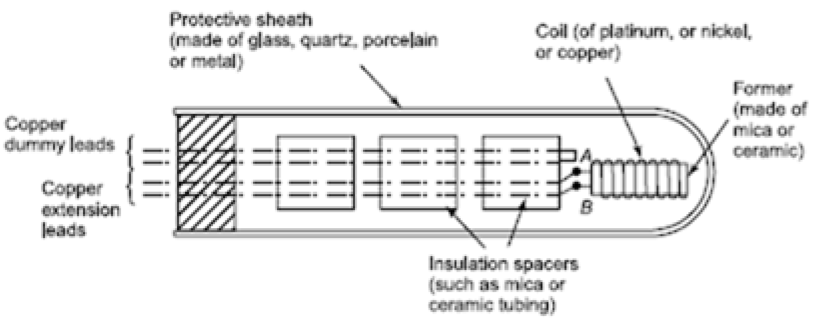


Figure 25.4

Rearranging gives: **temperature,** $\theta = \dfrac{R_\theta - R_0}{\alpha R_0}$

Values of $R0$ and α may be determined experimentally or obtained from existing data. Thus, if $R\theta$ can be measured, temperature θ can be calculated. This is the principle of operation of a resistance thermometer. Although a sensitive ohmmeter can be used to measure $R\theta$, for more accurate determinations a **Wheat- stone bridge circuit is used** as shown in Figure 25.5. This circuit compares an unknown resistance $R\theta$ with others of known values, $R1$ and $R2$ being fixed values and $R3$ being variable. Galvanometer G is a sensitive centre-zero microammeter. $R3$ is varied until zero deflection is obtained on the galvanometer, i.e. no current flows through G and the bridge is said to be 'balanced'.

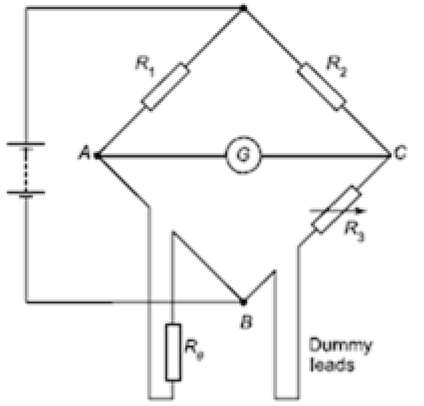


Figure 25.5

At balance: $R_2 R_\theta = R_1 R_3$

from which, $R_\theta = \dfrac{R_1 R_3}{R_2}$

and if R_1 and R_2 are of equal value, then $R_\theta = R_3$

A resistance thermometer may be connected between points A and B in Figure 25.5 and its resistance $R\theta$ at any temperature θ accurately measured. Dummy leads included in arm BC help to eliminate errors caused by the extension leads which are normally necessary in such a thermometer.

Limitations

Resistance thermometers using a nickel coil are used mainly in the range –100°C to 300°C, whereas platinum resistance thermometers are capable of measuring with greater accuracy temperatures in the range –200°C to about 800°C. This upper range may be extended to about 1500°C if high melting point materials are used for the sheath and coil construction.

Advantages and disadvantages of a platinum coil Platinum is commonly used in resistance thermometers since it is chemically inert, i.e. un-reactive, resists corrosion and oxidation and has a high melting point of 1769°C. A disadvantage of platinum is its slow response to temperature variation.

Applications

Platinum resistance thermometers may be used as calibrating devices or in applications such as heat- treating and annealing processes and can be adapted easily for use with automatic recording or control systems. Resistance thermometers tend to be fragile and easily damaged especially when subjected to excessive vibration or shock

MEASUREMENT OF LAW PRESSURE

Measurement of vacuum by two methods :

1. Direct measurement

Resulting in a displacement caused by the action of force [Spiral Bourdon tubes, flat or corrugated diaphragm, capsules and various other manometers]

2. Indirect measurement or inferential methods

Pressure is determined through the measurement of certain pressure controlled properties such as volume, thermal conductivity etc.

McLeod Gauge Vacuum Gauge is a inferential method of measuring vacuum

McLeod gauge

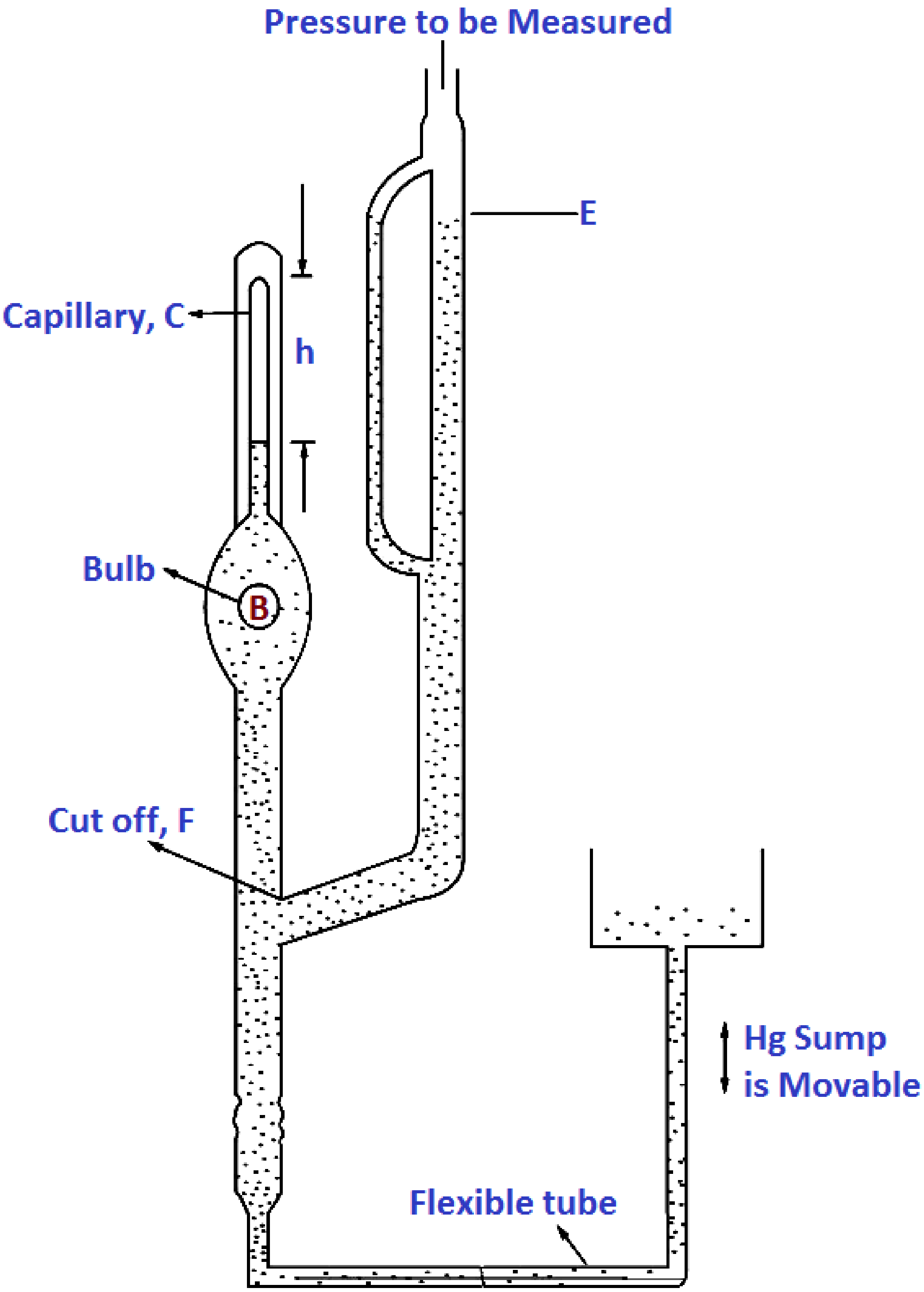
The working of McLeod Gauge is based on Boyles‟ fundamental equation.

$$p_1 = \frac{p_2 V_2}{V_1}$$

where p and V refer to pressure and volume respectively and subscripts 1 and 2 refer to initial and final conditions. Conventional McLeod gauge is made of glass. Refer Below Fig, It consists of the capillary „C‟, bulb „B‟ and the mercury sump which is connected to the lower end of the glass tube such that it can be moved up and down.

The pressure to be measured (the unknown pressure) is connected to the upper end of the glass part. When the mercury level in the gauge is below the cut off „F‟, the unknown pressure fills the gauge including the bulb B and capillary C.

When the mercury sump is moved up, the level in the gauge rises and when it reaches the cut off „F‟ a known volume of gas at pressure to be measured is trapped in bulb B and capillary C.



Mercury is then forced up into the bulb and capillary. Assume the sump is raised to such a level that the gas at the pressure to be measured which filled the volume above the cut off is now compressed to the volume represented by the column h. Suppose the original volume after then mercury reaches F is V0 . This is at a pressure being measured p1

$$V_0 \times p_1 = ah \times (p_1 + h) \quad = p_1 ah + ah^2$$

$$V_0 p_1 - p_1 ah = ah^2$$

$$p_1 (V_0 - ah) = ah^2$$

As 'ah' is <<< V_0 it is neglected.

$$p_1 = \frac{ah^2}{V_0}$$

Applications of McLeod gauge

McLeod gauge is used mainly for calibrating other inferential type of gauges. The shortcomings of the McLeod gauge are its fragility and the inability to measure continuously. The vapor pressure of Mercury sets the lower limit of measurement range of the gauge.

Advantages of the McLeod Gauge:

- It is independent of the gas composition.
- It serves as a reference standard to calibrate other low pressure gauges.
- A linear relationship exists between the applied pressure and h
- There is no need to apply corrections to the McLeod Gauge readings.

Limitations of McLeod Gauge:

- The gas whose pressure is to be measured should obey the Boyle's law
- Moisture traps must be provided to avoid any considerable vapor into the gauge.
- It measure only on a sampling basis.
- It cannot give a continuous output.

Temperature measurement

Introduction

Temperature is probably the most widely measured and frequently controlled variable encountered in industrial processing of all kinds. Measurement of temperature potential is involved in thermodynamics, heat transfer and many chemical operations.

"It may be defined as degree of hotness and coldness of a body or an environment measured on a definite scale."

Temperature is an intensive quantity independent of the size of the system. Temperature measurement depends upon the establishment of the thermodynamic equilibrium between the system and the device used to sense the temperature. The sensor has certain physical characteristics which change with temperature and this effect is taken as a measurement of the temperature.

Temperature measuringinstrument:

1. Liquid-in-glass thermometers
2. Bimetallic thermometer
3. Thermistors
4. Thermocouple
5. Resistance thermometers
6. Optical pyrometers

1. Liquid-In-Glass Thermometers

Construction

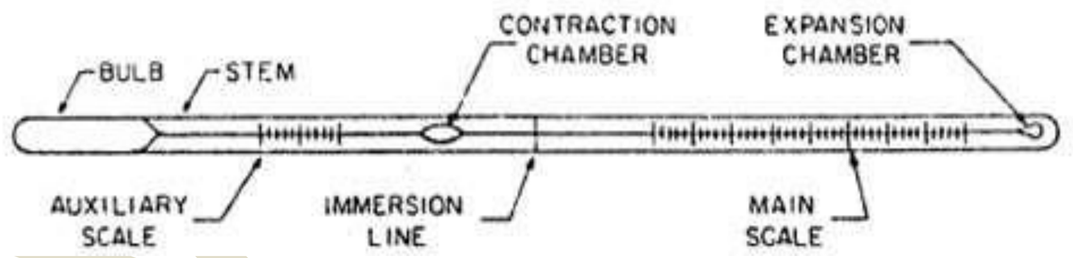


Figure 5.1 Liquid in Glass Thermometer

The components of a typical liquid-in-glass thermometer are shown in Fig. 8.1. These include:

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). It should be marked as for the main scale (below). 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 colored 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: An 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.

The unit consists of a glass envelope, a responsive liquid and an indicating scale. The envelope comprises a thick wailed glass tube with a capillary bore, and a spherical or cylindrical bulb filled with the liquid. The two parts are fused together and the top end of the capillary tube is sealed. The range of a liquid-in-glass thermometer is limited by the liquid, by the glass, and by the construction. The commonest and best liquid is mercury. The recommended range of use is from near the mercury freezing point (-38 °C) to about 350 °C with soda-lime glasses; higher temperatures require borosilicate or other special glasses. The capillary above the mercury is filled with a dry gas (frequently nitrogen) to prevent separation of the column and to inhibit distillation of the mercury; in the higher-temperature models, substantial gas pressures are required to raise the mercury boiling point above the range of the thermometer. Air is not a good filling gas because it may lead to oxidation of the mercury and consequent sticking of the latter in the capillary.

Working

Changes in the temperature will cause the fluid to expand and rise up the stem. Since the area of the stem is much less than the bulb, the respectively small changes of fluid volume will result in significant fluid rise in the stem. The length of the movement of the free surface of the fluid column serves, by a prior calibration, to indicate the temperature of the bulb. The laboratory work thermometers have a scale engraved directly on the glass stem, while the industry types have separate scale located adjacent to the stem. Quite often the top of the capillary tube is also bulb shaped to provide safety in case the temperature range of the instrument is inadvertently exceeded. The range of application of different liquids is stated in table 8.1

Liquid	*Range (^0C)*
Mercury	-35 to 510
Alcohol	-80 to 70
Toluene	-80 to 100
Pentane	-200 to 30
Creosote	-5 to 200

Table 5.1 Liquids used in Glass Thermometers

Salient features /characteristics:

- Simplicity of use and relatively low cost easily pot table
- Ease of checking for physical damage
- Absence of need for auxiliary power
- No need of additional indicating instruments
- Fragile construction; range limited to about 600^0C
- Lack of adaptability to remote reading
- Time lag between change of temperature and thermometer response due to relatively high heat capacity of the bulb.

CALIBRATION OF THERMOMETER

These thermometers arc generally designed and calibrated for one of the following three conditions shown in Fig. 5.2.

A. Total immersion — the bulb and liquid containing part of the capillary is exposed to the temperature being measured.
B. Complete immersion —the entire thermometer is exposed to the temperature being

measured.

C. Partial immersion—the liquid in the stem emerging from the liquid bath is subjected to the ambient temperature which may be radically different from the temperature of the liquid bath.

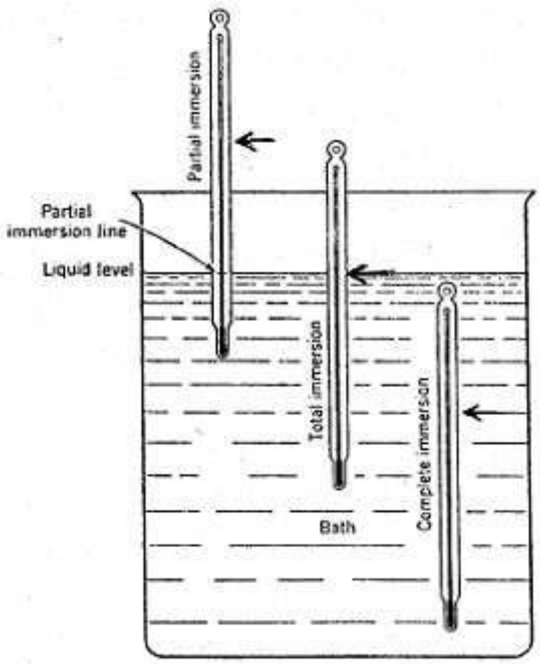


Fig 5.2 immersion techniques for the three types of liquid in glass thermometer

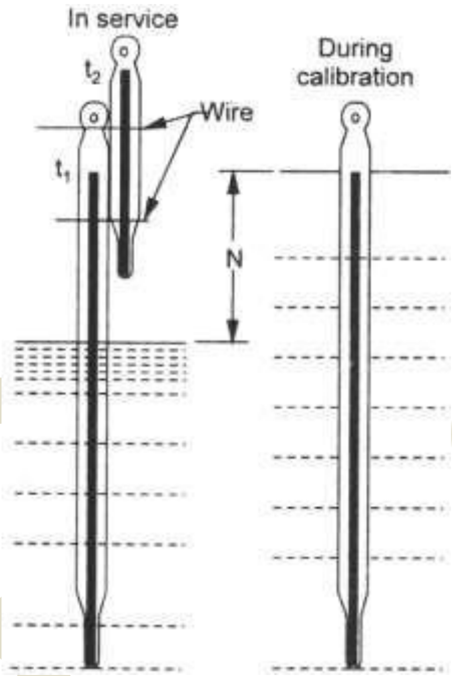


Fig. 5.3 correction technique for stem emergence effects

Generally, the glass stem thermometers are graduated for total immersion of bulb and stem. When the stem of a total-immersion thermometer is only partially immersed, the indicated temperature is corrected for the stem emergence effects. The ASME Power Test Codes recommend that a secondary thermometer be attached to the stem of the primary thermometer (Fig. 5.3) and that a correction to the observed temperature be made in accordance with the emergent-stem error given by:

( )

In this expression C_s is the stem correction in degrees in be added algebraically to the indicated temperature, N is the number of degrees of exposed or emergent stem, t_1 is the reading of the primary thermometer, and t_2 is the average temperature of the exposed stem as determined by the attached (secondary) thermometer.

Bimetallic Thermometer

Working principle

These thermometers use the following two principles:

7. All metals change in dimension, that is expand or contract when there is a change in temperature.
8. The rate at which this expansion or contraction takes place depend on the temperature co-efficient of expansion of the metal and this temperature coefficient of expansion is different for different metals.

Hence the difference in thermal expansion rates is used to produce a deflection which is proportional to temperature changes.

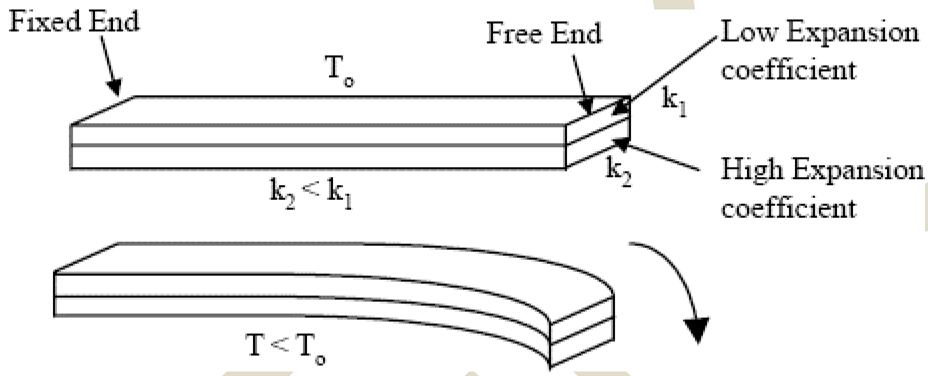


Figure 5.4 Principal of Bimetallic Thermometer

Construction and working

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 as shown in diagram. This deflection is linear and can be related to temperature changes.

The radius of the curvature of the bimetallic strip which was initially flat is determined using the following relationship.

$$\frac{\{\ (\quad)\quad(\quad)(\quad/\quad)\}}{(\qquad)(\qquad)(\qquad)}$$

Where,

R=radius of the curvature at the temperature T_2. T=

total thickness of the bimetallic strip = (t_1+t_2)

$m=\frac{t_1}{t_2}$ = ratio of thickness of low to high expansion materials,

$\square_1$ = coefficient of expansion of lower expansion metal.

α_2 = coefficient of expansion of higher expansion metal. T_1 = Initial temperature.

T_2 = temperature to be measured.

Different common forms of bimetallic sensors are listed.

1. Helix type.
2. Spiral type.
3. Cantilever type.
4. Flat type.

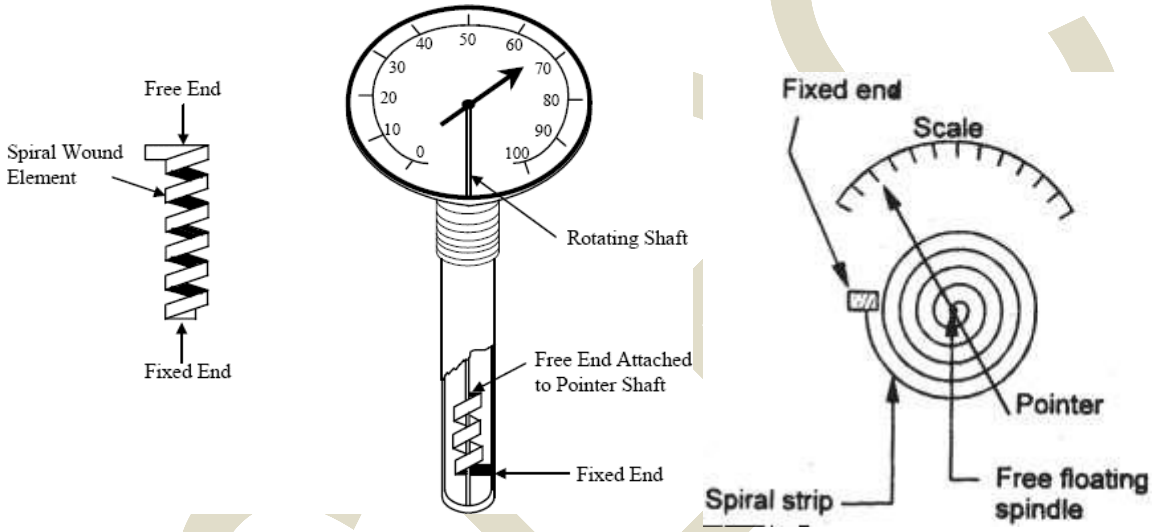


Figure 5.5 Types of Bimetallic Thermometer

One end of the helix is anchored permanently to the casing and the other end is secured to a pointer which sweeps over a circular dial graduated in degree of temperature. In response to temperature change, the bimetal expands and the helical bimetal rotates at its free end, thus turning the stem and pointer to a new position on the dial.

The curvature of bimetal spiral strip varies (fig.8.5) with temperature and causes a pointer to deflect. The continuous strip wound into helical or spiral form has the advantages of compactness while providing a long length of strip required for adequate indicator movement.

Metals used in bimetallic strips

High expansion

1. Brass
2. Nickel-iron alloy with chromium & manganese.

Low Expansion

1. Invar (alloy of nickel & iron).

Salient Characteristics

- Inexpensive; commonly used wherever an industrial mercury-in-glass thermometer can be employed
- Simple, compact and robust construction
- Practical range and accuracy characteristics of bimetal thermometers are summarized

Material	Expansion coefficient (k)
Aluminum	
Copper	
Steel	
Beryllium/copper	

Table 5.2 Thermal Expansion Coefficient

THERMISTORS

Construction and working

Thermistor is a contraction of term "Thermal Resistor'. They are essentially semiconductors which behave as registers with a high negative temperature coefficient. As the temperature increases, the resistance goes up. This is just opposite to the effect of temperature changes on metals. A high sensitivity to temperature changes (decrease in resistance as much as 6% for each 1^0C rise in temperature in some cases) makes the thermistors extremely useful for precision temperature measurement, control and compensation in the temperature range of - 100^0C to 300^0C.

The thermistors are composed of metal oxides. The most commonly used oxides are those of manganese, nickel, cobalt, iron, copper and titanium. The fabrication of commercial NTC thermistors uses basic ceramics technology and continues today much as it has for decades. In the basic process, a mixture of two or more metal oxide powders are combined with suitable binders, are formed to a desired geometry, dried, and sintered at an elevated temperature. By varying the types of oxides used, their relative proportions, the sintering atmosphere, and the sintering temperature, a wide range of resistivity and temperature coefficient characteristics can be obtained.

Metalized surface contact thermistors include the following:

- Bead
- Disks

- Chips (Wafers)
- Rods
- Washer

Bead Type 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.

Bead type thermistors include the following:

- Bare Beads
- Glass Coated Beads
- Ruggedized Beads
- Miniature Glass Probes
- Glass Probes
- Glass Rods
- Bead-in-Glass Enclosures

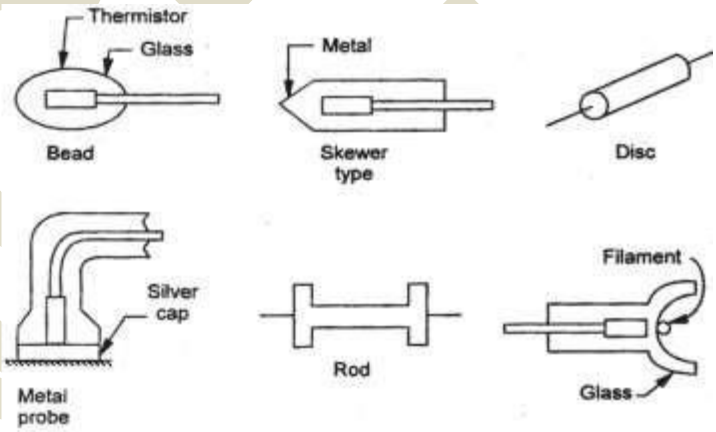


Figure 5.6 Types of Thermistors

Disks: Disk type thermistors are made by compressing a blend of oxide powders in a round die using presses similar to those used for making powdered metal parts or pharmaceutical tablets. The “green” disks are then sintered at high temperatures.

Chips: NTC chip thermistors are usually fabricated using a “tape-casting” or “doctor-blading” process in which slurry of material is spread out into a thick film sheet similar to the process used for making chip capacitors or ceramic substrates. The ceramic sheet material is then subjected to a controlled drying cycle. In the “green” state, the sheet of material is reasonably flexible and easy to handle. The dried material is then cut into slabs or squares that are stacked on ceramic setter sand sintered at high temperatures.

Rods: Rod-type thermistors are made by extruding a mixture of oxide powders and a suitable binder through a die. Their greater mass, longer thermal time constants and higher dissipation constants makes them suitable for applications involving temperature compensation, time delay or surge suppression.

Washers: Washer type thermistors are fabricated using techniques similar to those used for disks except that a hole is formed in the center during the pressing operation. Washers are usually connected to circuitry by means of spring clips or other hardware.

5.2 Thermocouple

When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, here is a continuous current which flows in the thermoelectric circuit. Thomas See beck made this discovery in 1821.

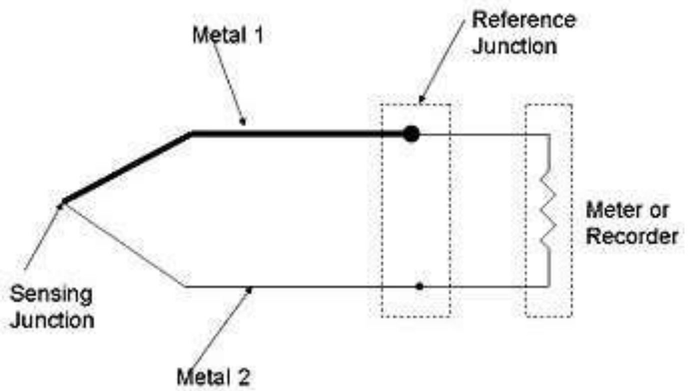


Figure 5.7 Basic Thermocouple Circuit

If this circuit is broken at the center, the net open circuit voltage (the See beck voltage) is a function of the junction temperature and the composition of the two metals.

changes in temperature the See beck voltage is linearly proportional to temperature:

e^{AB} □ □ T

Where α, the See beck coefficient, is the constant of proportionality.

The measurement is actually temperature difference, not an absolute temperature level, so a supplementary measurement is required to establish the reference temperature. Most tabulation set the reference value to the triple point of water (0^0C).

Thermo-electric effects arise in two ways:

- A potential difference always exists between two dissimilar metals in contact with each other (Peltiereffect)
- A potential gradient exists even in a single conductor having a temperature gradient (Thomson effect)

Incommercialinstruments,thethermocouplematerialsaresochosenthatthePeltierand Thomson emf's act in such a manner that the combined value is maximum and that varies directly with temperature.

Law of the Thermocouples

The actual application of thermocouple to the measurement requires consideration of following

Lows of homogeneous circuit—an electric current cannot be sustained in a circuit of a single homogeneous metal by th$_0$ application of heat alone.

Law of successive or intermediate temperatures: The emf generated in a thermocouple with junctions at temperatures T_1 and T_3 is equal to the sum of elf's generated by similar thermocouple, one acting between temperatures T_1 and T_2 and the other acting between T_2 and T_3, where T_2 lies between T_1 and T_3.

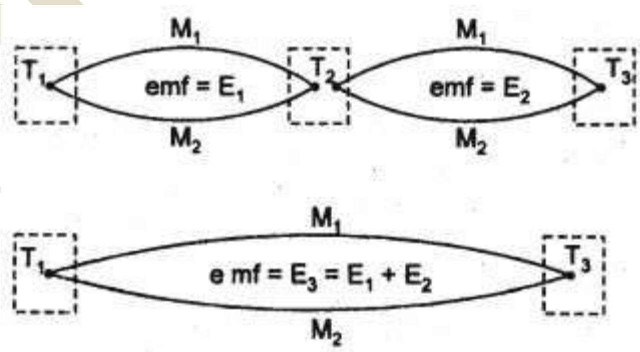


Fig.4.8 law of intermediate temperature

This law is used when making corrections to the thermocouple reading when the cold or reference junction temperature is different from the temperature at which the thermocouple was calibrated. Thus if Thermocouple calibrated with reference junction at 0^0C is used with this junction at 20C, the thermocouple will read correctly if the 'lost' emf due to a junction at 20^0C with reference at 0^0C is added to the measured emf. The lost emf values can be read from tables of corrections for the thermocouple concerned.

Law of intermediate metals: The introduction of a third metal into the thermocouple circuit will have no effect on the emf generated as long as the junctions of the third metal with the thermocouple metals are at the same temperature. Stated in other words: If the thermal emf's of any two metals with respect to a reference metal (such as M_3) arc known, the emf of the combination of two metals is the algebraic sum of their emf's against the reference metal.

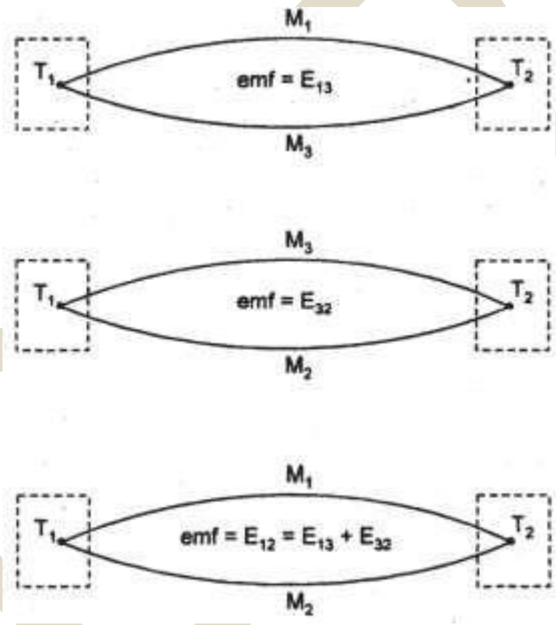


Fig.5.9 law of intermediate metal

Material	Maximum operating temperature( )
Mild steel	900
Nickel-chromium	900
Fused silica	1000
Special steel	1100
Mullite	1700
Rectrystallized alumina	1850
Beryllium	2300

Magnesia	2400
Zirconium	2400
Thorium	2600

Table.5.3 Thermocouple Material

5.3 Metal resistancethermometer

This thermometer is an instrument used to measure the temperature variation in control room.

Working principle

In each metallic conductor, their resistance changes when its temperature is changed. By calculating the variation in resistance, the temperature variations may be calculated. The thermometer which utilizes this phenomenon is called "resistance thermometer".

Construction

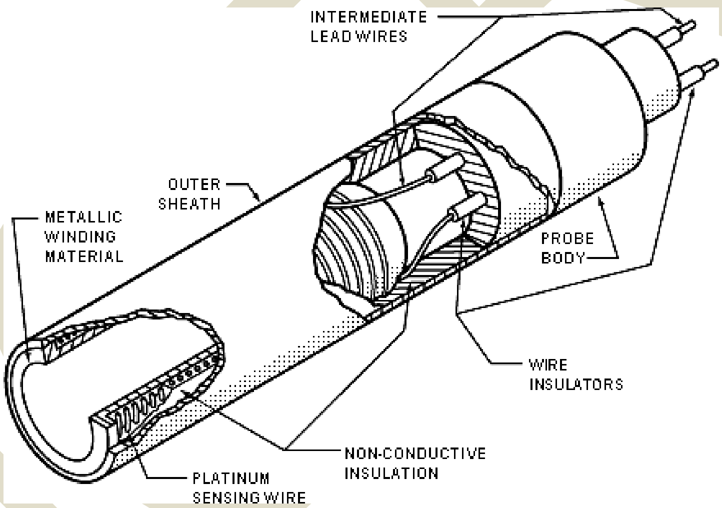
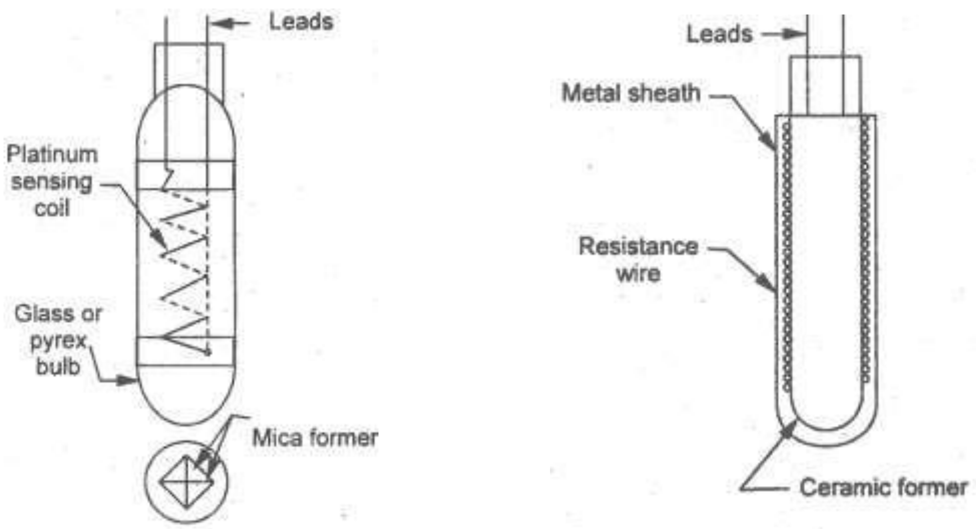


Figure.5.10 Construction of Resistance Thermometer

The construction of resistance thermometer detector is shown in figure. RTD uses platinum, nickel or copper as a resistance element. Generally, platinum wire is wound on either ceramic bobbin to form a resistance element. This resistance element is placed inside the hollow structure called protection tube. It is made up of stainless steel or carbon steel.



(A) Laboratory type *(B). Industrial type*

Figure 5.11 Resistance Thermometers

Internally lead wire is used to connect resistance element with external lead terminals. Lead wire covered by insulated tube for short circuit prevention. Fiber glass is used for low and medium temperature and a ceramic insulation for high temperature.

Protection tube is used to protect the resistance element and internal lead wires from ambient conditions. Protection tube is fitted with the mounting attachment to install the resistance temperature detector to measuring point.

Operation

Initial resistance is measured by using Wheatstone bridge. Probe tip of the RTD is placed near the heat source. Outer cover uniformly distributes heat to sensing resistance element. As the temperature varies, the resistance of the material also varies. Now, final resistance is again measured. From the above measurement, variation in temperature can be calculated as follows,

$Rt = R0\ (1+Dt)$

$Dt = ((Rt/R0)-1)/x$

Where,

Rt = resistance at C.

R0 = Resistance at room temperature. Dt

= Difference in temperature.

X = Temperature coefficient of RTD material.

Thus from the above formula by knowing Rt, R0 and x, the difference in temperature can be calculated.

Advantages:

- Accuracy is more.
- More linear than thermocouple.
- No necessary for temperature compensation.
- Performance is stable for long period.

Disadvantages:

- Expensive.
- Their change in temperature is very small even for large change in input temperature.
- External current source is required.
- Low sensitivity.

5.4 Optical pyrometer (Disappearing filament Type)

Basic Principle of optical pyrometer:

The principle of temperature measurement by brightness comparison is used in optical pyrometer. A colour variation with the growth in temperature is taken as an index of temperature.

This optical pyrometer compares the brightness of image produced by temperature source with that of reference temperature lamp. The current in the lamp is adjusted until the brightness of the lamp is equal to the brightness of the image produced by the temperature source. Since the intensity of light of any wave length depends on the temperature of the radiating object, the current passing through the lamp becomes a measure of the temperature of the temperature source when calibrated.

Construction of optical pyrometer:

The main parts of an optical pyrometer are as follows:

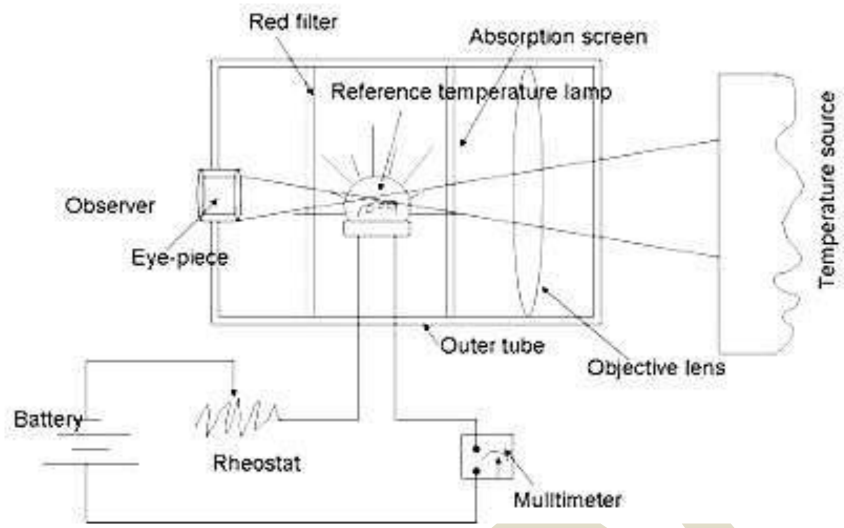


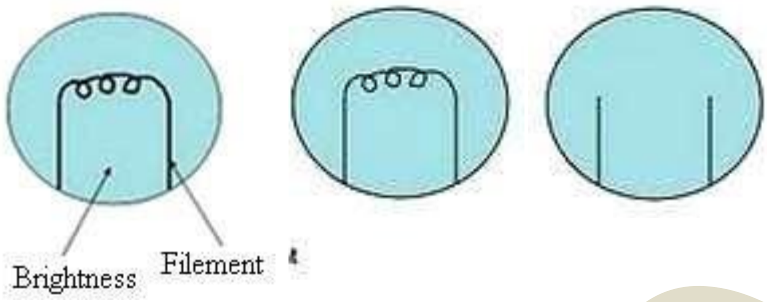
Fig.5.12 optical pyrometer

An eye piece at one end and an objective lens at the other end. A power source (battery), rheostat and mill voltmeter (to measure current) connected to a reference temperature bulb. An absorption screen is placed in between the objective lens and reference temperature lamp. The absorption screen is used to increase the range of the temperature which can be measured by the instrument. The red filter between the eye piece and the lamp allows only a narrow band of wavelength of around 0.65mui.

Operation of optical pyrometer:

When a temperature source is to be measured, the radiation from the source is focused onto the filament of the reference temperature lamp using the objective lens. Now the eye piece is adjusted so that the filament of the reference temperature lamp is in sharp focus and the filament is seen super imposed on the image of the temperature source. Now the observer starts controlling the lamp current and the filament will appear dark as in figure

A. if the filament is cooler than the temperature source, the filament will appear bright as in figure
B. if the filament is hotter than the temperature source, the filament will not be seen as in figure
C. If the filament and temperature source are in the same temperature.



(a) (b) (c)

a. filament (dark) cooler then temperature source
b. filament (bright) more than temperature source
c. filament (disappeared) equal brightness of filament & temperature source

Fig.5.13 image of temperature source

Hence the observer should control the lamp current until the filament and the temperature source have the same brightness which will be noticed when the filament disappears as in figure (c) in the superimposed image of the temperature source [that is the brightness of the lamp and the temperature source are same]. At the instance, the current flowing through the lamp which is indicated by the mill voltmeter connected to the lamp becomes a measure of the temperature of the temperature source when calibrated.

Applications of optical pyrometer:

- Optical pyrometers are used to measure temperature of molten metal or heated materials.
- Optical pyrometers are used to measure temperature of furnace and hot bodies.

Advantages of optical pyrometer:

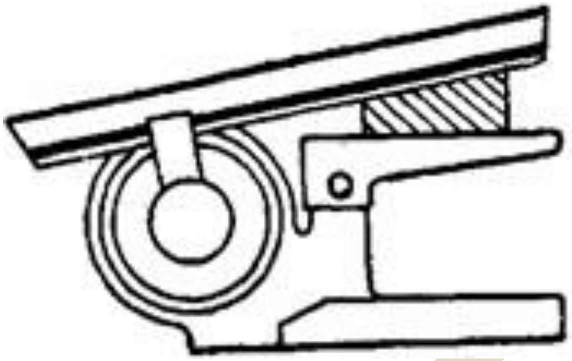
- Physical contact of the instrument is not required to measure temperature of the temperature source.
- Accuracy is high + or – 5'C.
- Provided a proper sized image of the temperature source is obtained in the instrument, the distance between the instrument and the temperature source does not matter.
- The instrument is easy to operate.

Limitations of the Optical pyrometer:

- Temperature of more than 700'C can only be measured since illumination of the temperature source is a must for measurement.
- Since it is manually operated, it cannot be used for the continuous monitoring and controlling purpose.

MODULE 5

LINEAR&ANGULARMEASUREMENT



Introduction

- Linear measurement applies to measurement of lengths, diameters, heights, and thickness including external and internal measurements.
- The line measuring instruments have series of accurately spaced lines marked on them, e.g. scale. The dimension to be measured is aligned with the graduations of the scale.
- Linear measuring instruments are designed either for line instruments, the measurement is taken between two end surfaces as in micrometers, slip gauges etc.
- The instruments used for linear measurements can be classified as:

1. Direct measuring instruments
2. Indirect measuring instruments

- The direct measuring instruments are of two types:

1. Graduated
2. Non Graduated

- The graduated instruments include rules, vernier calipers, vernier height gauges, vernier depth gauges, micrometers, dial indicators etc.
- The non-graduated instruments include calipers, trammels, telescopic gauges, surface gauges, straight gauges, wire gauges, screw pitch gauges, thickness gauges, slip gauges etc. They can also be classified as:

1. Non-precision instruments such as steel rule, calipers etc.
2. Precision measuring instruments, such as vernier instruments, micrometers, dial gauges etc.

Vernier Instruments

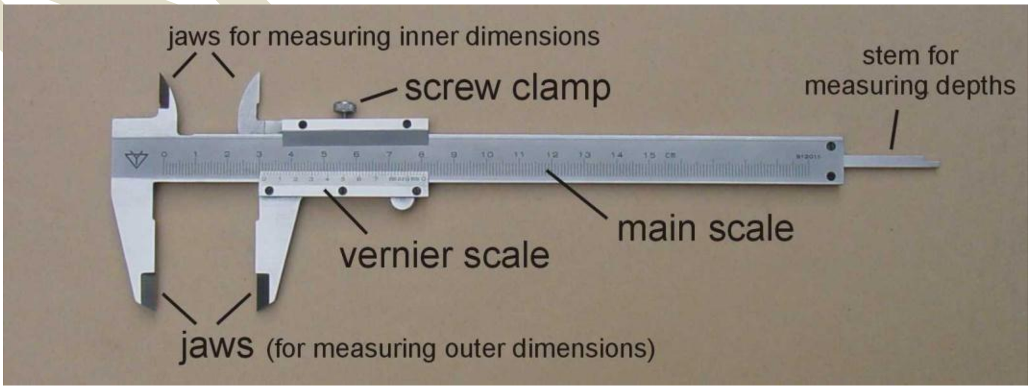
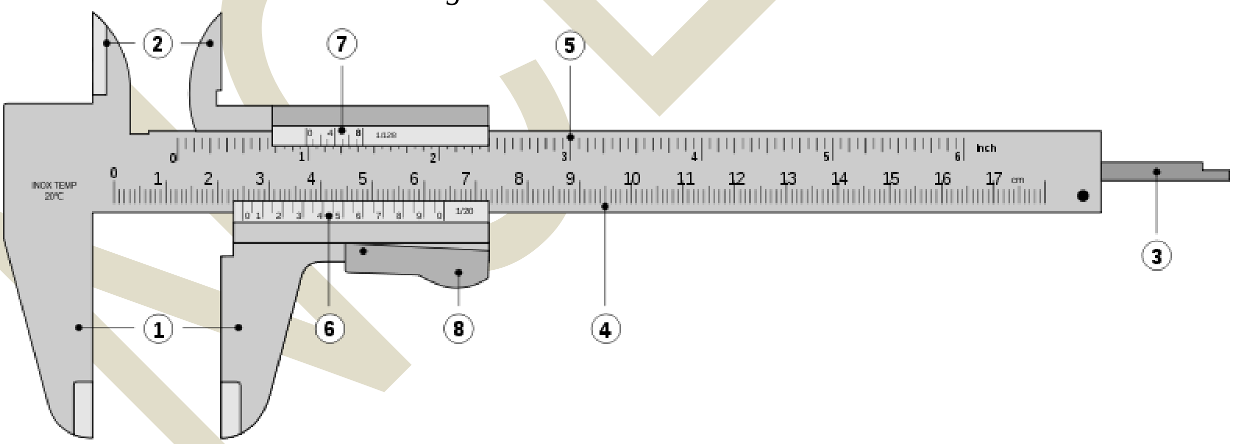


Figure 2.1 Vernier Instrument

- The principle of vernier is that when two scales or divisions slightly different in size are used, the difference between them can be utilized to enhance the accuracy of measurement.
- The vernier caliper essentially consists of two steel rules and these can slide along each other. One of the scales, i.e., main scale is engraved on a solid L-shaped frame. On this scale cm graduations are divided into 20 parts so that one small division equals 0.05 cm. One end of the frame contains a fixed jaw which is shaped into a contact tip at its extremity.
- The three elements of vernier caliper, viz, beam, fixed jaw, and sliding jaw permit substantial improvements in the commonly used measuring techniques over direct measurement with line graduated rules.
- The alignment of the distance boundaries with the corresponding graduations of the rule is ensured by means of the positive contact members (the jaws of the caliper gauges).
- The datum of the measurement can be made to coincide precisely with one of the boundaries of the distance to be measured.
- The movable jaw achieves positive contact with the object boundary at the opposite end of the distance to be measured. The closely observable correspondence of the reference marks on the slide with a particular scale value significantly reduces the extent of read- out alignment errors.

Figure 2.2 Vernier Instruments



- A sliding jaw which moves along the guiding surface provided by the main scale is coupled to a vernier scale. The sliding jaw at its left extremity contains another measuring tip.

- When two measuring tip surfaces are in contact with each other, scale shows zero reading. The finer adjustment of the movable jaw can be done by the adjusting screw
- First the whole movable jaw assembly is adjusted so that the two measuring tips just touch the part to be measured. Then lock nut B is tightened. Final adjustment depending upon the sense of correct feel is made by the adjusting screw.
- The movement of adjusting screw makes the part containing locking nut A and sliding jaw to move, as the adjusting screw rotates on a screw which is in a way fixed to the movable jaw. After final adjustment has been made, the locking nut A is also tightened and the reading is noted down
- . The measuring tips are so designed as to measure inside as well as outside dimensions.

1. Outside jaws: used to measure external diameter or width of an object
2. Inside jaws: used to measure internal diameter of an object
3. Depth probe: used to measure depths of an object or a hole
4. Main scale: gives measurements of up to one decimal place (in cm).
5. Main scale: gives measurements in fraction (in inch)
6. Vernier gives measurements up to two decimal places (in cm)
7. Vernier gives measurements in fraction (in inch)
8. Retainer: used to block movable part to allow the easy transferring a measurement

Reading the VernierScale

- For understanding the working of vernier scale let us assume that each small division of the main scale is 0.025 units.
- Say, the vernier scale contains 25 divisions and these coincide exactly with 24 divisions of main scale. So now one vernier division is equal to 1/25 of 24 scale divisions, i.e., 1/25 x 24 x 0.025 = 0.024 unit. Therefore, difference between one main scale small division and one vernier division (least count of the instrument) equals 0.025—0.024, i.e. 0.001 unit. It means if the zero of main scale and zero of vernier coincide, then the first vernier division will read 0.001 units less than the 1 small scale division. Second vernier division will read 0.002 unit less than 2 small scale divisions and so on. Thus if zero vernier scale lies in between two small divisions on main scale its exact value can be judged by seeing as to which vernier division is coinciding with main scale division.

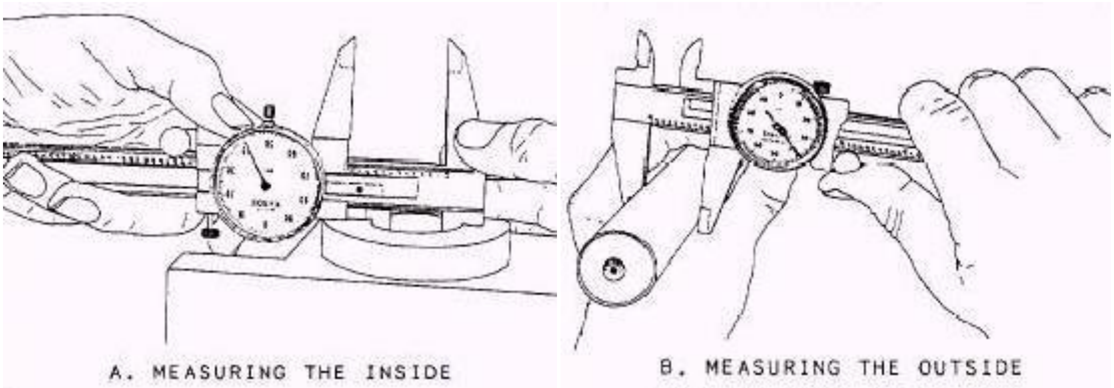


Figure 2.3 Practical Applications of Vernier Calipers

- Thus to read a measurement from a vernier caliper, note the units, tenths and fortieths which the zero on the vernier has moved from the zero on the main scale. Note down the vernier division which coincides with a scale division and add to previous reading the number of thousands of a unit indicated by the vernier divisions
- e.g., reading in the scale shown in Fig. is 3 units + 0.1 unit + 0.075 unit + 0.008 unit = 3.183 units. When using the vernier caliper for internal measurements the width of the measuring jaws must be taken into account. (Generally the width of measuring jaw is 10 mm for Metric System).

Types of Vernier Calipers

- According to IS 3651—1974 (Specification for vernier caliper), three types of vernier calipers have been specified to meet the various needs of external and internal measurements **up to 2000 mm** with vernier **accuracy of 0.02, 0.05 and 0.1 mm.**
- The three types are called types A, B, C and have been shown in Figs. 2.75, 2.76 and 2.79 respectively. All the three types are made with only one scale on the front of the beam for direct reading.
- Type A has jaws on both sides for external and internal measurements, and also has a blade for depth measurements. Type B is provided with jaws on one side for external and internal measurements. Type C has jaws on both sides for making the measurements and for marking operations.

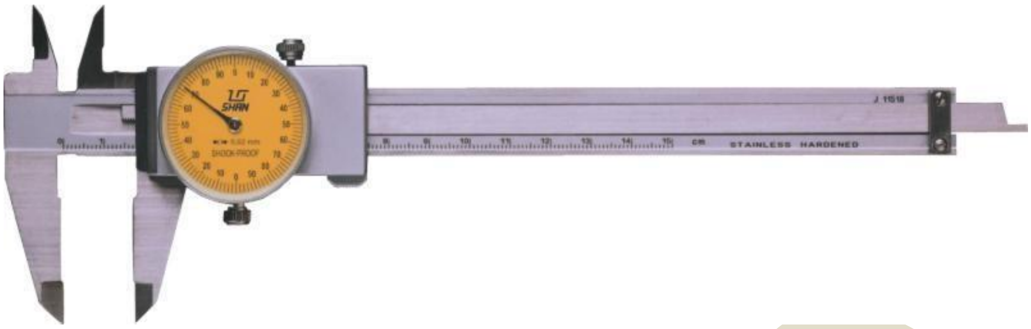


Figure 2.4 Vernier Caliper with Dial

- All parts of the vernier calipers are made of **good quality steel** and the measuring faces **hardened** to **650 H.V. minimum.** The recommended measuring ranges (nominal sizes) of vernier calipers as per IS 3651—1974 are 0—125, 0—200, 0—250. 0—300; 0—500, 0—750, 0—1000, 750—1500 and 750— 2000 mm.
- On type A, scale serves for both external and internal measurements, whereas in case of types B and C, the main scale serves for external measurements and for marking purposes also in type C, but on types B and C internal measurements are made by adding width of the internal measuring jaws to the reading on the scale. For this reason, the combined width for internal jaws is marked on the jaws in case of types B and C calipers. The combined width shou1d be uniform throughout its length to within 0.01 mm.
- The beam for all the types is made flat throughout its length to within the tolerances of 0.05 mm for nominal lengths up to 300 mm, 0.08 mm from 900 to 1000 mm, and 0.15 mm for 1500 and 2000 mm sizes, and guiding surfaces of the beam are made straight to within 0.01 mm for measuring range of 200 mm and 0.01 mm every 200 mm measuring range of larger size.
- The measuring surfaces are given a fine ground finish. The portions of the jaws between the beam and the measuring faces are relieved. The fixed jaw is made an integral part of the beam and the sliding jaw is made a good sliding fit along with the beam and made to have seizure-free movement along the bar.
- A suitable locking arrangement is provided on the sliding jaw in order to effectively clamp it on the beam. When the sliding jaw is clamped to the beam at any position within the measuring range, the external measurir$_1$g faces should remain square to the guiding surface of the beam to within 0.003 mm per 100 mm. The measuring surfaces of the fixed and sliding jaws should be coplanar to within 0.05 mm when the sliding jaw is

clamped to the beam in zero position. The external measuring faces are lapped flat to within 0.005 mm. The bearing faces of the sliding jaw should preferably be relieved in order to prevent damage to the scale on the beam. Each of the internal measuring surfaces should be parallel to the corresponding external measuring surface to within

0.025 mm in case of type B and C calipers. The internal measuring surfaces are formed cylindrically with a radius not exceeding one-half of their combined width.

Errors in Measurements With Vernier Calipers

- Errors are usually made in measurements with vernier calipers from manipulation of vernier caliper and its jaws on the work piece.
- For instance, in measuring an outside diameter, one should be sure that the caliper bar and the plane of the caliper jaws are truly perpendicular to the workpiece's longitudinal centre line
- i.e. one should be sure that the caliper is not canted, tilted, or twisted. It happens because the relatively long, extending main bar of the average vernier calipers so readily tips in one direction or the other.
- The accuracy of the measurement with vernier calipers to a great extent depends upon the condition of the jaws of the caliper. The accuracy and the natural wear, and warping of vernier caliper jaws should be tested frequently by closing them together tightly or setting them to the 0.0 point of the main and vernier scales. In this position the caliper is held against a light source. If there is wear, spring or warp a knock-kneed condition as shown in Fig. (a) Will be observed. If measurement error on this account is expected to be greater than 0.005 mm the instrument should not be used and sent for repair.
- When the sliding jaw frame has become worn or warped that it does not slide squarely & snugly on main caliper beam, then jaws would appear as shown in fig. Where a vernier caliper is used mostly for measuring inside diameters, the jaws may become bowlegged as in Fig. (c) Or it's outside edges worn clown as in Fig. (d).

Care in the Use of Vernier Calliper

- No play should be there between the sliding jaws on scale, otherwise the accuracy of the vernier caliper will be lost. If play exists then the gib at the back of jaw assembly must be bent so that gib holds the jaw against the frame and play is removed.
- Usually the tips of measuring jaws are worn and that must be taken into account. Most of the errors usually result from manipulation of the vernier caliper and its jaws on the

work piece.

- In measuring an outside diameter it should be insured that the caliper bar and the plane of the caliper jaws are truly perpendicular to the work piece's longitudinal centre line. It should be ensured that the caliper is not canted, tilted or twisted.
- The stationary caliper jaw of the vernier caliper should be used as the reference point and measured point is obtained by advancing or withdrawing the sliding jaw.
- In general, the vernier caliper should be gripped near or opposite the jaws; one hand for the stationary jaw and the other hand generally supporting the sliding jaw. The instrument should not be held by the over-hanging "tail" formed by the projecting main bar of the caliper.
- The accuracy in measurement primarily depends on two senses, viz., sense of sight and sense of touch (feel).
- The short-comings of imperfect vision can however be overcome by the use of corrective eye-glass and magnifying glass. But sense of touch is an important factor in measurements. Sense of touch varies from person to person and can be developed with practice and proper handling of tools.
- One very important thing to note here is that sense of touch is most prominent in the finger-tips, therefore, the measuring instrument must always be properly balanced in hand and held lightly in such a way that only fingers handle the moving and adjusting screws etc. If tool be held by force, then sense of feel is reduced.
- Vernier calliper must always be held at short leg of main scale and jaws never pulled.

Vernier height gauge

- Vernier height gauge is similar to vernier calliper but in this instrument the graduated bar is held in a vertical position and it is used in conjunction with a surface plate.

- **Construction:**

A vernier height gauge consists of

1. A finely ground and lapped base. The base is massive and robust in construction to ensure rigidity and stability.
2. A vertical graduated beam or column supported on a massive base.
3. Attached to the beam is a sliding vernier head carrying the vernier scale and a clamping screw.

4. An auxiliary head which is also attached to the beam above the sliding vernier head. It has fine adjusting and clamping screw.
5. A measuring jaw or a scriber attached to the front of the sliding vernier

Figure 2.5 Vernier Height Gauge

- **Use.**

- The vernier height gauge is designed for accurate measurements and marking of vertical heights above a surface plate datum.
- It can also be used to measure differences in heights by taking the vernier scale readings at each height and determining the difference by subtraction.
- It can be used for a number of applications in the tool room and inspection department.

The important features of vernier height gauge are:

- All the parts are made of good quality steel or stainless steel.
- The beam should be sufficiently rigid square with the base.
- The measuring jaw should have a clear projection from the edge of the beam at least equal to the projection of the base' from the beam.
- The upper and lower gauging surfaces of the measuring jaw shall be flat and parallel to the base.
- The scriber should also be of the same nominal depth as the measuring jaw so that it may be reversed.
- The projection of the jaw should be at least 25 mm.
- The slider should have a good sliding fit for all along the full working length of the beam.
- Height gauges can also be provided with dial gauges instead of vernier.

This provides easy and exact reading of slider movement by dial a gauge which is larger and clear.

- **Precautions.**

- When not in use, vernier height gauge should be kept in its case.
- It should be tested for straightness, squareness and parallelism of the working faces of the beam, measuring jaw and scriber.
- The springing of the measuring jaw should always be avoided.

Vernier Depth Gauge

- Vernier depth gauge is used to measure the depths of holes, slots and recesses, to locate centre distances etc. It consists of

1. A sliding head having flat and true base free from curves and waviness.

2. A graduated beam known as main scale. The sliding head slides over the graduated beam.
3. An auxiliary head with a fine adjustment and a clamping screw.

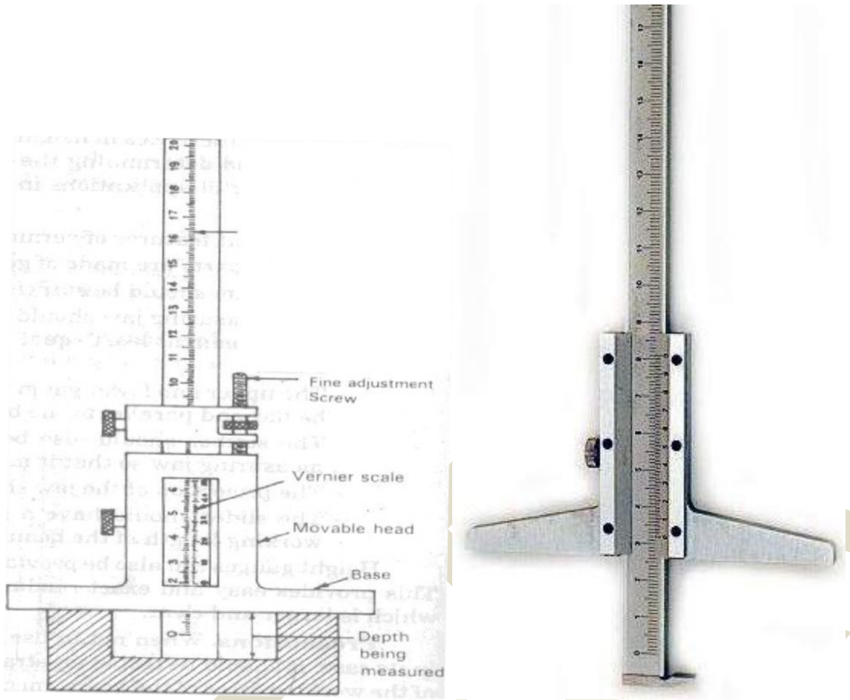


Figure 2.6 Vernier Depth Gauge

- The beam is perpendicular to the base in both directions and its ends square and flat.
- The end of the sliding head can be set at any point with fine adjustment mechanism locked and read from the vernier provided on it, while using the instrument, the base is held firmly on the reference surface and lowers the beam into the hole until it contacts the bottom surface of the hole.
- The final adjustment depending upon the sense of correct feel is made by the fine adjustment screw. The clamping screw is then tightened and the instrument is removed from the hole and reading taken in the same way as the vernier calliper. While using theinstrument it should be ensured that the reference surface op which the depth gauge base is rested is satisfactorily true, flat arid square.

Micrometers

- The micrometer screw gauge essentially consists of an accurate screw having about 10 or 20 threads per cm and revolves in a fixed nut.
- The end of the screw forms one measuring tip and the other measuring tip is constituted by a stationary anvil in the base of the frame. The screw is threaded for

certain length and is plain afterwards. The plain portion is called sleeve and its end is the measuring surface.

- The spindle is advanced or retracted by turning a thimble connected to the spindle. The spindle is a slide fit over the barrel and barrel is the fixed part attached with the frame.
- The barrel is graduated in unit of 0.05 cm. i.e. 20 divisions per cm, which is the lead of the screw for one complete revolution.
- The thimble has got 25 divisions around its periphery on circular portion. Thus it sub- divides each revolution of the screw in 25 equal parts, i.e. each division corresponds to 0.002 cm. A lock nut is provided for locking a dimension by preventing motion of the spindle.

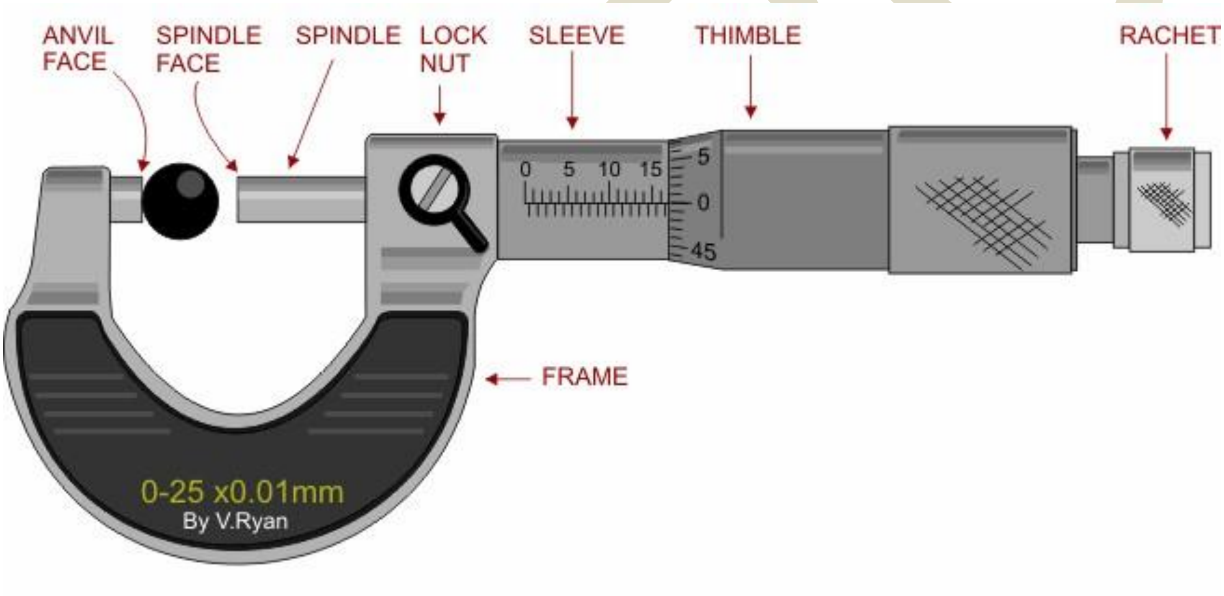


Figure 2.7 Micrometers

- Ratchet stop is provided at the end of the thimble cap to maintain sufficient and uniform measuring pressure so that standard conditions of measurement are attained.
- Ratchet stop consists of an overriding clutch held by a weak spring.
- When the spindle is brought into contact with the work at the correct measuring pressure, the clutch starts slipping and no further movement of the spindle takes place by the rotation of ratchet. In the backward movement it is positive due to shape of ratchet.

Reading a Micrometer:

- In order to make it possible to read up to **0.0001** inch in micrometer screw gauge, a vernier scale is generally made on the barrel.

- The vernier scale has 10 straight lines on barrel and these coincide with exact 9 divisions on the thimble. Thus one small deviation on thimble is further subdivided into 10 parts and taking the reading one has to see which of the vernier scale division coincides with division of the thimble.
- Accordingly the reading for given arrangement in fig. will be, On

  main barrel : 0.120”

  On thimble : 0.014”

  On vernier scale : 0.0001”

  Total reading : 0.1342”
- Before taking the reading anvil and spindle must be brought together carefully and initial reading noted down. Its calibration must be checked by using standard gauge blocks.

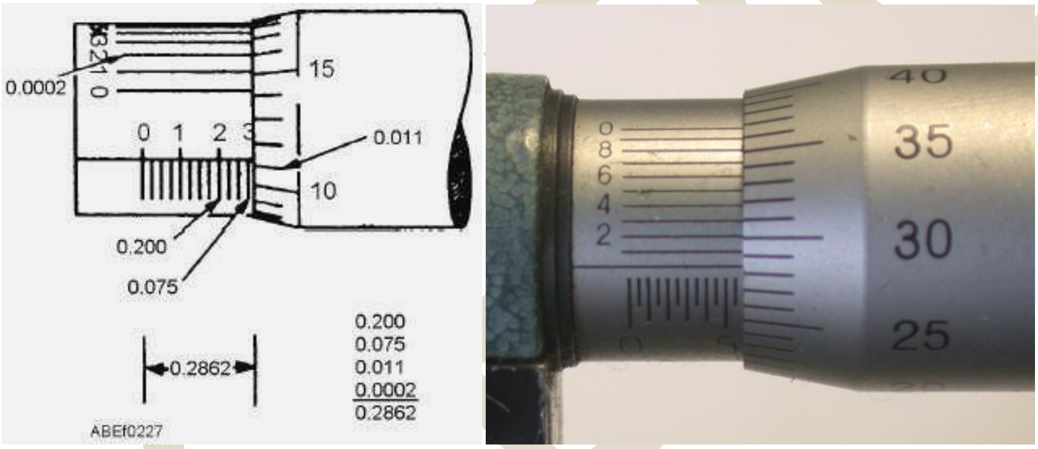


Figure 2.8 Practical Applications of Micrometers

- In metric micrometers, the pitch of the screw thread is 0.5 mm so that one revolution of screw moves it axially by 0.5 mm. Main scale on barrel has least division of 0.5 mm. the thimble has 50 divisions on its circumference.
- One division on thimble = 0.5 / 50 mm = 0.1 mm
- If vernier scale is also incorporated then sub divisions on the thimble can be estimated up to an accuracy of 0.001 mm.
- Reading of micrometer is 3.5 mm on barrel and 7 divisions on thimble

  = 3.5+7 x 0.001= 3.5 + 0.07 = 3.57 mm

Cleaning the Micrometer:

- Micrometer screw gauge should be wiped free from oil, dirt, dust and grit.

- When micrometer feels gummy and dust ridden and the thimble fails to turn freely, it should never be bodily dunked in kerosene or solvent because just soaking the assembled micrometer fails to float the dirt away.
- Further it must be remembered that the apparent stickiness of the micrometer may not be due to the grit and gum but to a damaged thread and sprung frame or spindle.
- Every time the micrometer is used, measuring surface, the anvil and spindle should be cleaned. Screw the spindle lightly but firmly down to a clean piece of paper held between spindle and anvil.
- Pull the piece of paper put from between the measuring surface. Then unscrew the spindle few turns and blow out any fuzz or particles of papers that may have clung to sharp edges of anvil and spindle.

Precautions in using Micrometer

- In order to get good results out of the use of micrometer screw gauge, the inspection of the parts must be made as follows. Micrometer should be cleaned of any dust and spindle should move freely.
- The part whose dimension is to be measured must be held n left hand and the micrometer in right hand. The way for holding the micrometer is to place the small finger and adjoining finger in the U – Shaped frame.
- The forefinger and thumb are placed near the thimble to rotate it and the middle finger supports the micrometer holding it firmly.
- The micrometer dimension is set slightly larger than the size of the part and part is slid over the contact surfaces of micrometer gently. After it, the thimble is turned till the measuring pressure is applied.
- In the case of circular parts, the micrometer must be moved carefully over representative arc so as to note maximum dimension only. Then the micrometer reading is taken.
- The micrometers are available in various sizes and ranges, and corresponding micrometer should be chosen depending upon the dimension.
- Errors in reading may occur due to lack of flatness of anvil, lack of parallelism of the anvils at part of scale or throughout, inaccurate setting of zero reading, etc. various tests to ensure these conditions should be carried out from time to time.

Bore gauge:

- The dial bore gauges shown in fig. are for miniature hole measurements.
- The gauge is supplied with a set of split ball measuring contact points which are hard chrome-plated to retain original spheres.
- Along with the measuring probes, setting rings are also provided to zero set the indicator whenever the probes are interchanged.

Actual ring size is engraved on the ring frames to the closest 0.001 mm value.

Figure 2.9 Bore gauges

2.2 Dial indicators

- **Introduction**

- Dial indicators are small indicating devices using mechanical means such as gears and pinions or levers for magnification system. They are basically used for making and checking linear measurements.
- Many a times they are also used as comparators. Dial indicator, in fact is a simple type of mechanical comparator.
- When a dial indicator is used as an essential part in the mechanism any set up for comparison measurement purposes; it is called as a gauge.
- The dial indicator measures the displacement of its plunger or a stylus on a circular dial by means of a rotating pointer.
- Dial indicators are very sensitive and versatile instruments.
- They require little skill in their use than other precision instruments, such as micrometer vernier callipers, gauges etc. However, a dial indicator by itself is not of much unless it is properly mounted and set before using for inspection purposes.

Uses:

- By mounting a dial indicator on any suitable base and with various attachments, it can be used for variety of purposes as follows.
  1. Determining errors in geometrical forms, e.g., ovality out-of-roundness, taper etc.
  2. Determining positional errors of surfaces, e.g., in squareness, parallelism, alignment etc.
  3. Taking accurate measurements of deformation (extension compression) in tension and compression testing of material.
  4. Comparing two heights or distances between narrow limits (comparator). The

practical applications of the use of dial indicator are:

  1. To check alignment of lathe centers by using a suitable accurate bar between centers.
  2. To check trueness of milling machine arbors.
  3. To check parallelism of the shaper ram with table surface or like.

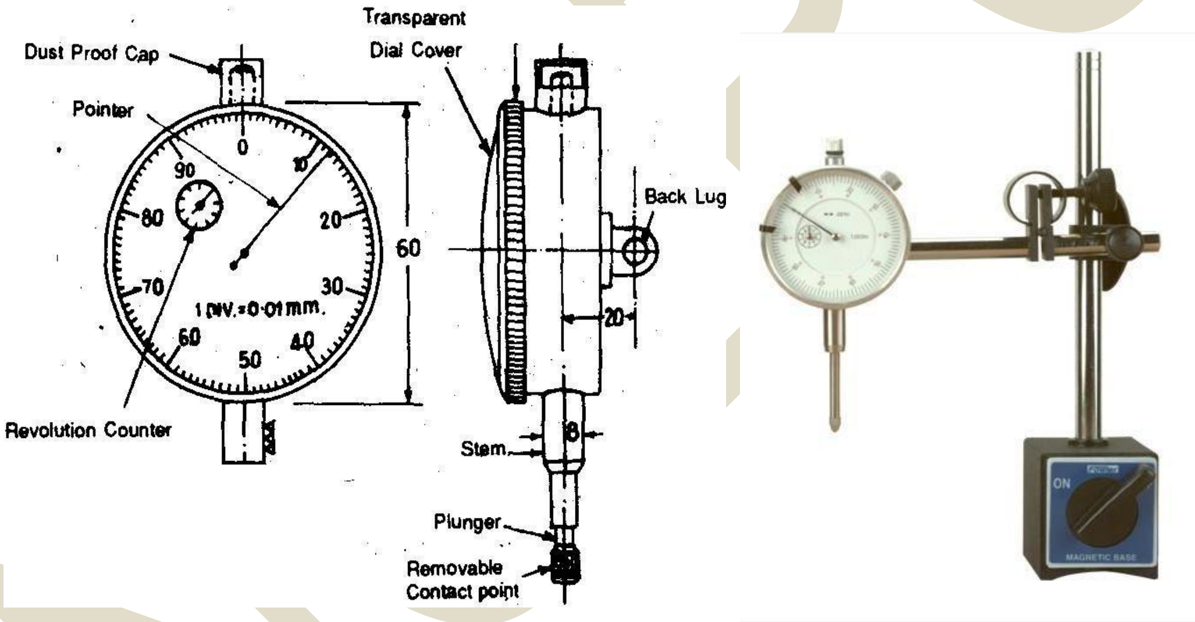
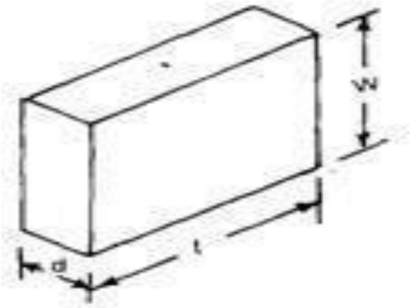


Figure 2.10 Dial Indicators

Slip Gauges

- Slip gauges or gauge blocks are universally accepted end standard of length in industry. These were introduced by Johnson, a Swedish engineer, and are also called as johanson gauges



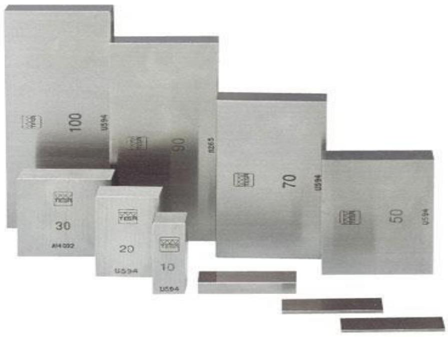


Figure 2.11 Dimensions of a Slip Gauge

- Slip gauges are rectangular blocks of high grade steel with exceptionally close tolerances. These blocks are suitably hardened through out to ensure maximum resistance to wear.
- They are then stabilized by heating and cooling successively in stages so that hardening stresses are removed,After being hardened they are carefully finished by high grade lapping to a high degree of finish, flatness and accuracy.
- For successful use of slip gauges their working faces are made truly flat and parallel. A slip gauge is shown in fig. 3.36. Slip gauges are also made from tungsten carbide which is extremely hard and wear resistance.
- The cross-sections of these gauges are 9 mm x 30 mm for sizes up to 10 mm and 9 mm x 35 mm for larger sizes. Any two slips when perfectly clean may be wrung together. The dimensions are permanently marked on one of the measuring faces of gauge blocks

- Gauges blocks are used for:

1. Direct precise measurement, where the accuracy of the work piece demands it.
2. For checking accuracy of vernier callipers, micrometers, and such other measuring instruments.
3. Setting up a comparator to a specific dimension.
4. For measuring angle of work piece and also for angular setting in conjunction with a sine bar.
5. The distances of plugs, spigots, etc. on fixture are often best measured with the slip gauges or end bars for large dimensions.
6. To check gap between parallel locations such as in gap gauges or between two mating parts.

Telescopic Gauges

- The telescopic gauge is used for measuring internal diameter of holes, slots and grooves etc. It consists of a handle with two rods in a tube at one end and a working screw at the other end. The rods having spherical contacts can slide within a tube and are forced apart by an internal spring.
- The locking screw can lock the rods at any desired position through a spring. While taking measurements, the rods are pressed closer and inserted into the hole to be measured. The rods then open out to touch the metal surface, of the hole on both sides. They are then locked in position by means of a locking screw. The telescopic gauge is then taken out from the hole. The dimension across the tips is measured by micrometer or Verniercaliper.

Introduction to Angular Measurement

- Angular measurements are frequently necessary for the manufacture of interchangeable parts. The ships and aero planes can navigate confidently without the help of the site of the land; only because of precise angular measuring devices can be used in astronomy to determine the relation of the stars and their approximate distances.
- The angle is defined as the opening between two lines which meet at a point. If one of the two lines is moved at a point in an arc, a complete circle can be formed.
- The basic unit in angular measurement is the right angle, which is defined as the angle between two lines which intersect so as to make the adjacent angles equal.
- If a circle is divided into 360 equal parts. Each part is called as degree (^{0}). Each degree is divided in 60 minutes (‘), and each minute is divided into 60 seconds (“).
- This method of defining angular units is known as sexagesimal system, which is used for engineering purposes.
- An alternative method of defining angle is based on the relationship between the radius and arc of a circle. It is called as radian.
- Radian is defined as the angle subtended at the centre by an arc of a circle of length equal to its radius.
- It is more widely used in mathematical investigation.

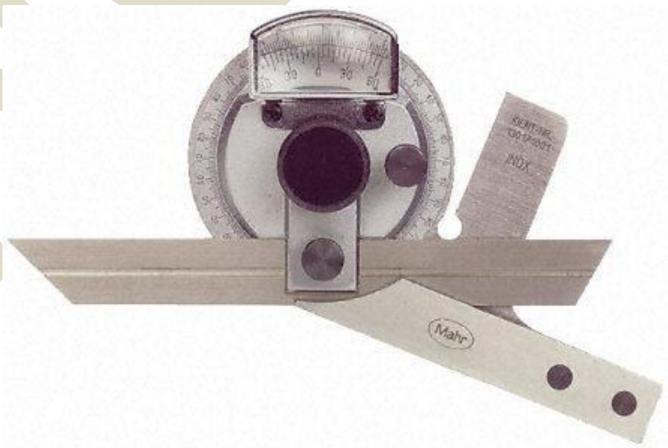
  2 radians = 360, giving,

  1 radian = 57.2958 degrees.

- In addition linear units such as 1 in 30 or millimeters per meter are often used for specifying tapers and departures from squareness or parallelism.

Bevel Protector

- It is probably the simplest instrument for measuring the angle between two faces of component.
- It consists of a base plate attached to the main body, and an adjustable blade which is attached to a circular plate containing vernier scale. The adjustable blade is capable of rotating freely about the centre of the main scale engraved on the body of the instrument and can be locked in any position.
- An acute angle attachment is provided at the top; as shown in fig. for the purpose of measuring acute angles. The base of the base plate is made flat so that it could be laid flat upon the work and any type of angle measured. It is capable of measurement from 0^0 to 360^0
- The vernier scale has 24 divisions coinciding with 23 main scale divisions. Thus the least count of the instrument is 5'. This instrument is most commonly used in workshops for angular measurements till more precision is required.
- A recent development of the vernier bevel protector is optical bevel protector. In this instrument, a glass circle divided at 10' intervals throughout the whole 360^0 is fitted inside the main body.
- A small microscope is fitted through which the circle graduations can be viewed. The adjustable blade is clamped to a rotating member who carries this microscope. With the aid of microscope it is possible to read by estimation to about 2'.



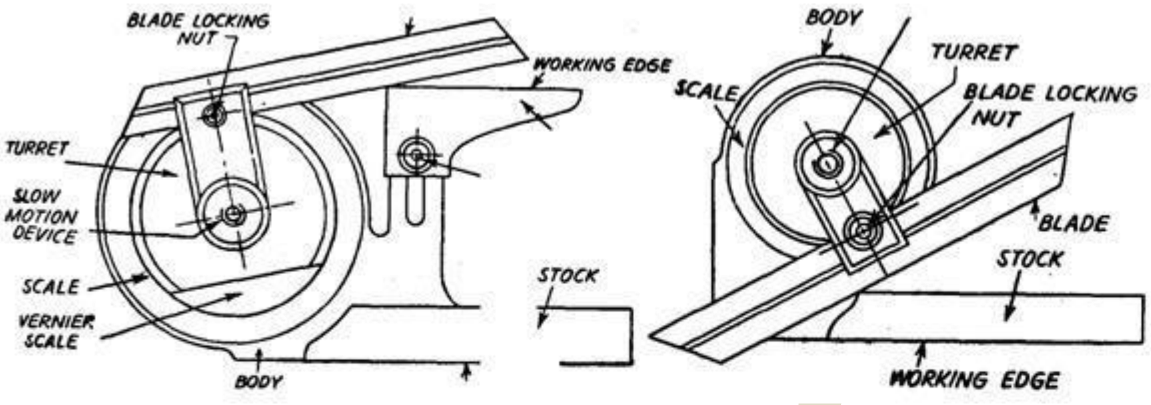


Figure 2.12 Bevel Protector

Universal Bevel Protector

- It is used for measuring and laying out of angles accurately and precisely within 5 minutes. The protector dial is slotted to hold a blade which can be rotated with the dial to the required angle and also independently adjusted to any desired length. The blade can be locked in any position.

Bevel Protectors as Per Indian Standard Practice

The bevel protectors are of two types, viz.

1. Mechanical Bevel Protector, and
2. Optical Bevel Protector.

1. Mechanical bevel protector:

- The mechanical bevel protectors are further classified into four types; A, B, C and D.
- In types A and B, the vernier is graduated to read to 5 minutes of arc whereas in case of type C, the scale is graduated to read in degrees and the bevel protector is without vernier or fine adjustment device or acute angle attachment.
- The difference between types A and B is that type A is provided with fine adjustment device or acute angle attachment whereas type B is not. The scales of all the types are graduated either as a full circle marked 0—90—0—90 with one vernier or as semicircle marked 0—90—0 with two verniers 180^0 apart.
- Type D is graduated in degrees and is not provided with either vernier or fine adjustment device or acute angle attachment.

2. Optical bevel protector:

- In the case of optical bevel protector, it is possible to take readings up to approximately 2 minutes of arc. The provision is made for an internal circular scale which is graduated in divisions of 10 minutes of arc.

- Readings are taken against a fixed index line or vernier by means of an optical magnifying system which is integral with the instrument. The scale is graduated as a full circle marked 0—90—0—90. The zero positions correspond to the condition when the blade is parallel to the stock. Provision is also made for adjusting the focus of the system to accommodate normal variations in eye-sight. The scale and vernier are so arranged that they are always in focus in the optical system.

Various Components of Bevel Protectors

Body: It is designed in such a way that its back is flat and there are no projections beyond its back so that when the bevel protector is placed on its back on a surface plate there shall be no perceptible rock. The flatness of the working edge of the stock and body is tested by checking the squareness of blade with respect to stock when blade is set at 90^0.

Stock: The working edge of the stock is about 90 mm in length and 7 mm thick. It is very essential that the working edge of the stock be perfectly straight and if at all departure is there, it should be in the form of concavity and of the order of 0.01 mm maximum over the whole span.

Blade: It can be moved along the turret throughout its length and can also be reversed. It is about 150 or 300 mm long, 13 mm wide and 2 mm thick and ends beveled at angles of 45^0 and 60^0 within the accuracy of 5 minutes of arc. Its working edge should be straight upto
0.02 mm and parallel upto 0.03 mm over the entire length of 300 mm. It can be clamped in any position.

Actual Angle Attachment

It can be readily fitted into body and clamped in any position. Its working edge should be flat to within 0.005 mm and parallel to the working edge of the stock within 0.015 mm over the entire length of attachment.

The bevel protectors are tested for flatness, squareness, parallelism, straightness and angular intervals by suitable methods.

Sine Principle and Sine Bars

- The sine principle uses the ratio of the length of two sides of a right triangle in deriving a given angle. It may be noted that devices operating on sine principle are capable of “self generation.”

- The measurement is usually limited to 450 from loss of accuracy point of view. The accuracy with which the sine principle can be put to use is dependent in practice, on some form of linear measurement.
- The sine bar in itself is not a complete measuring instrument. Another datum such as a surface plate is needed, as well as other auxiliary equipment, notably slip gauges, and indicating device to make measurements. Sine bars used in conjunction with slip gauges constitute a very good device for the precise measurement of angles.
- Sine bars are used either to measure angles very accurately or for locating any work to a given angle within very close limits.
- Sine bars are made from high carbon, high chromium, corrosion resistant steel, hardened, ground and stabilized.

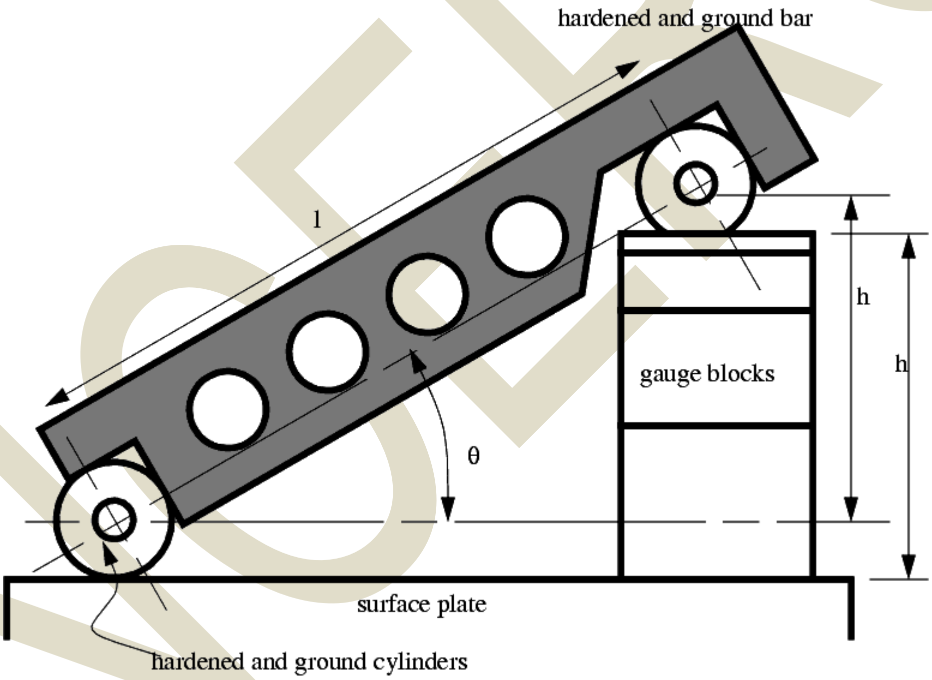


Figure 2.13 Use of sine bar

Where, L = distance between centers of ground cylinder (typically 5'' or 10'') H = height of the gauge blocks

Θ=theangleoftheplane Θ

= a sin (h/l)

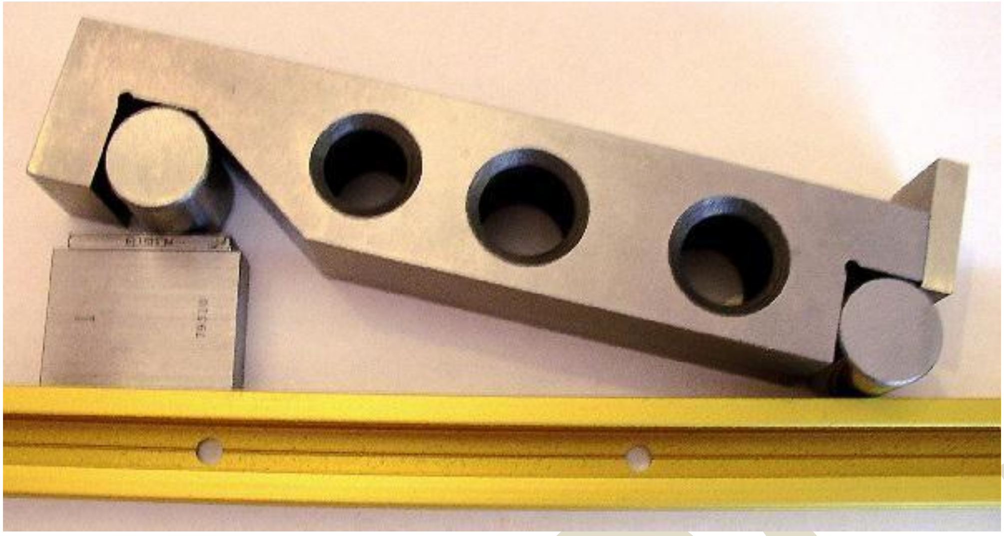


Figure 2.14 Practical Application of sine bar

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 q. Then sin □= h/l, where l is the distance between the center of the rollers. Thus knowing, 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 □ 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 gaugesChecking 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 protector.

   Let the angle be 8. Then the sine bar is set at an angle □ and clamped to an angle plate. Next, the work is placed on sine bar and clamped to 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 work surface. Fig.

   If deviation noted down by the dial indicator is ôh over a length *l′* of work, then height of slip gauges by which it should be adjusted is equal to = ôh x *l/l'*

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 fiducially 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. Surface plate shows the use of height gauge for obtaining two readings for either of the 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.

1.4 Angle Gauges

- The first set of combination of angle gauges was devised by Dr. Tomlinson of N.P.L. With thirteen separate gauges used in conjunction with one square block and one parallel straight-edge, it is possible to set up any angle to the nearest 3" In the same way, as slip gauges are built up to give a linear dimension, I the angle gauges can be build up to give a required angle.
- Angle gauges PIVOT are made of hardened steel and seasoned carefully to ensure permanence of angular accuracy, and the measuring faces are lapped and polished to a high degree of accuracy and flatness like slip gauges. These gauges are about 3 inch (76.2 mm) long, 5/8 inch (15.87 mm) wide with their faces lapped to within 0.0002 mm and angle between the two ends to ±2 seconds.
- The secret of this system in having any angle in step of 3" is the adoption of a mathematical series of the values of the angles of various gauges of the set.
- The thirteen gauges can be divided into three series; degrees, minutes and fractions of a

minute. The gauges available in first series are of angle 1^0, 3^0, 9^0, 27^0, and 41^0. Second series comprises 1', 3', 9'and 27'angle gauges and this series has 0.05', 0.1', 0.3'and 0.5' (or 3", 6", 18" and 30") angle gauges.

- All these angle gauges in combination can be added or subtracted, thus, making a large number of combinations possible. There are two sets of gauges available, designated as A and B. The standard A contains all the above 13 gauges. Standard B contains only 12 gauges and does not have, the 0.05' angle gauge.
- Direct combination enables computation of any angle up to 81^0 40.9'and angles larger than this can be made up with the help of the square block. However, an additional gauge of 9^0 can also be supplied with the set to obtain a full 90^0 angle without the use of the square. Fig. illustrates how the gauges can be used in addition and subtraction. The procedure used for making various angles is as follows e.g. say, we have to build up an angle of 57^0 38' 9".
- First we pay our attention towards degree only. So 57^0 could be built up as $41^0 + 27^0 - 9^0 + 1^0 - 3^0$
- Next if the minutes are less than 40', they could be built up directly, otherwise number of degrees must be increased by 1^0 and the number of minutes necessary to correct the total is subtracted. Here now 34'could be built 27'+9'—3'+ 1' and lastly 9" is built up as 0.1'+ 0.05'.
- It may be noted that each angle gauge is marked with engraved V which indicates the direction of included angle. When the angles of individual angle gauges are to be added up then the Vs of all angle gauges should be in line and when any angle is to be subtracted, its engraved V should be in other direction.
- Thus it is seen that any angle could be made up but the block formed by the combination of a number of these gauges is rather bulky and, therefore, cannot be always directly applied to the work. But these gauges being used as reference and taking the aid of other angle measuring devices will be a good proposal at many places.
- Angle gauge blocks seem to lack the requisites for use as primary standards because errors are easily compounded when angle blocks are wrung in combination. Further the absolute verification of angle blocks is usually dependent on some other primary standard.

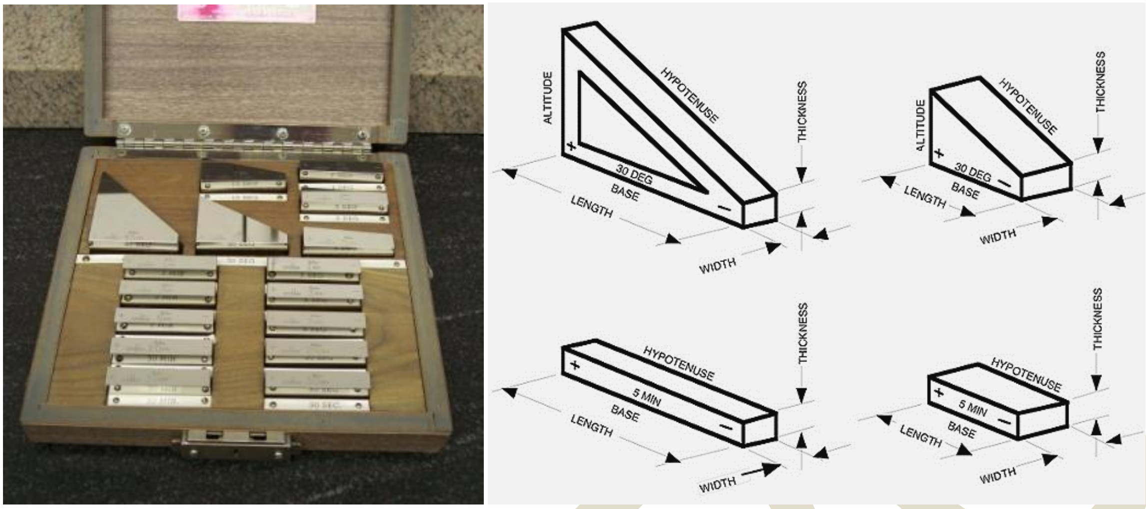


Figure 2.15 Set of angle gauges

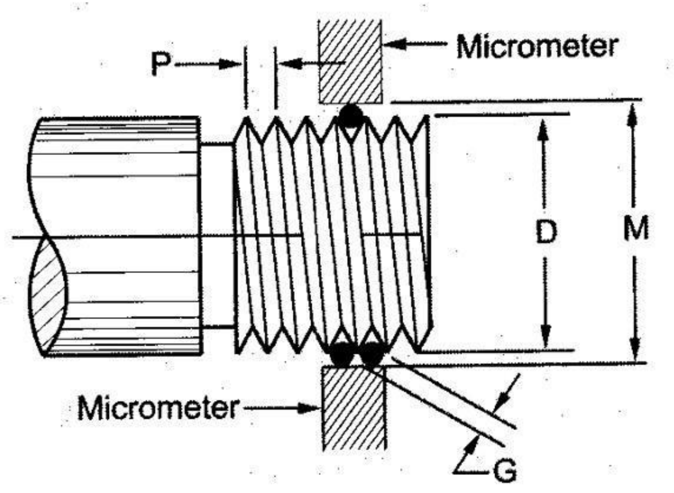
Uses of Angle Gauges

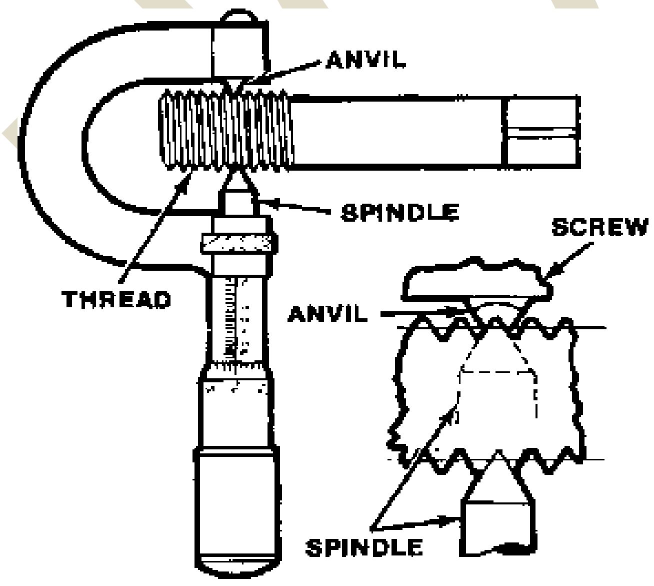
- Direct use of angle gauges to measure the angle in the die insert:
- To test the accuracy of the angle in the die insert, the insert is placed against an illuminated glass surface plate or in front of an inspection light box. The combination of angle gauges is so adjusted and the built-up combination, of angle gauges carefully inserted in position so that no white light can be seen between the gauge faces and die faces. It may be noted that when all the engraved Vs on the angle gauges are in the same line, all angles are added up. In case some engraved Vs on angle gauges are on other side, those angles are subtracted.

Use of angle gauges with square plate:

- As already indicated, the use of square plate increases the versatility of the application of angle gauges. Generally, the square plate has its 90^0 angles guaranteed to within 2 seconds of arc. Where very high degree of accuracy is required, the four corners of the square plate are numbered as A, B, C and D, and a test certificate are issued with each set of angle gauges, giving the measured angle of each corner. The whole set up is placed against an illuminated glass surface plate. It may be noted that the use of slip gauges has to be made in order to facilitate the testing.

So far, we have used angle gauges to obtain a visual comparison of an angular dimension under test. It has also been realized that though it may be possible to obtain good results but it is difficult to give an estimate of the actual angular error. For very precise angular measurements, angle gauges are used in conjunction with angle dekkor.


P
Micrometer
D
M
Micrometer
G


ANVIL
SPINDLE
SCREW
THREAD
ANVIL
SPINDLE

Introduction

- Threads are of prime importance, they are used as fasteners. It is a helical groove, used to transmit force and motion. In plain shaft, the whole assembly, the object of dimensional control is to ensure a certain consistency of fit.
- In case of thread work, the object is to ensure mechanical strength of the screw thread, being governed by the amount of flank contact rather than by fit in a threaded hole.
- The performance of screw threads during their assembly with nut depends upon a number of parameters such as the condition of the machine tool used for screw cutting, work material and tool.
- The inspection of the screw threads reveals the nature of defects present the geometric aspects of screw threads are relatively complex with respect to the interrelationship of pitch diameter, variation in lead, helix and flank angle.
- The gauging of screw threads is the process of determining the extent to which screw thread conform dimensionally to the prescribed limits of size.

Screw Thread Terminology

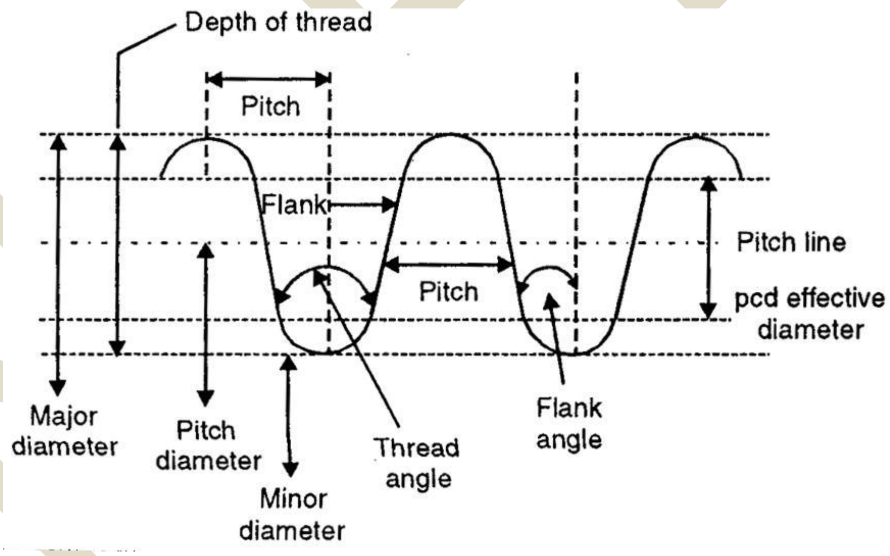


Figure8.1Screw Thread Terminology

The various elements of screw threads are as shown in Figure 8.1.

- **Lead:** The axial distance advanced by the screw in one revolution is the lead.
- **Pitch:** It is the distance measured parallel to the screw threads axis between the corresponding points on two adjacent threads in the same axial plane. The basic pitch is equal to the lead divided by the number of thread starts.

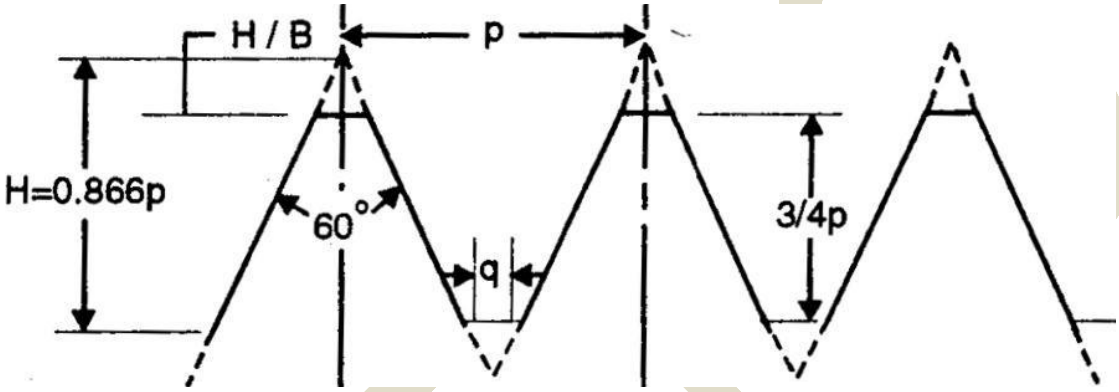
- **Minor diameter:** It is the diameter of an imaginary co-axial cylinder which touches the roots of external threads.
- **Major diameter:** It is the diameter of an imaginary co-axial cylinder which touches the crests of an external thread and the root of an internal thread.
- **Pitch diameter:** It is the diameter at which the thread space and width are equal to half of the screw thread
- **Helix angle:** It is the angle made by the helix of the thread at the pitch line with the axis. The angle is measured in an axial plane.
- **Flank angle:** It is the angle between the flank and a line normal to the maxis passing through the apex of the thread.
- **Height of thread:** It is the distance measured radially between the major and minor diameters respectively.
- **Depth of thread:** It is the distance from the tip of thread to the root of the thread measured perpendicular to the longitudinal axis.
- **Form of thread:** This is the shape of the contour of one complete thread as seen in axial section.
- **External thread:** A thread formed on the outside of a work piece is called external thread.
- **Internal thread:** A thread formed on the inside of a work piece is called internal thread.
- **Axis of the thread:** An imaginary line running longitudinally through the center of the screw is called axis of the thread.
- **Angle of the thread:** It is the angle between the flanks or slope of the thread measured in an axial plane.

Thread Form

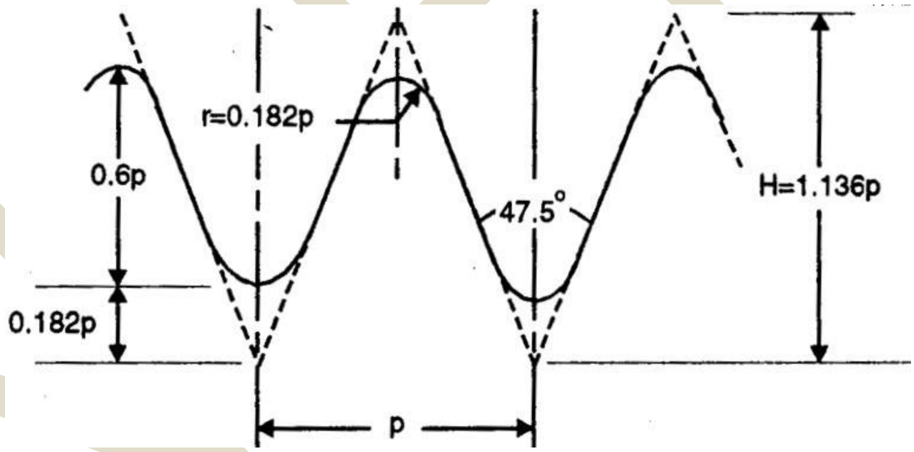
The form of the thread groove is a distinctive feature by means of which screw threads may be grouped into two types.

1. V threads are used for fastening purposes. Typical forms are B.S.W, B.A, unified, metric etc.
2. Transmission threads, used to cause displacements in a mechanism. The common examples may be lead screw of lathe; the typical forms are square and acme type of threads.

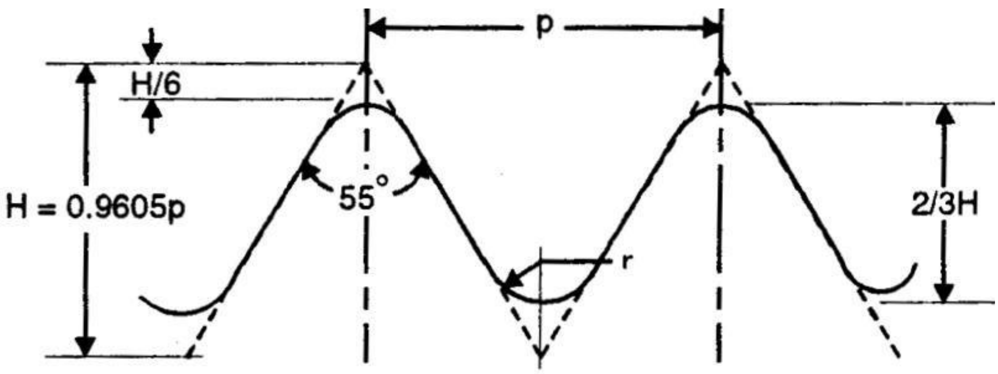
- It has an included angle of 55° between the flanks and equal radii at crest and root. These are intended for use as standard nuts, bolts and pipe work. It is defined in a plane which contains the axis of the thread.
- The B.A. thread was introduced by British Association. In metric threads, there is angle and clearance at crest and root so that contact between mating threads takes place only on the flanks.
- The acme thread has an included angle of 29° and is used for lead 84 screws and feeds on machine tools. It has flat crests and roots. A screw and nut may be located on major or minor diameter.



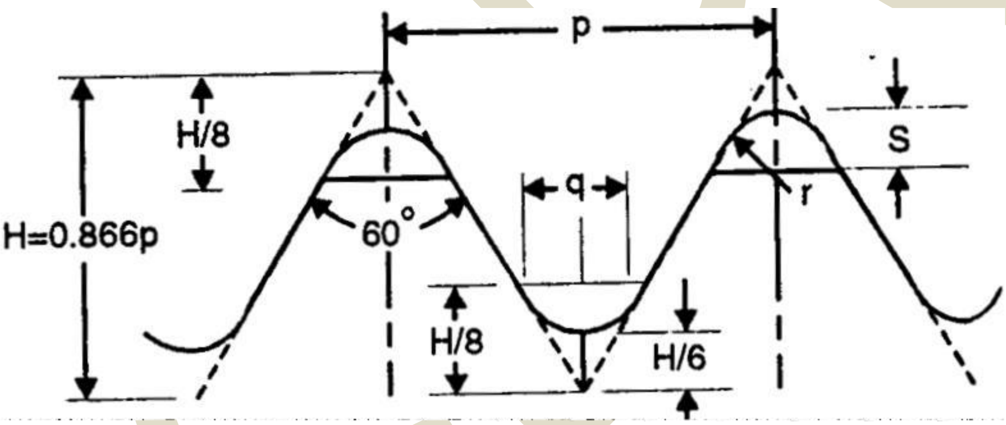
(a) V thread



(b) B.A. Thread



(c) Whithworth thread



(d) Unified Thread

Figure 8.2 Types of Thread

Screw thread measuring instruments

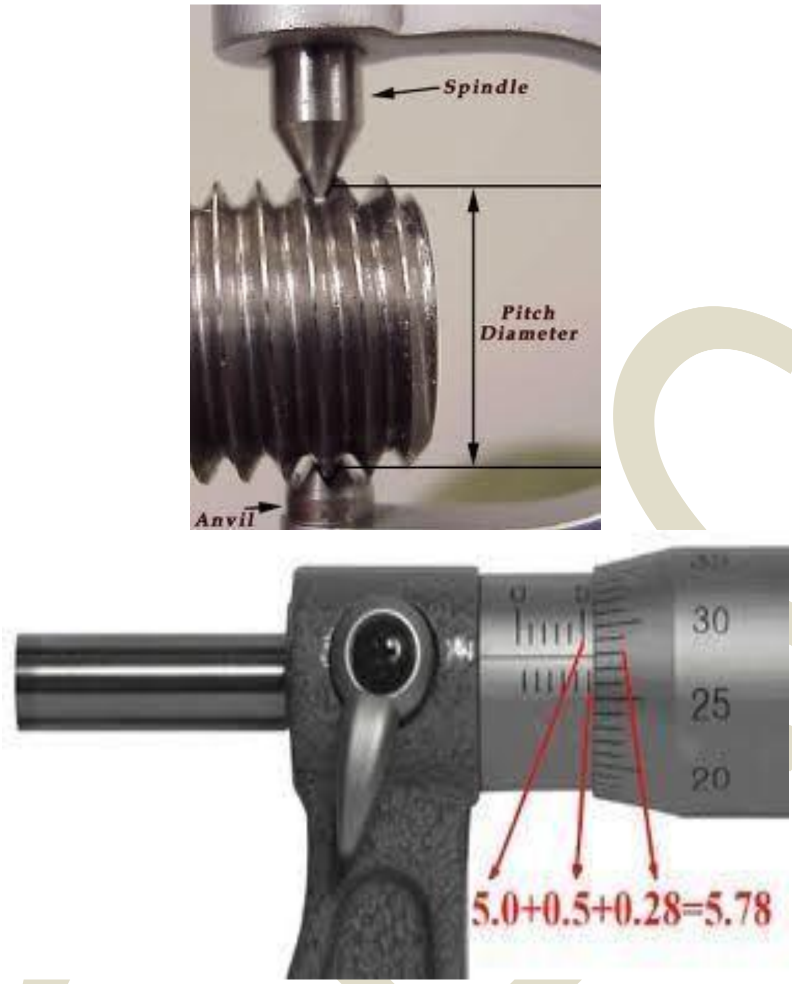
There are various instruments to measure the dimensions of thread as per below.

- Screw thread micrometer
- Screw pitch gauge
- Three wire method

3. Screw thread micrometer

- It is used for accurate measurement of pitch diameter of screw threads. The micrometer has a pointed spindle and a double V-anvil, both correctly shaped to contact the screw thread of the work being gauged.
- It directly reads in terms of pitch diameter as the zero reading of the micrometer corresponds to the closed position of anvil and spindle when both are in perfect match

with eachother.



Fiure.8.3 Use of Screw Thread Micrometer

- The angle of the V-anvil and the conical point at the end of the spindle corresponds to the included angle of the profile of the thread.
- The V-anvil is allowed to swivel in the micrometer frame so that it can accommodate itself to the helix angle of the thread. The extreme point of cone is rounded so that it will not bear on the root diameter at the bottom of the thread, and similarly clearance is provided at the bottom of the groove in the V -anvil so that it will not bear on the thread crest.
- The spindle point of such a micrometer can be applied to the thread of any pitch provided the form or included angle is always the same.
- The V-anvil is however limited in its capacity; a number of different blocks being required to cover a full range.

Figure.8.4 Screw Thread Micrometer with Anvils

4. Screw Pitch gauge

- According to IS: 4211-1967, the gauges which help to identify the thread pitch of IS Metric screw threads in the pitch range 0.25 to 6.0 mm are made in the form of24 blades (made of suitable tool steel sheet and 0.5 mm thick), 23 for checking the pitches and one having an ISO profile of 60°.
- All these blades are assembled in a protective sheath. All the blades are suitably hardened and tempered to a hardness of 540 HV and properly finished and sharp edges removed. These are suitably hinged in the sheath with screw and nut arrangement, and can be easily removed and rotated about.

Figure 8.5 Screw Pitch Gauge

5. **Three wire method**

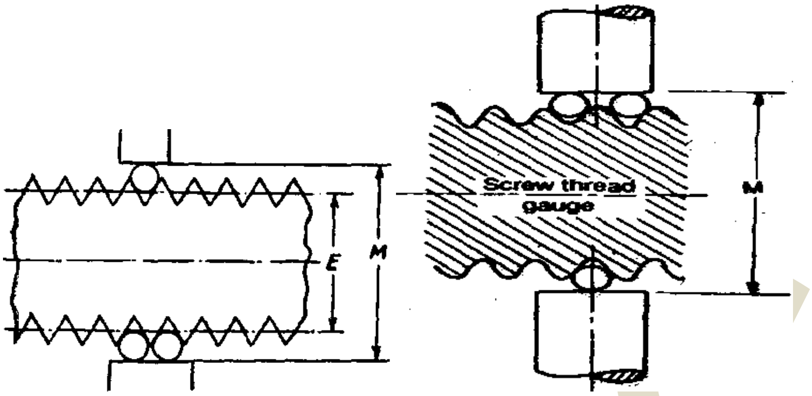


Figure 8.6 Three Wire Method of Measuring Effective Diameter

- In this method three Wires of equal ad precise diameter are placed in the thread groves at opposite sides of the screw and measuring the distance M over the outer surfaces of the wires with the micrometer
- Out of the three wires in the set two wires are placed on one side and the third on the other side as shown in Fig.8.6.
- The wires are either held in hand or secured in the grooves by applying grease in the threads or by sticking the ends of the wires Vaseline. These wires may also be hung through threads on a stand. Any such method, however, must ensure freedom to the wires to adjust themselves under the micrometer pressure.

This method ensures the alignment of micrometer anvil faces parallel to the thread axis. Therefore, this method of measuring effective diameter is more accurate. The effective diameter can now be calculated with following known elements:

8.1. The reading of the micrometer (this is the distance across the top of wires say AI) then,

M = E + Q, where E = effective diameter and Q is the constant depending upon the wire diameter and flank angle.

8.2. The wire diameter

8.3. the thread angle θ, and

8.4. $Q = W(1 + \csc\theta) - {}^{p}/_{2} \cot\theta$, where W = diameter of the wire and p = pitch.

Thus the effective diameter $E = M - Q = M - \{W \cdot (1 + \csc\theta) - {}^{p}/_{2} \cdot \cot\theta\}$

We can measure the value of M practically and then compare with the theoretical values .with the help of formulae derived above. After finding correct value of M and knowing d, E can be found out. If the theoretical and practical values of M (i.e. measured over wires) differ, then this or is due to one or more of the quantities appearing in the formula.

- Effect of lead angle on measurement by 3-wire method. If the lead angle is large (as with worms; quick traversing lead screw, etc.) then error in measurement is about 0.0125 mm when lead angle is 4.5° for 60° single thread series.
- For lead angles above 4.5° compensation for rake and compression must also be considered.
- There is no recommendation for B.S.W. threads.

Measurement of Various Elements of Thread

- The methods discussed here are from the point of view of measurement of gauges, but they can obviously be applied to precise work, threading tools, taps and hobs etc.
- We will be 'dealing with the measurement of most important six elements, i.e. major, minor and effective· diameters, pitch, angle and form of thread.

(a) Measurement of Minor Diameter (Floating Carriage Micrometer):

- Floating carriage micrometer is used to measure the minor diameter. It is suitable for almost all kinds of threads.
- The V-piece is available in various sizes having suitable radii at the edge. The standardis kept between the micrometer anvils with the help of V- pieces as shown in Figure.The fiducially indicator anvil is used to maintain the same constant pressure at the time of measurement.
- The diameter of standard cylinder is known to us and the reading is taken for the V- pieces in position as r_1. Now without changing the position of fiducially indicator anvil, the standard cylinder is replaced by screw. The reading is now taken for the screw thread in position as r_1. If d is the minor diameter of a screw thread then the value of d can be calculated as,

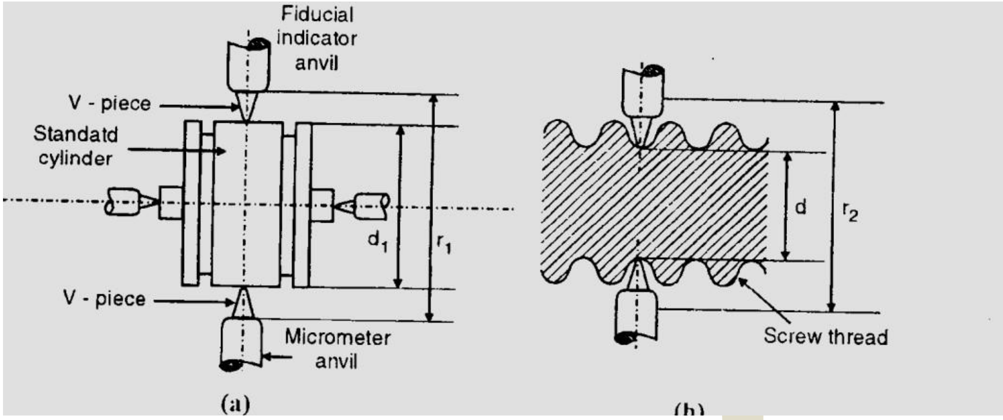


Figure 8.7 Measurement of Minor Diameter

Minor dia. d = (diameter of standard cylinder) ± (difference between the readings) $d = d_1 \pm (r_2 - r_1)$

(b) Measurement of MajorDiameter:

- The major diameter of the screw threads can be checked by the use of micrometer or vernier callipers as in plain diameter measurement. The major diameter is measured by bench micrometer as shown in the figure.
- It uses constant measuring pressure i.e. the measurements are made at the same pressure. Fixed anvil is replaced by fiducially indicator Figure 8.8.
- The work piece is held in hand and the machine can be used as a comparator to avoid the pitch errors of micrometers.
- Instead of slip gauge, a calibrated setting cylinder is used as a setting standard, as it gives similarity of contact at the anvils. The cylinder is held and the readings of micrometer are noted.
- The diameter of setting cylinder isapproximately equal to the major diameter. The cylinder is replaced by threaded work pieces and the readings are noted for the same reading of fiducial indicator.

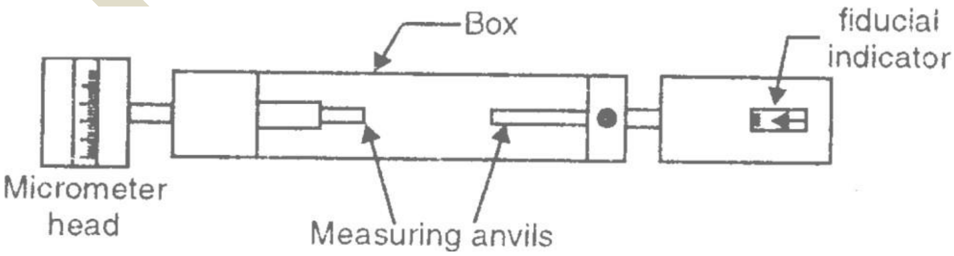


Figure 8.8 Bench Micrometer

If d_1 = diameter of setting cylinder

r_1 = reading of micrometer on setting cylinder r_2

= micrometer reading on the thread

Then major diameter = $d_1 + (r_2 - r_1)$

(c) Effective Diameter:

- It is defined as the diameter of the imaginary co-axial cylinder intersecting the thread in such a manner that the intercept is on the generator of the cylinder.
- It represents the size of flanks and is the most important diameter of the thread. The effective diameter or pitch diameter can be measured by the following methods:
  1. One wire, two wires or three wire method.
  2. Micrometer method.
- There is no difference between one wire, two wire and three wire method. The two wire method is employed.
- Then floating carriage micrometer is available for the measurement purpose. The two or three wire method will yield accurate results
- only when i) The screw thread pitch (P) has no errors. ii) Thread angle is correct.

Measurement of Effective Diameter by One Wire Method:

- This method is used for measuring effective diameter of counter pitch threads and during manufacturing of threads.
- One wire is placed between two threads at one side and on the other side the anvil of the measuring micrometer is placed in contact with the crests as shown in the Figure.
- The drawback of this method is that the micrometer axis may not remain exactly at right angles to the thread axis. The micrometer reading is noted on a standard gauge, whose dimensions may be same as to be obtained by this method.

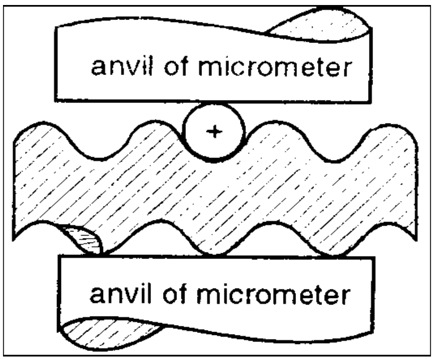


Figure 8.9 One Wire Method

- Actual measurement over wire on one side and threads on the other side should be equal to the size of gauge and plus or minus the difference in two micrometer reading.

- **Measurement of Effective Diameter by Two Wire Method:**

- The wires used are made of hardened steel to sustain the wear and tear. It may be given high degree of accuracy and finish by lapping to suit various pitches.
- The effective diameter of a screw thread may be assured by placing two wires or rods of identical diameter between the flanks of thread.

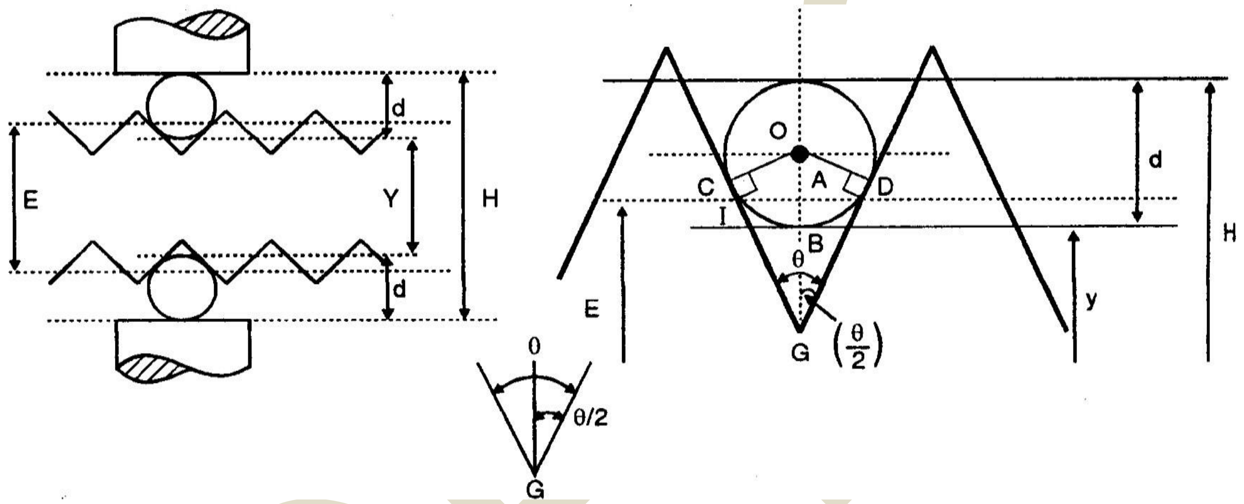


Figure 8.10 Two Wire Method

(d) Minor diameter of internal threads

Minor diameter of internal threads can be measured conveniently by the following methods:

1. Using taper parallels. The taper parallels are pairs of wedges having radiused and parallel outer edges. The diameter across their outer edges can be changed by sliding them over each other as shown in Fig. 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. This method is suitable for smaller diameter threads.

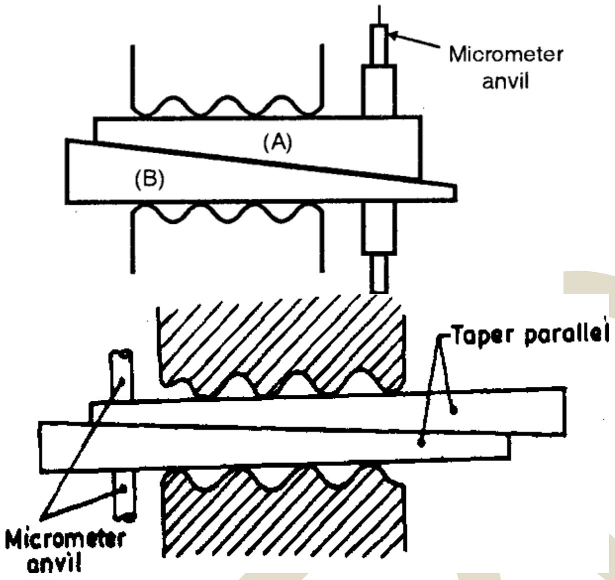


Figure 8.11measurement of Minor Diameter of Internal Using Taper Parallels

2. Using rollers. For threads bigger than 10 mm diameter, precision rollers are inserted inside the thread and proper slip gauge inserted between the rollers as shown in Fig 8.12. so that firm contact is obtained. The minor diameter is then the length of slip gauges plus twice the diameter of rollers

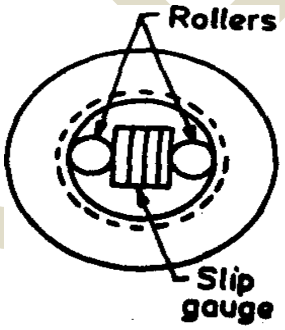


Figure 8.12 Measurement of minor diameter of internal thread using rollers

APPENDIX I
CONTENT BEYOND THE SYLLABUS

APPENDIX I
CONTENT BEYOND THE SYLLABUS

THE ADVACED SENSORS

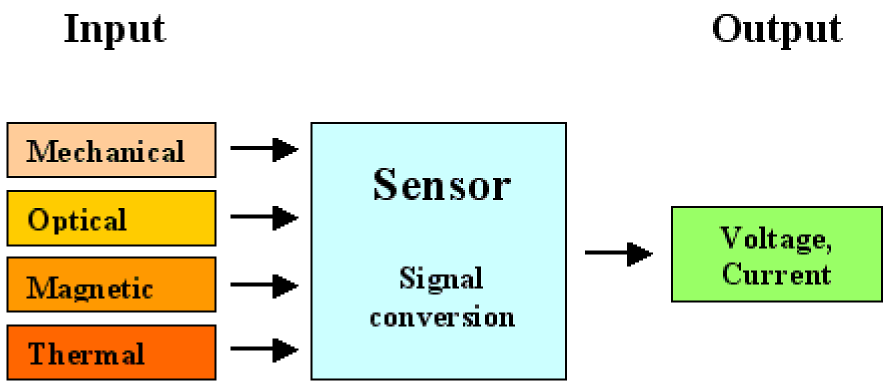
Many significant and exciting innovations and inventions begin made in sensor research and development daily. Micro- and nanotechnology, novel materials, and smaller, smarter, and more effective electronic systems will play an important role in the future of sensors

Sensors are relevant to every aspect of human life and they can improve the world through diagnostics in medical applications; improved performance of energy sources like fuel cells and batteries and solar power; improved health and safety and security for people; sensors for exploring space; and improved environmental monitoring.

Presently, conventional sensors such as potentiometers and force-sensing resistors are widely used but technological progress and the use of micromachining is allowing the manufacturers to increase number of sensors but also to achieve significantly higher speeds and sensitivity.

Sensor Internals

A sensor converts physical parameters into a usable electrical signal. The conventional integrated sensor has three main parts, including the sensing component (capacitor, photodiode, transistor, resistors, etc.) signal conditioning and processing (linearization, amplification, filtering and compensation) and lastly the sensor interface (wires, sockets and plugs to communicate the results with other interconnected electronic components).



By means of low-cost analog-to-digital converters, signal processing is increasingly shifted from the higher system level to the sensor level.

New Sensing Paradigms

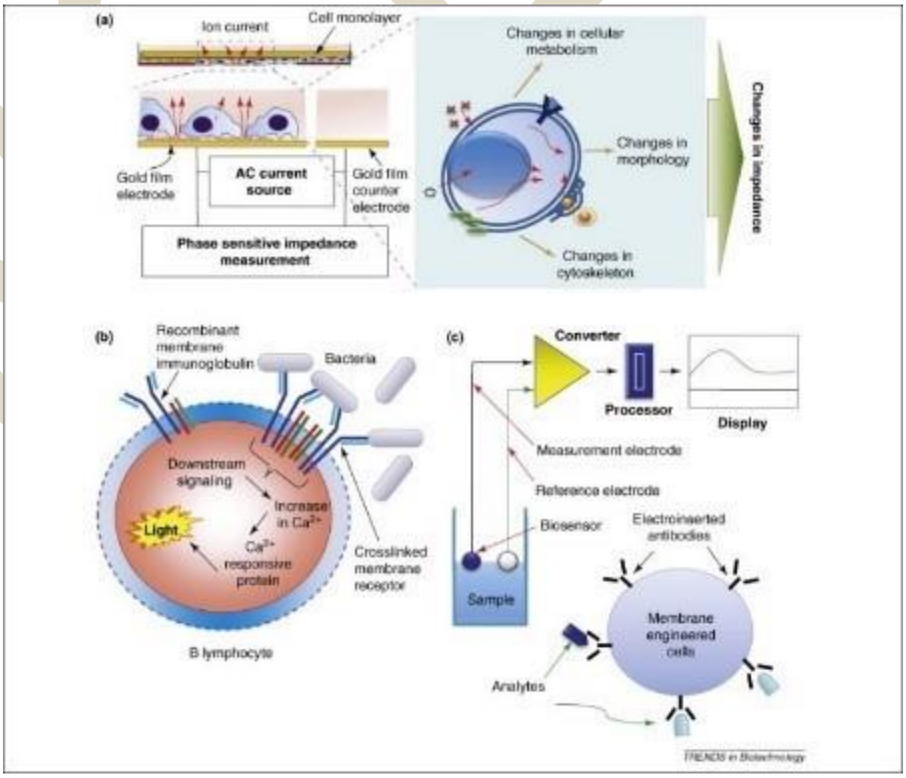
Parameters like temperature, humidity, Pressure, etc. have found widespread usage in various applications. With technological progress and requirements arising in various fields, new sensing parameters are being explored for advanced sensors.

The 'unobservable' sensing

It breaks new ground in sensing biohazards, smells, material stresses, pathogens, level of corrosion and chemicals in material.

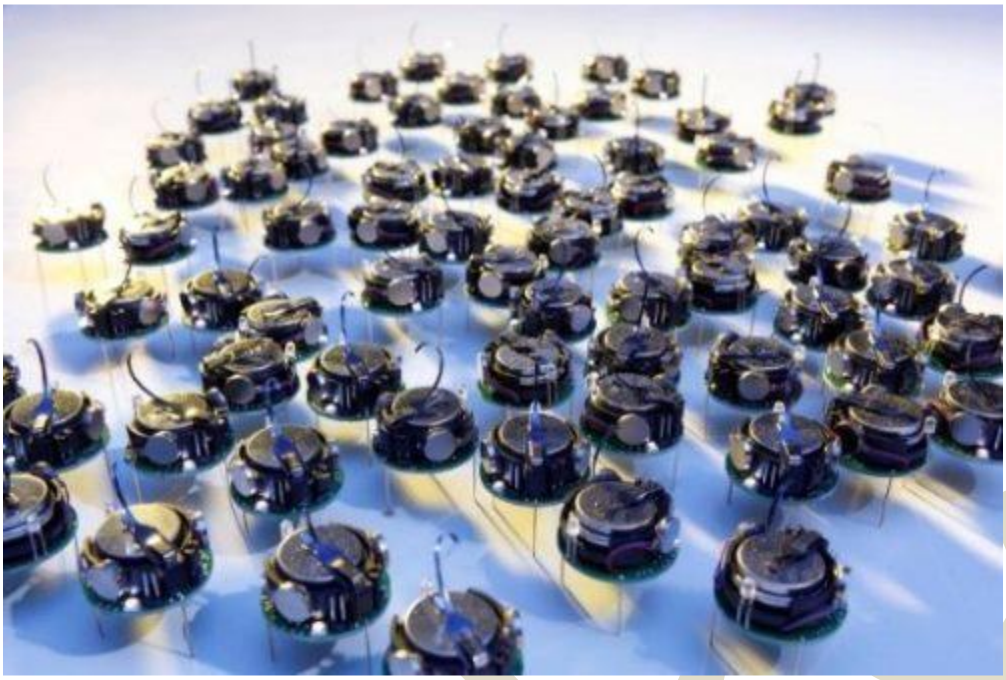
Live cell-based sensing

an amalgamation of sensor technology and living cells, allow scientist to understand the biological effect of medicines, environment and biohazards.



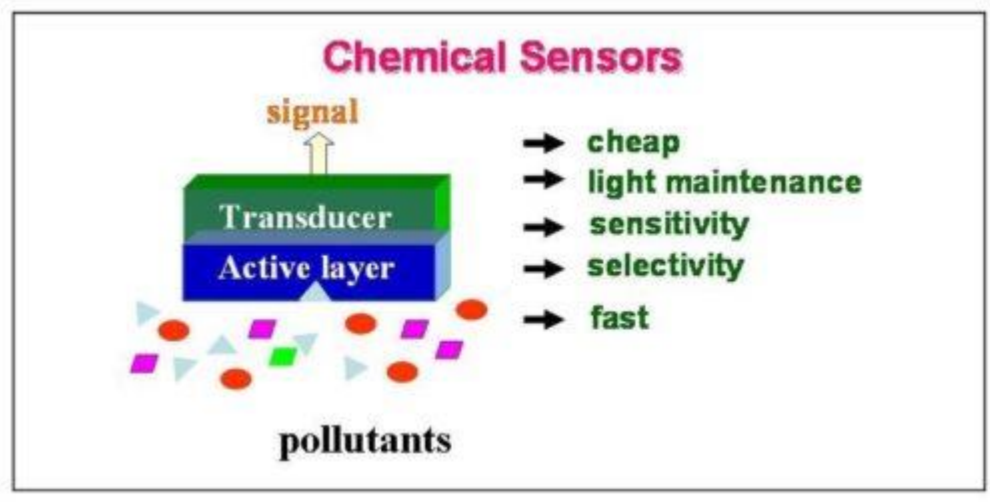
Sensor swarms

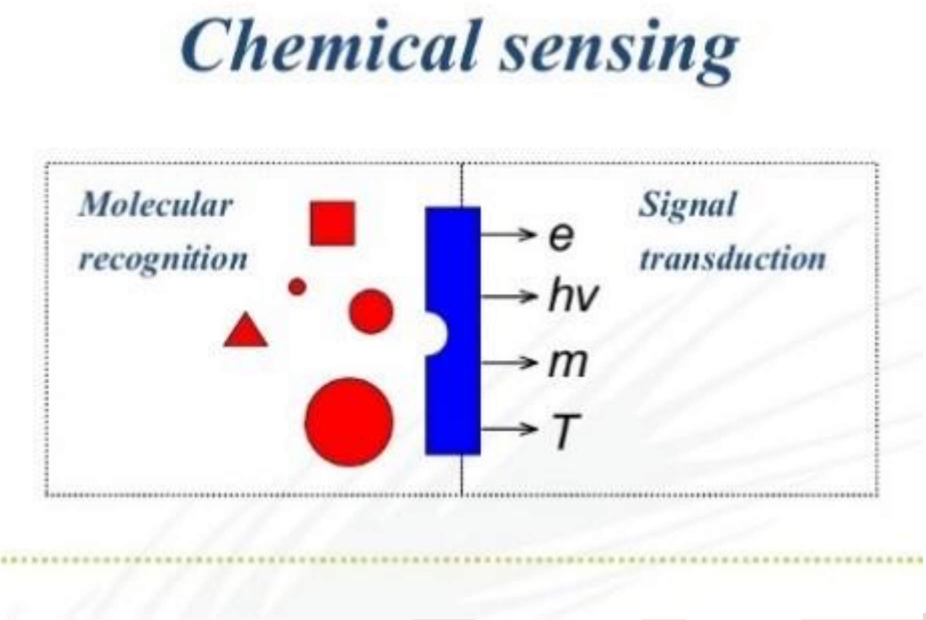
Sensor Swarms coordinate their activities, deciding what to measure and where through a self-learning system directing their movements and data collection.



Chemical Reactant Sensors

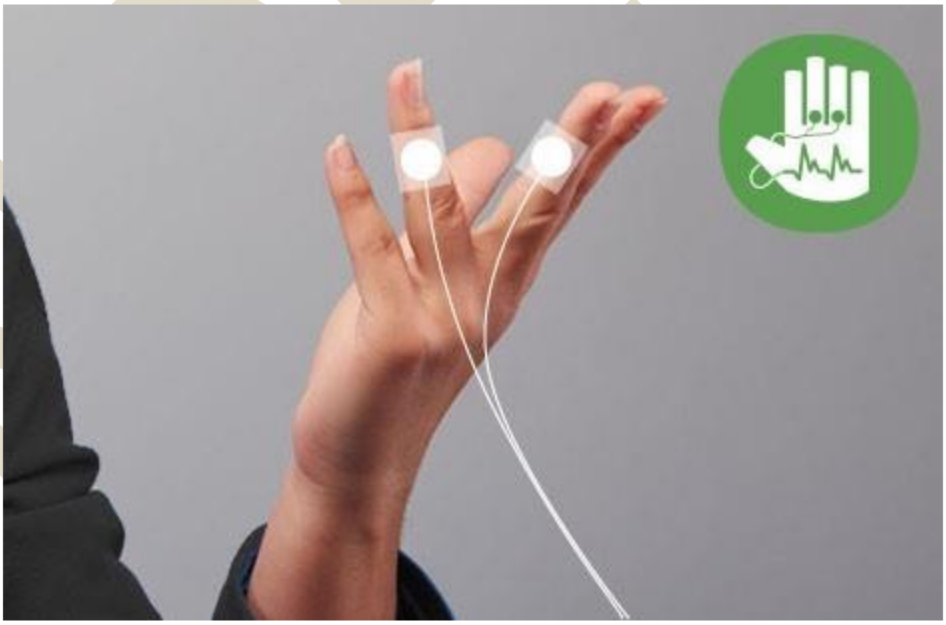
Chemical reactant sensors designed as electronic noses that reacts with specific compounds in the air to detect biohazards, gas leaks, rusts and even alcohol on the breath.





Galvanic Skin Response Sensors

Galvanic skin response sensors might appear to be straight out of science fiction. This remarkable technology senses various features of the skin, ranging from temperature to moisture, and has managed to effectively correlate these observations with emotion and mood. Besides the obvious applications to virtual reality (a mood or reaction-dependant plot twist in a movie or video game!), this creates the potential to monitor and study mental health and patient recovery in unprecedented detail. Similarly, it allows for the potential to tailor air-conditioning to individual preferences.

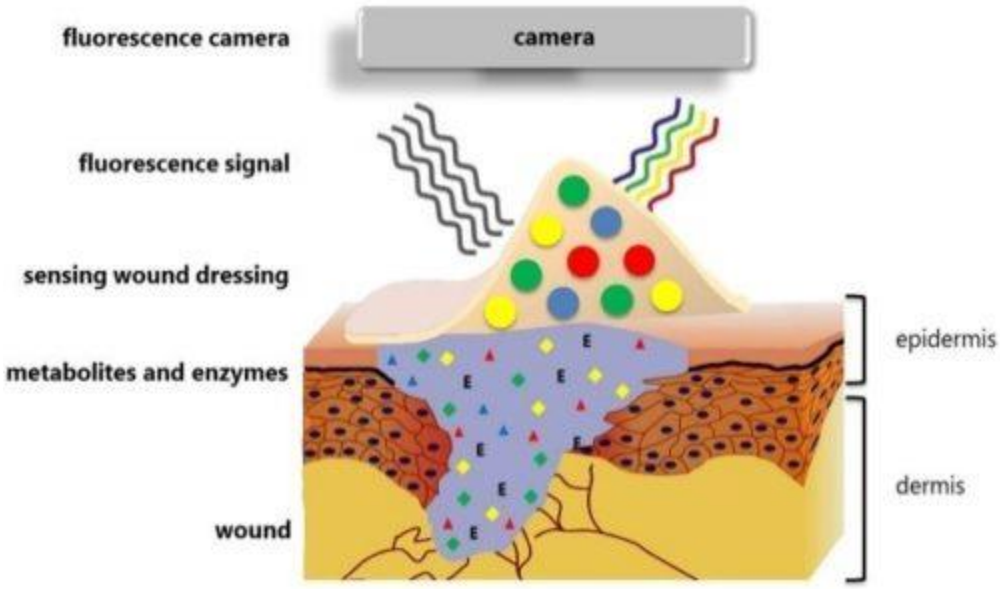


EEG/EOG Sensors

Electroencephalograms and electrooculograms (EEGs and EOGs) are a fascinating subset of sensing technology that tracks the electric fields produced by fluctuations in brain and eye activity respectively. EEG data can be accurately used to learn and replicate hand gestures from human test subjects. EOGs offer a unique advantage – they track eye movements and can be used in virtual reality, for attention measurement and psychological research and a host of other decisions. The EEG/ EOG Combi Electrode can be used for the simplified recording of the Sleep Profile through the single EEG and two EOG signals.

Sensors in Wound Healing

For certain kinds of post-operative care, it's extremely important to keep a patient well-hydrated in a humid environment. Moisture sensing in wound is crucial as a moist wound heals faster. Above figure show The design and function of the smart wound dressing. The biosensors in the dressing can detect key parameters for wound healing, like neutrophil elastase concentration, by changes in fluorescent signal.



Personal Radar

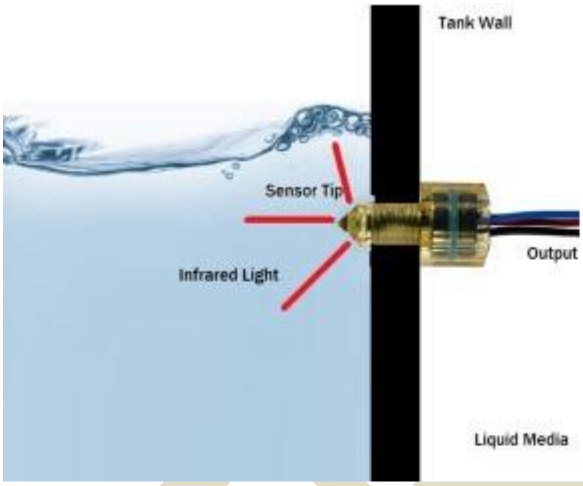
Humans see in the optical light spectrum, and it's natural to assume that our devices – if they could see – would use the optical spectrum, too. But processing visible light takes a lot of signal power to separate individual objects and ranges. A radar device, on the other hand, uses millimeter-wave radio and takes only milliwatts of power. Personal Radar can help navigate mobile robots through the real world.

Radio Imaging

Another trend we saw was the expansion of ultra-wide band radio, WiFi and Bluetooth, into 3D radio imaging. It's a way to locate people and objects inside a building that can give context to what is going on in an area of interest for relatively low cost. Radio imaging can tell not only where someone is, but what they're doing – and it can see through walls.

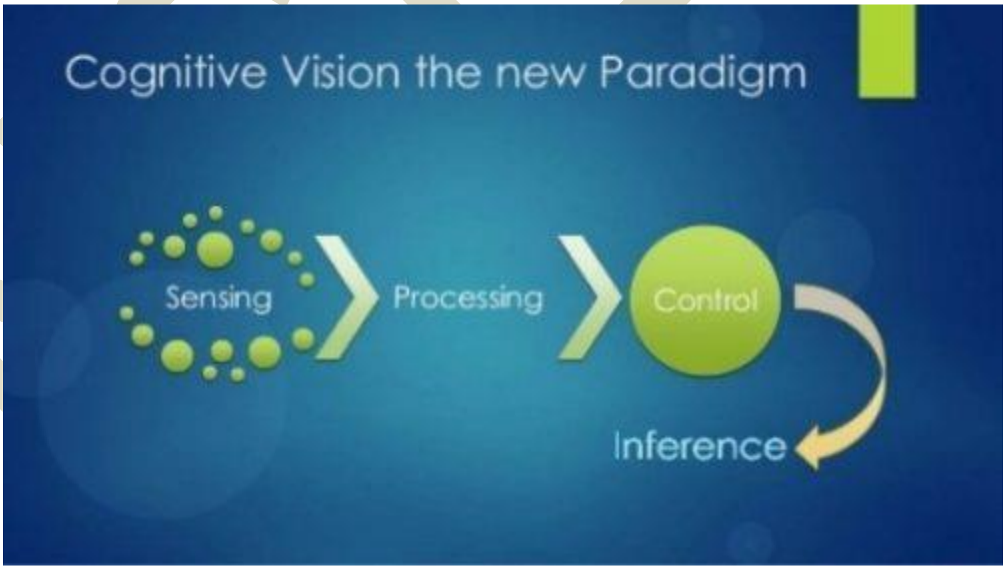
Optical Sensing

An optical sensor converts light rays into an electronic signal. The purpose of an optical sensor is to measure a physical quantity of light and, depending on the type of sensor, then translates it into a form that is readable by an integrated measuring device. Optical Sensors are used for contact-less detection, counting or positioning of parts. Optical sensors can be either internal or external. External sensors gather and transmit a required quantity of light, while internal sensors are most often used to measure the bends and other small changes in direction. The measurands possible by different optical sensors are Temperature, Velocity Liquid level, Pressure, Displacement (position), Vibrations, Chemical species, Force radiation, pH- value, Strain, Acoustic field and Electric field.



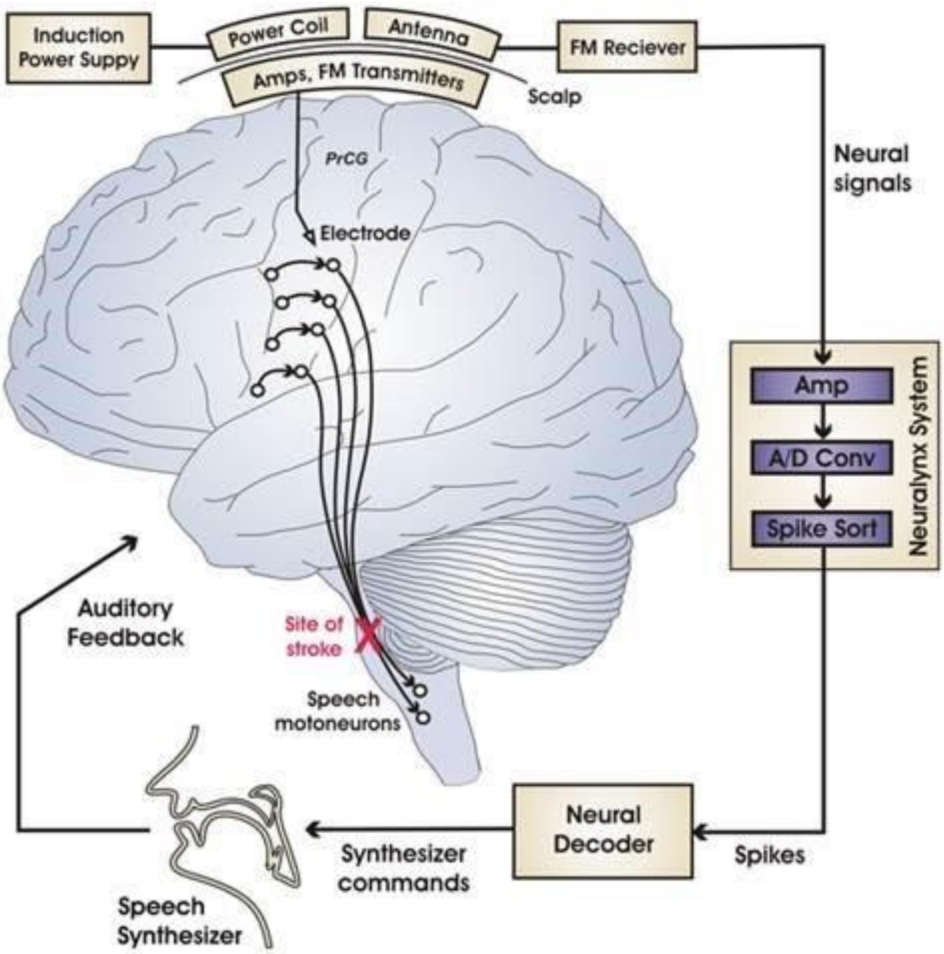
Cognitive vision

Cognitive vision include methods for acquiring, processing, analyzing and understanding digital images, and extraction of high-dimensional data from the real world in order to produce numerical or symbolic information, e.g., in the forms of decisions. Understanding in this context means the transformation of visual images (the input of the retina) into descriptions of the world that can interface with other thought processes and elicit appropriate action.



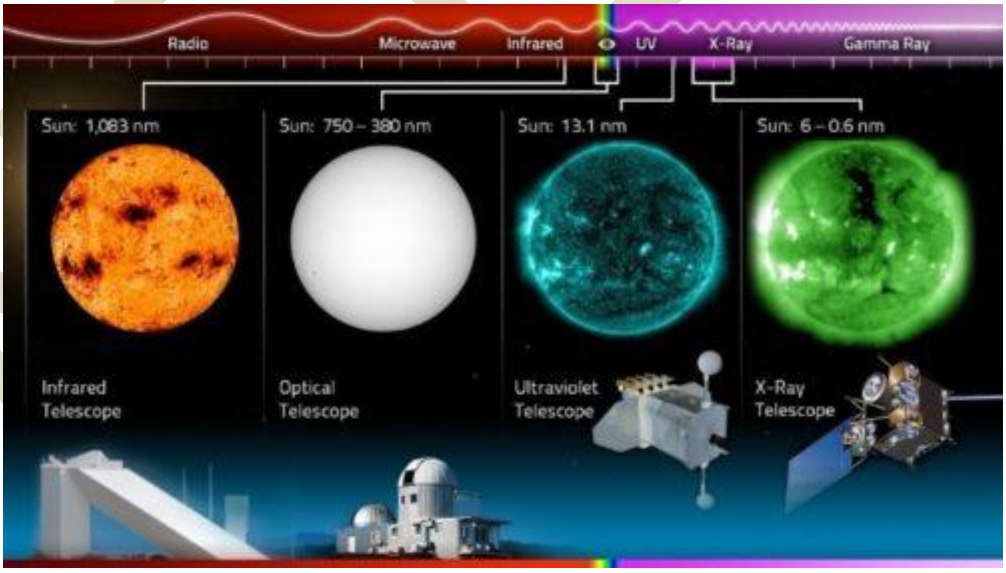
Thoughts into Speech Sensors

The breakthrough, which is up to 90 percent accurate, will be a boon for paralyzed patients who cannot speak and could help read anyone's thoughts ultimately.



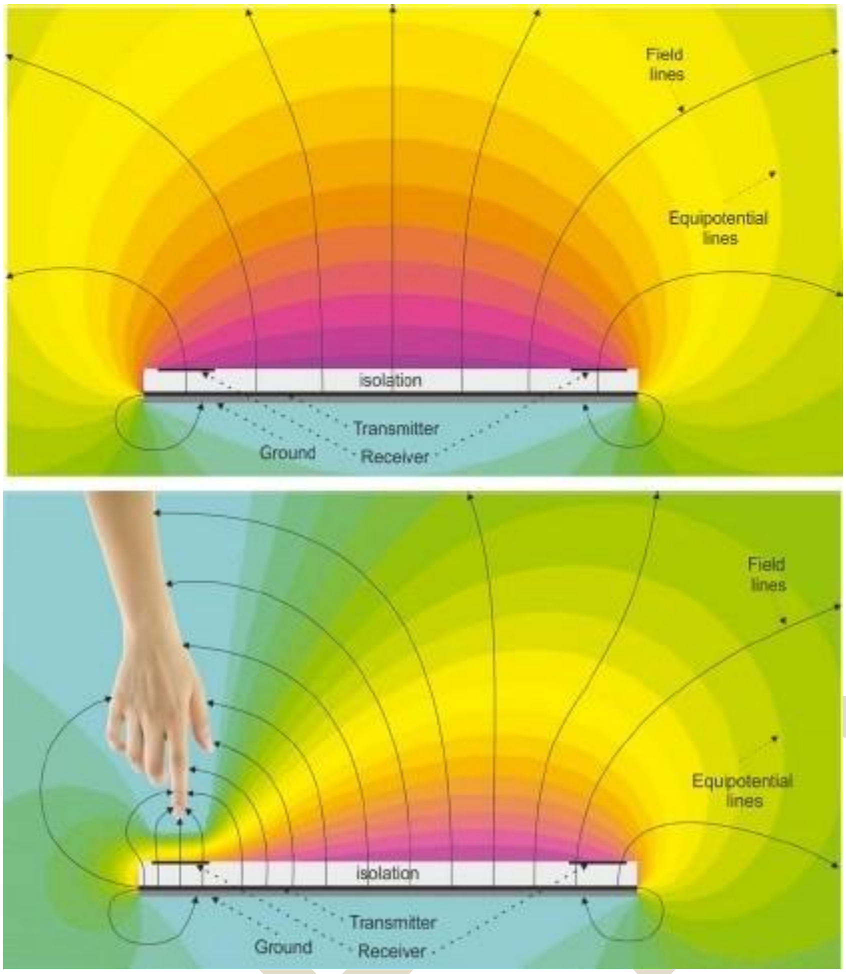
Multi wavelength image sensor

Space exploration is one of the potential application for multi wavelength image sensors.



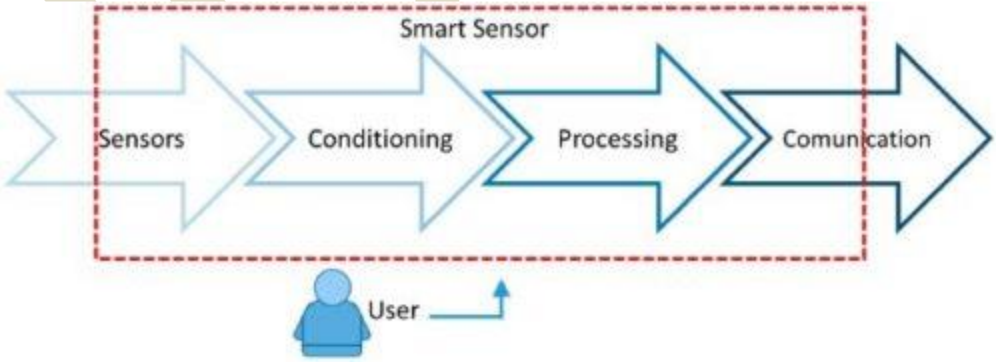
Electric field or E-field sensing

uses electrodes and the electric field between them. This sensing can be used for smarter airbag, in which the bag will not deploy prematurely, by taking into consideration not only the passenger's head position, but also the passenger's size and weight. Microchip's GestIC(r) technology is a patented 3D sensor technology that utilizes an electric field (E-field) for advanced proximity sensing.



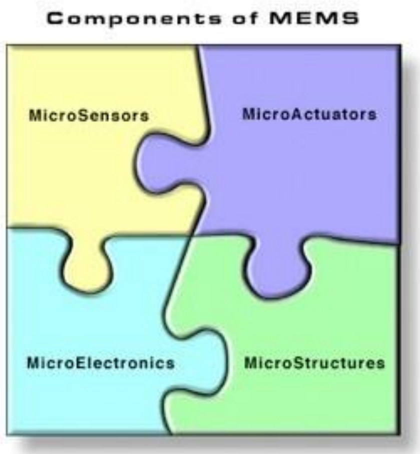
Smart sensors

Smart sensors differ from traditional integrated sensors since they have the added benefit of processing capabilities, due to the onboard microprocessor. Hence, the sensing signal passes through microprocessor where processing takes place, and a more informative output is given to the end user. The main principle of smart sensors is that combining sensor technology with silicon microprocessors not only offers customized outputs and interpretive power but also considerably improves sensor system capabilities and performance.



One major effect of smart sensor technology is that it ensures improved integrity and reliability of results. Intelligent features like self-calibration, compensated measurements and self-healing can be added at the main sensor level. The smart sensor can evaluate its status or health and evaluate even the legitimacy of processed data. Overall, the sensor and microprocessor combination allows for the creation of a highly adaptable system.

Micromachining and microelectromechanical systems (MEMS) technology



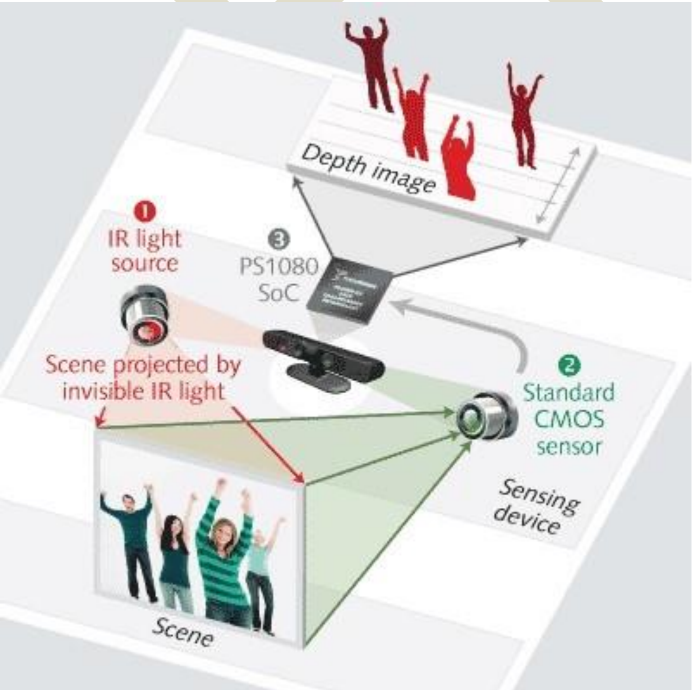
Micro-Electro-Mechanical Systems (MEMS), is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of microfabrication. The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimeters. MEMS technology in microsensors is allowing the manufacture of an increasing number of sensors on a microscopic scale. In most cases, microsensors can reach significantly higher speeds and sensitivity compared with macroscopic sensors.

Integrated smart sensors

Newer sensor technology has now integrated vital components of a smart sensor on a chip.

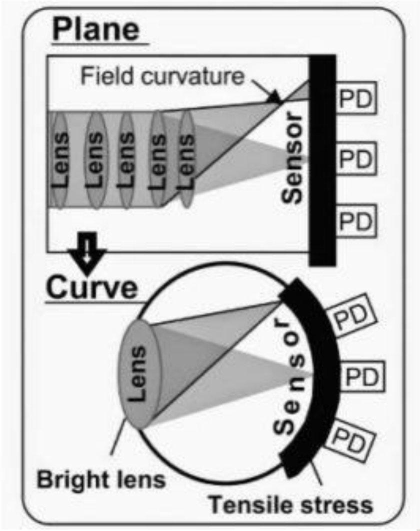
Gesture Recognition and 3D Sensor Technology

The TrueDepth camera is used for facial recognition functions.



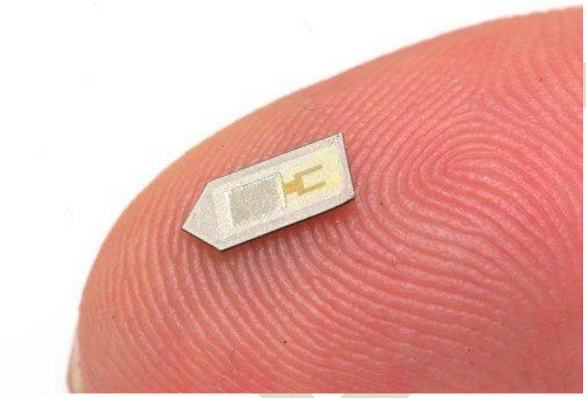
Curved sensor

It could dramatically improve image quality captured with digital cameras.



Biodegradable sensors

Tiny sensors made out of thin sheets of silicon are able to monitor temperature and pressure inside the skull, then melt away after they've done their job, according to researchers led by John Rogers at the University of Illinois at Urbana-Champaign and Wilson Ray at the Washington University School of Medicine in St. Louis.

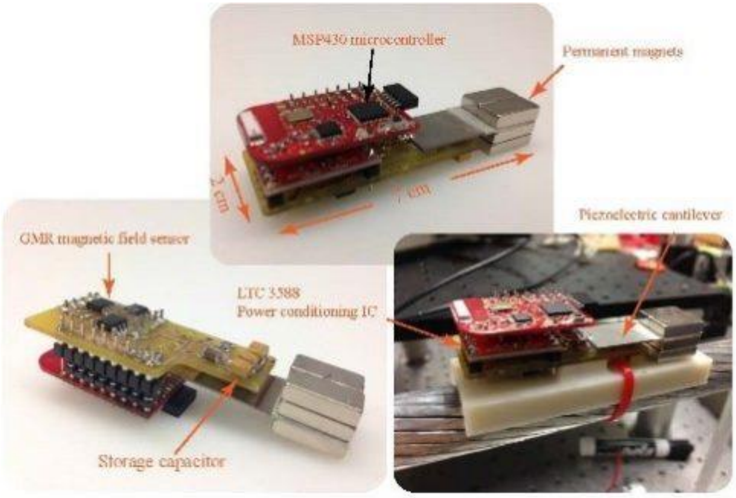


Self-healing sensors

It repairs themselves in the event of a disaster or other structural disruptions.

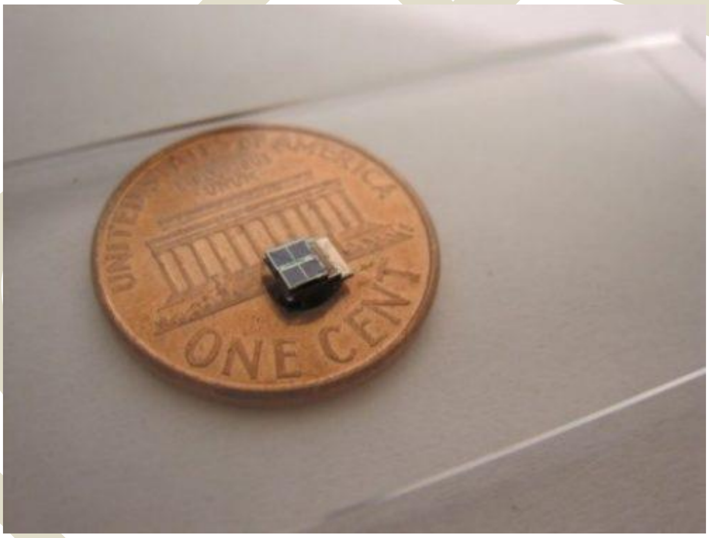
Self-powered sensors

There are several energy sources present in our environment, of which the most common ones may include: vibration, thermal gradient, radiation and power (solar and EM fields). The power output of an energy harvester depends on two factors: the power density of ambient energy sources and the effectiveness of conversion mechanisms. Body sensor networks are powered using the heat difference between the patient's body and surrounding air find applications in medical care. Above project show, self-powered wireless sensor node for the monitoring of overhead power lines. The node is powered by an electromechanical AC energy harvester.



Smart dust

Smart dust emerged on the scene primarily due to military research. The militaries are using surveillance devices such as UAVs (Unmanned Aerial Vehicles) and satellites to understand what their 'enemies' are doing. Since it is imperative to keep the surveillance devices from being detected by the enemy, collection of real time data has limits. Thus, Smart dust emerged as a technology that could overcome these limits. Microscopic sensors powered by vibrations, monitor situations ranging from battlefield activities, structural strength of buildings and clogged arteries.

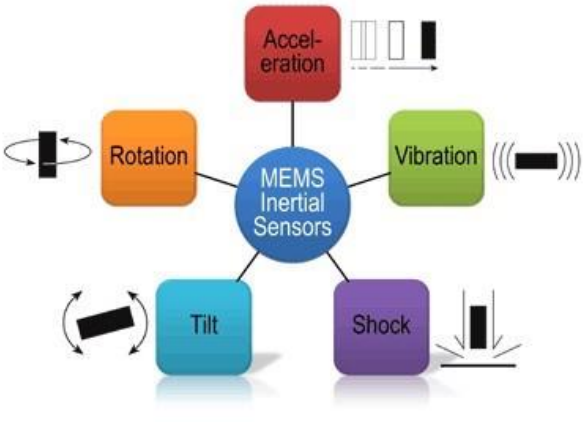


Sensor Fusion

It is a process by which data from many different sensors are "fused" to compute something more than could be determined by any one sensor alone. This allows for an improvement in application or system performance. "It 's all about bringing the relevant data together from multiple sensors to provide a bigger picture of what's going on in a system.

Inertial sensing

inertial sensing modular clusters to manage the vast number of sensing functions that will be required for vehicle dynamics, navigation, safety, and steer-by-wire applications.



Advancements in Sensor Technology

Seed technology

Seed Technology intelligent systems that are self-monitoring, self-correcting and repairing, and self-modifying or morphing not unlike sentient beings. The ability for a system to see (photonic technology), feel (physical measurements), smell (electronic noses), hear (ultrasonic), think/communicate (smart electronics and wireless), and move (sensors integrated with actuators), is progressing rapidly and suggests an exciting future for sensors.

Ubiquitous sensor networks(USNs)

USNs incorporate the integration of multiple kinds of sensors into one large information processing pipeline – this could include camera data, motions sensors, vibration data, sound and so on. USNs have tremendous applications in security and surveillance – with efficient integration, they approach the efficiency of a human guard, while limiting the cost, and widening the area under surveillance. Like many technologies developed for defense, this has also leaked out to the entertainment industry – virtual reality is having a ball with the scope that USNs offer. VR now has the potential to react not just to your hand movement – but to your body temperature and facial expression that distinguish a frantic wave for help from a friendly one!

Biometric

The future of biometric technology via smart sensors lies in the integration of facial recognition and voice recognition. Future biometrics will be more foolproof and will be able to withstand intruder attacks as the sensors will be more accurate.

Advance Sensor Applications

Micro and Nano-sensor implants in patients track the healing process for internal injuries, enable health care professionals to take remedial action based on continual data from the system.

Audio-Beam Forming

Originally developed for military applications, audio-beam forming uses an array of microphones to gather 3D orientation information about the source of a sound. The military found it useful for locating hidden snipers and other dangers; car designers are finding it similarly useful for audio commands, and speakerphone noise reduction

Diagnostic Imaging

Imagine swallowing one disposable smart pill rather than having an intrusive colonoscopy procedure. This simple, non-intrusive test offers the benefit of remotely visualizing the colon and gastrointestinal tract to identify polyps and also detect colorectal cancer. Researchers and scientists has started developing advanced nano-sensors that can travel in a patient's blood and transmit signals to a smartphone. The sensors will be able to detect impending heart attacks, or infection and notify the user. The other possibility of ingestible sensors is providing truly personalized medicine based on the genetic data of a patient. That can go a long way in the early diagnosis and management of chronic diseases like cancer.

Smartphones

Smartphones will have even more sensors. These sensors will likely be for recognizing which activity the user is doing. For instance, the barometer and accelerometer allow the phone to detect when the user is walking and also when climbing stairs and in which direction. Some researchers have even studied air pollution using special sensors in prototype smartphone.

Home sensors

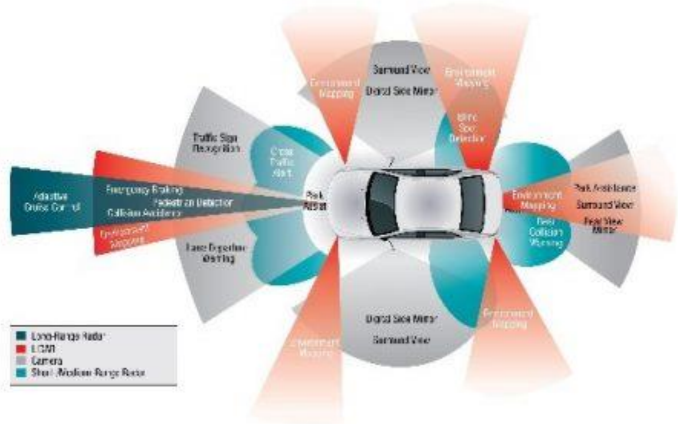
Future Sensors in smart homes will provide additional healthcare feature to help in monitoring vulnerable people. Imagine a smart home that has round buttons placed at strategic points to help assist people suffering from memory loss to do a series of tasks during the day. Care providers would simply get a notification via text or email when any part of the prescribed routine is not complete.

Smart traffic systems

Future Sensor technology could be used to save people's lives. For instance, smart traffic systems with the capability of disabling a vehicle's inbuilt control system when on the verge of a head-on-collision or fatal crash can easily be the panacea of the present day road carnages claiming millions every year.

Autonomous vehicles

Autonomous vehicles are the future of smart sensors in transportation. As such, in future there going to be more saved lives with fewer road accidents, more reclaimed land since autonomous cars do not need more driving space, more saved energy and money, and higher productivity.



Stealth technology

Stealth Technolgy Advances in the Sensor technology will make concealment of movements and positions from their enemies difficult. Hence in effect, stealth technology will get even harder to achieve and will be significantly more expensive to acquire. In effect, the future battle space will be one that is open and visible to all.

Advanced uniforms

Soldiers should expect more advanced uniforms fitted with sophisticated sensors. These uniforms will be able to monitor the vital signs of the user and recommend swift, appropriate actions. The uniform would be woven with fiber optic sensors to offer a complete sensing structure of the whole body. Thus, team leaders and generals will now track their troops after deployment easily.