SENSORS AND MEASURING INSTRUMENTS

(22EC101135)

Module 1

MEASUREMENTS AND MEASURING DEVICES

Introduction

A wide variety of instruments are used by scientists, engineers, and other people to conduct measurements. These tools can be as basic as stopwatches, rulers, and scales, or as complex as particle accelerators and electron microscopes used by scientists and engineers.

An instrument is a device or system designed to maintain a functional relationship between the physical variables being measured and their specified properties. It allows communication between a human observer and the operator of a machine or other piece of equipment. The aforementioned functional relationship is only valid as long as the system's static calibration remains constant. The instrument performance of a measurement system is typically described in terms of a combination of its static and dynamic characteristics.

Functional Elements of a Measurement System

Measurement systems must be systematically organized and analyzed in order to comprehend a measuring instrument or system. Functional elements can be used to provide a general description of how a system or measuring device operates. Every functional element consists of one or more components that carry out specific and necessary steps in the measurement. The fine details of an instrument's or system's physical components are not provided by the functional elements. These could be considered fundamental components, the extent of which is defined by how well they work rather than how they are made.

The main functional elements of a measurement system are:

i) Primary sensing element
ii) Variable conversion element
iii) Variable manipulation element
iv) Signal conditioning element
v) Data transmission element
vi) Data presentation element.

Primary sensing element

Initial contact with the quantity or variable being measured is established by a measurement system's primary sensing element. Accordingly, the measurement is initially detected by the primary sensor or detector. Following then, an analog electrical signal is instantaneously created from the measurement. A transducer serves this purpose. In general, a transducer is a device that changes the form of energy used. There are only a few measuring systems where this definition is useful. Transducers are instruments that convert physical quantities into electrical quantities. There may be a difference in the analogous form of the detector element and sensor's output when measuring a quantity. An electrical signal is subsequently produced from this output by a transducer.

Variable conversion element

The variable sensing element's output can produce any kind of signal. There could be an electrical or mechanical signal coming from it. It could be an electrical parameter such as voltage, frequency, etc., or the deflection of an elastic member. The sensor's output may occasionally not be suitable for the measurement system. For the instrument to work as intended, it might be necessary to convert this sensor's output signal into a different suitable format while preserving its informational value. For example, a transducer called a stain gauge can help convert the sensing element's output, which is a very small displacement that is difficult to measure mechanically, into a corresponding electrical signal for further processing.

Variable manipulation element

A signal of any type can be produced by the variable sensing element's output. Signals from mechanical or electrical sources could be the source. It might be the deflection of a flexible component or a voltage, frequency, or other electrical parameter. A sensor's output may occasionally not be appropriate for the measurement system. The output signal from the sensor may need to be converted into a different, acceptable format while keeping the information contained in it in order for the instrument to function as intended. For instance, a transducer known as a stain gauge can be used to convert the ultra-small displacement that is produced by the sensing element and is challenging to measure mechanically into a corresponding electrical signal for additional processing.

Signal conditioning element

Information is contained in the transducers' output signal, which the system processes further. Numerous transducers typically produce a voltage or another type of electrical signal, and frequently, these signals are produced at very low voltages—of the order of mV or even μV. Unwanted signals, such as noise, may contaminate this signal as a result of an external source interfering with the original output signal. An additional issue is that the processing equipment itself may distort the signal. Before the signal can be transmitted to the following stage, any undesired contamination or distortion that has been detected in it must be eliminated. If not, we might obtain extremely distorted outcomes that are not representative of its true value.

The prevention or removal of signal distortion or contamination is the answer to these issues. Signal conditioning refers to the procedures used on the signal to eliminate signal distortion or contamination. Along with variable manipulation and conversion, the term "signal conditioning" refers to a wide range of additional tasks. Amplification, attenuation, integration, differentiation, addition, and subtraction are just a few examples of the many linear signal conditioning techniques. Certain operations, like modulation, filtering, clipping, etc., might not be linear. In order to prepare the signal for transmission to the following stage of the system, signal conditioning procedures are applied to it. The Signal Conditioning Element is the component in any instrument or instrumentation system that carries out this function.

Data transmission element

The components of an instrument are physically separated in a few different scenarios. Data transmission between elements becomes necessary in these kinds of circumstances. We refer to the element that carries out this task as a data transmission element. For instance, control stations on Earth are physically apart from satellites or aircraft. Control stations use complex telemetry systems to transmit radio signals to direct the movements of aircraft or satellites. The intermediate stage is the term used to describe the signal conditioning and transmission phase.

Data presentation element

Giving information about the quantity being measured to the personnel using the instrument or system for monitoring, controlling, or analyzing is the aim of the data presentation element. A format that is simple to read must be used to present the information. In the event that data needs to be monitored, visual display devices are necessary. These devices could be voltmeters and ammeters, or other analog or digital indicating instruments. Devices like high-speed cameras, televisions, CRT storage, printers, analog and digital computers, and magnetic tape recorders could be used if the data needed to be recorded. Control and analysis are done with computers and control components. The final stage of a measurement system is referred to as the terminating stage.

The data presentation element's job is to give information about the quantity being measured to the personnel using the instrument or system so they can monitor, control, or analyze it. An easily readable format must be used to present the information. If data is to be monitored, visual display devices must be used. These devices could be analog or digital indicating devices, like ammeters and voltmeters. Devices like magnetic tape recorders, high-speed cameras, televisions, CRT storage, printers, and analog and digital computers could be used if the data needed to be recorded. For analysis and control, computers and control components are utilized. The term "terminating stage" describes a measurement system's final stage.

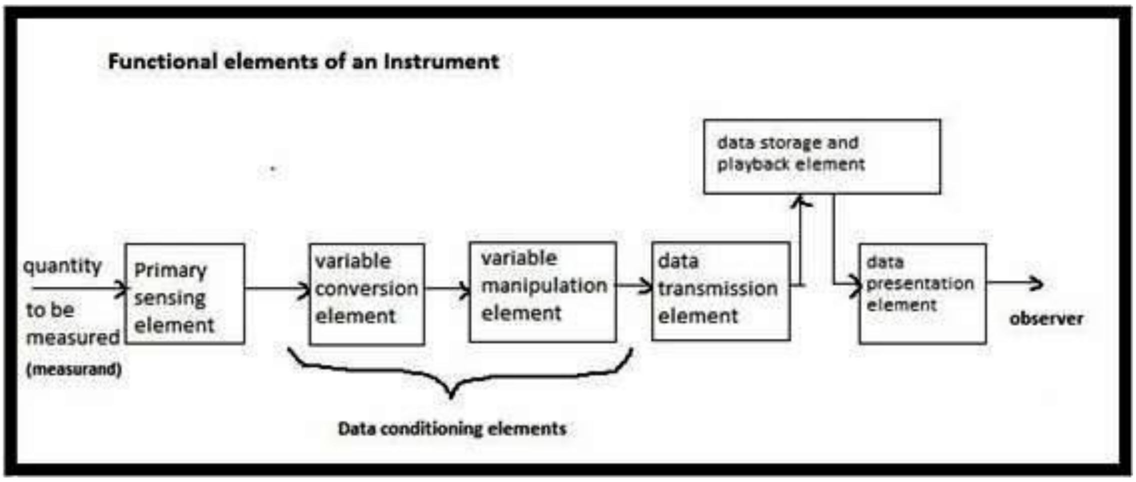


Fig. Block diagram of functional elements of a measurement system / instrument

Functional Elements of a Bourdon Pressure Gauge

Let's examine the simple Bourdon tube pressure gauge shown in the following figure as an example of a measurement system. An excellent example of a measurement system is this gauge. In this case, the variable conversion element and the primary sensing element are the Bourdon tube. It recognizes the input quantity, which is pressure in this case. Pressurization causes the closed end of the Bourdon tube to move. Thus, pressure is converted into a small displacement. The closed end of the Bourdon tube is mechanically connected to a sector-pinion gearing arrangement. The small displacement is amplified by the gearing arrangement, which rotates the pointer through a wide angle. As a result, the mechanical linkage acts as a data transmission element and the gearing arrangement as a data manipulation component. The dial scale on the gauge body represents the quantity being measured and is a component of the data presentation. With this device, analog information is transmitted.

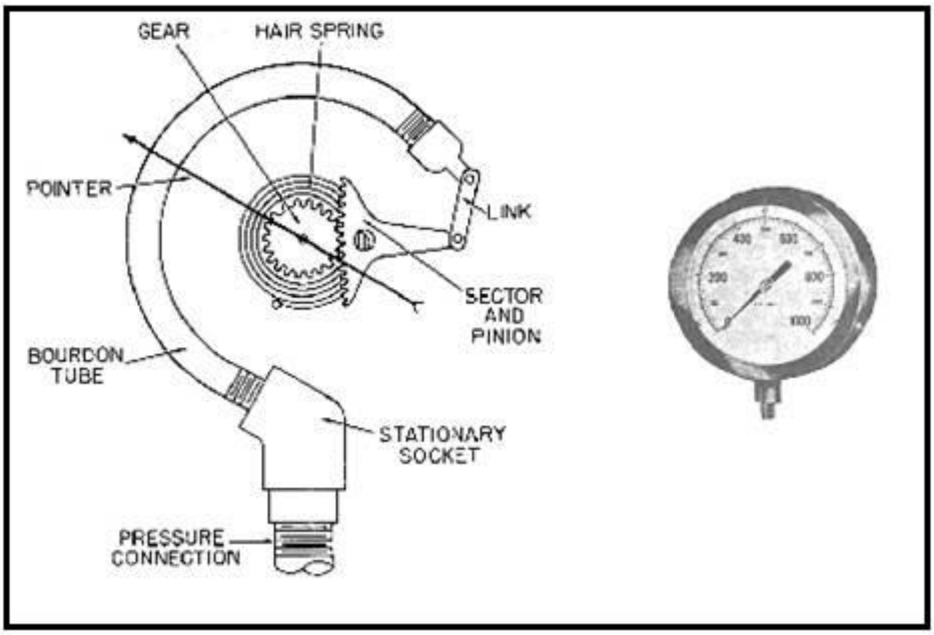


Fig. Bourdon Pressure gauge, the pressure measuring instrument

Errors:

Errors arise due to: 1. Inaccurate sighting of the measurement, or parallax error

2. Error in calibration (should the scale not be drawn precisely).

3. Zero error: This occurs when a device is either incorrectly set to zero or lacks a zero.

4. Damage (if there is any faulty or damaged equipment).

5. The measurement device's limit of reading (the measurement is only as accurate as the smallest unit

Definition of Error

1. Limit of Reading: the measuring device's smallest unit of measurement.

2. Half of the reading limit is the Greatest Possible Error, also known as the Absolute Error.

3. The Upper and Lower Limits: these represent the lowest and maximum values that a measurement can fall within.

TYPES OF ERRORS

Errors are typically divided into the following three main categories:

Gross error

This category of errors typically results from improper instrument reading, improper data recording during experimentation, or improper instrument use by the instrument operator.
As long as people are involved, there will undoubtedly be some serious mistakes made. Even though it's probably impossible to completely eradicate glaring mistakes, one should make an

effort to prevent them. It might be necessary to take the following steps to lessen the effects of gross errors.
When reading and documenting the data, extreme caution should be used.
Different experimenters should take two or more readings.

Systematic error

Four categories can be used to classify systematic errors:

Instrumental Error

The main causes of these errors are as follows:
due to inherent instrument shortcomings (which could be brought on by issues with the mechanical structure's design, calibration, or operation).
because the instruments were misused. One possible reason for this could be that one of the instruments' zero adjustments was missed.
because of how the instruments are loaded. These mistakes can be avoided, or at least minimized, by applying the following techniques:
Measurement protocol needs to be well thought out.
After these errors are found, correction factors need to be used.
Carefully recalibrate the device.
Make intelligent use of the instrument.

Observational Errors

because of the types, whether digital or analog, on the instrument display.
due to parallax, where the measurement point and the eye should line up exactly.
Note: Digital display instruments can be used to completely eliminate these errors.

Environmental Errors

because of factors outside the measuring device, like the surroundings of the instrument. Changes in pressure, humidity, dust, vibration, or external magnetic or electrostatic fields can all contribute to these conditions. Corrective measures like the following can be used to reduce or eliminate these errors:
Maintain the state as much as you can.
Utilize tools or equipment that is resistant to these impacts.
Use a method that gets rid of these disruptions.

Random error

Even after accounting for all systematic and obvious errors, some experiments' results vary from one to the next. It is impossible to eliminate or reduce these errors because the cases of these errors are not identified. Statistical analysis can be used to determine the best outcome when these kinds of errors occur.

Error in Measurement

The difference between a quantity's real value and the value obtained from the measurement is known as the measurement's error. The random error (triggered by the measuring instrument's accurateness boundary) can be improved (reduced) by repeating the measurement, but the systemic error (caused by an incorrect calibration of the measuring instrument) cannot be improved.).

Absolute error

It can be summed up as the discrepancy between the variable's measured and expected values. e = absolute error in this case Yn = predicted value Xn = value that was measured

$$e = Y_n - X_n \qquad \text{(Equation 1.1)}$$

c) Relative error (Percent of Error) To express the error as a percentage,

$$Percent\ error = \frac{absolute\ error}{expected\ error} \times 100\%$$

$$Absolute\ error,\ e = Y_n - X_n$$

$$Percent\ error = \frac{Y_n - X_n}{Y_n} \times 100\%$$

Problem: The expected value of the voltage across a resistor is 50V; however, measurement yields a value of 49V. Calculate

a) The absolute error
b) The percent of error

PERFORMANCE CHARACTERISTICS:

The performance characteristics of an instrument are mainly divided into twocategories:

i) Static characteristics

ii) Dynamic characteristics

Static characteristics:

"Static characteristics" refers to the set of standards established for the instruments that are used to measure quantities that exhibit either slow temporal variation or are mostly constant, meaning they do not vary with time.

The various static characteristics are:

i) Accuracy
ii) Precision
iii) Sensitivity
iv) Linearity
v) Reproducibility
vi) Repeatability
vii) Resolution
viii) Threshold
ix) Drift
x) Stability
xi) Tolerance
xii) Range or span

Accuracy:

a) It refers to how closely the reading matches the actual value of the quantity that needs to be measured. The following are some ways to express accuracy:

b) Point accuracy:

There is only one specific scale point at which this accuracy is specified.

About the accuracy at any other point on the scale, it provides no information.

c) Accuracy as percentage of scale span:

Scale range can be used to express the accuracy of an instrument with uniform scale.

d) Accuracy as percentage of true value:

Defining accuracy in terms of the actual value of the quantity being measured is the most effective way to conceptualize it. Precision can be defined as the degree of agreement between a set of measurements, given a fixed value of a quantity. It is a measure of reproducibility.

The precision is composed of two characteristics

Conformity:

Let us consider an ohmmeter measuring a resistor whose true value is 2385692. However, because there is no appropriate scale, the reader can consistently read a value of 2.4 M. It is a precision error brought about by the scale reading's limitations.

a) Number of significant figures:

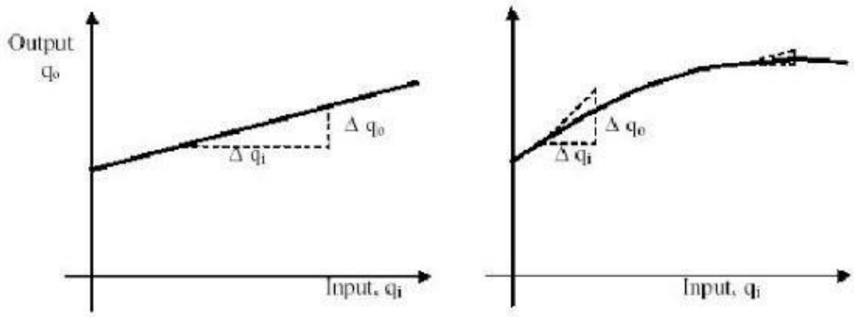
The number of significant figures used to express the reading indicates the measurement's precision. The important numbers provide precise information about the amount's magnitude and measurement accuracy.
The precision can be represented mathematically as follows:
Where, P = precision

$$P = 1 - \left| \frac{X_n - \overline{X_n}}{\overline{X_n}} \right|$$

Xn = Value of nth measurement
Xn = Average value the set of measurement values

Sensitivity:

The instrument's sensitivity indicates the smallest change in the measured variable that it reacts to. Its definition is the relationship between changes in an instrument's output and changes in the value of the quantity to be measured. It can be expressed mathematically as,



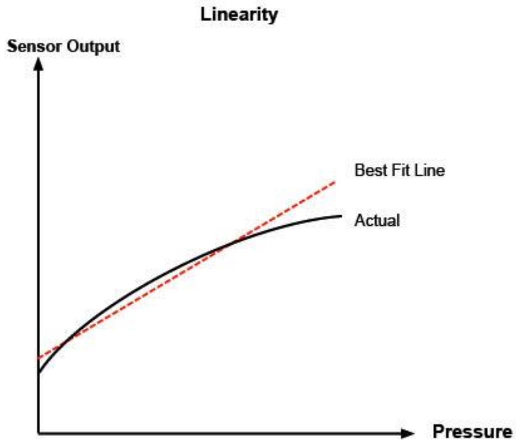
$$\text{Sensitivity} = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

$$= \frac{\Delta q_o}{\Delta q_i}$$

As a result, if the calibration curve is linear as displayed, the instrument's sensitivity is represented by the calibration curve's slope. Should the calibration curve not be linear as depicted, the sensitivity will fluctuate depending on the input. As the reciprocal of sensitivity, inverse sensitivity, also known as the deflection factor, is defined. Deflection factor, or inverse sensitivity, equals 1.

Linearity:

A measure of a measurement's consistency across its whole range is called linearity. Though it can be deceptive when used alone, it is generally a reliable indicator of a sensor's performance quality. Simply put, linearity indicates the degree to which the measurement made by the instrument matches reality.



Resolution: It will once more be discovered that the output remains unchanged until a specific increment is exceeded if the input is gradually increased from an arbitrary input value. Resolution is the name given to this increase.

Threshold: There will be a minimum value below which there is no discernible change in the output when the instrument input is increased very gradually from zero. This lowest number establishes the instrument's threshold.

Stability:

It is the capacity of an apparatus to maintain its functionality for the duration of its designated operating life.

Tolerance: The tolerance is a number that is used to define the maximum allowable error in the measurement.

Range or span: An instrument's range, or span, is the set of lowest and maximum values for a quantity that it is intended to measure.

Dynamic characteristics:

The term "dynamic characteristics" refers to the set of standards established for the instruments that are subject to quick changes over time.

The various static characteristics are:

Speed of response

Measuring lag

Fidelity

Dynamic error

Speed of response: The quickness with which a measurement system adapts to variations in the measured quantity is its definition.

Measuring lag: It is the inability of a measurement system to react quickly enough to changes in the quantity being measured. Two types of measuring lags exist:

Retardation type: Under this scenario, the measurement system starts responding as soon as the measured quantity changes.

Time delay lag: In this instance, the application of the input is followed by a dead time before the measurement system responds. A measurement system's fidelity is determined by how well it detects changes in the measurand quantity without introducing dynamic error.

Dynamic error: If no static error is assumed, it is the discrepancy between the measurement system's indicated value and the actual value of the quantity that changes over time. Measurement error is another name for it.

Calibration

The difference between the quantity's indicated value and its actual value as determined over time by the measurement system, if no static error is assumed. It is also known as measurement error.

Definition of Calibration :

To remove the unknown accuracy of the original device, a device must be calibrated by comparing it to a known, accurate standard. A known sample of the variable to be measured must therefore be introduced precisely in order to calibrate a measuring system. The calibration process then establishes the proper output scale for the measurement system; in other words, the readout device of the measurement system needs to be adjusted until its scale accurately reads the known sample of the variable that has been introduced.

Purpose of Calibration :

1) To obtain meaningful results, any measuring system must be calibrated.

2) If the measuring and sensing systems are not the same, then the system must be calibrated as an integrated whole in order to account for each component's propensity to produce error.

3) The readout device should display an output equal to the known measured input close to the full-scale input value after calibration, which is typically accomplished by making adjustments so that it produces zero output for zero-measured input.

4) Any calibration of a measuring system must be carried out in an environment that is as similar to the one in which the actual measurements are to be taken as feasible.

The system's calibration standard should normally be at least ten times more accurate than the accuracy of the intended measurement system. 5) It is also essential to know the reference measured input with even more precision.

Calibration procedure

There are two different methods for calibrating instruments:

(a) Primary calibration (b) Secondary calibration

(a) Primary calibration

In accordance with this process, a system is calibrated against a primary standard. Primary calibration refers to the process of calibrating flow meters where the flow is ascertained by measuring the volume or mass of fluid in addition to time.

(b) Secondary calibration

This process involves using a primary calibration-calibrated device as a secondary standard for subsequent calibration of less accurate devices.

As a secondary standard for calibrating other flow devices, a turbine-style flow meter is employed.

Secondary calibration is of two types namely

(i) Direct calibration

(ii) Indirect calibration

(i) Direct calibration

The device to be calibrated is connected in series with a standard device in this procedure. Comparing the two devices' readings over the intended range allows for calibration to be completed.

(ii) Indirect calibration

In this procedure, a standard device and the device to be calibrated are connected in series. Calibration can be finished by comparing the readings from the two devices over the designated range.

Errors Due To Calibration:

Before being used, every instrument needs to be calibrated. The process of calibrating a measurement system involves providing it with a known input and taking the appropriate steps to ensure that the system's output and input match.

A reading with a higher degree of error will be displayed if the instrument is not calibrated correctly which is called as calibrationerror. These errors are fixed because they were introduced into the measurement system due to incorrect calibration.

Statistical Analysis of Random Uncertainties

All instruments must be calibrated before being used. Giving a measurement system a known input and taking the necessary actions to make sure the system's output and input match are the steps involved in calibrating the system.

If the instrument's calibration is off, a reading with a larger degree of error will be shown. This is referred to as a calibration error. Because of improper calibration, these errors were introduced into the measurement system and have been corrected.

With one more example, we review the idea of random error. Let's return to the previously discussed stopwatch example. We came to the conclusion that our ability to determine when to stop the stopwatch is not entirely certain. We could stop the stopwatch a little too early or a little too late, depending on how random we are in our decisions. This will show up as random error with a normal, or Gaussian, distribution over the course of multiple measurements.

As was previously mentioned, systematic errors are mistakes brought on by instruments or other forms of recurring bias. Assume we have created a five-trial experiment where we use a scale to measure the mass of a substance. Unbeknownst to us, the scale doesn't zero correctly even though we zero it before every measurement. Hence, a systematic error results from the mass measurement being off by the same amount for each trial. In situations where systematic errors are suspected, statistics should not be used because it is incapable of detecting such errors. Rather, by employing calibration standards and other verification methods, an experimentalist should try to minimize systematic errors.

Mean and Standard Deviation

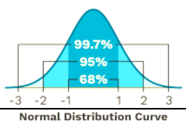
Statistical methods can be employed to characterize the data set once we are certain that systematic errors have been adequately reduced and that the residual error is probabilistic. The best estimate of the true quantity, x, given N measurements of a given quantity, is the mean, x, of the measurements:

$$\overline{X} = \frac{\sum X}{N}$$

The error, σx, can also be estimated. In order to achieve this, we consider the deviation of each measured value from the mean. The deviation of a specific trial from the mean is represented by the value xi - x (also called a residual). Since the residuals always add up to zero due to the way the definition of x is constructed, we are unable to sum the residuals. Subsequently, the square the residuals, add them up, and calculate the square root of the total to obtain the standard deviation, or σ:

$$s_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

n = The number of data points
x_i = Each of the values of the data
$\bar{x}$ = The mean of x_i



Normal Distribution Curve

The average uncertainty of measurements x1,__, xN is described by the standard deviation. The term "root-mean-squared" (RMS) deviation is another name for it occasionally. Moreover, the term "standard deviation" is occasionally defined differently, substituting the value of "N" in (28) with "N - 1". In particular, when N is small, the result of x obtained from this second definition is more conservative. However, the differences between the two forms are often minimal. It is safest to use the form with (N – 1) if we are not sure which method to use.

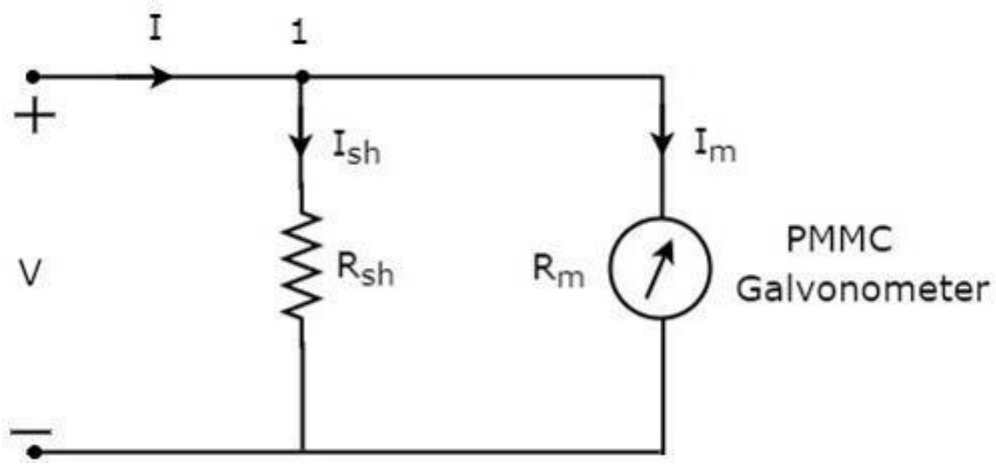
Measuring Instrumenting

DC Ammeters

The rate of electric charge flow is known as current. Direct Current (DC) is the term used to describe the current that results when this electric charge only flows in one direction. DC ammeter is the name of the device that measures direct current.

The Permanent Magnet Moving Coil (PMMC) galvanometer can function as a DC ammeter when a resistor is connected in parallel with it. Another name for the parallel resistance found in DC ammeters is shunt resistance, or just shunt. In order to measure the large value DC current, the resistance value should be taken into consideration.

The figure below displays the DC ammeter circuit diagram.



The electrical circuit branch where the DC current is to be measured and this DC ammeter must be connected in series. The elements share the same voltage and are connected in parallel. Because the two components in the circuit above are connected in parallel, the voltage across the galvanometer voltage across resistance, Rm, and the shunt resistor, Rsh, are therefore equal.

Mathematically, it can be written as

$$I_{sh} R_{sh} = I_m R_m$$

$$R_{sh} = I_m R_m / I_{sh} I_{sh}$$

The **KCL equation** at node 1 is

$$-I + I_{sh} + I_m = 0$$

(Equation 1)

$$-I + I_{sh} + I_m = 0$$
$$\Rightarrow I_{sh} = I - I_m$$

Substitute the value of I_{sh} in Equation 1.

$$R_{sh} = \frac{I_m R_m}{I - I_m} \qquad \text{(Equation 2)}$$

Take, I_m as common in the denominator term, which is present in the right hand side of Equation 2

$$R_{sh} = \frac{I_m \quad R_m}{I_m\left(\frac{I}{I_m} - 1\right)}$$

$$\Rightarrow R_{sh} = \frac{R_m}{\frac{I}{I_m} - 1} \qquad \text{(Equation 3)}$$

Where,

R_{sh} is the shunt resistance

R_m is the internal resistance of galvanometer

I is the total Direct Current that is to be measured

I_m is the full scale deflection current

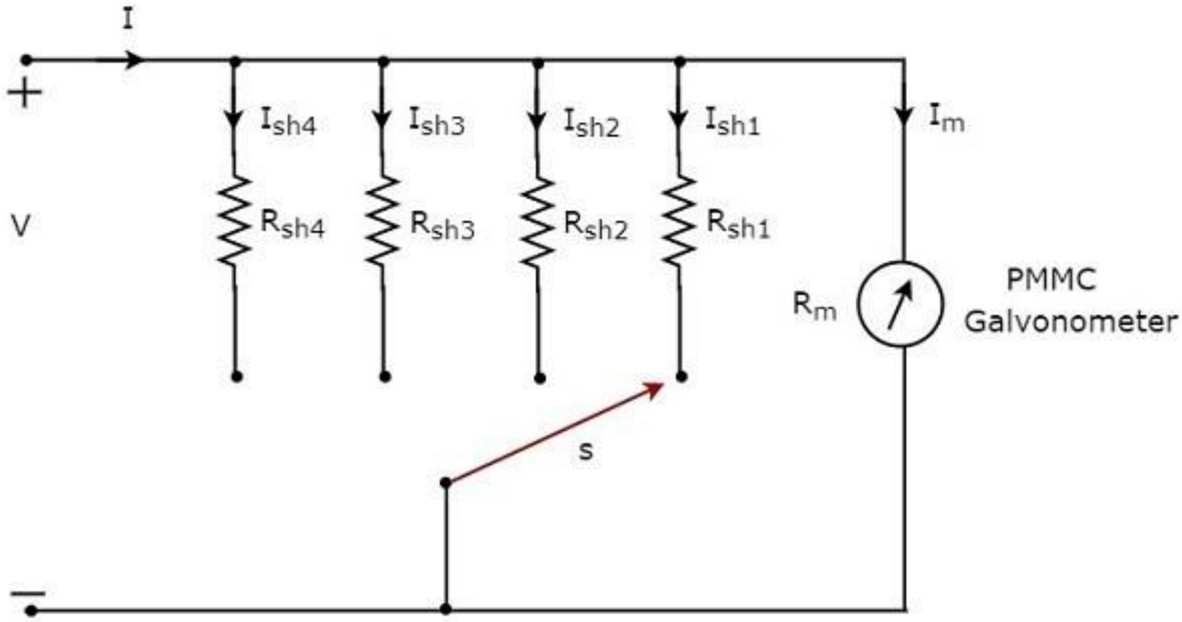
The ratio of total Direct Current that is to be measured, I and the full scale deflection current of the galvanometer, I_m is known as **multiplying factor, m**. Mathematically, it can be represented as

$$m = \frac{I}{I_m} \qquad \text{(Equation 4)}$$

$$R_{sh} = \frac{R_m}{m-1} \qquad \text{(Equation 5)}$$

Multi Range DC Ammeter

This DC ammeter needs to be connected in series with the electrical circuit branch where the DC current is to be measured. With a parallel connection, all of the components have the same voltage. The circuit above has two components connected in parallel, which means that the voltage across the shunt resistor, Rsh, and the galvanometer voltage across resistance, Rm, are exactly equal.



Attach this multi-range DC ammeter in series with the branch to measure the necessary direct current range in an electric circuit. The desired range of currents can be chosen by connecting the switch to the proper shunt resistor.

Let m1, m2, m3, and m4 be the multiplying factors of the DC ammeter when we consider the total direct currents to be measured as I1, I2, I3, and I4, respectively. The following lists the formulas for each multiplying factor.

$$m_1 = I_1 / I_m$$

$$m_2 = \frac{I_2}{I_m}$$

$$m_3 = \frac{I_3}{I_m}$$

$$m_4 = \frac{I_4}{I_m}$$

In above circuit, there are four **shunt resistors**, $R_{sh1}, R_{sh2}, R_{sh2}$ and R_{sh4}. Following are the formulae corresponding to these four resistors.

$$R_{sh1} = \frac{R_m}{m_1 - 1}$$

$$R_{sh2} = \frac{R_m}{m_2 - 1}$$

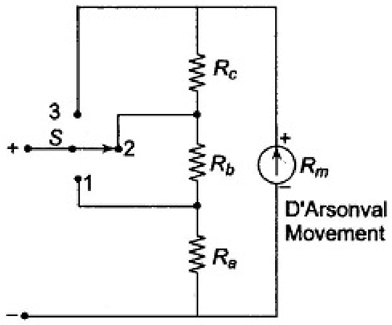
$$R_{sh3} = \frac{R_m}{m_3 - 1}$$

$$R_{sh4} = \frac{R_m}{m_4 - 1}$$

The above formulae will help us find the resistance values of each shunt resistor.

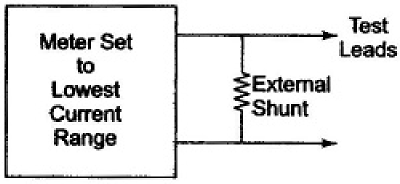
The Aryton Shunt or Universal Shunt:

The Aryton shunt makes it impossible for the meter to be in the circuit without one. The slight increase in overall resistance is the cost incurred to obtain this benefit. The circuit of an Aryton shunt ammeter is depicted in Figure. When the switch is in position "1," resistance R is in parallel with the series combination of R R and the meter movement in this circuit. Because of this, the shunt's current flow is greater than the meter movement's, protecting the latter and reducing its sensitivity. When the switch is in the "2" position, the meter movement is connected in series with resistance R and R connected in parallel. The circuit must have an Aryton shunt in order for the meter to work. There is a price for this benefit: a small rise in overall resistance. Figure shows the circuit of an Aryton shunt ammeter. Resistance R is connected in parallel to the circuit's series combination of R R and the meter movement when the switch is in position "1." This reduces the meter movement's sensitivity and protects it by allowing the shunt to have a higher current flow than it does. Resistance R and R are connected in parallel when the switch is in the "2" position, and the meter movement is connected in series with them.



Aryton Shunt

Extending of Ammeter Ranges:

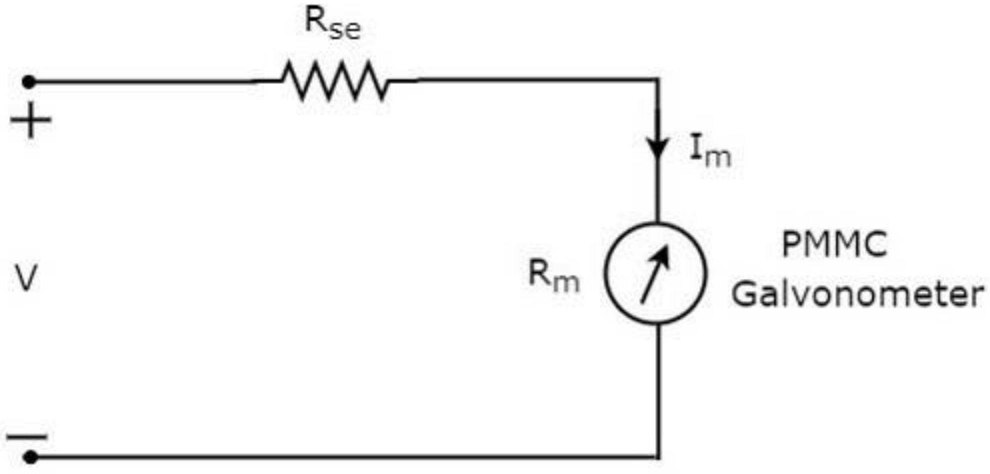


Extending of Ammeters

As illustrated in Fig., the range of an ammeter can be extended to measure high current values by connecting external shunts to the basic meter movement, which is typically the lowest current range. Remember that you cannot shorten the range of the basic meter movement. (If the meter is used to measure 1 μA using a 100 μA movement with 100 scale division, for example, it will deflect by only one division. As a result, it is practically impossible to go below the fundamental range.)

DC Voltmeters

The DC voltage across any two points in an electric circuit can be measured with a DC voltmeter. The Permanent Magnet Moving Coil (PMMC) galvanometer and resistor combined function as a DC voltmeter if they are connected in series. Alternatively known as series multiplier resistance, or just multiplier, the series resistance used in DC voltmeters belongs to this category. It basically restricts the current passing through the galvanometer so as to keep the current flowing through the meter from going over the full deflection value of the scale. Below is a figure that displays the DC voltmeter circuit diagram.



This DC voltmeter must be positioned between the two points in an electric circuit where the DC voltage is to be measured.Wrap the above circuit's loop with KVL.

$$V - I_m R_{se} - I_m R_m = 0 \quad \text{(Equation 1)}$$

$$\Rightarrow V - I_m R_m = I_m R_{se}$$

$$R_{se} = (V - I_m R_m)/ I_m \qquad \text{(Equation 2)}$$

R_{se} is the series multiplier resistance

V is the full range DC voltage that is to be measured

I_m is the full scale deflection current

R_m is the internal resistance of galvanometer

The voltage drop across the galvanometer, Vm, is the ratio of the full range DC voltage to be measured, Vand. This ratio is represented by the multiplying factor, m. Based on mathematics, it can be

$$m = V/V_m \qquad \text{(Equation 3)}$$

The full range DC voltage that needs to be measured, V, can be found using Equation 1.

$$V = I_m R_{se} + I_m R_m \qquad \text{(Equation 4)}$$

The full scale deflection current (Im) and the internal resistance (Rm) of the galvanometer multiply to produce the DC voltage drop across the device. It can be expressed mathematically as

$$V_m = I_m R_m \qquad \text{(Equation 5)}$$

Substitute, Equation 4 and Equation 5 in Equation 3.

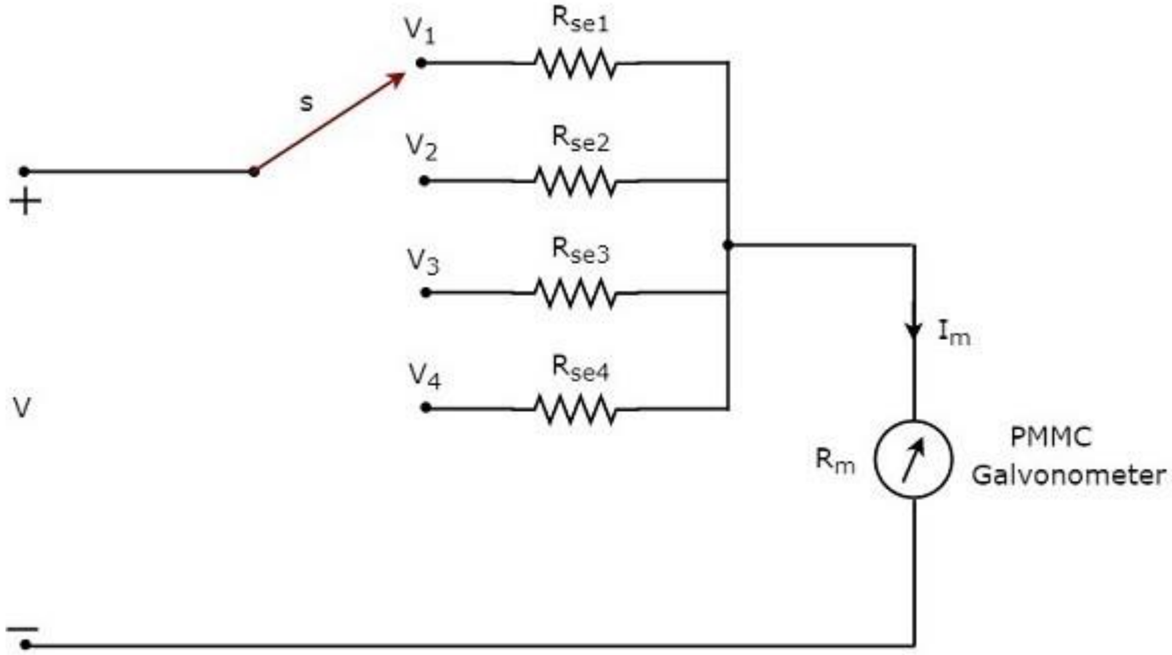
$$\Rightarrow m = \frac{R_{se}}{R_m} + 1$$

$$\Rightarrow m - 1 = \frac{R_{se}}{R_m}$$

$$R_{se} = R_m\,(m - 1) \qquad \text{(Equation 6)}$$

Multi Range DC Voltmeter

Measurements within a specific DC voltage range can be made with the DC voltmeter.



Using multiple parallel multiplier resistors in place of a single multiplier resistor is necessary if we want to use the DC voltmeter to measure DC voltages over a range of values. The PMMC galvanometer is connected in series with the entire stack of resistors. The figure below displays the circuit diagram for a multi-range DC voltmeter.

One can measure a specific range of DC voltages with the DC voltmeter.

A single multiplier resistor cannot be used to measure the DC voltages of multiple ranges with a DC voltmeter; instead, multiple parallel multiplier resistors must be used, and the PMMC galvanometer is connected in series with the entire set of resistors. The multi range DC voltmeter's circuit diagram is displayed in the figure below.

$$m_1 = \frac{V_1}{V_m} \qquad m_3 = \frac{V_3}{V_m}$$

$$m_2 = \frac{V_2}{V_m} \qquad m_4 = \frac{V_4}{V_m}$$

The four series multiplier resistors in the circuit above are designated as Rse1, Rse2, Rse3, and Rse4. These four resistors' corresponding formulas are listed below.

$$R_{se1} = R_m (m_1 - 1)$$

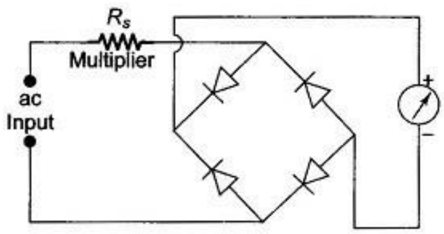
$$R_{se2} = R_m (m_2 - 1)$$

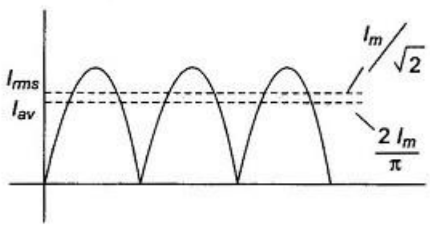
$$R_{se3} = R_m (m_3 - 1)$$

$$R_{se4} = R_m (m_4 - 1)$$

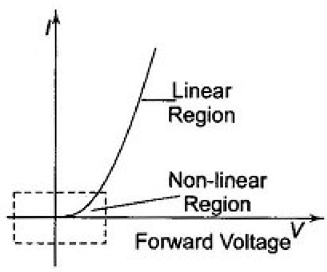
AC Voltmeter using Rectifiers:

AC Voltmeters with rectifier-based technology: These meters usually pair a PMMC movement with a rectifier configuration. The recommendation is for silicon diodes due to their low reverse current and high forward current ratings.





A multiplier, a bridge rectifier, and a PMMC movement make up the circuit of the ac voltmeter shown in Figure. An oscillating full wave dc is produced by the bridge rectifier. A consistent deflection proportional to the average current value is shown by the meter because of the movable coil's inertia. For an alternating sine wave input, the meter scale is typically calibrated to yield the RMS value.



Reducers that are useful are non-linear devices, especially when the forward current is low. As a result, on a low range voltmeter, the meter scale is typically crowded at the lower end and is not linear. Because of the diode's high forward resistance in this section, the meter's sensitivity is low. Additionally, the temperature affects the diode resistance.

The rectifier tends to bypass higher frequencies and displays capacitance characteristics when reverse biased. For every 1 kHz increase in frequency, the meter reading could be off by as much as 0.5%.

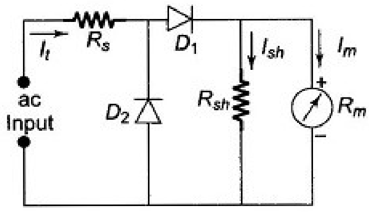
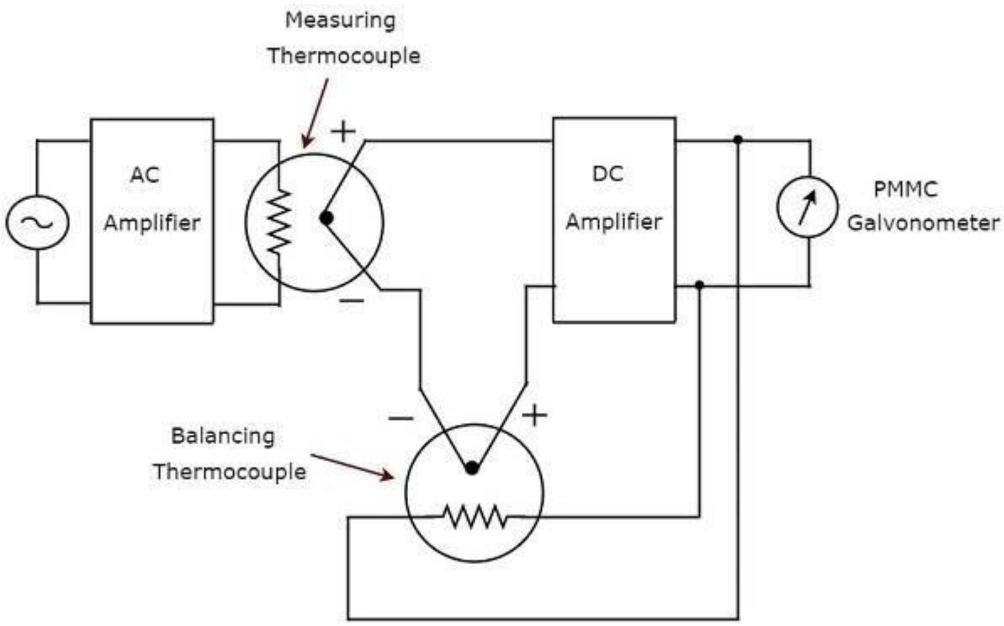


Figure shows an example of a common rectifier type ac voltmeter setup. In response to the average value of this half cycle, diode D1 conducts during the positive half of the input cycle, which deflects the meter. In order to move the operating point into the linear region of the characteristic curve and draw more current through the diode D1, the meter movement is shunted by a resistor. Diode D2 conducts and the measuring circuit's current flows in the opposite direction during the negative half-cycle.

True RMS Responding AC Voltmeter

Simply put, the true RMS responding AC voltmeter responds to the true RMS values of the AC voltage signal, as suggested by its name. This voltmeter determines the RMS values of the AC voltage. A real RMS responding AC voltmeter's circuit diagram can be seen in the figure below.



The circuit described above includes a PMMC galvanometer, two thermocouples, a DC amplifier, and an AC amplifier. The signal from the AC amplifier is amplified. The circuit above makes use of two thermocouples: a balancing thermocouple and a measuring thermocouple. An output voltage proportional to the RMS value of the AC voltage signal is produced by the thermocouple measurement.

Any type of thermocouple can change an input quantity square into a normal quantity. This indicates that there is a non-linear relationship between a thermocouple's input and output. One way to mitigate the impact of a thermocouple's non-linear behavior is to incorporate an additional thermocouple into the feedback circuit. The thermocouple used in the circuit above is referred to as a balancing thermocouple for this reason.

At the DC amplifier's input, a couple made up of the measuring and balancing thermocouples form a couple. Consequently, the meter reacts to the actual RMS value of the AC voltage signal without fail.