Quality of Measurements

The Static Characteristics in Instrumentation are considered for instruments which are used to measure an unvarying process condition. The static performance characteristics are obtained by one or another form of a process called calibration.

An Instrument and Measurement and other Static Characteristics such as accuracy, precision, repeatability, resolution, errors, sensitivity, etc can be defined as follows.

1. Instrument: A device or mechanism used to determine the present value of the quantity under measurement.

2. Measurement: The process of determining the amount, degree, or capacity by comparison (direct or indirect) with the accepted standards of the system units being used.

3. Accuracy: The degree of exactness (closeness) of a measurement compared to the expected (desired) value.

4. Resolution: The smallest change in a measured variable to which an instrument will respond.

5. Precision: A measure of the consistency or repeatability of measurements, i.e. successive reading do not differ. (Precision is the consistency of the instrument output for a given value of input).

6. Expected value: The design value, i.e. the most probable value that calculations indicate one should expect to measure.

7. Error: The deviation of the true value from the desired value.

8. Sensitivity: The ratio of the change in output (response) of the instrument to a change of input or measured variable.

Error in Measurement:

Error in Measurement is the process of comparing an unknown quantity with an accepted standard quantity. It involves connecting a measuring instrument into the system under consideration and observing the resulting response on the instrument. The measurement thus obtained is a quantitative measure of the so called “true value” or “expected value”. As it is very difficult to define the true value, the term “expected value” is used.

Any measurement is affected by many variables, therefore the results rarely reflect the expected value. For example, connecting a measuring instrument into the circuit under consideration always changes the circuit parameters and makes the measurement to differ from the expected value.

Some factors that affect the measurements are related to the measuring instruments themselves. Other factors are related to the person using the instrument. The degree to which a measurement nears the expected value is expressed in terms of the error of measurement.

Error may be expressed either as absolute or as percentage of error. Absolute error may be defined as the difference between the expected value of the variable and the measured value of the variable, or

$$e = Y_n - X_n$$

where e = absolute error

Y_n = expected value

X_n = measured value

$$\text{Therefore } \% \text{ Error} = \frac{\text{Absolute value}}{\text{Expected value}} \times 100$$

It is more frequently expressed as an accuracy rather than error.

$$\text{Therefore} \quad A = 1 - \left| \frac{Y_n - X_n}{Y_n} \right|$$

where A is the relative accuracy.

Accuracy is expressed as % accuracy

$$a = 100\% - \%\ \text{error}$$

$$a = A \times 100\ \%$$

where a is the % accuracy.

Types of Static Error:

The static error of a measuring instrument is the numerical difference between the true value of a quantity and its value as obtained by measurement, i.e. repeated measurement of the same quantity gives different indications.

Types of Static error are categorized as (i) Gross errors or human errors, (ii) Systematic errors, and (iii) Random errors.

Gross Errors: These errors are mainly due to human mistakes in reading or in using instruments or errors in recording observations. Errors may also occur due to incorrect adjustment of instruments and computational mistakes.

These errors cannot be treated mathematically.

The complete elimination of gross errors is not possible, but one can minimize them. Some errors are easily detected while others may be elusive.

One of the basic gross errors that occurs frequently is the improper use of an instrument. The error can be minimized by taking proper care in reading and recording the measurement parameter.

Systematic Error:

These errors occur due to shortcomings of the instrument, such as defective or worn parts, or ageing or effects of the environment on the instrument.

These errors are sometimes referred to as bias, and they influence all measurements of a quantity alike. A constant uniform deviation of the operation of an instrument is known as a systematic error.

There are basically three types of systematic errors (i) Instrumental, (ii) Environmental, and (iii) Observational.

(I) Instrumental Errors

Instrumental errors are inherent in measuring instruments, because of their mechanical structure. For example, in the D'Arsonval movement, friction in the bearings of various moving components, irregular spring tensions, stretching of the spring, or reduction in tension due to improper handling or overloading of the instrument.

Instrumental errors can be avoided by

(a) selecting a suitable instrument for the particular measurement applications. (Refer Examples 1.3 (a) and (b)).

(b) applying correction factors after determining the amount of instrumental error.

(c) calibrating the instrument against a standard.

(II) Environmental Errors

Environmental errors are due to conditions external to the measuring device, including conditions in the area surrounding the instrument, such as the effects of change in temperature, humidity, barometric pressure or of magnetic or electrostatic fields.

These errors can also be avoided by (i) air conditioning, (ii) hermetically sealing certain components in the instruments, and (iii) using magnetic shields.

(III) Observational Errors

Observational errors are errors introduced by the observer. The most common error is the parallax error introduced in reading a meter scale, and the error of estimation when obtaining a reading from a meter scale.

These errors are caused by the habits of individual observers. For example, an observer may always introduce an error by consistently holding his head too far to the left while reading a needle and scale reading.

In general, systematic errors can also be subdivided into static and dynamic errors. Static errors are caused by limitations of the measuring device or the physical laws governing its behavior. Dynamic errors are caused by the instrument not responding fast enough to follow the changes in a measured variable.

Random Errors

These are errors that remain after gross and systematic errors have been substantially reduced or at least accounted for. Random errors are generally an accumulation of a large number of small effects and may be of real concern only in measurements requiring a high degree of accuracy. Such errors can be analyzed statistically.

These errors are due to unknown causes, not determinable in the ordinary process of making measurements. Such errors are normally small and follow the laws of probability. Random errors can thus be treated mathematically.

For example, suppose a voltage is being monitored by a voltmeter which is read at 15 minutes intervals. Although the instrument operates under ideal environmental conditions and is accurately calibrated before measurement, it still gives readings that vary slightly over the period of observation. This variation cannot be corrected by any method of calibration or any other known method of control.

SOURCES OF ERROR

The sources of error, other than the inability of a piece of hardware to provide a true measurement, are as follows:

1. Insufficient knowledge of process parameters and design conditions

2. Poor design

3. Change in process parameters, irregularities, upsets, etc.

4. Poor maintenance

5. Errors caused by person operating the instrument or equipment

6. Certain design limitations

Example 1.1 (a):

The expected value of the voltage across a resistor is 70V. However, the measurement gives a value of 71V. Calculate the (i) Absolute error (ii) % error (iii) Relative accuracy and (iv) % Accuracy.

Soln:

(i) Absolute error $e=|Y_n - X_n|= |70-71| = 1$ V

(ii) % Error = $(|(Y_n - X_n)|/ Y_n) \times 100 = (1/70) \times 100 = 1.43\%$

(iii) Relative accuracy = $1 - (|(Y_n - X_n)|/ Y_n) = 1 - 0.143= 0.857$

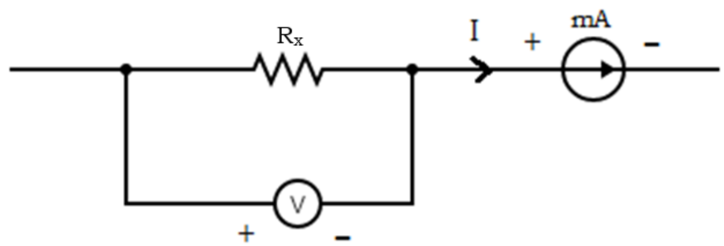
(iv) % Accuracy = 100-1.43% = 85.70 %

Example 1.3 (a):

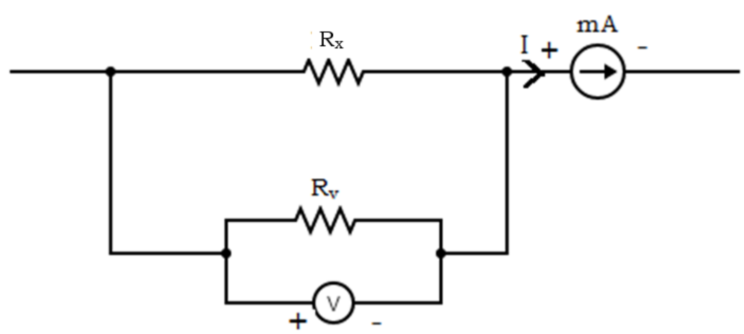
A voltmeter having a sensitivity of 1 kΩ/V is connected across an unknown resistor in series with a milliammeter reading 80V on 150 V scale. When the milliameter reads 10mA, calculate the (i) Apparent resistance of the unknown resistor (ii) Actual resistance of the unknown resistor due to loading effect of the voltmeter and (iii) % error due to loading of voltmeter.

Soln:

(i) Apparent resistance = 80V/10mA = 8 kΩ



(ii) If the loading of the voltmeter is also considered, then, the resistance offered by voltmeter Rv in parallel with the unknown resistance Rx, as shown in the following figure should be considered as the total equivalent resistance of the circuit. The milliammeter current reading 10 mA is due to this equivalent resistance.



Equivalent resistance Re= Rx || Rv, where Rv = 150 x 1 kΩ = 150 kΩ

Re = (Rv Rx) / (Rv+Rx)

Re(Rv+Rx)=RvRx

ReRv+ReRx = RvRx

ReRv=RvRx-ReRx

ReRv=Rx(Rv-Re)

Or Rx=ReRv/(Rv-Re)

Rx=8x150/(150-8) = 8x150/142=8.45 kΩ

(iii) % Error = ((Actual resistance-Apparent resistance)/Actual resistance) x 100

= (8.45-8/8.45) x 100 = 5.3 %

Precision Example:

When an unknown voltage is measured by a voltmeter at 10 different times, it gives the following 10 measurements. Calculate the Precision of the voltmeter for the 6th measurement.

Sl no	Measurement in volts
1	98
2	101
3	102
4	97
5	101
6	100
7	103
8	98
9	106
10	99

Average value of the measurements Xa= (sum of all measurements)/10 =1005/10=100.5 V

Precision at the nth measurement, Pn = 1 - abs [Xn-Xa)/Xa]
Therefore, the Precsion at 6th measurement, P_6 is

P_6= 1 – abs[(X_6-Xa)/Xa] = 1 – abs[(100-100.5)/100.5] = 1 – abs[-0.5/100.5] = 0.995.

D'Arsonval Movement (Electrical Analog Meter):

The main aim of a measuring system is to presnt the data in an understandable manner to the user / observer. The data presentation device is called as an output device or terminating device. The D'Arsonval movement is a current sensing mechanism which is used in DC Ammeter, ohm meter and Voltmeter.

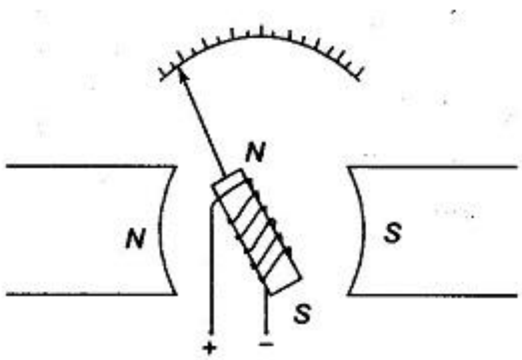
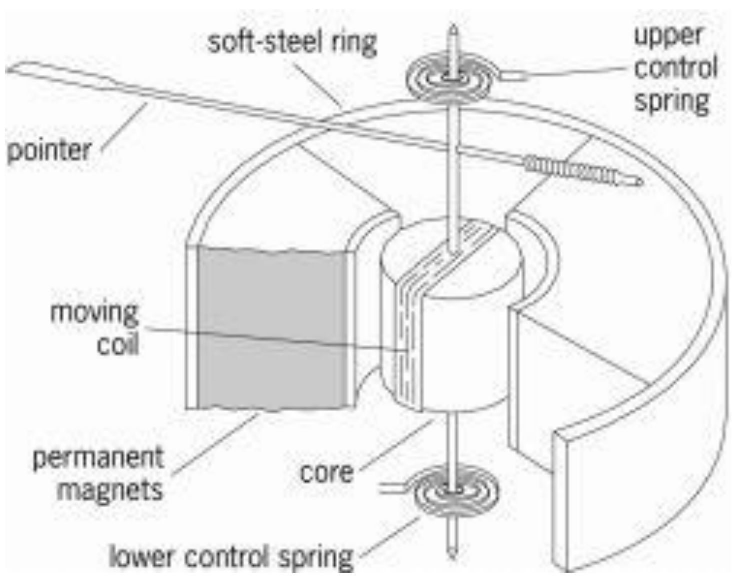


Fig. 2.1 — D'Arsonval Principle

Priniciple of D'Arsonval Movement:

When an electric current is passed through a coil placed in a magnetic field, it experiences a force. This force causes a torque in the coil that is fixed to a spindle. The spindle can rotate in fixed bearings. The rotation of the spindle is proportional to the electric current passed through the coil. This torque that is produced is balanced after a movement against the restoring torques of springs. The torque that is produced that tends to rotate the spindle is termed as D'Arsonval Movement.



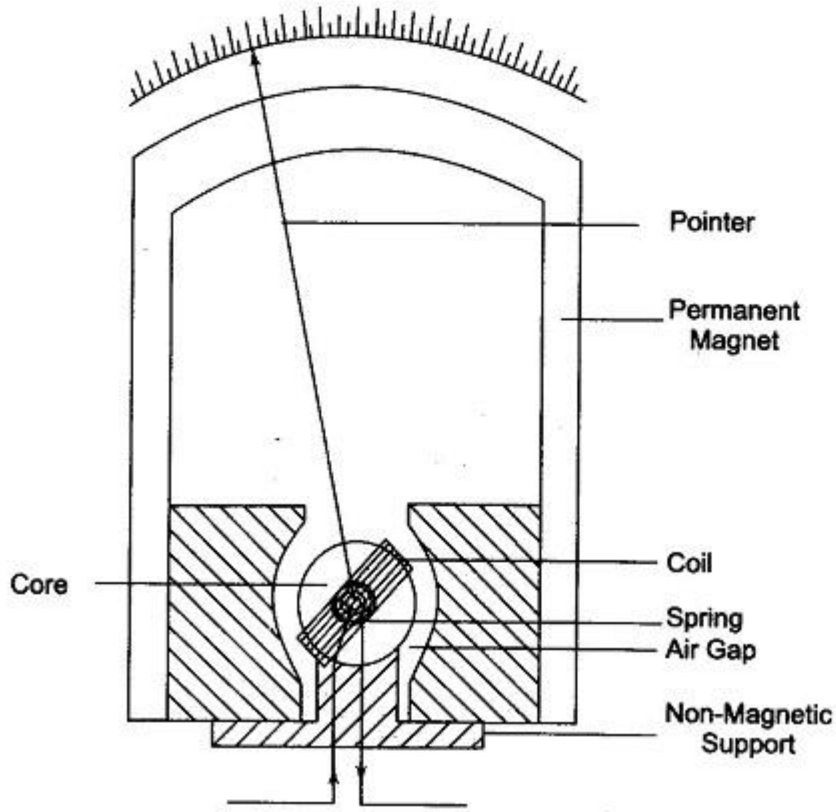


Fig. 2.2 Modern D'Arsonval Movement

DC Ammeter:

DC Ammeter – The PMMC galvanometer constitutes the basic movement of a dc ammeter. Since the coil winding of a basic movement is small and light, it can carry only very small currents. When large currents are to be measured, it is necessary to bypass a major part of the current through a resistance called a shunt, limiting the current in the movement to carry not more than its maximum capacity (Im) as shown in Fig. 3.1. The resistance of shunt can be calculated using conventional circuit analysis. Referring to Fig. 3.1

Rm = internal resistance of the movement.

Ish = shunt current

Im = full scale deflection current of the movement

I = full scale current of the ammeter + shunt (i.e. total current)

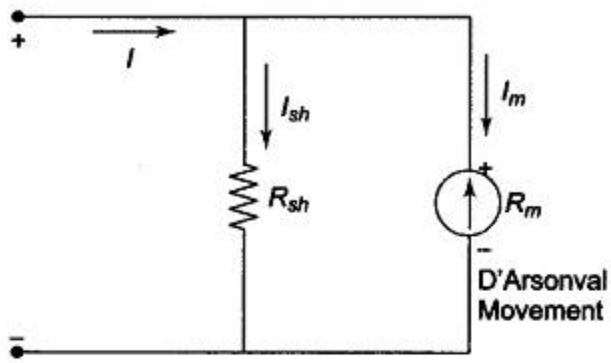


Fig. 3.1 Basic dc Ammeter

Since the shunt resistance is in parallel with the meter movement, the voltage drop across the shunt and movement must be the same. Therefore $V_{sh} = V_m$

$$I_{sh} R_{sh} = I_m R_m, \qquad R_{sh} = \frac{I_m R_m}{I_{sh}}$$

But $\quad I_{sh} = I - I_m$

hence $\quad R_{sh} = \dfrac{I_m R_m}{I - I_m}$

For each required value of full scale meter current, we can determine the value of shunt resistance.

Multirange Ammeters:

The current range of the dc ammeter may be further extended by a number of shunts, selected by a range switch. Such a meter is called a multirange ammeter, shown in Fig. 3.2.

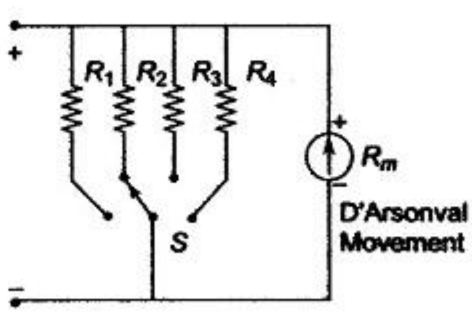


Fig. 3.2 Multirange Ammeter

The circuit has four shunts R1, R2, R3 and R4, which can be placed in parallel with the movement to give four different current ranges. Switch S is a multiposition switch, (having low contact resistance and high current carrying capacity, since its contacts are in series with low resistance shunts). Make before break type switch is used for range changing.

If an ordinary switch is used for range changing, the meter does not have any shunt in parallel while the range is being changed, and hence full current passes through the meter movement, damaging the movement. To avoid this, a make before break type switch is used. The switch is so designed that when the switch position is changed, it makes contact with the next terminal (range) before breaking contact with the previous terminal. Therefore the meter movement is never left unprotected.

Multirange ammeters are used for ranges up to 50A. When using a multirange ammeter, first use the highest current range, then decrease the range until good upscale reading is obtained. The resistance used for the various ranges are of very high precision values, hence the cost of the meter increases.

Multirange Voltmeter:

As in the case of an ammeter, a dc voltmeter can be converted into a multirange voltmeter by connecting a number of resistors (multipliers) along with a range switch to provide a greater number of workable ranges. Figure 4.2 shows a multirange voltmeter using a three position switch and three multipliers R1, R2, and R3 for voltage values V1, V2, and V3.

Figure 4.2 can be further modified to Fig. 4.3, which is a more practical arrangement of the multiplier resistors of a multirange voltmeter. In this arrangement, the multipliers are connected in a series string, and the range selector selects the appropriate amount of resistance required in series with the movement. This arrangement is advantageous compared to the previous one, because all multiplier resistances except the first have the standard resistance value and are also easily available in precision tolerances: The first resistor or low range multiplier, R4, is the only special resistor which has to be specially manufactured to meet the circuit requirements.

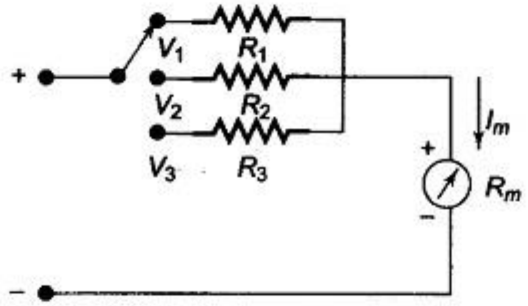


Fig. 4.2 Multirange Voltmeter

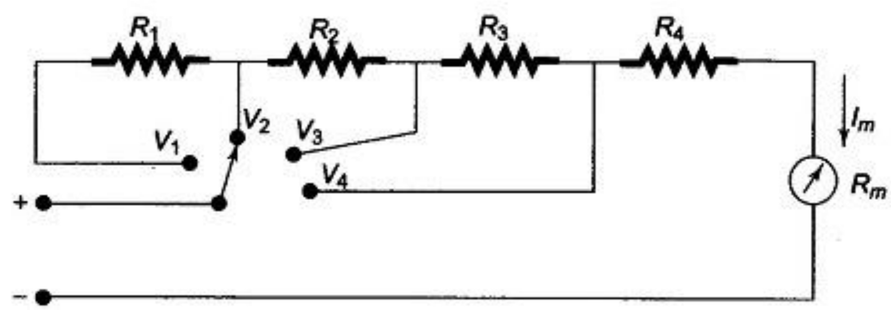


Fig. 4.3 Multipliers Connected in Series String

For Fig. 4.2, $V_1=Im(R_1+Rm)$ or $R_1=(V_1/Im)-Rm$

For Fig. 4.3, $V_4=Im(R_4+Rm)$ or $R_4=(V_4/Im)-Rm$

$V_3=Im(R_3+R_4+Rm)$ or $R_3+R_4=(V_3/Im)-Rm$

$V_2=Im(R_2+R_3+R_4+Rm)$ or $R_2+R_3+R_4=(V_2/Im)-Rm$

$V_1=Im(R_1+R_2+R_3+R_4+Rm)$ or $R_1+R_2+R_3+R_4=(V_1/Im)-Rm$