People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University Hama Lakhdar University in El Oued
faculty of technology
Department of Mechanical Engineering

Course materials

Matter

Measurement and Instrumentation

For 3rd year students Energy

Sectors: Mechanical Engineering

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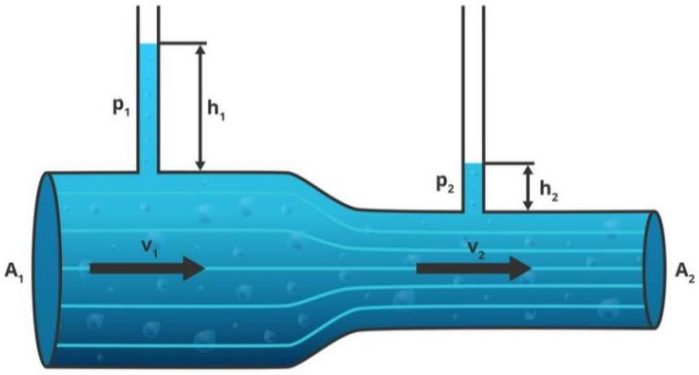

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Préface

This pedagogical booklet aims to provide students with essential tools and knowledge for mastering various measurement techniques essential in engineering and scientific applications. It has been meticulously structured to offer a clear and practical understanding of measurement instruments, error analysis.

Tailored specifically for third-year mechanical engineering students specializing in energetic, this booklet covers a wide range of topics, including mechanical, pneumatic, and optical measurement instruments, as well as advanced systems for temperature, flow, velocity, and pressure measurements. The content is organized into three comprehensive chapters, each allocated five weeks of study, ensuring a balanced and thorough learning approach.

Chapters Overview:

1. **Measurements of Thicknesses and Lengths** – Explores various instruments and methods, emphasizing error analysis.
2. **Temperature Measurements** – Covers thermal sensors, calibration, error sources, and automatic data acquisition techniques.
3. **Measurements of Flow, Velocity, and Pressure** – Discusses diverse instruments, signal processing, and experiment optimization.

I express my heartfelt gratitude to my colleagues and mentors who provided valuable insights during the preparation of this work. Their guidance has been instrumental in shaping this booklet to meet academic and professional standards.

I encourage students to use this booklet as a foundational guide and a practical reference throughout their academic journey. May it serve as a valuable resource in understanding the principles and applications of measurement systems.

Abdeljalil LAOUINI Eloued, October 2024

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General Introduction

General introduction

Measurements are a vital component in various industrial, engineering, and scientific fields, playing a pivotal role in understanding and analyzing the physical properties of materials and systems. Through measurements, we can control processes, ensure quality, and achieve optimal performance. Fundamental measurement processes include determining material thickness, measuring dimensions, assessing temperatures, gauging flow rates, measuring speed, and determining pressure. Each of these processes relies on specialized techniques and tools that provide accurate and reliable data.

In manufacturing industries, precise measurements are essential to ensure products meet required specifications and standards. In engineering fields, measurements aid in designing and developing effective and safe systems. In scientific research, measurements enable scientists to conduct reliable experiments and accurately analyze results.

Measurements are not just about tools and data; they are the essence of the process that ensures product quality, system efficiency, and process safety. By understanding and utilizing appropriate measurement techniques, we can achieve continuous improvement in performance and ensure the quality of products and services across various fields.

First Chapter

Thickness And Length Measurements

Introduction

The measurement of thicknesses and lengths is a fundamental aspect in many engineering and industrial applications. The accuracy of these measurements depends on the use of specialized tools and precise techniques to ensure optimal results. This section explores the various instruments used for measuring thicknesses and lengths, including mechanical, pneumatic, and optical instruments. Additionally, it addresses the appreciation of errors that may arise during the measurement processes, highlighting the importance of understanding and correcting these errors to achieve higher accuracy in results. This study aims to provide the reader with a comprehensive understanding of the tools and techniques used in measuring thicknesses and lengths, as well as the significance of error evaluation in improving measurement quality across different fields.

I. Some definitions

1. Metrology

It is the science of measurement.

2. Measurement

It is the set of experimental operations aimed at determining the numerical value of a quantity.

3. The measurand

It is the specific physical quantity that is the subject of measurement.

4. Uncertainty

The result of measuring a quantity X cannot be fully defined by a single number. It must be characterized by a pair (x, dx) where dx represents the uncertainty on x due to various errors related to the measurement: $x - dx < X < x + dx$.

5. The absolute error

It is the difference between the true value of the measurand and its measured value. It is expressed in the unit of measurement.

6. The relative error

It is the ratio of the absolute error to the measurement result. It is expressed as a percentage of the measured quantity.

II. Mechanical instruments

In mechanics, it is important to know how to take measurements. The quality of these measurements depends on the precision of the measuring instrument used. In cases of exceptionally precise measurements, it is necessary to have all the required instruments.

1. Dimensional measurements using the Ruler and tape

a) Tape

✓ **Its uses**

It is preferred for measuring long objects such as pipes and is widely used in sheet metal work, metal panels, metal furniture manufacturing, aluminum work, and pipe network installations.

Figure 1: *Tape*

The meter's graduation is according to one of two systems: the International System or the English system. In the International System, the unit of length is the meter, which is divided into centimeters and millimeters, as shown in the diagram. In the English system, the graduation is divided into inches and feet, with one foot equal to 12 inches.

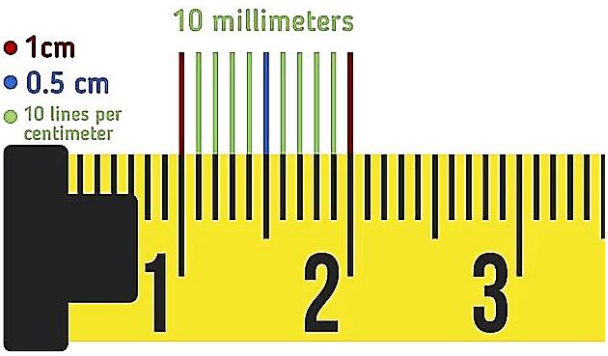


Figure 2:Graduation of tape in centimeters in the International System

✓ **Method of measurement and reading with a tape**

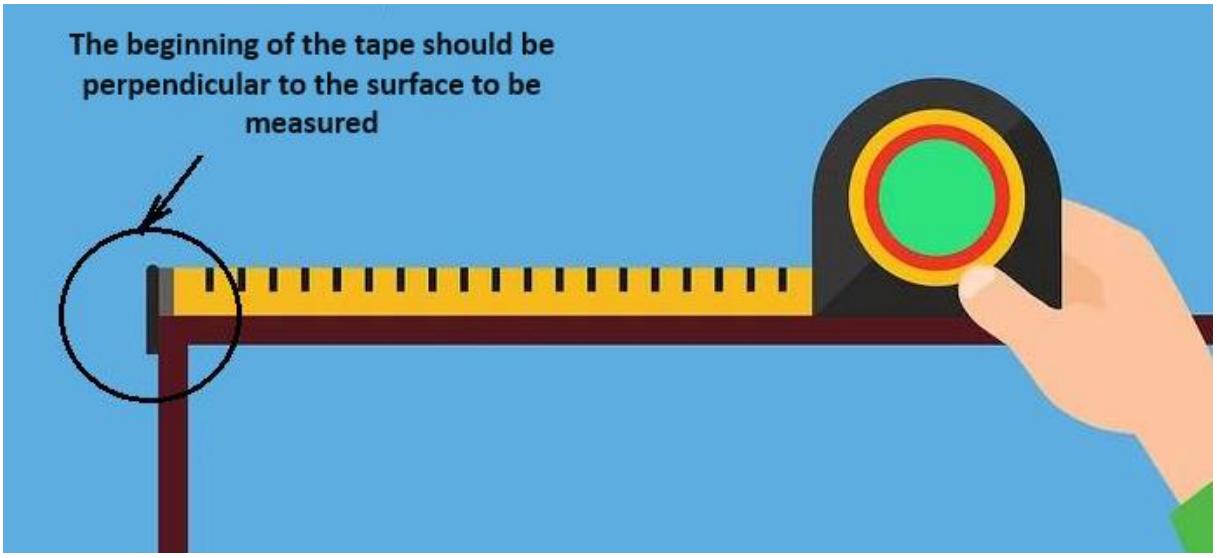


Figure 3: Place the end of the tape on the edge of the object to be measured

❖ Implement the safety and security procedures specific to the laboratory.

❖ Place the first end of the meter on the edge of the workpiece and ensure it is perpendicular to it, as shown in the diagram.

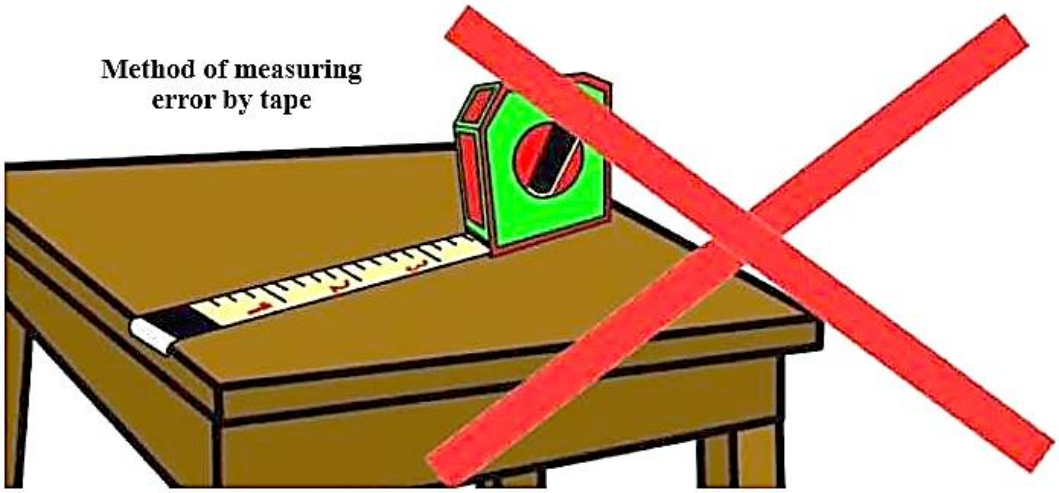


Figure 4: Make sure the tip of the tape is perpendicular to the surface to be measured

- Mark the part to be measured with a marking gauge.
- Read the next higher whole number, then the fractional unit parts.

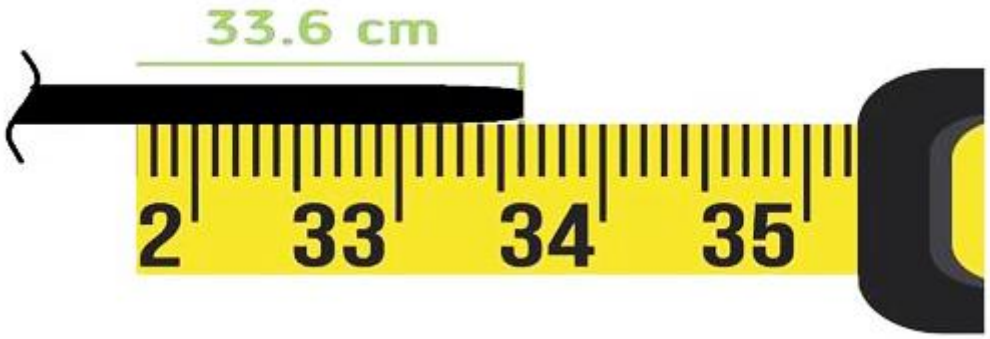


Figure 5: Reading with a tape

b) Rule

A ruler is a geometric instrument, also used for technical drawing and measuring distances. Strictly speaking, a ruler is used to draw straight lines.

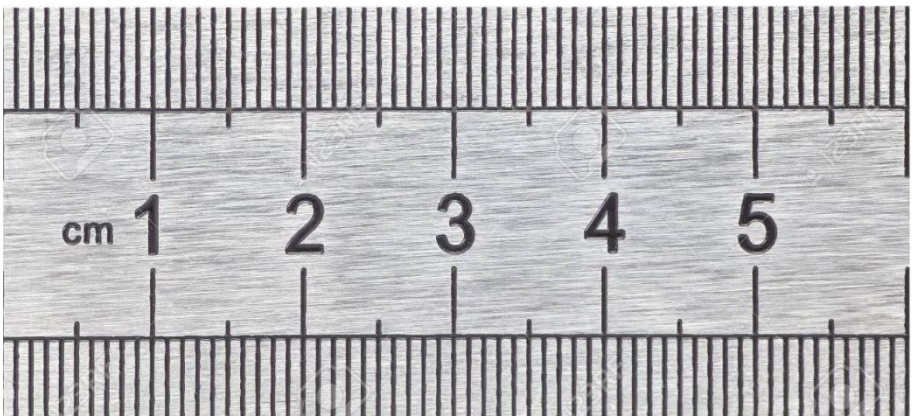


Figure 6:Rule

A ruler is typically made of wood, metal, plexiglass, or flexible composite material. Modern rulers generally include a scale, which allows lengths to be measured by comparison, usually to the nearest millimeter.

2. Dimensional transfer using the (CALIPERS) Divider

There are various types of calipers depending on their intended use. Some are used for measurement, while others are used for marking out, which involves transferring dimensions onto a workpiece or drawing circles. calipers are made from medium-carbon steel and come in several types classified according to the shape of their legs. These include the straight calipers, the forked side calipers, the two-legged side calipers, and the spherical calipers. The legs of the calipers can be fixed with a rivet or adjusted with a spring, as shown in the diagram.

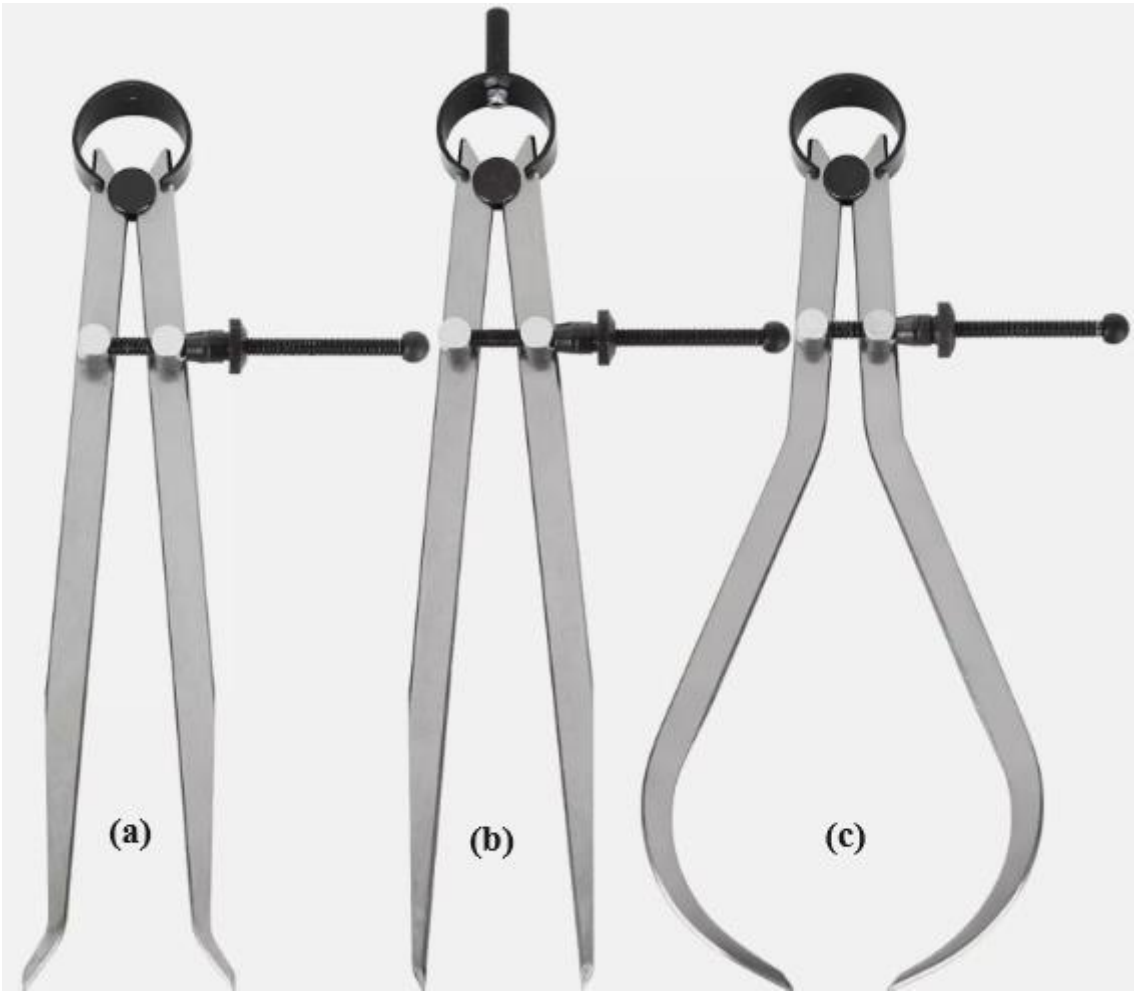


Figure 7: The different types of calipers (a) Inside calipers, (b) straight caliper, (c) Outside calipers

The external caliper is used to measure and check the diameters and external dimensions of various workpieces during machining. The internal caliper is used to obtain internal measurements. The caliper is inserted into the space to be measured and then opened outward slowly until the arms make contact with the edge of the space. The caliper is then removed while maintaining pressure on the legs to retain the accuracy of the measurement. The measurement is then read using a vernier caliper or a ruler. The forked caliper, also known as a marking caliper or a straight caliper, consists of two flat, straight legs, each with a fork-shaped tip. It is used to transfer dimensions onto a workpiece or to mark or draw circles on it. The use

Figure 8: Outside calipers and uses

Figure 9: Inside calipers and uses

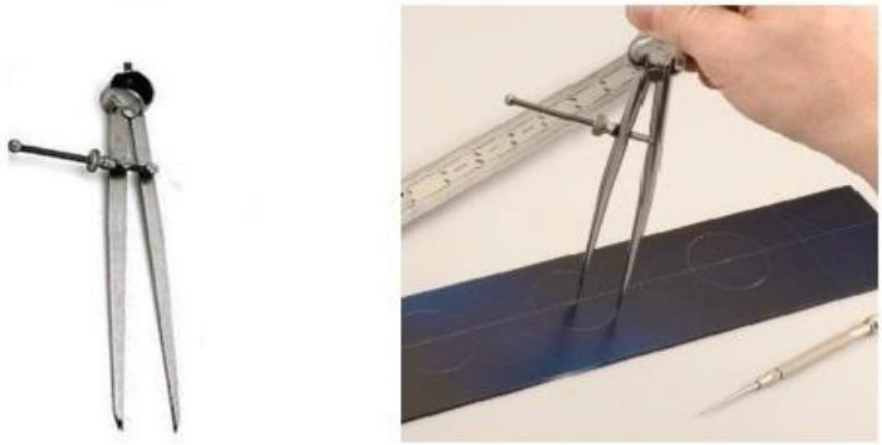


Figure 10: Inside calipers and uses

3. Dimensional measurements using the Vernier caliper

The vernier caliper is used to measure dimensions and lengths that are difficult to measure with a metric ruler, such as the internal and external diameters of pipes and their depths. It is more accurate than a metric ruler, with a precision of up to 0.02 mm, and can measure dimensions up to 10 cm in length.

a) Components of the vernier caliper

The vernier caliper consists of two main parts:

The fixed part: This part contains a fixed jaw connected to the main scale, which is usually graduated in metric (millimeters, mm) on one side and in English (inches, in) on the other side. The main scale is used to read the whole millimeters.

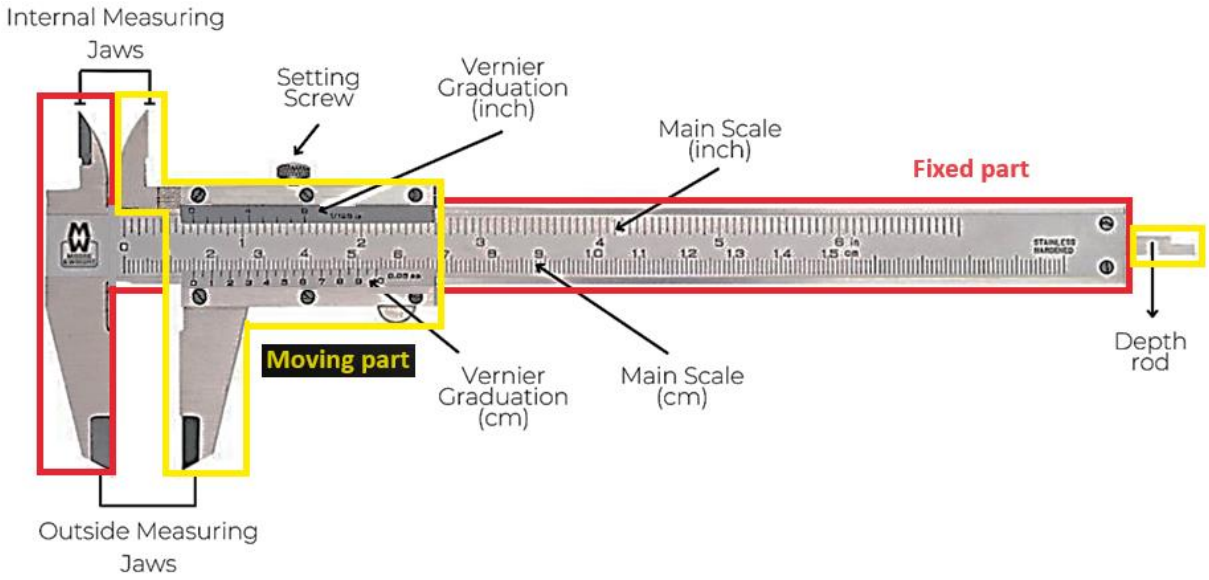


Figure 11: The vernier caliper

The movable part: This consists of a slider that holds the movable jaw and the part called the vernier scale. The vernier scale is a small scale that slides along a main scale called the caliper, which is part of the metric ruler. The vernier scale is graduated in fractions of a millimeter and is used to measure decimal fractions. The accuracy of the device is determined by the divisions on the vernier scale. The typical vernier measurement accuracy is either 0.1 mm (1/10 mm), 0.05 mm (1/20 mm), or 0.02 mm (1/50 mm). At the end of the movable part of the vernier caliper, there is a rod used to measure the depths of holes and deep grooves (stem for depth measurements).

The above diagram provides a complete detail of the vernier caliper and its following components:

- **Main scale (caliper):** It is graduated in millimeters on one side and inches on the other side.
- **Vernier:** It is a small scale that slides along the main scale (caliper).
- **External jaws:** One is fixed, and the other is movable, as shown in figure, and they are used to measure large internal diameters.
- **Internal jaws:** They are used to measure small external diameters.

b) Uses of vernier caliper

The vernier caliper is used to measure internal or external dimensions or depths, as shown in the following diagram.

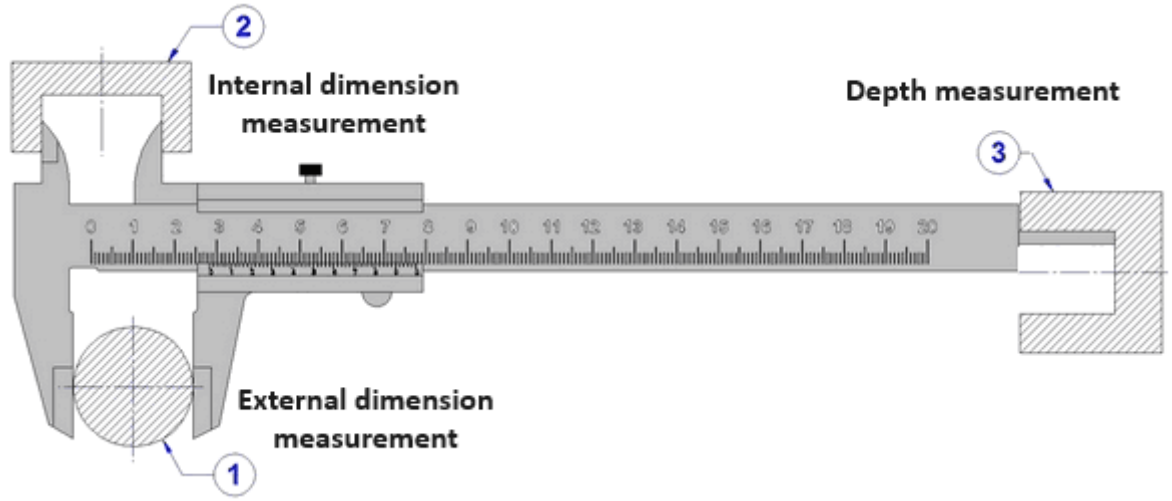


Figure 12: Types of measurements that can be measured with a vernier caliper

c) Vernier accuracy

The accuracy of the vernier is the smallest division on the vernier scale and is calculated using the following formula:

$$\text{Accuracy} = 1/n$$

Where (n) is the number of divisions (parts) on the vernier scale.

If the smallest division on the caliper is 1 mm, and the number of divisions on the vernier scale is 10 (n = 10), it is called a Ten vernier. Its accuracy is (1 / 10) = 0.1 mm.

If the smallest division on the caliper is 1 mm, and the number of divisions on the vernier scale is 20 (n = 20), it is called a Twenty vernier. Its accuracy is (1 / 20) = 0.05 mm

If the smallest division on the caliper is 1 mm, and the number of divisions on the vernier scale is 50 (n = 50), it is called a fiftieth vernier. Its accuracy is (1 / 50) = 0.02 mm.

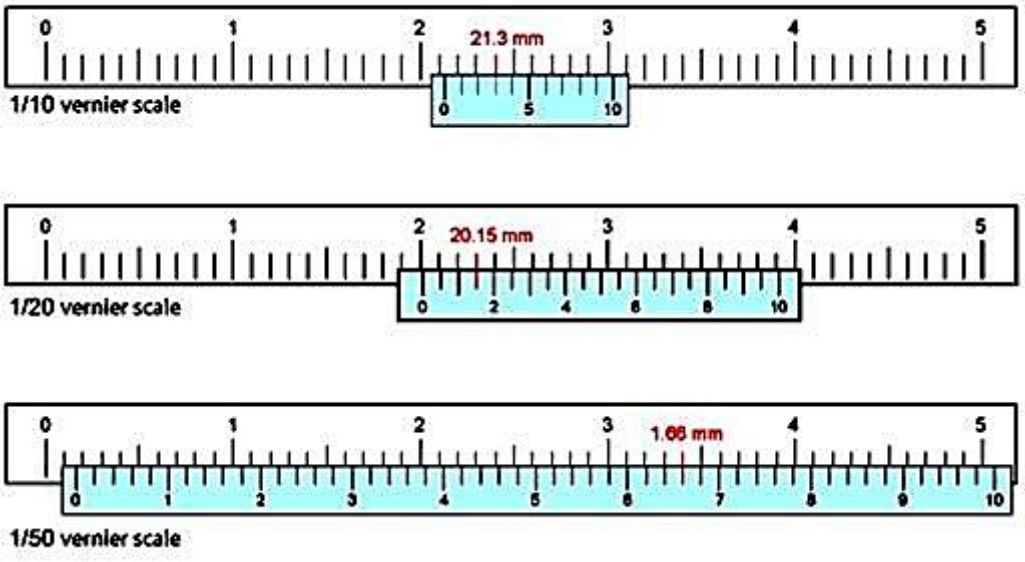


Figure 13: Different types of vernier calipers according to accuracy

d) Types of Calipers

- ✓ **Vernier Caliper**

is a basic linear measuring tool commonly used as a precision instrument that can be used to accurately measure internal and external distances within your economic budget.

Figure 14: Vernier Caliper

✓ **Digital Calipers**

This is a high-quality ergonomic caliper with IP67 certification, making it safe for use in harsh working environments with direct contact to coolant, oil, water, and chemicals.

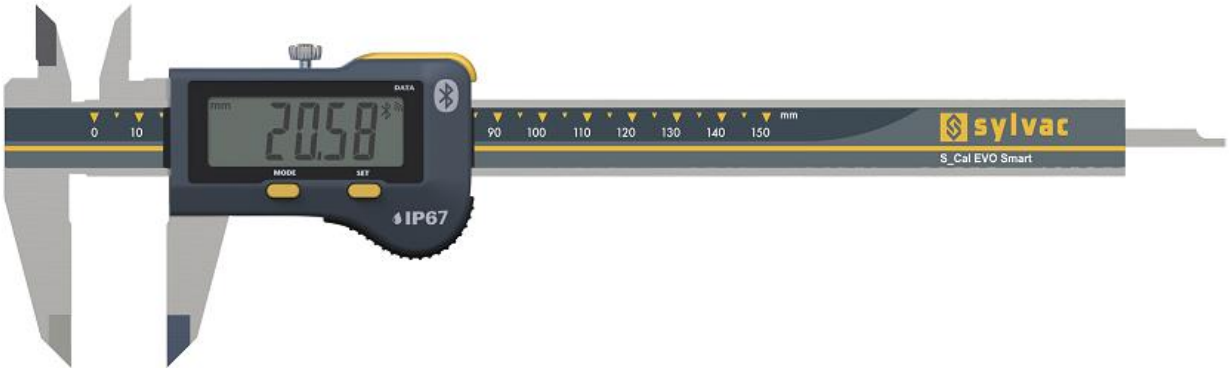


Figure 15: Digital Caliper

✓ **Dial Caliper**

The CDP Series Dial Calipers are the ultimate digital calipers for fabricators of mechatronics, aeronautical parts.

Figure 16: Dial Caliper

e) How to read values off a vernier caliper

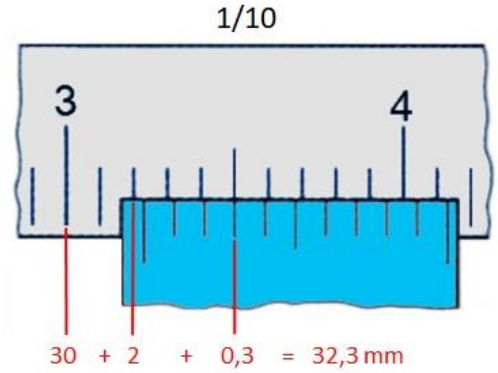


Figure 17: Reading on the vernier caliper with an accuracy of 1/10

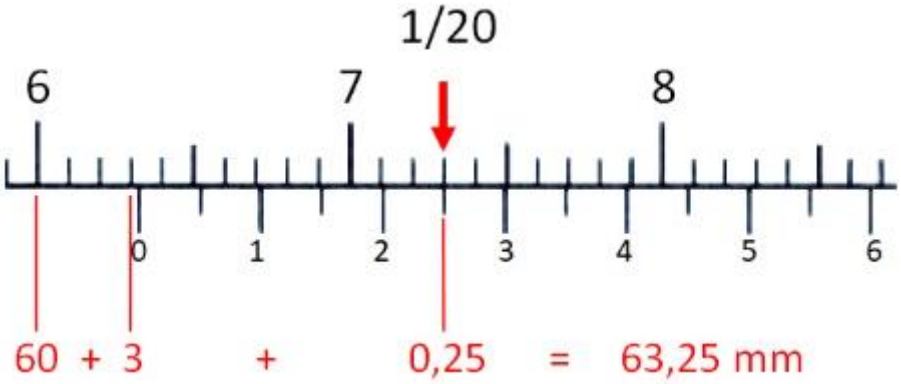


Figure 18: Reading on the vernier caliper with an accuracy of 1/20

- Read the whole number of millimeters on the main scale before the zero of the vernier.
- Identify the vernier graduation that is best aligned with any graduation on the main scale.
- Read the vernier scale, the number located before the aligned graduations. This number indicates the number of tenths of a millimeter.
- Count the number of divisions after the number and multiplied by the vernier scale's accuracy (1/10, 1/20, 1/50), This gives the hundredths of a millimeter corresponding to the measured dimension.

In the example:

- Number of graduations before the zero on the vernier ► 2 = 2 mm ► for the millimeter reading.

- Number on the vernier before the aligned graduation: 6 = 0.6 mm ► for the reading of tenths of a millimeter.
- 4th aligned graduation: the number 6 multiplied by 0.02 ► 4 × 0.02 = 0.08 ► for the reading of hundredths of a millimeter.

So, The reading is 02+0.6+0.08=2.68

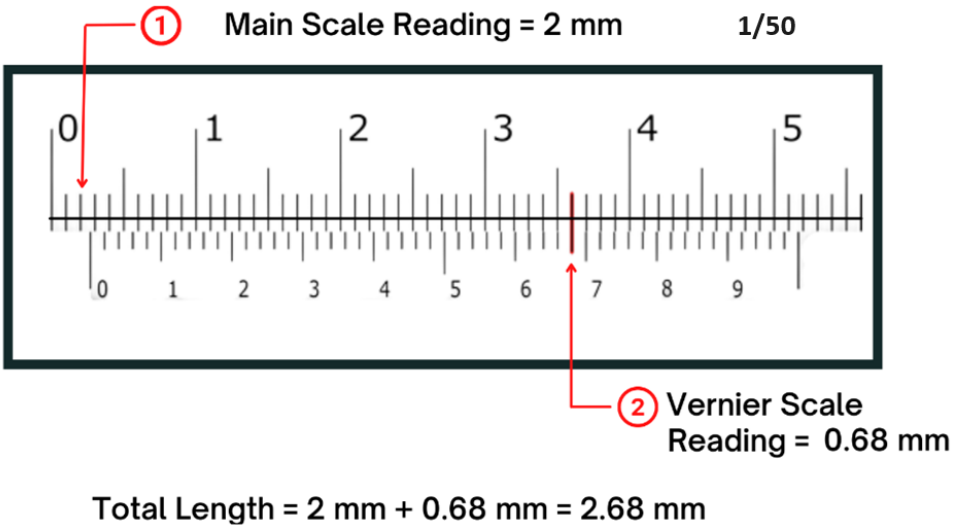


Figure 19: Reading on the vernier caliper with an accuracy of 1/50

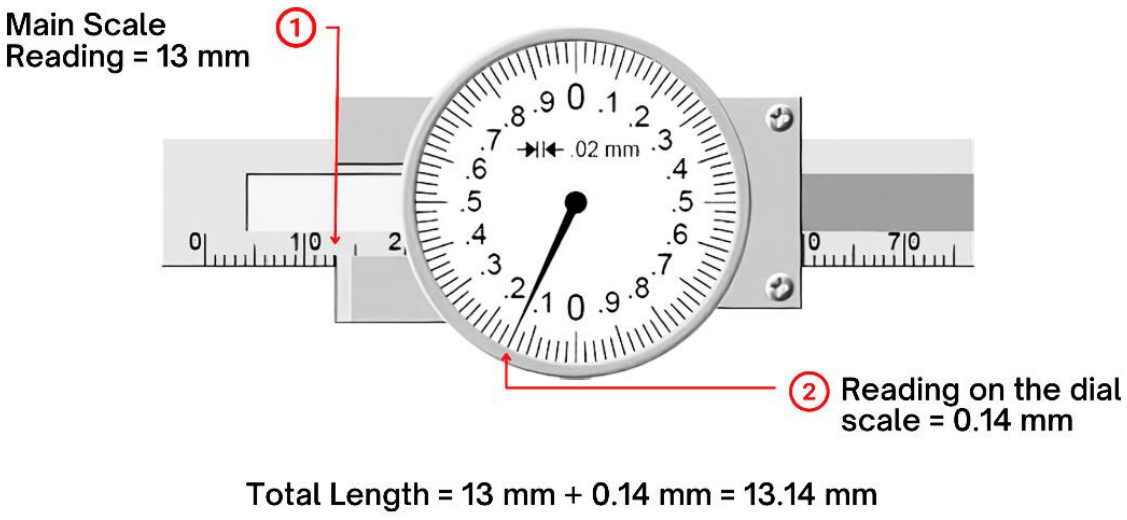
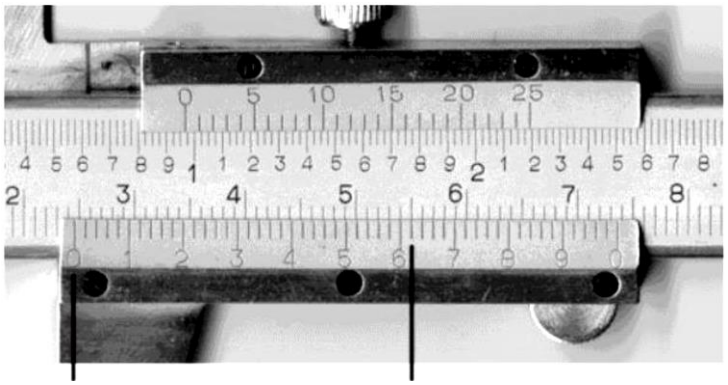


Figure 20: Reading on the dial caliper

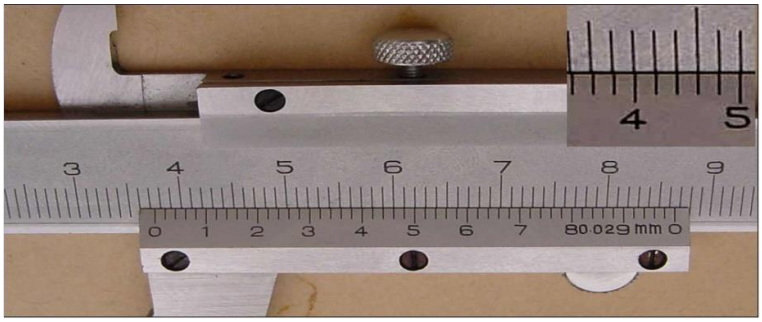
f) Practical test

The trainee should be able to perform the following within 10 minutes:

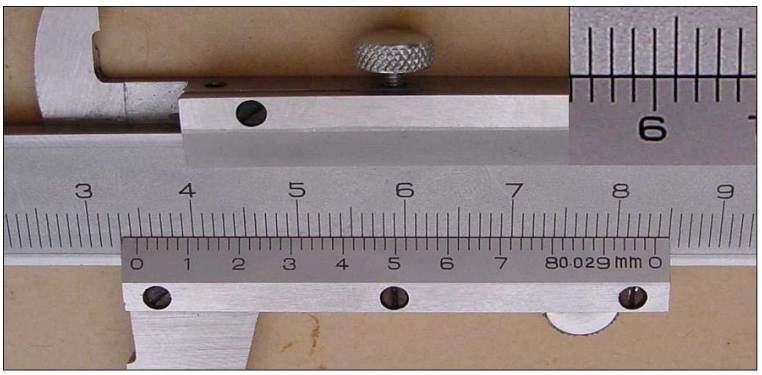
- Determine the accuracy of the vernier caliper shown in the following figures, then determine the measurement value.



Accuracy: …….. Measurement value: ……..



Accuracy: …….. Measurement value: ……..



Accuracy: …….. Measurement value: ……..

4. Dimensional measurements using the micrometer

The micrometer allows for the measurement of both internal and external linear dimensions. Calibration and reading of internal and external micrometers are done in the same way. Measurements are taken at specific points in contact with the surfaces to be measured.

a) Components of a micrometer

The external micrometer gauge consists of two main parts.

The fixed part: contains the frame or structure of the device, shaped like a "U" which supports the remaining stationary and moving components of the device. The frame supports both the anvil and the spindle (measuring rod), which are used to hold the workpiece whose dimensions are to be measured. The frame also carries the main scale for measurement or the longitudinal scale sleeve.

The main moving part: is the measuring sleeve, which, when rotated using the ratchet knob, moves the spindle to hold the workpiece being measured.

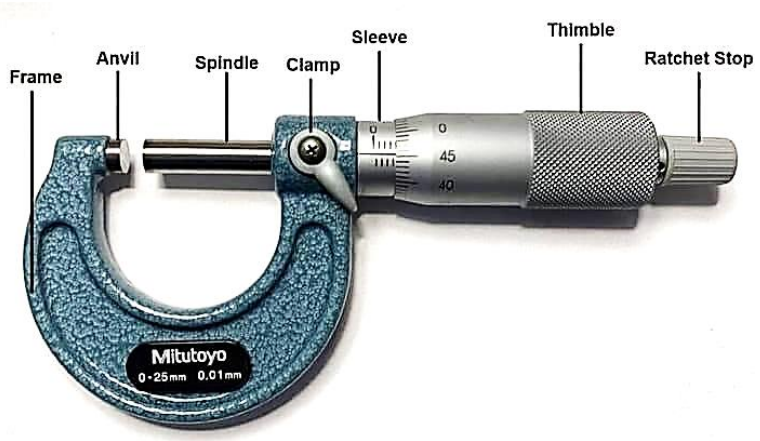


Figure 21: The components of the external micrometer gauge

The main scale for measurement is usually graduated in millimeters (1 mm) on one side and in 0.5 mm increments on the bottom. The circumference of the measuring sleeve is divided into 50 parts, and a full rotation of the sleeve moves the measuring spindle by 0.5 mm.

b) Micrometer sensitivity

The accuracy of the micrometer is the smallest graduation on the main measuring sleeve, while the sensitivity of the micrometer is the ratio of the smallest unit of measurement on the main scale to the number of graduations (parts) on the rotating thimble = (S/n).

whereas:

S: The smallest unit of measurement on the main scale.

n: The number of graduations (divisions) on the rotating thimble.

For example

If the smallest graduation on the main scale is 0.5 mm so (S=0.5), and the number of graduations on the rotating thimble is 50 (so n=50).

Micrometer sensitivity = (0.5/50) = 0.01 mm

Figure 22: The measurement range of the micrometer is (0-25 mm) and accuracy 0.01 mm

c) Micrometer reading

The measurement result on the micrometer is the sum of the upper integer part of the main scale, the lower graduation of the main scale, and the value on the rotating sleeve.

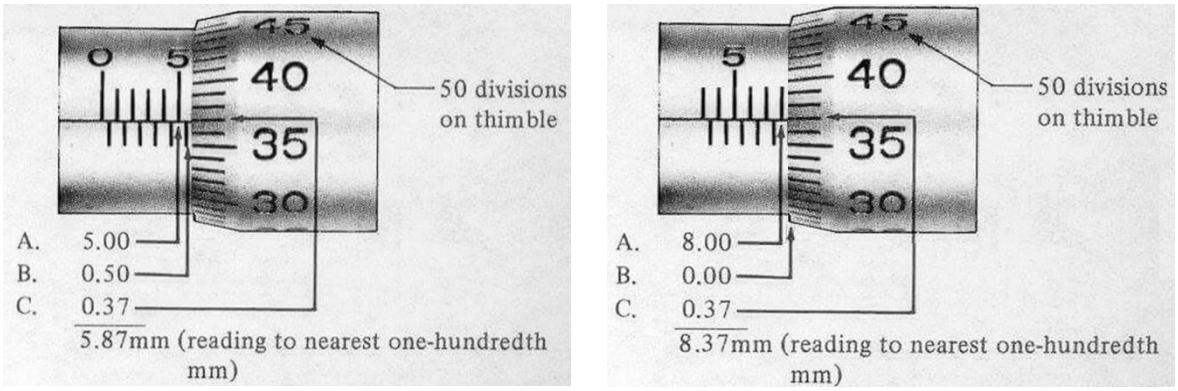


Figure 23: Reading method

Upper Integer of the Main Scale: Note the integer value on the main scale.

Lower Graduation: Note the value on the main scale.

Value on the Rotating Sleeve: Note the value indicated on the rotating sleeve.

Final Measurement: The measurement result is the sum of these three values.

d) Setting and calibrating the micrometer

Clean the micrometer jaws by placing a piece of cardboard between the jaws and gently closing them on it, then pulling the cardboard outward.

Close the jaws using the knurled part of the measuring sleeve or the rear screw.

Check if the zero point is aligned with the reference line. If the zero is not aligned with the reference line, it means the micrometer needs adjustment.

Use the wrench provided with the micrometer, as shown in the diagram, to turn the longitudinal scale cylinder until the division line on the cylinder aligns with the zero point on the measuring sleeve.

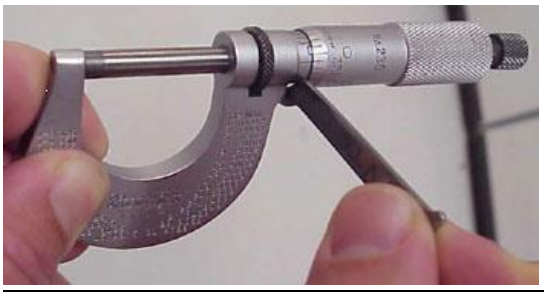
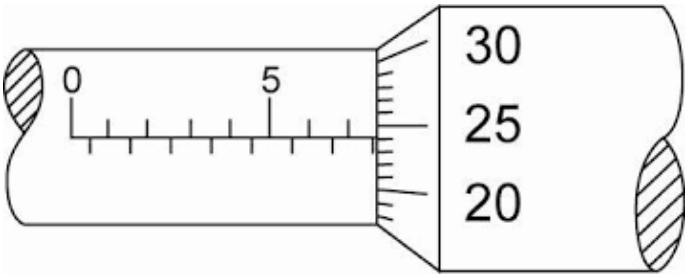
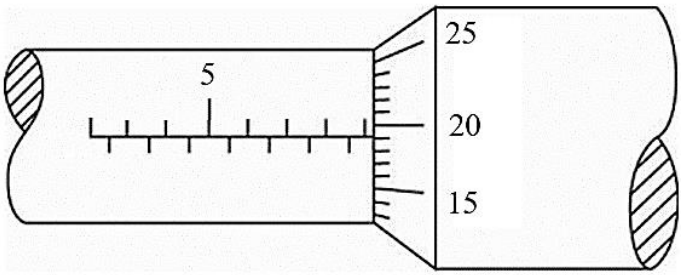


Figure 24: Calibrating the micrometer

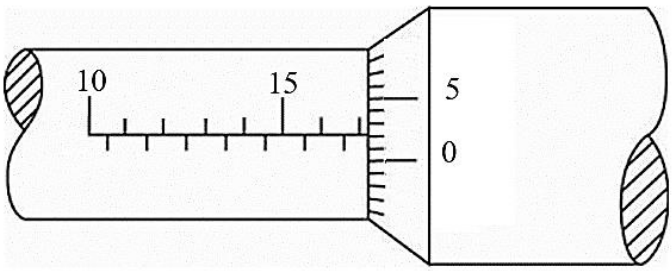
e) Examples of readings



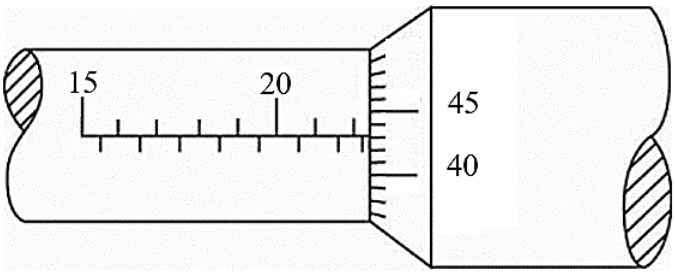
Reading value ……



Reading value ……



Reading value ……



Reading value ……

5. Dial indicator

Dial gauges are measurement tools with a graduated dial used to test the flatness of surfaces, the uniformity of rotating shafts, and to determine deviations in dimensions and measurements of manufactured parts from the specifications and designs.

Figure 25: Dial indicator with a stand

It mainly consists of a sensitive sensing column, a mounting column, a fixed scale, and a rotating scale, as shown in Figure 130. The dial gauge is also used with a spirit level to check the axes of the machines and adjust their movement.

a) The components of a dial indicator

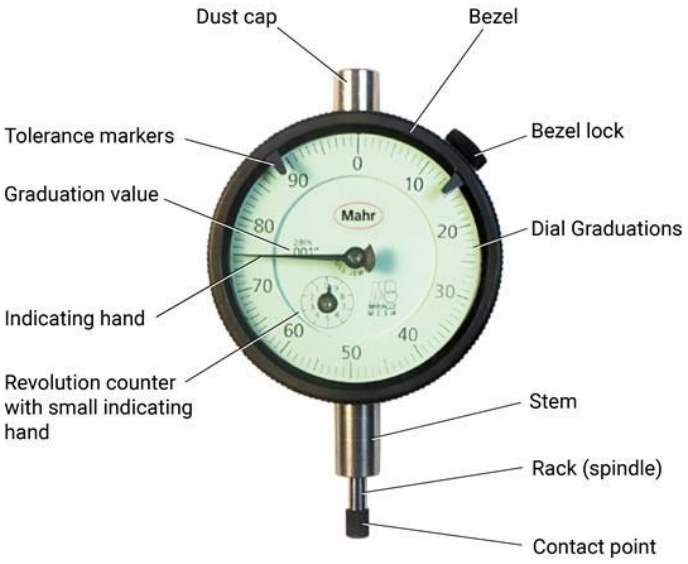


Figure 26: Components of a dial indicator

b) Description and Reading

The dial indicator consists of:

- A indicating hand controlled by the contact point. One full revolution of this indicating hand equals a difference of 1 mm.
- A dial graduations divided into 100 equal parts, each representing 1/100th of a millimeter (there are also dial indicators that allow for reading to 1/1000th of a millimeter);
- A small dial that indicates the number of revolutions of the dial graduations;
- The entire large graduation (bezel) can rotate around the axis of the watch, so that the "zero" division can be positioned at will in front of the central hand.

c) Use

By mounting a dial indicator on an appropriate base (as shown in Figure above) and using various accessories, it can be employed for various purposes, such as:

- Determination of geometric shape errors, such as cylindricity, conicity, and straightness of a line …
- Determination of geometric position errors, such as parallelism …
- Taking precise measurements of deformation during tensile and compressive material testing.
- Comparing two distances or heights.

The practical applications of using a dial indicator are as follows:

- Checking alignments in a lathe machine;
- Checking the accuracy of milling machine shafts;
- Checking the parallelism of the shaping ram with the surface of the table.

d) Example of use

To perform a measurement, a zero point is established using, for example, a gauge block. With the body of the dial indicator fixed, the workpiece to be measured is placed under the dial indicator, which then indicates the difference between the reference point and the dimension of the measured workpiece.

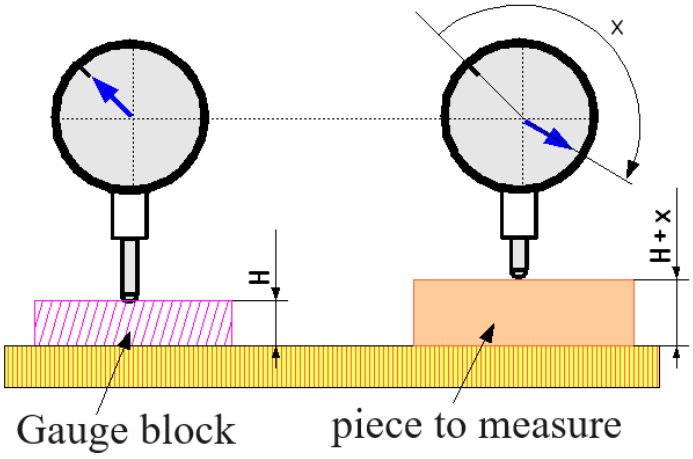


Figure 27: Measure by comparison

III. Pneumatic instruments

1. Direct-blow measuring plugs

Pneumatic measuring systems are widely used in the mechanical industry for dimensional control of mechanical parts due to their advantages (non-contact measurement, self-cleaning of the parts to be inspected, easy maintenance, the ability to achieve high amplification, robust and reliable devices, etc.). Among these systems, direct-blow measuring plugs are used to inspect both through and blind bores.

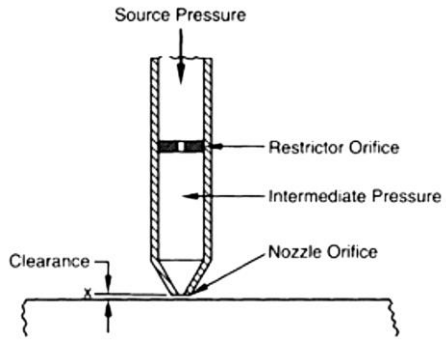


Figure 28.a: Measuring principle

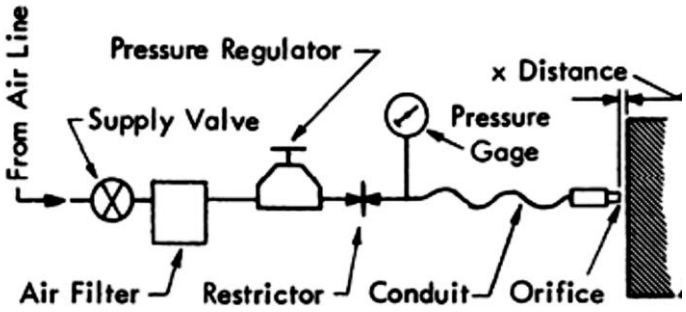


Figure 28.b: Back pressure air gauge

Before starting the dimensional inspection, the pressure must be set to a reference dimension that indicates a value of zero on the gauge. If the measured dimension is larger, the pressure should be lower, and if the measured dimension is smaller, the pressure should be higher than the reference pressure.

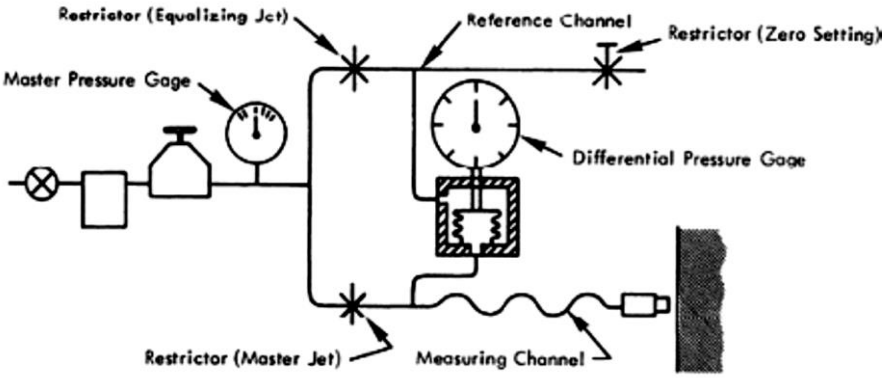


Figure 29: Method of measurement

For bores, the measurement is performed without contact by two diametrically opposed measuring nozzles, positioned recessed relative to the outer cylinder of the pneumatic plug (Figure 1.9). This measurement can be either static or dynamic. By rotating the plug within the

part, ovality can be determined, and by translating the plug, taper can be measured. The measuring plug can be manufactured with three nozzles for triangulation measurement. The measurement range is from 3 mm to 150 mm, with a measuring span from 0.010 mm to 0.160 mm.

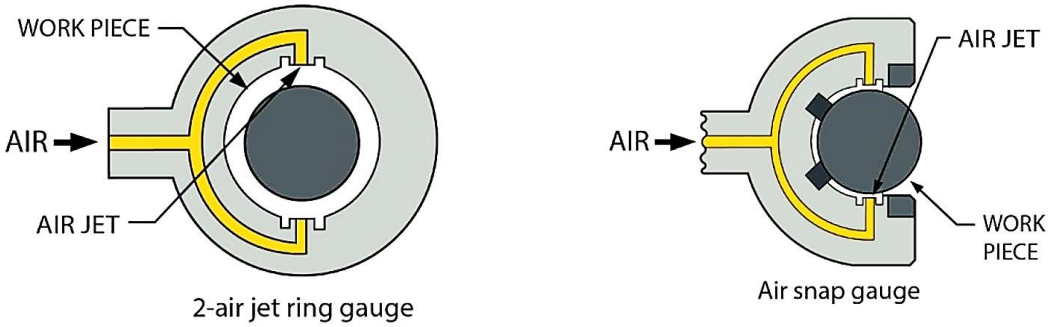


Figure 30: Different types of nozzles

IV. Optical instruments

1. Projector profile

Profile projectors are optical measurement devices that project a profile image of a zone or a characteristic of a part onto a screen. It also offers superb image quality for accurately measuring the X-Y coordinates of a feature. They come in two versions: horizontal or vertical. The horizontal projection is useful for inspecting cylindrical components, while the vertical projection is effective for inspecting small components. The projector is also used in the production of small items made of metal, plastic, rubber, or electronics.

Figure 31: Vertical profile projector

- Horizontal or vertical projection system
- Suitable for cylindrical components
- Inspection of small elements
- Interchangeable magnification lenses
- Diascopic projection (for profile/contour examination) or episcopic projection (for surface examination)
- Digital color touchscreen

V. Assessment of errors

The measurement error is therefore the difference between the measured value and the exact value, the latter being unknown. Among these errors we can cite:

1. Systematic errors:

These are errors arising from the measuring device, the measurement process, or the operator, which are repetitive and constant. It is an error that takes the same (unknown) value with each measurement.

For example:

- Design or manufacturing error of the measuring device.
- Calibration, zeroing, or adjustment defects in the measuring device.
- Usage conditions of the device not in accordance with the device specifications.
- Parallax error in reading an indication.

7. Random errors related to operating conditions

This is an error that takes on a different value during each measurement, a value that we will have to try to estimate.

8. Accuracy Error

The ability of a measuring instrument to provide indications that are equal to the true value of the measured quantity under given conditions.

$$j = M - \bar{M}$$

$$\bar{M} = \frac{1}{n}\sum_{i=1}^{i=n} \grave{M}_{\iota}$$

Where:

M: The true value of reading.

$\bar{M}$: Average reading values.

n: Number of times read.

M_i: The value of reading every time.

9. Precision Error

Precision is the ability of a measuring instrument to provide very close values for the same quantity under identical conditions. It represents the dispersion of measurements Mi of the same quantity and is characterized by its estimated standard deviation:

$$\sigma = \sqrt{\frac{1}{n-1} \times \sum_{i=1}^{i=n} (M_i - \bar{M})^2}$$

The precision error is equal to 6 times the value of the standard deviation.

$$F = 6 \times \sigma$$

10. Repeatability Error

The deviation observed during successive measurements of the same quantity under identical conditions (same operator, same location, measurements taken consecutively over a short period, same method).

11. Reproducibility

The deviation observed during successive measurements of the same quantity while varying the conditions (changes in operator, location, time, or method).

Conclusion

This chapter provided an essential introduction to the principles and tools used in thickness and length measurements, which are fundamental aspects of metrology. Beginning with definitions of key concepts such as measurement, the measurand, uncertainty, absolute error, and relative error, the chapter established a strong theoretical foundation for understanding measurement accuracy.

A variety of mechanical instruments were explored, including rulers, tapes, calipers, vernier calipers, micrometers, and dial indicators. Each tool was detailed in terms of its components, operation, uses, and accuracy. The chapter also introduced practical aspects, such as reading and calibrating instruments, performing dimensional measurements, and transferring measurements using tools like calipers.

By combining theoretical insights with practical examples, this chapter equips students with the knowledge and skills needed to perform precise dimensional measurements, an essential competence in engineering and technical fields.

Second Chapter

Temperature Measurements

Introduction

Temperature measurement is a fundamental aspect of various scientific, industrial, and medical applications, playing a vital role in monitoring and controlling processes. The accuracy and efficiency of these measurements depend on selecting the appropriate instruments and understanding their operating principles.

This section explores a wide range of temperature measurement tools and techniques, including temperature scales, thermocouples, thermistors, infrared detectors, and pyrometers. Each device's unique operating principles, types, benefits, and limitations are examined to provide a comprehensive understanding of their applications.

The section also highlights the importance of automatic data acquisition systems, with a focus on tools like Arduino Uno, which simplify measurement processes and enhance precision.

In addition, it addresses common errors associated with thermal sensors and strategies to minimize them, along with essential precautions for using each type of sensor to ensure reliable and stable measurements.

This content is designed to offer a thorough understanding of temperature measurement technologies and best practices, enabling the selection of the most suitable instruments for specific applications.

Temperature is an intensive property that can be measured in two different ways.

- At the atomic scale, it is related to the average kinetic energy of the constituents of matter.
- At the macroscopic level, certain properties of bodies that depend on temperature (such as specific volume, electrical resistivity, etc.) can be used to construct temperature scales.

I. Temperature scales

The oldest scale is the centesimal scale (1742), which arbitrarily assigns the values of 0 and 100 degrees to melting ice and boiling water, respectively, under normal atmospheric pressure. Since the temperature defined in this way depends on the phenomenon chosen (the expansion of a fluid) to construct the standard thermometer, the Celsius scale is preferred, defined from the Kelvin scale by:

$$T\ (C^{\circ}) = T\ (K) - 273.15$$

This latter scale, which is the one used in the International System of Units (SI), does not depend on any particular phenomenon and thus defines absolute temperatures. Absolute zero (-273.15°C) has been approached to within a few millionths of a degree. The physical phenomena that occur at very low temperatures have significant applications (such as superconductivity). In the field of high temperatures, plasma torches can reach 50,000 K, and high-power lasers used in research on controlled nuclear fusion can produce temperatures exceeding 100 million degrees for very brief periods.

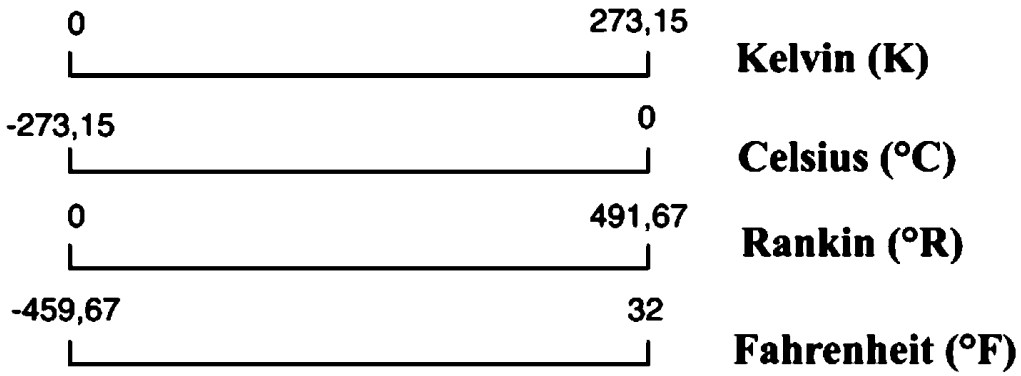


Figure 1: Temperature scales

II. Thermocouple

In physics, thermocouples are used for temperature measurement. They are inexpensive and allow for measurement over a wide range of temperatures. Their main drawback is their accuracy: it is relatively difficult to obtain measurements with an error smaller than 0.1 - 0.2°C. Temperature measurement with thermocouples is based on the Seebeck effect.

Figure 2: Thermocouples

1. Operating principle

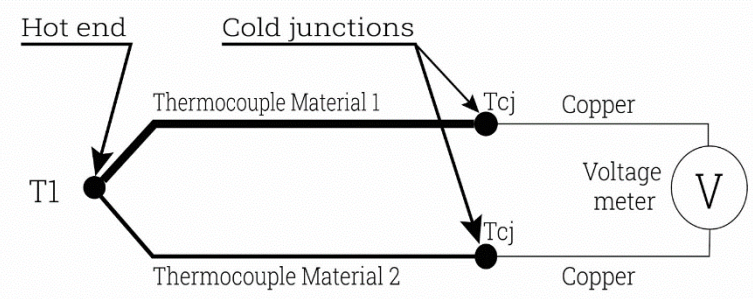


Figure 3: Thermocouple components

A thermocouple primarily uses the Seebeck effect to obtain a temperature measurement. If two wires made of different metals are joined at one end and the temperature of this junction is increased, a voltage e_{AB} appears at the free ends of the wires.

You can determine the heated end temperature from the measurement of e_{AB}

We call:

- **Hot junction**: The junction of the thermocouple assembly subjected to the temperature to be measured; this is the sensor junction.
- **Cold junction**: The junction of the thermocouple assembly maintained at a known temperature or at 0°C; this is the reference junction.

2. Different types of thermocouples

The range of use and the price of a thermocouple depend on the two metals used. Each pair of metals is associated with a standardized letter. Here are the designations corresponding to the main thermocouples used in industry:

Code littéral	Couple	Usage continue Usage intermittent	Précision en %	Remarques
K	Nickel - Chrome Nickel - Aluminium	0°C à 1100°C -180°C à 1300°C	1,5	Bien adapté aux milieux oxydants
T	Cuivre Cuivre - Nickel	-185°C à 300°C -250°C à 400°C	0,5	
J	Fer Cuivre - Nickel	20°C à 700°C -180°C à 750°C	1,5	Pour milieu réducteur
E	Nickel - Chrome Cuivre - Nickel	0°C à 800°C -40°C à 900°C	1,5	Utilisation sous vide ou milieu légèrement oxydant
R	Platine - 13% Rhodium Platine	0°C à 1600°C 0°C à 1700°C	1	
S	Platine - 10% Rhodium Platine	0°C à 1550°C 0°C à 1700°C	1	Résistance à l'oxydation à la corrosion

Table 1: Thermocouple components A table showing the main types of thermocouples and their characteristics

The two metals, a and b, of different types, are connected by two junctions (forming a thermocouple) at temperatures T1 and T2.

Due to the Seebeck effect, the thermocouple generates a potential difference that depends on the temperature difference between the junctions, $T_e = T_1 - T_2$

To measure an unknown temperature, one of the two junctions must be maintained at a known temperature, such as the melting point of ice (0°C). It is also possible that this reference temperature is measured by a sensor (ambient temperature, for example). Therefore, temperature measurement is indirect, as thermocouples actually measure a difference in electrical potential.

3. Compensation cables

Compensation cables are used in two cases:

- ❖ When the metals forming the pair are very expensive (especially precious metals).
- ❖ When the distance between the temperature sensor and the reference junction is large.

A classic example of using compensation cables: For platinum thermocouples, which are expensive, it is necessary to use compensation cables for cost efficiency. However, it is important to note that if the temperature at the connection point increases, the measurement will be inaccurate.

4. Mounting thermocouples

a) Assembly only

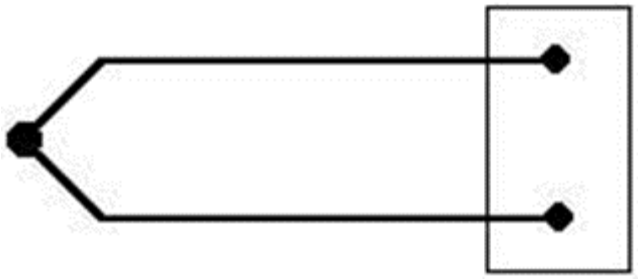


Figure 4: Thermocouple assembly only

The thermocouple goes to the measuring instrument where the cold junction correction is performed.

b) Mounting with extension cable

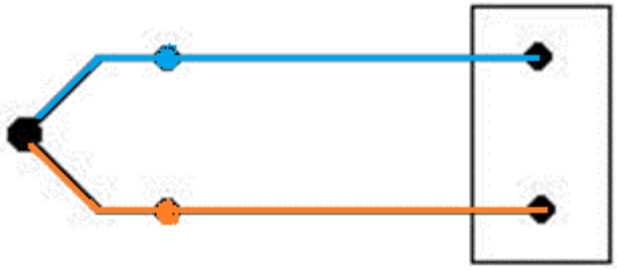


Figure 5: Thermocouple mounting with extension cable

The extensions are made with wires of the same type as those constituting the thermocouple.

c) Assembly with compensation cable

Figure 6: Thermocouple assembly with compensation cable

The extensions are made with wires of a different type than those constituting the thermocouple, but with thermoelectric characteristics that are very similar within a given temperature range.

5. Benefits

- Wide temperature ranges: from 0 to 1600 K
- Robust: resistant to shocks and vibrations
- Fast response (ms)
- Reliable and accurate
- Reproducible

6. Disadvantages

- Reference temperature required
- Non-linear response
- Low sensitivity for certain types of thermocouples

III. Thermistor

Thermistors are simply resistors that have the property of varying with temperature. When connected in series with a generator, which has a variable resistance, they allow a current to pass through that also varies with their temperature. There are two types of thermistors:

1. NTC (Negative Temperature Coefficient)

These are thermistors whose resistance decreases uniformly with temperature. The response curve is negative: the resistance decreases as the temperature increases. Resistance-temperature relationship of NTC (Negative Temperature Coefficient) thermistors.

2. PTC (Positive Temperature Coefficient)

Are thermistors whose resistance increases significantly with temperature within a limited temperature range (typically between 0°C and 100°C), but decreases outside this range according to a law of the type: $R(T) = R_0 \, e^{B\left(\frac{1}{T}-\frac{1}{T_0}\right)}$ with T in K (and B between 3000 and 5000K).

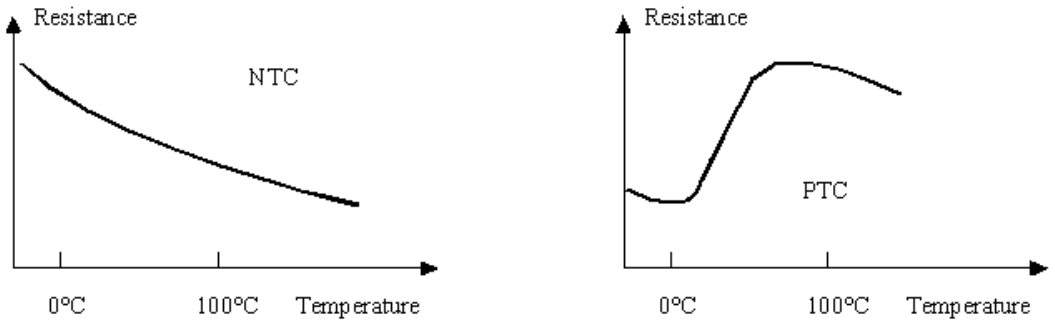


Figure 7: Negative and Positive Temperature Coefficient

They are used as:

- Temperature sensors;
- Overcurrent and overheating protection element in the form of a fuse;
- Self-regulating heating element.

Figure 8: Thermistor

Thermistors can only be used within a temperature range not exceeding 300°C.

A thermistor is a passive component made from semiconductor material, meaning it only conducts at high temperatures.

Temperatures are expressed in Kelvin, and the constants B and T0 are characteristics of the component. R(T) and R(T0) are in the same unit (kΩ).

3. Characteristics

- metal oxide-based resistors.
- low footprint.

4. Advantage

- Fast response time, less expensive.

5. Disadvantages

- Non-linear characteristic, variability in series specifications, sensitive to self-heating and variations in connection resistances.

IV. Infrared detector

An infrared (IR) detector is a device designed to sense and measure infrared radiation, which is emitted by objects based on their temperature. Infrared detectors are widely used in various fields for their ability to detect heat and radiation that is invisible to the human eye.

Figure 9: Infrared detector

1. How It Works

Infrared detectors capture IR radiation and convert it into an electrical signal. The intensity of this signal corresponds to the amount of heat emitted by the object. Two main types of detectors are used:

- ✓ **Thermal Detectors**: Measure heat changes caused by absorbed IR radiation.
- ✓ **Photonic Detectors**: Detect IR photons and convert them into electrical signals for precise measurements.

2. Uses and Benefits

Infrared detectors are widely employed in various fields:

- **Industrial Applications**: Monitoring equipment and processes for overheating.
- **Healthcare**: Thermography for diagnosing medical conditions.
- **Security Systems**: Motion sensors and night vision devices.
- **Research and Development**: Analyzing heat distribution and thermal properties.

V. Pyrometers

These are optical (photovoltaic) detectors of a few square millimeters that generate a current when exposed to infrared radiation. When placed close to the surface whose temperature you want to measure, they provide a signal proportional to the surface temperature if the temperature variations are small. Their advantage is that they allow for non-contact measurement, thus avoiding disturbance to the surface being measured.

1. Why use infrared thermometers?

Knowing the temperature of products is very important, both for manufacturing and for quality control and maintenance. Precise temperature monitoring helps to improve product quality and productivity. Downtime is reduced since manufacturing processes are always conducted under optimal conditions.

What are the advantages of non-contact temperature measurement?

- Instantaneous measurement (in milliseconds) for fast processes.
- Measurement of moving targets.
- Measurement of targets that are difficult to access or located in hazardous areas (high-voltage components, distant targets, or those behind a window).
- Measurement of temperatures above 1300°C. No aging or corrosion, whereas contact thermometers can only withstand such temperatures for a limited time (e.g., in combustion chambers).

After mentioning the advantages, it is important to highlight the conditions that must be observed when using infrared thermometers:

- The object to be measured must be optically visible to the infrared thermometer. Dust, dense smoke, and obstacles can interfere with the measurement.
- The optics of the measurement head must be kept clean.

Summary: The main advantages are the response time, the ability to measure moving objects, no wear and tear, and the capability to measure temperatures from -50°C to +3000°C.

2. The infrared measurement system

An infrared thermometer is comparable to the human eye. The pupil of the eye corresponds to the optics that focus the radiation (photon flux) from the object being measured

onto the detector (the retina). The detector then converts the received information into a signal that is transmitted to the display (the brain). The following figure shows an infrared measurement system.

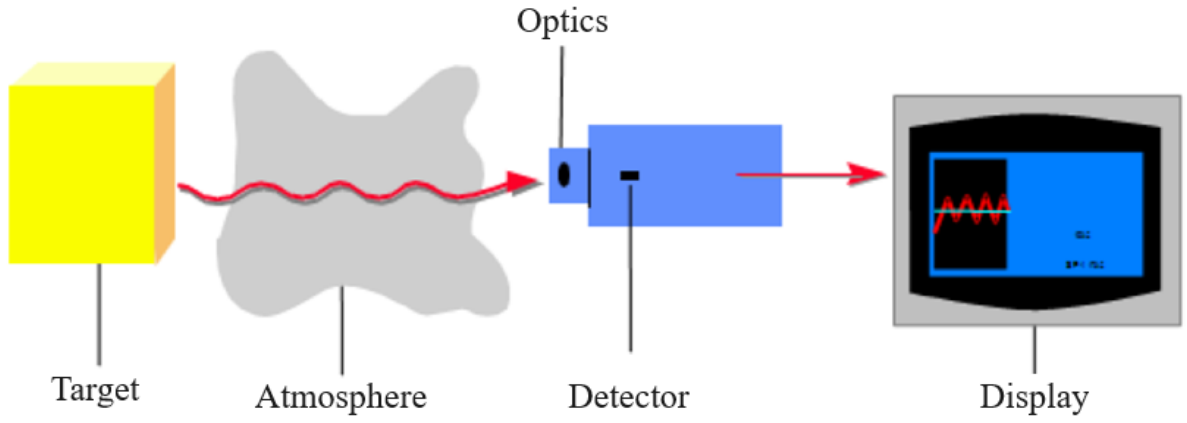


Figure 10: Infrared measurement system

Type	Gamme de température en °C
Thermocouple	-270 à 2700
Résistance métallique	-260 à 1400
Thermistance	-100 à 450
Transistor	-50 à 150
Pyromètre optique	300 à 3000
Pyromètre à dilatation de solide	-60 à 500
Pyromètre à dilatation de liquide	-35 à 700
Thermomètre à dilatation de gaz	-100 à 600
Thermomètre à dilatation de liquide	-55 à 600

Table 2: Temperature range of different thermal sensors

VI. Errors related to thermal sensors

Measurements made by a sensor are generally subject to some degree of imprecision. The difference between the actual value of the quantity being measured and the measured value

is called measurement error. Two types of errors can be distinguished: systematic errors and random errors.

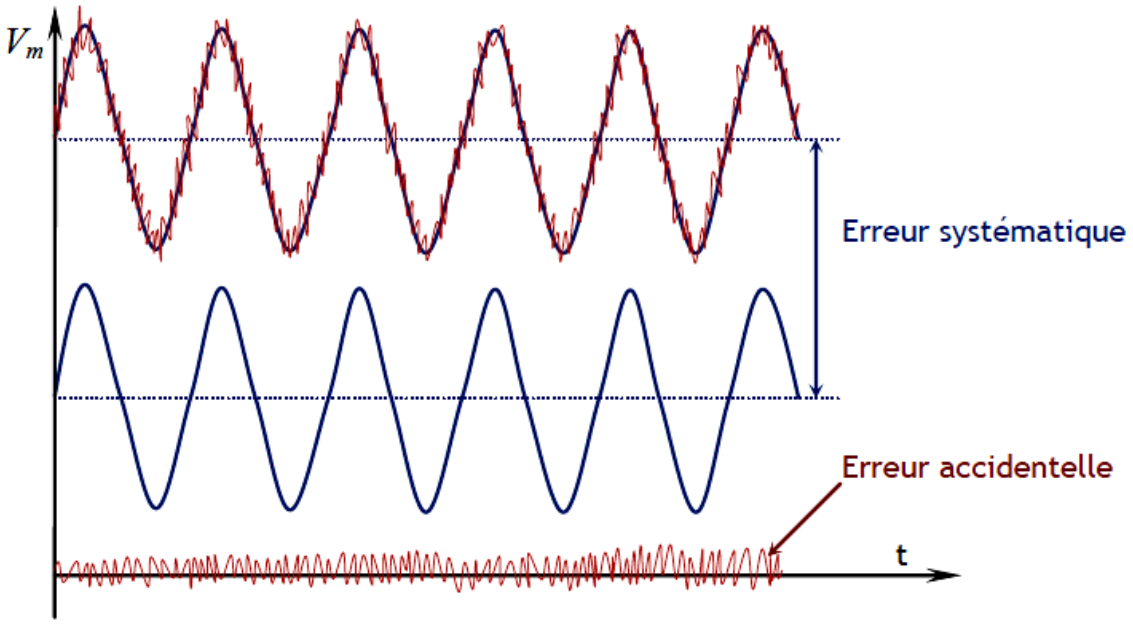


Figure 11: Illustration of the Two Types of Errors (Systematic and Random)

1. Systematic errors

Have several possible sources. They stem from an error in the calibration curve, an incorrect value of a reference quantity, an erroneous correction applied to the measurements, or a deviation from the linearity of a sensor assumed to be linear. Systematic errors introduce the same bias, which can potentially be reduced through recalibration.

2. Accidental errors

Can be caused by an incorrect reading of a deviation device, a mobility error (sensor insensitive to certain variations of the measured quantity), environmental noise (thermal, amplifiers of conditioning electronics, etc.), fluctuations in supply voltages, and more. Their reduction involves improving the acquisition chain devices or post-processing the signal.

3. The choice of sensors

The type of measurement will determine the type of sensor. The choice of the appropriate sensor depends on various criteria:

- ❖ The application
- ❖ The measurement range

- The accuracy
- The reliability
- The response time
- The price
- The lifespan
- Its shape

The following table summarizes the different types of temperature sensors, their advantages and disadvantages, and their areas of use.

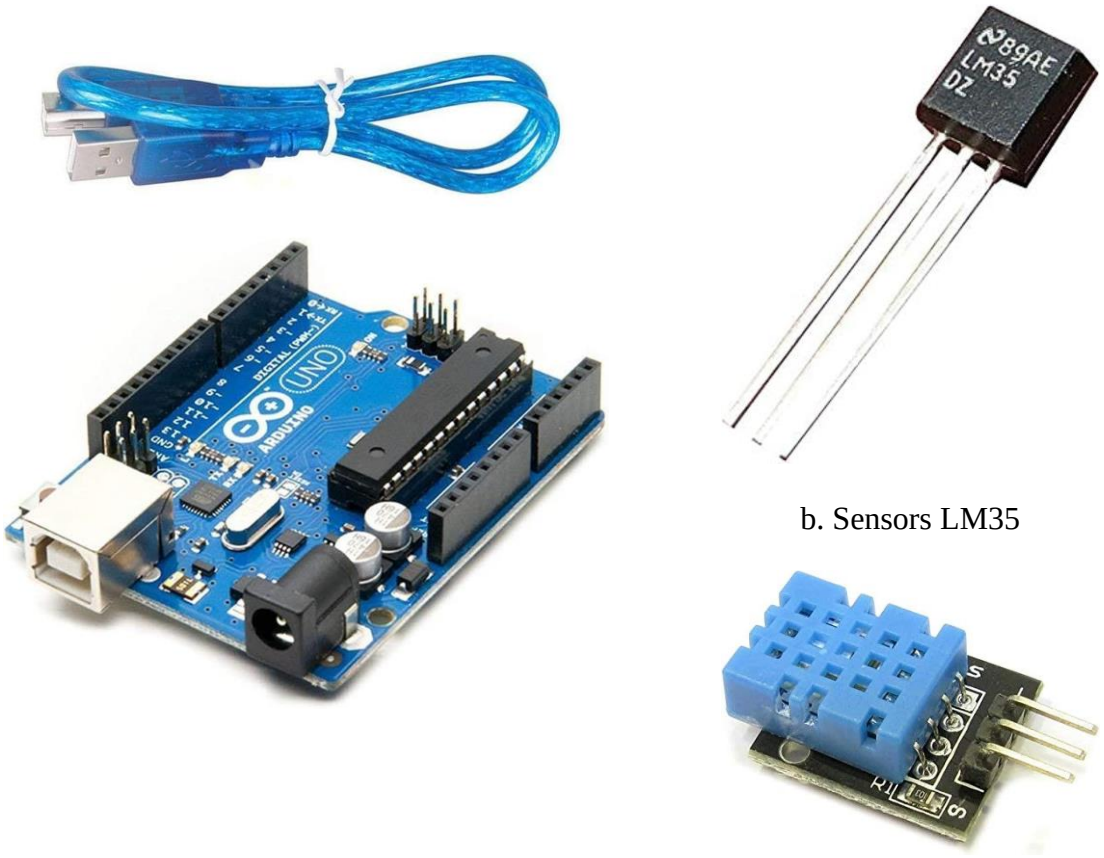
Instrument Type	Advantages	Disadvantages	Usage Range
Liquid Expansion Thermometer (Mercury)	✓ Easy to use ✓ Affordable ✓ High sensitivity	✓ Fragile ✓ High response time ✓ Narrow measurement range	✓ From -39°C to 600°C
Solid Expansion Thermometer (Bimetallic strip, stem thermometers)	✓ Linear scale ✓ Inexpensive ✓ Robust ✓ Linear scale for stem thermometers	✓ Susceptible to overheating (bimetallic) ✓ Fragile (stem thermometers) ✓ Expensive (stem thermometers)	✓ Bimetallic: -50°C to 450°C ✓ Stem thermometers: 0°C to 900°C
Gas Expansion Thermometer	✓ Simple design ✓ Robust ✓ Inexpensive ✓ Linear scale ✓ Decent response time	✓ Large external tube size (Ø15)	✓ From -100°C to 650°C
Electrical Resistance Thermometer	✓ Low bulk ✓ Diameter < 2 mm ✓ Wide temperature range	✓ Fairly high cost ✓ Non-linear scale ✓ Large dimensions	✓ Platinum: -200°C to 100°C ✓ Copper: -130°C to 180°C ✓ Nickel: -130°C to 250°C
Electrical Thermistor Thermometer	✓ Very compact	✓ Non-linear scale	✓ From -120°C to 500°C
	✓ Very wide temperature range ✓ Point measurement	✓ Non-linear scale (requires calibration at multiple points) ✓ Unstable above 1600K	✓ Copper-Constantan: -200°C to 300°C

			✓ Iron-Constantan: 200°C to 700°C ✓ Nickel-Chromium/Nickel Alloy: 300°C to 1100°C ✓ Platinum-Rhodium/Platinum: 1000°C to 1600°C
Pyrometers	✓ Access to high temperatures ✓ Unlimited lifespan ✓ Great flexibility of use ✓ Non-contact measurement ✓ Very low response time	✓ Difficult calibration (depends on the medium being measured)	✓ 500°C to 2000°C

VII. Automatic data acquisition and acquisition cards

Using Arduino Uno for Temperature Measurement

The Arduino Uno is an open-source platform that facilitates the connection of various sensors and automates measurement processes, including temperature measurement. It can be used with sensors like the LM35 or DHT11, where the Arduino board processes the analog signals coming from the sensors and converts them into digital data, which can then be displayed on a screen or transmitted to a computer for processing and analysis.



a. Carte Arduino Uno

b. Sensors LM35

c. Sensors DHT11

Figure 12: Arduino Uno with Sensors Used for Temperature Measurement

4. Key Advantages of Using Arduino Uno for Temperature Measurement

- Ease of Programming: The Arduino IDE provides a simple programming environment for reading data from sensors.
- Low Cost: Arduino is an economical option, making it suitable for a wide range of applications.

- Scalability: It can be connected to a variety of sensors and other components.
- Measurement Accuracy: When using high-quality sensors, accurate temperature readings can be achieved.

5. How to Use

- Connecting the Sensor to the Arduino Board: The sensor can be connected to the analog inputs on the Arduino.
- Programming: A program is set up to read the signals from the sensor and calibrate them to convert the values into temperature readings.
- Displaying Data: The data can be displayed on an LCD screen or sent to another device via serial communication.

6. Connection Diagram of the LM35 Temperature Sensor with Arduino

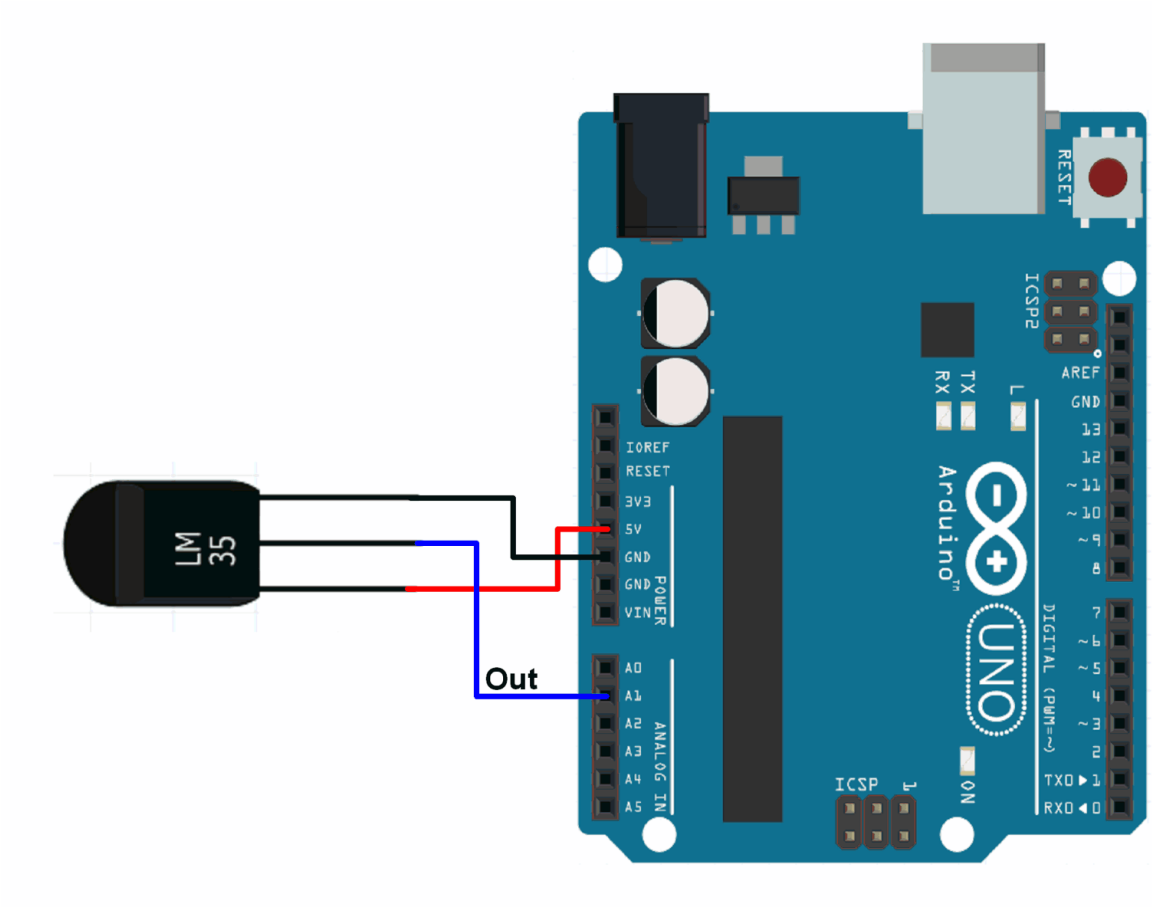


Figure 13: Connection Diagram of the LM35 Temperature Sensor with Arduino

In this way, the Arduino Uno provides a practical and effective solution for measuring and controlling temperature in various applications.

7. Code for the LM35 Temperature Sensor with Arduino Uno

```
const int lm35_pin = A1; /* LM35 O/P pin */

void setup() {
  Serial.begin(9600);
}

void loop() {
  int temp_adc_val;
  float temp_val;
  temp_adc_val = analogRead(lm35_pin);   /* Read Temperature */
  temp_val = (temp_adc_val * 4.88); /* Convert adc value to equivalent voltag
  temp_val = (temp_val/10); /* LM35 gives output of 10mv/°C */
  Serial.print("Temperature = ");
  Serial.print(temp_val);
  Serial.print(" Degree Celsius\n");
  delay(1000);
}
```

VIII. Precautions for use

1. Thermocouples

When a thermocouple is subjected to high temperatures beyond its range of use, it may undergo physicochemical changes, potentially leading to temperature measurement errors or even its deterioration. Furthermore, mechanical stresses should be avoided during its use.

2. Thermistors

Avoid Mechanical Stress: Thermistors are sensitive to mechanical shocks and vibrations, which can affect their accuracy and stability. Handle them carefully during installation and use.

Temperature Limits: Always ensure the thermistor is used within its specified temperature range. Exceeding this range can lead to permanent damage or inaccurate readings.

Proper Insulation: Make sure the thermistor is properly insulated from any environmental factors that could interfere with its operation, such as moisture, dust, or chemicals.

Conclusion

This chapter has provided a comprehensive exploration of temperature measurement techniques, focusing on various sensors and instruments used in practical applications. It began with an introduction to temperature scales and then delved into the operation and characteristics of thermocouples, thermistors, infrared detectors, and pyrometers. Each type of sensor was analyzed in terms of its working principle, benefits, and limitations, along with the appropriate usage scenarios.

The chapter also highlighted the importance of error management in temperature measurements, distinguishing between systematic and accidental errors. Practical considerations, such as sensor selection, mounting techniques, and calibration methods, were thoroughly covered to ensure accurate readings.

Additionally, the use of modern technologies like Arduino Uno for temperature measurement and automatic data acquisition was introduced, showing how these tools can enhance measurement capabilities and data reliability.

By combining theoretical knowledge with hands-on practices, this chapter equips students with a solid understanding of temperature measurement systems, preparing them for practical applications in both academic and industrial settings.

Third Chapter

Flow, Velocity and Pressure Measurements

Introduction

Accurate measurement of flow rates, velocities, and pressures is essential in engineering and scientific research, influencing fluid system design and optimization. This section covers various flow meters, including Pitot tubes, Prandtl tubes, hot-wire and hot-film anemometers, and advanced methods like Doppler laser anemometry and PIV. It also explores pressure measurement techniques using mechanical and piezoelectric sensors, along with electrical methods. Signal processing will be discussed to ensure accurate data interpretation. Emphasizing experimental design and calibration, this overview provides a foundation for understanding fluid measurement methodologies.

I. Flow Measurements

1. The Different Types of Flow Meters

A flowmeter is a device used to measure the flow rate of a fluid, either liquid or gas. In general, the measurement of flow rate is derived from the fluid's velocity as it passes through a known cross-sectional area.

$$Q_v = v * S$$

Where:

- Q_v: Volumetric flow rate in (m^3/s)
- V: Fluid velocity in (m/s)
- S: Cross-sectional area in (m^2)

Therefore, instruments designed to measure flow rates are primarily used to determine the velocity of the fluid.

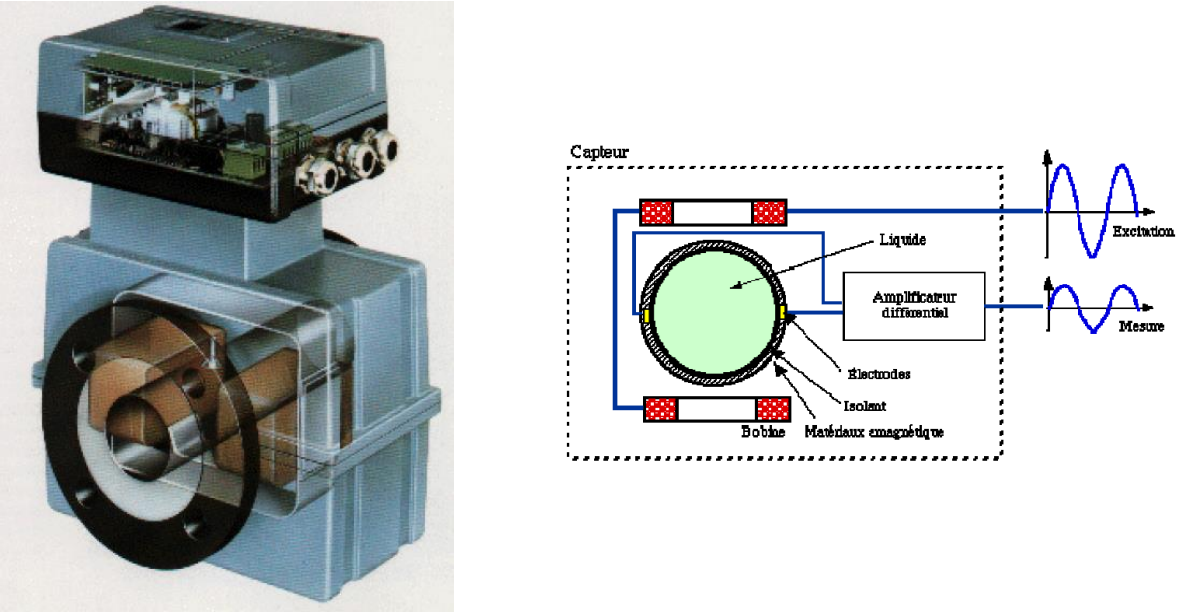


Figure 1: Electromagnetic Flowmeter

Advantages

- The measurement is independent of the physical properties of the fluid (e.g., pressure, temperature, density, viscosity, electrical conductivity, etc.).
- No pressure loss.
- Absence of moving parts.
- High precision and repeatability.
- Corrosion resistance.

2. Mechanical Flowmeters with Electrical Signal Conversion

A test body placed in the measurement pipe is either set into rotation (turbine rotor) or displacement (rotameter float, paddle) under the effect of the fluid's velocity. An appropriate sensor, tachometric in the first case or positional in the second case, delivers an electrical signal proportional to the flow rate.

a) Turbine Flowmeter

The fluid flow causes a turbine placed along the axis of the measurement pipe to rotate. Its rotational speed, measured by a tachometer, is proportional to the fluid's flow velocity. The turbine's rotational speed can be measured using an inductive sensor. Each blade passing in front of the sensor affects the magnetic field, and the flux variation in the receiving coil

generates a pulse with each passage. The number of pulses per unit of time (frequency) is proportional to the instantaneous flow rate.

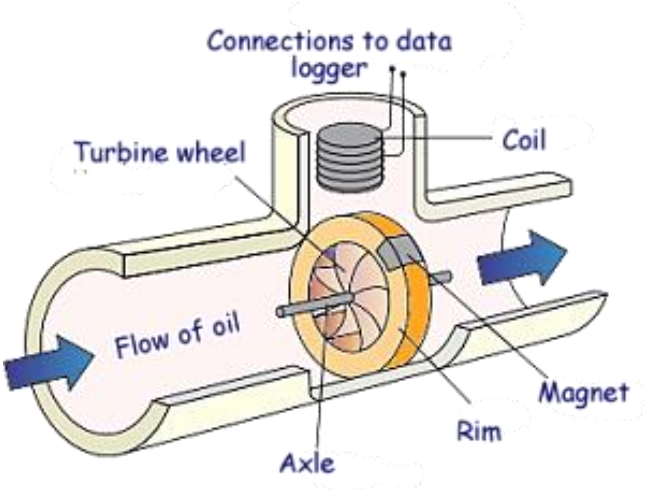


Figure 2: Turbine Flowmeter

Operating Principle:

- ✓ The fluid enters the flow meter and passes through a rotor equipped with paddles.
- ✓ The velocity of the fluid drives the rotation of the rotor.
- ✓ A sensor measures the number of rotations or the rotational speed of the paddles, which is directly proportional to the volumetric flow rate.
- ✓ The collected data is then converted into an electrical signal or a mechanical reading to indicate the flow rate.

Advantages

- ✓ Sensitivity to impurities: Debris or viscous fluids can affect performance.
- ✓ Flow rate limitations: Less effective for very low or very high flow rates.
- ✓ Mechanical wear: The paddles may wear out over time, requiring periodic maintenance.

Disadvantages

- ✓ Sensitivity to impurities: Debris or viscous fluids can degrade performance.
- ✓ Flow rate limitations: Less effective for very low or very high flow rates.

- ✓ Mechanical wear: The paddles may wear out over time, requiring regular maintenance.

Applications

- ✓ Oil and gas industry: Measurement of fuel or gas flow rates.
- ✓ Water treatment: Monitoring of flows in purification systems.
- ✓ Food industry: Tracking of fluids in production lines.

The paddle wheel flow meter remains an economical and efficient solution for numerous applications requiring precise flow measurements under controlled conditions.

b) Rotameter

A rotameter consists of a small float placed in a vertical conical tube. The float is in equilibrium due to the balance of forces: the upward force from the fluid flow and the downward gravitational force. As the flow rate increases, the float rises, and as the flow rate decreases, the float moves downward. The flow rate is proportional to the displacement of the float, with the float's position indicating the rate of flow. This relationship allows the rotameter to provide an easy and direct measurement of flow.

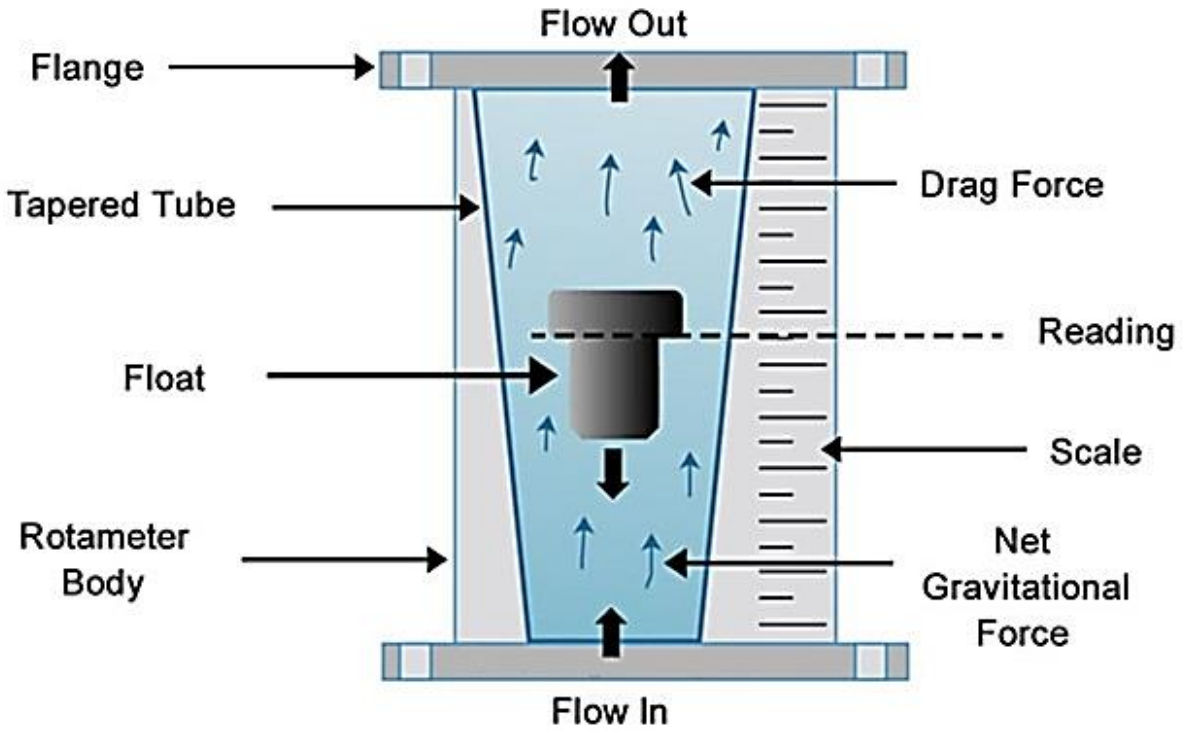


Figure 3: Rotameter

Principle of Operation

- ✓ A float is placed inside a vertically mounted conical tube.
- ✓ As the fluid flows upwards through the tapered tube, the float is lifted by the upward force exerted by the flow.
- ✓ The float's position is determined by the balance between the force of the fluid flow pushing it upwards and its weight pulling it down.
- ✓ The position of the float indicates the flow rate, with the scale on the side of the tube calibrated to show the flow rate corresponding to the float's height.

Applications

- ✓ Chemical Industry: Used for measuring the flow of liquids and gases in pipelines.
- ✓ Water Treatment: Monitoring water flow rates in filtration systems and treatment plants.
- ✓ Medical Devices: Utilized in equipment like anesthesia machines to measure the flow of gases.
- ✓ Food and Beverage Industry: Monitoring the flow of liquids during production and processing.

Advantages

- ✓ Simplicity: Easy to install and operate with minimal maintenance.
- ✓ Cost-effective: Economical for low to moderate flow measurements.
- ✓ Direct Measurement: Provides a visual, direct reading of flow rate.

Disadvantages

- ✓ Limited Range: Less accurate for very high or very low flow rates.
- ✓ Sensitivity to Viscosity: The accuracy can be affected by fluid viscosity or density.
- ✓ Particulate Contamination: Debris or particulates in the fluid can obstruct the float, causing errors.

c) Vane Flowmeter

A vane flowmeter is a device used to measure the flow rate of liquids or gases in a pipeline. It operates by using a rotor (vane) inside the pipe that moves in response to the fluid flow. The vane is subjected to the forces exerted by the fluid, its own weight, and potentially a return spring. The equilibrium position of the vane, which is directly related to the flow rate, can be converted into an electrical signal using a potentiometer attached to the vane's axis.

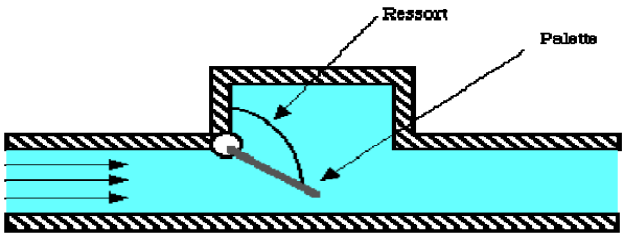


Figure 4: Vane Flowmeter

Applications

- ✓ Industrial Flow Measurement: Used in chemical processing, oil and gas, water treatment, and HVAC systems.
- ✓ Hydraulic Systems: Measuring the flow of hydraulic fluids.
- ✓ Food and Beverage: Monitoring the flow of liquids such as oils, juices, and milk.

Advantages

- ✓ Simple Design: Easy to install and maintain.
- ✓ Accurate: Provides precise measurements for moderate flow rates.
- ✓ Versatile: Can handle various fluid types, including viscous liquids.

Disadvantages

- ✓ Wear and Tear: Mechanical components may wear out, especially when measuring abrasive fluids.
- ✓ Limited Range: Not suitable for extremely high or low flow rates.
- ✓ Pressure Drop: The rotor creates some resistance to the fluid, causing a minor pressure drop.

The **vane flowmeter** is widely used due to its simplicity and reliability, particularly in industrial and commercial settings where consistent flow measurement is necessary.

3. Ultrasonic Flowmeter

An ultrasonic flowmeter is a type of flow measurement device that uses ultrasonic sound waves to determine the flow rate of a fluid in a pipeline. It operates based on the principle of measuring the time it takes for an ultrasonic pulse to travel through the fluid, and how the flow of the fluid affects this travel time.

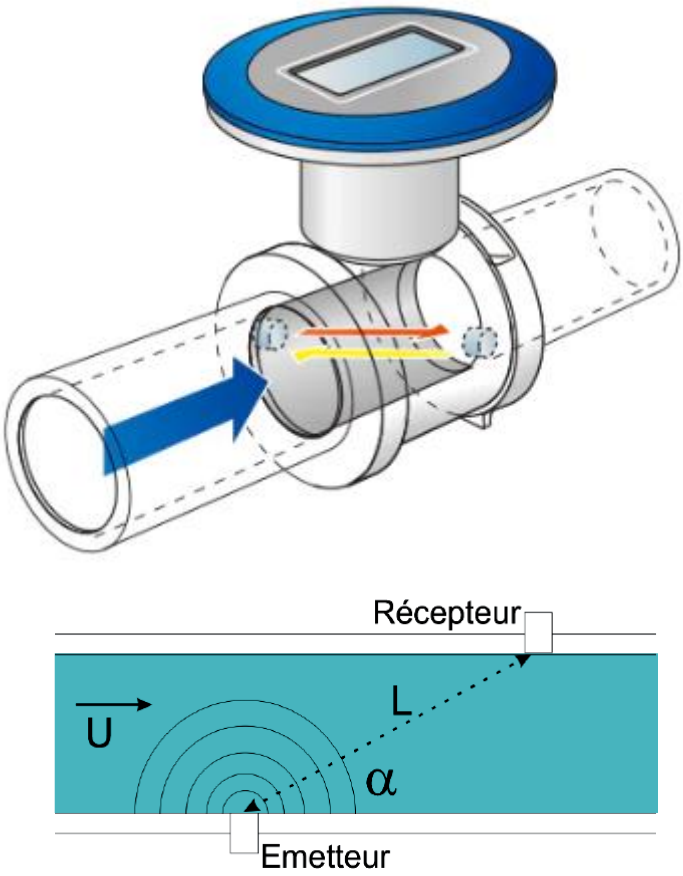


Figure 5: Ultrasonic Flowmeter

$$t = \frac{L}{C + U\cos\alpha}$$

Where

t: Time in seconds (s).

C: The fluid velocity in m/s.

U: The speed of sound in the fluid in m/s.

L: The distance between the transmitter/receiver.

α: The angle between U and the direction defined by the transmitter/receiver pair.

Principle of Operation

There are two main types of ultrasonic flowmeters: Transit-time and Doppler flowmeters.

Transit-Time Ultrasonic Flowmeters

- ✓ In this type, two ultrasonic transducers are placed on opposite sides of the pipe.
- ✓ One transducer sends an ultrasonic pulse upstream, and the other sends a pulse downstream.
- ✓ The flow of the fluid affects the time it takes for each pulse to travel between the transducers.
- ✓ If the fluid is moving in the same direction as the pulse, the downstream pulse travels faster, while the upstream pulse travels slower. The difference in travel times is used to calculate the flow rate.

Doppler Ultrasonic Flowmeters

- ✓ This type measures the frequency shift (Doppler effect) of ultrasonic waves reflected by particles or bubbles in the fluid.
- ✓ As the fluid moves, the frequency of the reflected ultrasonic signal shifts, and the amount of shift is proportional to the flow velocity.

Advantages

- ✓ Non-Invasive: No need to physically alter the pipe, which means no interruption to the system.
- ✓ Accurate: Provides precise flow measurements for various fluid types, especially in large pipes.
- ✓ Low Maintenance: No moving parts means less wear and tear, reducing maintenance costs.
- ✓ Flexible: Can be used for a wide variety of fluid types, including gases and liquids.

Disadvantages

- ✓ Limited for Dirty Fluids: Doppler flowmeters may require particles or bubbles in the fluid, which can be a limitation for clean or low-density fluids.
- ✓ High Initial Cost: Ultrasonic flowmeters can be expensive compared to traditional flow measurement devices.
- ✓ Installation Sensitivity: Requires proper alignment and installation for accurate readings.

4. Differential Pressure Flowmeter

A differential pressure (DP) flowmeter is a device used to measure the flow rate of fluids (liquids or gases) in a pipeline. It operates based on the principle of measuring the pressure difference across a flow restriction or constriction placed within the pipe. The flow rate is then calculated based on this pressure difference, as the fluid's velocity increases at the restriction, leading to a drop in pressure.

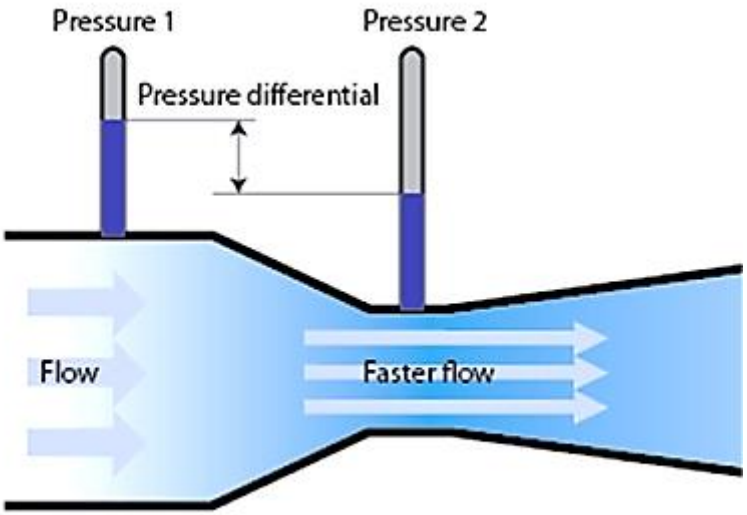


Figure 6: Differential Pressure Flowmeter

Principle of Operation

- ✓ The fluid flows through a pipe where a flow restriction (such as an orifice plate, venturi tube, or flow nozzle) is installed.
- ✓ The restriction causes a pressure drop, and the difference in pressure is measured at two points: one upstream and one downstream of the restriction.
- ✓ According to the Bernoulli principle, the pressure drop is directly related to the square of the flow velocity. The flow rate can be calculated using the pressure differential and a flow coefficient that depends on the type of restriction used.

Types of Differential Pressure Flowmeters

- ✓ **Orifice Plate Flowmeters:** The orifice plate creates a sharp restriction in the flow path, causing a pressure drop. The pressure difference across the plate is used to calculate the flow rate.
- ✓ **Venturi Tube Flowmeters:** A venturi tube has a gradually narrowing section, followed by a larger opening. The pressure drop between the narrowest part and the wider section is used to determine the flow rate.
- ✓ **Flow Nozzle Flowmeters:** Similar to the venturi tube but with a simpler, more abrupt restriction. The pressure difference across the nozzle is used to calculate the flow rate.

Advantages

- ✓ **Accurate and Reliable:** Provides accurate flow measurement, especially for clean, single-phase fluids.
- ✓ **Wide Flow Range:** Suitable for a wide range of flow rates.
- ✓ **Proven Technology:** The technology has been widely used for many years and is trusted for a variety of industrial applications.
- ✓ **Versatile:** Can be used for both liquids and gases, depending on the application.

Disadvantages

- ✓ **Pressure Drop:** The restriction in the pipe causes a pressure drop, which may affect the process or system efficiency.
- ✓ **Complex Calibration:** Requires proper calibration to ensure accurate readings, especially in changing flow conditions.
- ✓ **Not Suitable for Dirty or Slurry Fluids:** It may not work well for fluids with particulates, slurries, or high viscosity.
- ✓ **Flow Conditioning:** Requires straight pipe lengths upstream and downstream of the flow element for accurate measurement.

II. Velocity Measurement

Accurate measurement of fluid velocity is crucial in various industries and applications, ranging from airspeed measurement in aviation to monitoring fluid flow in pipelines. Several instruments are used to measure velocity, each suited for specific conditions and types of fluids. Among these, the Pitot tube and hot-wire and hot-film anemometers are widely used for measuring the velocity of gases and liquids.

1. The Pitot tube

The Pitot tube is a simple device used to measure the flow velocity of a fluid by measuring the dynamic pressure exerted by its movement. This device is widely used in aeronautics, and the following section of the document focuses on this field. It is also used in hydraulics to measure the velocity of a liquid in a pipe, the speed of a boat, a submarine, etc.

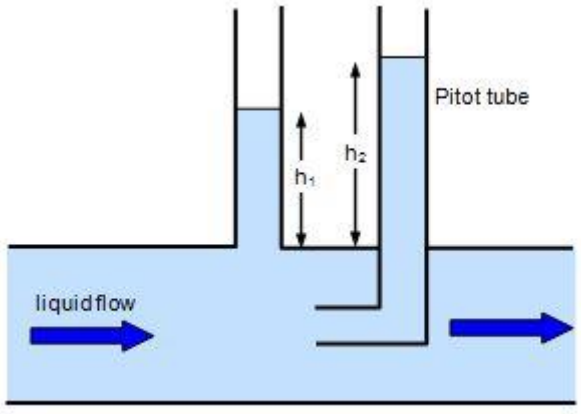


Figure 7: Pitot tube

Principle of Operation

The Pitot tube works by measuring the difference between two pressures:

- ✓ Stagnation Pressure (Total Pressure): This is the pressure measured at the front of the Pitot tube where the fluid is brought to rest (stagnant), typically by facing the flow directly. It includes both the static pressure and the dynamic pressure from the fluid's velocity.
- ✓ Static Pressure: This is the pressure exerted by the fluid when it is not moving, measured through small holes on the side of the tube, perpendicular to the flow direction.

The dynamic pressure (the pressure due to the fluid's velocity) is the difference between the stagnation pressure and static pressure. This pressure difference is then used to calculate the velocity of the fluid.

Formula for Fluid Velocity

$$v = \sqrt{\frac{2\,(P_0 - P)}{\rho}}$$

Where

v: Fluid velocity

P_o: Stagnation pressure

P: Static pressure

ρ: Fluid density

Advantages

- ✓ Simplicity: The Pitot tube is simple in design, easy to install, and inexpensive.
- ✓ Accuracy: Provides accurate velocity measurements when the flow is steady and the pipe diameter is large enough.
- ✓ No Moving Parts: Since it doesn't have moving components, it requires minimal maintenance and has a long lifespan.

Disadvantages

- ✓ Limited to Clean Fluids: Pitot tubes are not suitable for measuring the velocity of dirty fluids or gases with particles, as these can clog the tube.
- ✓ Requires Straight Pipe Length: For accurate measurements, the flow must be steady, and the tube requires a certain straight length of pipe both upstream and downstream to ensure proper fluid flow.
- ✓ Sensitivity to Fluid Properties: The accuracy of the measurements can be affected by the fluid's density and temperature.

2. Hot-Wire and Hot-Film Anemometers

Hot-wire and hot-film anemometers are devices used to measure fluid flow velocity, primarily in gases. They operate by detecting the cooling effect of the fluid on a heated wire or film. The change in temperature or resistance is then used to calculate the flow velocity. These instruments are highly sensitive and are commonly used in research and precise flow measurements.

Hot-Wire Anemometers

A hot-wire anemometer is a device used to measure the velocity of fluid flow, especially in gases. It operates on the principle of heat transfer, where a thin wire is heated by an electrical current. When the fluid flows over the wire, it cools the wire, causing a change in its resistance. This change in resistance is proportional to the fluid velocity, allowing for precise flow measurements.

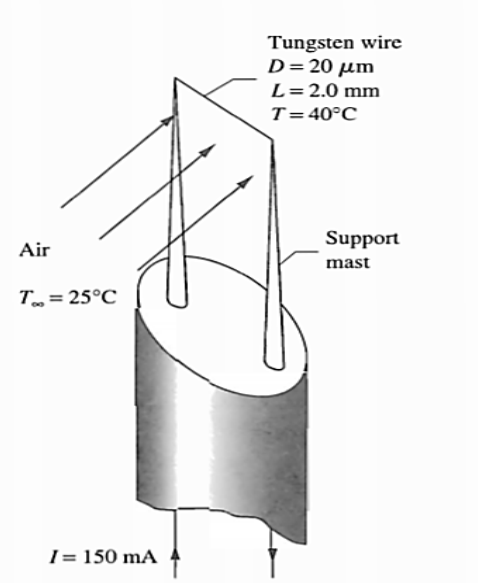


Figure 8: Hot-wire anemometer

Working Principle

- ✓ The wire is heated to a temperature higher than the surrounding fluid using an electrical current.
- ✓ As the fluid flows over the wire, it carries away heat, causing the wire to cool.
- ✓ The degree of cooling depends on the velocity of the fluid. Faster flow results in more cooling, which leads to a greater change in the wire's electrical resistance.
- ✓ The change in resistance is measured and used to calculate the velocity of the fluid.

Applications

- ✓ Airflow Measurement: Commonly used in wind tunnels and HVAC systems to measure air velocity.
- ✓ Industrial Applications: Used for monitoring the flow of gases in various industrial processes.
- ✓ Research: Often employed in fluid dynamics research due to its high sensitivity and accuracy.

Advantages

- ✓ High Sensitivity: Capable of measuring very low flow velocities.
- ✓ Small Size: Can be used in tight spaces or for small flow channels.
- ✓ Real-Time Measurements: Provides immediate results, making it useful for dynamic flow conditions.

Disadvantages

- ✓ Temperature Sensitivity: Requires temperature compensation as fluid temperature can affect resistance measurements.
- ✓ Fragility: The wire is delicate and can be damaged by high-velocity fluids or particles in the flow.
- ✓ Limited to Clean Fluids: Works best with clean gases as particulates can damage the wire.

Hot-Film Anemometers

A hot-film anemometer is a device used to measure the velocity of fluid flow, similar to a hot-wire anemometer but with a more durable design. Instead of a thin wire, it uses a thin metallic or ceramic film coated onto a substrate. The working principle relies on heat transfer: the cooling effect of the flowing fluid on the heated film is used to determine the flow velocity.

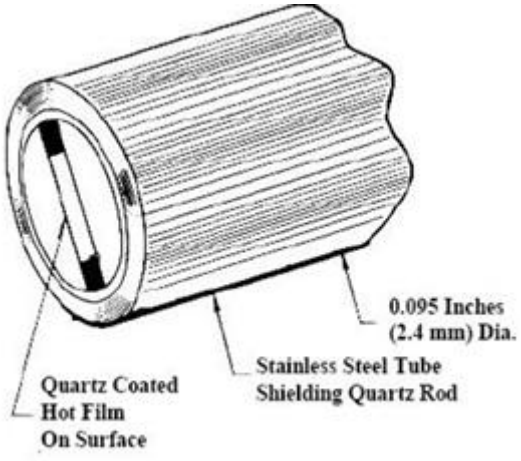


Figure 9: Hot- film anemometer

Working Principle

- ✓ The hot-film element is heated electrically to a temperature higher than the surrounding fluid.
- ✓ As the fluid flows over the film, it dissipates heat from the surface.
- ✓ The amount of cooling depends on the velocity of the fluid. Faster flows lead to more cooling.
- ✓ The change in electrical resistance of the film due to cooling is measured and correlated to the fluid velocity.

Advantages

- ✓ Durability: More robust than hot-wire anemometers, making them suitable for use in environments with particulates or liquids.
- ✓ High Accuracy: Provides precise velocity measurements, especially in turbulent flows.
- ✓ Versatility: Can measure both gases and liquids effectively.

Disadvantages

- ✓ Cost: Generally more expensive than hot-wire anemometers.
- ✓ Calibration: Requires frequent calibration to maintain accuracy, especially in variable temperature conditions.
- ✓ Complexity: Slightly more complex to operate compared to hot-wire systems.

Hot-film anemometers are widely favored for their robustness and ability to function in challenging environments, making them indispensable in both industrial and research applications.

III. Pressure Measurements

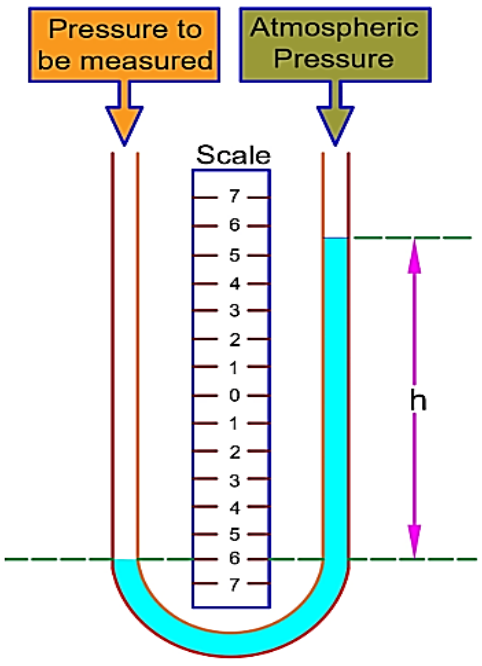
Pressure measurement is essential in many fields to ensure the safety and efficiency of systems. Tools like manometers and piezoelectric sensors are commonly used for accurate readings, each serving specific applications based on their unique principles and advantages.

1. Manometer

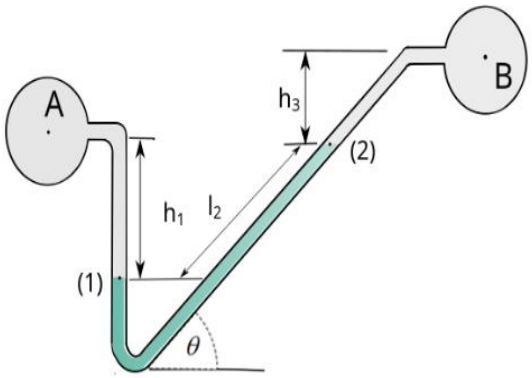
A manometer is a simple and effective device used to measure pressure in liquids or gases. It operates by balancing the pressure of a fluid column against the pressure being measured, using the principles of hydrostatics.

Types of Manometers

- ✓ U-Tube Manometer: Comprises a U-shaped tube partially filled with liquid. The difference in liquid column heights corresponds to the pressure difference.
- ✓ Inclined Manometer: Similar to a U-tube but with an inclined arm for greater sensitivity in low-pressure measurements.
- ✓ Digital Manometer: Uses electronic sensors for more precise and easier-to-read measurements.



a)



b)

c)

Figure 10: a) U-Tube Manometer, b) Inclined Manometer, c) Digital Manometer

Advantages

- Simple, cost-effective, and reliable for a wide range of pressures.
- No external power source required for basic types.

Disadvantages

- Limited to static or slow-changing pressures.
- Requires careful alignment and handling to avoid measurement errors.

Manometers remain a vital tool in pressure measurement, especially in situations where simplicity and reliability are key.

2. Piezoelectric Sensors

History

The deformation, under the effect of a mechanical force, of certain crystals or ceramics known as anisotropic, induces the appearance of an electric voltage U; this is the direct piezoelectric effect, discovered in 1880 by Pierre and Jacques Curie.

Definition

A piezoelectric sensor is a device that utilizes the piezoelectric effect. The piezo element detects mechanical vibrations and waves propagating through a material. Shocks, impacts, and strikes are detected without latency.

This piezo sensor is ideal for detecting small shocks and pressures, which are converted into an electrical signal. It can also be used as a small transducer. Piezoelectric force sensors offer numerous advantages for industrial applications:

Figure 11: Piezoelectric Sensors

Piezoelectric Materials

Quartz is the most well-known material, but it is not commonly used in practice for force or pressure piezoelectric sensors.

Conclusion

This chapter covered the key techniques for measuring flow rates, velocities, and pressures. Mechanical flowmeters (such as turbine, rotameter, and vane flowmeters), advanced technologies like ultrasonic and differential pressure flowmeters, as well as modern sensors like Pitot tubes and anemometers, were discussed.

Finally, pressure measurements using manometers and piezoelectric sensors were explored. These tools provide a practical understanding of measurement principles and their applications in various fields.

General Conclusion

General Conclusion

The pedagogical booklet has provided a comprehensive overview of essential measurement techniques for students in engineering and technical fields. It covered the fundamental concepts of metrology, focusing on accurate measurements of dimensions, temperature, and flow/velocity/pressure. By combining theoretical insights with practical applications, the booklet aimed to equip students with the necessary skills to effectively use various instruments, from mechanical tools like rulers, calipers, and micrometers, to advanced temperature sensors such as thermocouples, thermistors, and infrared detectors.

It also highlighted the importance of managing measurement errors, selecting appropriate sensors, and calibrating instruments to ensure reliability. The introduction of modern technologies, such as the use of Arduino for data acquisition, added a practical dimension to the learning experience, enabling students to engage with contemporary measurement systems. By understanding the principles, uses, and limitations of each tool, students are better prepared to perform precise measurements in both academic experiments and real-world engineering applications. This pedagogical booklet serves as a foundational guide to mastering measurement techniques, providing the groundwork for successful practice across various engineering disciplines.

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الملخص

تقدم هذه المطبوعة البيداغوجية الموجهة لطلبة السنة الثالثة طاقوية دراسة شاملة حول تقنيات القياس الهندسي والفيزيائي، حيث يتناول الفصل الأول قياسات السماكة والطول باستخدام أدوات ميكانيكية مثل المسطرة، الشريط المتري، الكالیبِر الفيرنييري، والميكرومتر، مع شرح مكوناتها وطرق استخدامها وقراءة القيم بدقة. يركز الفصل الثاني على قياسات درجات الحرارة باستخدام تقنيات كالمزدوجات الحرارية، المقاومات الحرارية، والكواشف بالأشعة تحت الحمراء، بالإضافة إلى معالجة الأخطاء واستعراض تطبيقات عملية باستخدام أنظمة الأتمتة مثل .Arduino Uno أما الفصل الثالث فيتطرق إلى قياسات التدفق، السرعة، والضغط باستخدام أجهزة متنوعة مثل عدادات التدفق، أنبوب بيتو، وأجهزة قياس الضغط الكهروضغطية، مع شرح مبادئ عملها وتطبيقاتها العملية. تهدف هذه المطبوعة إلى تمكين الطلبة من اختيار الأدوات المناسبة وإجراء قياسات دقيقة، مما يعزز قدرتهم على تطبيق المعرفة النظرية في المجالات الصناعية والهندسية.

الكلمات المفتاحية :الأدوات الميكانيكية، المزدوج الحراري، البيرومتر البصري، التدفق، مقياس شدة الريح، أنبوب بيتو، Arduino Uno.

Abstract

This handbook, designed for third-year energy engineering students, offers a detailed overview of measurement techniques. It covers thickness and length measurements using mechanical tools like rulers, Vernier calipers, and micrometers, alongside explanations of their components and usage. Temperature measurement techniques, including thermocouples, thermistors, and infrared detectors, are addressed with practical applications and error analysis, emphasizing automation systems like Arduino Uno. Additionally, it explores flow, velocity, and pressure measurements using flowmeters, Pitot tubes, and piezoelectric sensors, focusing on their principles and practical uses. The handbook aims to equip students with the knowledge and skills needed for accurate measurements and the application of theoretical concepts in engineering and industrial fields.

Keywords: Mechanical tools, thermocouple, optical pyrometer, flow, anemometer, Pitot tube, Arduino Uno.