Module 1

Syllabus

- Measurement standards–Errors-Types of Errors- Statistics of errors, Need for calibration.
- Classification of instruments, secondary instruments–indicating, integrating and recording
- Operating forces - essentials of indicating instruments - deflecting, damping, controlling torques.
- Ammeters and voltmeters - moving coil, moving iron, constructional details and operation,

principles shunts and multipliers – extension of range.

Measurement

It is essentially the act or the result of a comparison between a given quantity (whose magnitude is unknown) and a quantity of the same kind chosen as a standard .The device used for comparing the unknown quantity with the unit of measurement or a standard quantity is called a measuring instrument.

Standard

A standard of measurement is a physical representation of a unit of measurement. A standard means known accurate measure of a physical quantity. Depending upon the degree of accuracy required for the work, the standards are subdivided into following four categories.

Primary Standards (Reference Standards).

Secondary Standards (Calibration Standards).

Tertiary Standards (Inspection Standards).

Working Standards (Workshop Measuring Standards).

Primary Standards (Reference Standards):-The primary standard is also known as Master Standard, and is preserved under the most careful conditions. These standards are not commonly in use. They are maintained at National Standard Laboratories at different countries. The main function of the primary standard is calibration and verification of secondary standards.

Secondary Standards (Calibration Standards):-The secondary standard is more or less similar to the primary standard. They are nearly close in accuracy with primary standards. The secondary standard is compared at regular intervals with primary Standards and records their deviation. They are used occasionally for comparing the territory standards.

Tertiary Standards (Inspection Standards):-The Tertiary standard is the first standard to be used for reference purpose in workshops and laboratories. They are used for comparing the working standards. These are not used as frequently and commonly as the working standards but more frequency than secondary standards.

Working Standards (Workshop Measuring Standards):-The working standard is used for actual measurement in workshop or laboratories by the workers. These standards should also be as accurate as possible to the tertiary standard. But sometimes, lower grades of materials can be used for their manufacturing to reduce cost.

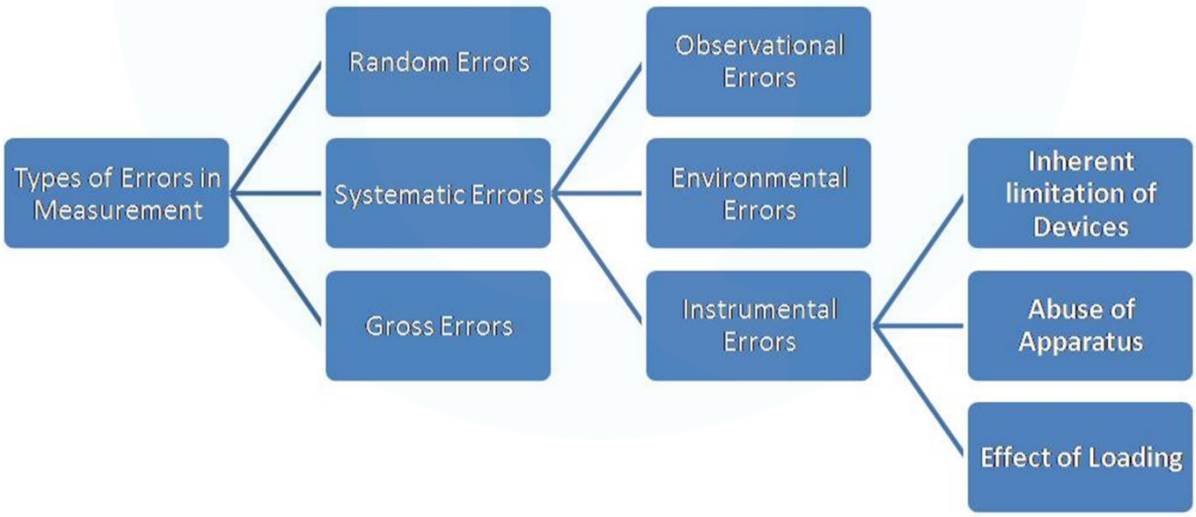
Sources of errors

The errors in measurement may happen from the various sources which are generally categorized into the following types.

Gross Errors

Systematic Errors

Random Errors



1) Gross Errors

The gross error occurs because of the human mistakes. Manual errors in reading instruments or recording and calculating measurement results are known as Gross errors. Generally, these errors occur during the experiments, where the experimenter might read or record a value different from the actual one, probably due to poor sight. The gross error can only be avoided by taking the reading carefully.Two methods can remove the gross error.

- Precautious reading and recording of data.

- Taking multiple readings, by different persons. A close agreement between different readings ensures removal of any gross error.

2) Systematic Errors

Errors which occur due to changes in environment conditions, instrumental reasons or wrong observations. These errors are of three types

a) Instrumental Errors

b) Environmental Errors

c) Observational Errors

2 a) Instrumental Errors

These errors occur due to a) shortcomings in the instruments b) improper use of instruments and c) loading effect of the instrument.

(a) Inherent Shortcomings of Instruments – Such types of errors are inbuilt in instruments because of their mechanical structure. They may be due to manufacturing, calibration or operation of the device. These errors may cause the error to read too low or too high.

For example – weak spring, friction etc.

(b) Misuse of Instrument – The error occurs in the instrument because of the fault of the operator. A good instrument used in an unintelligent way may give an erroneous result.

For example –failure to adjust the zero of instruments, poor initial adjustment etc.

(c) Loading Effect – It is the most common type of error which is caused by the instrument in measurement work.

For example, when the voltmeter is connected to the high resistance circuit it gives a misleading reading.

A voltmeter having a sensitivity of 1000 Ω/V reads 100 V on its 150 V scale when connected across an unknown resistor in series with a milli-ammeter. When the milliammeter reads 5 mA, calculate :

a) apparent resistance of the unknown resistor.

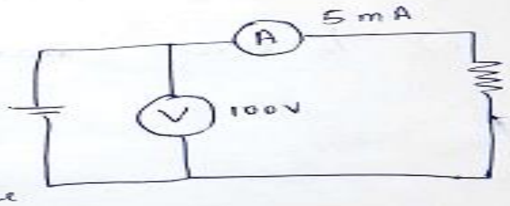
b) actual resistance of the unknown resistor

c) error due to the loading effect of voltmeter.

Solution

Total circuit resistance

$$R_T = \frac{100}{5 \times 10^{-3}} = 20\,k\Omega$$



Neglecting the resistance of milli-ammeter the value of unknown resistor

$R_x = 20\,k\Omega$

b) Resistance of voltmeter

$$R_v = 1000 \times 150 = 150\,k\Omega$$

Since the voltmeter and unknown resistance are in parallel

Total resistance, $R_T = \dfrac{R_x \cdot R_v}{R_x + R_v}$

$$20\,k\Omega = \frac{R_x \cdot 150\,k\Omega}{R_x + 150\,k\Omega}$$

$$R_x = 23.077\,k\Omega$$

c) % error = $\dfrac{\text{measured value} - \text{true value}}{\text{true value}} \times 100$

$$= \frac{20 - 23.077}{23.077} \times 100 = \underline{\underline{-13.33\%}}$$

2) Repeat the example if the milliammeter reads 800mA and the voltmeter reads 40V on its 150V scale.

a) $R_T = \dfrac{40}{800 \times 10^{-3}} = 50\,\Omega$

b) $R_v = 1000 \times 150 = 150\,k\Omega$

$$R_T = \frac{R_x \cdot R_v}{R_x + R_v}$$

$$50 = \frac{R_x \cdot 150\,k\Omega}{R_x + 150\,k\Omega}$$

$$R_x = \underline{\underline{50.017\,\Omega}}$$

c) % error = $\dfrac{50.0 - 50.017}{50.017} \times 100 = \underline{\underline{-0.034\%}}$

2 b) <u>Environmental Errors</u>

These errors are due to the external condition of the measuring devices. Such types of errors mainly occur due to the effect of temperature, pressure, humidity, dust, vibration or because of the magnetic or electrostatic field. The corrective measures employed to eliminate or to reduce these undesirable effects are

- Make sure to keep the ambient physical conditions constant.
- Use instruments which have ample immunity to effects of environmental changes.
- Use different techniques, for example sealing the instrument, to eliminate the effects.
- By applying the computed corrections.

2 c) <u>Observational Errors</u>

Such types of errors are due to the wrong observation of the reading. These errors occur due to a mismatch between a line of vision of the observer and the pointer above the instrument scale. This is also termed as Parallax error which occurs when the observer is unable to have a vision aligned with the pointer. Since they occur on Analog instruments, using digital display can eliminate these errors.

3. <u>Random Errors</u>

These errors occur due to a group of small factors which fluctuate from one measurement to another. The situations or disturbances which cause these errors are unknown, hence they are termed as Random errors.

<u>Methods of measurement</u>

Basically, there are two methods of measurements

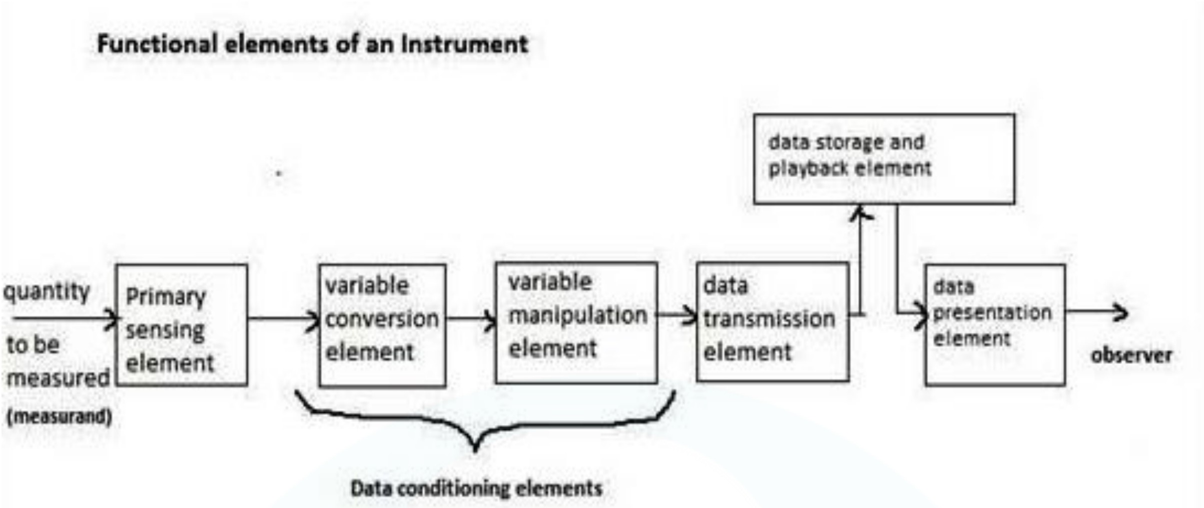
1) Direct comparison methods

2) Indirect comparison methods

In direct comparison methods, the unknown quantity is determined by direct comparison with a standard of the given quantity. The result is expressed in terms of a chosen unit for the standard and a numerical multiplier. Direct comparison methods of measurement are simple, but it is not always possible, feasible and practicable to use them. The involvement of a person in these methods make them inaccurate and less sensitive

In indirect comparison methods, the transducing element converts the measurand to an analogous form

Elements of Generalized measurements system



Primary sensing element

The measurand is first detected by primary sensor or detector followed by conversion of measurand into an analogous electrical signal. This is done by a transducer. A transducer is defined as a device which converts a physical quantity into an electrical quantity. The first stage of a measurement system is known as a detector transducer stage.

Variable conversion element

The output signal of the variable sensing element may be any kind. It may be a voltage, frequency or some other electrical parameters. Sometimes, the output from the sensor is not suited to the measurement system. This part converts this output signal from the sensor to some other suitable form while preserving the information content of the original signal. Eg: Analog to digital converter

Variable manipulation element

Variable manipulation means a change in numerical value of the signal. The function of a variable manipulation element is to manipulate the signal presented to this element while preserving the original nature of the signal. For example, a voltage amplifier acts as a variable manipulation element. The amplifier accepts a small voltage signal as input and produces an output signal which is also voltage but of greater magnitude. Element that follows primary sensing element in any instrument or measurement system is called data conditioning element.

Data transmission element

There are several situations where the elements of an instrument are actually physically separated. In such situations it becomes necessary to transmit data from one element to another. The element that performs this function is called a Data Transmission Element. For example satellites or the air planes are physically separated from the control stations at earth.

Data presentation element

The function of data presentation element is to convey the information about the quantity under measurement to the personnel handling the instrument or the system for monitoring, control, or analysis purposes. The information conveyed must be in a convenient form.

STATIC CHARACTERISTICS

1) Accuracy

Accuracy is the ability of the instrument to measure the accurate value. In other words, it is the closeness of the measured value to a standard or true value.

2) Precision

Precision means two or more values of the measurements are close to each other. The precision is used for finding the consistency or reproducibility of the measurement. Consider the 100V, 101V, 102V, 103V and 105V are the different readings of the voltages taken by the voltmeter. The readings are nearly close to each other. They are not exactly same. But as the reading are close to each other then we say that the readings are precise.

3) Sensitivity: It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured. Consider an ammeter which gives a deflection of 45 degree for a current of 5 A then sensitivity is 9 degree/A

4) Resolution: If the input is slowly increased from some arbitrary input value (nonzero), it will again be found that output does not change at all until a certain increment is exceeded. This increment is called resolution. Smallest measurable input change.

5) Threshold: If the instrument input is increased very gradually from zero there will be some minimum value below which no output change can be detected. This minimum value defines the threshold of the instrument. Smallest measurable input.

6) Range or span: The minimum & maximum values of a quantity for which an instrument is designed to measure is called its range or span.

7) Drift: Undesired change in the output-input relationship over a period of time. No drift means that with given input the measured value do not vary with time.

8) Linearity: If the input and output varies in a proportional manner then the system is linear. It is closeness to which curve approximates straight line.

Errors in measurement

True Value (*A*): True value of a quantity to be measured may be defined as the average of an infinite number of measured values when the average deviation due to various contributing factors tends to zero. This is an ideal case.

Static error/ Absolute error (δA) : The difference between the measured value A_m & the true value A of unknown quantity. $\delta A = A_m - A$

Relative/Percentage error: Ratio of absolute error to the true value of the quantity to be measured is relative static error.

$$\text{i.e., relative error, } \varepsilon_r = \frac{\delta A}{A} = \frac{\text{Absolute error}}{\text{True value}}$$

When the absolute error δA) is negligible, i.e., when the difference between the true value A and the measured value A_m of the unknown quantity is very small or negligible then the relative error may be expressed as,

$$\varepsilon_r = \frac{\delta A}{A_m}$$

$$\text{i.e., percentage error} = \varepsilon_r \times 100$$

Limiting or Guarantee error: The measured value of the unknown quantity may be more than or less than the true value of the measurand. So the manufacturers have to specify the deviations from the specified value of a particular quantity in order to enable the purchaser to make proper selection according to his requirements. The limits of these deviations from specified values are defined as limiting or guarantee errors. The magnitude of a given quantity having a specified magnitude A_m and a maximum or a limiting error $\pm\delta A$ must have a magnitude between the limits $A = A_m \pm \delta A$

Statistical Analysis

This method is used to estimate the value or error when unpredictable or random errors are dominant. Statistical analysis will give the deviation from the true value. It is employed by taking a large number of readings of a particular parameter and calculations are made in the following ways.

1) Arithmetic Mean

The most probable value of a measured variable is the arithmatic mean of the number of readings taken. The arithmetic mean of n measurements at a specific count of the variable x is given by the expression

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} = \frac{\sum_{n=1}^{n} x_n}{n}$$

where $\bar{x}$ = Arithmetic mean

x_n = nth reading taken

n = total number of readings

2) Deviation from the Mean

This is the departure of a given reading from the arithmetic mean of the group of readings. If the deviation of the first reading, x_1, is called d_1 and that of the second reading x_2 is called d_2, and so on,The deviations from the mean can be expressed as

$$d_1 = x_1 - \bar{x}\,,\; d_2 = x_2 - \bar{x}\; \ldots, \text{ similarly } d_n = x_n - \bar{x}$$

The deviation may be positive or negative. The algebraic sum of all the deviations must be zero.

3) <u>Average Deviations</u>

The average deviation is an indication of the precision of the instrument used in measurement. Average deviation is defined as the sum of the absolute values of the deviation divided by the number of readings. The absolute value of the deviation is the value without respect to the sign. Average deviation may be expressed as

$$D_{av} = \frac{|d_1| + |d_2| + |d_3| + \cdots + |d_n|}{n}$$

or

$$D_{av} = \frac{\sum |d_n|}{n}$$

where D_{av} = average deviation

$|d_1|, |d_2|, \ldots, |d_n|$ = Absolute value of deviations

and n = total number of readings

4) <u>Standard Deviation</u>

The standard deviation of an infinite number of data is the Square root of the sum of all the individual deviations squared, divided by the number of readings. It may be expressed as

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n}}$$

$$\sigma = \sqrt{\frac{d_n^2}{n}}$$

where σ = standard deviation

The standard deviation is also known as root mean square deviation, and is the most important factor in the statistical analysis of measurement data. Reduction in this quantity effectively means improvement in measurement. For small readings ($n < 30$), the denominator is frequently expressed as ($n — 1$) to obtain a more accurate value for the standard deviation.

<u>Calibration</u>

The calibration is the process of checking the accuracy of the result by comparing it with the standard value. In other words, calibration checks the correctness of the instrument by comparing it with the reference standard. It helps us in determining the error occur in the reading and adjusts the values for getting the ideal reading. Over time there is a tendency for results and accuracy to 'drift'. To be confident in the results being measured, there is an ongoing need to maintain the calibration of equipment throughout its lifetime for reliable, accurate and repeatable measurements. The goal of calibration is to minimise any measurement uncertainty by ensuring the accuracy of test equipment. Calibration quantifies and controls errors or uncertainties within measurement processes to an acceptable level.

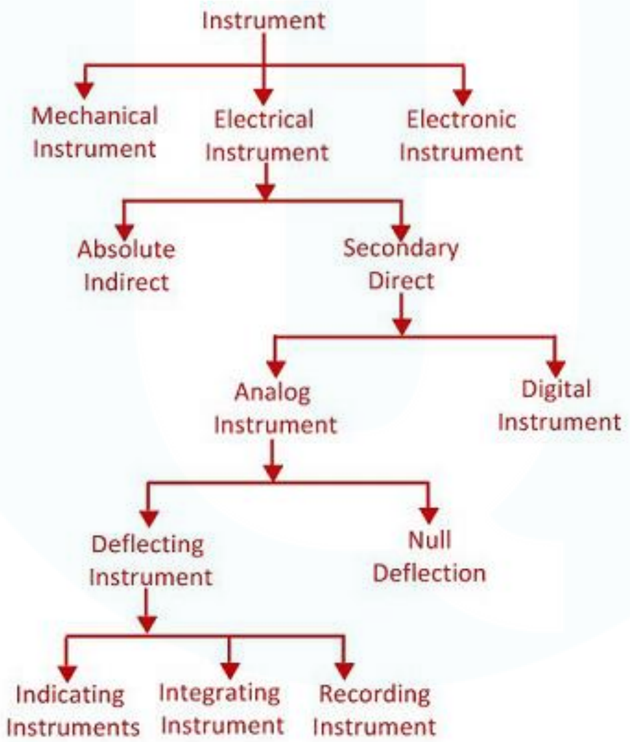
Classification of Measuring Instruments

The term measurement means the comparison between the two quantities of the same unit. The magnitude of one of the quantity is unknown, and it is compared with the predefined value. The measuring instrument categorized into three types:

Electrical Instrument:- The electrical instrument is used for measuring electrical quantities likes current, voltage, power, etc.

Electronic Instrument:- Electronic instruments use semiconductor devices. The electronic instrument has quick response time. Eg:- CRO

Mechanical Instrument:-The mechanical instrument uses for measuring the physical quantities.eg:- Vernier caliper



Different types of electrical instrument are

1) Absolute Instrument

These instruments give output in terms of physical constant of the instruments. The physical constant means the angle of deflection, degree and meter constant. It is also called a **Primary Instrument or Indirect Instrument**. Such instruments do not require comparison with any other standard.The tangent galvanometer is the examples of the absolute instruments. It works by using a compass needle to compare a magnetic field generated by the unknown current to the magnetic field of the Earth.

2) **Secondary Instrument**

The instrument gives the value of the quantity to be measured directly into the deflection. This instrument is known as 'Secondary Instrument'. It is also called as Direct Instruments. These instrument values are required to compare with absolute instruments or standard value of the instruments. The output of this type of device is directly obtained, and no mathematical calculation requires for knowing their value. Secondary instruments are divided into a) analog instrument b) digital instrument

Digital instrument:-The digital instrument gives the output in the numeric form**.** The instrument is more accurate as compared to the analogue instrument because no human error occurs in the reading.

Analog instrument:-The instrument whose output varies continuously is known as the analogue instrument. The analogue instrument has the pointer which shows the magnitude of the measurable quantities. The analogue device classifies into two types.

Analog instruments are classified as

Null Type Instrument:-In this instrument, the zero or null deflection indicates the magnitude of the measured quantity. The instrument has high accuracy and sensitivity. In null deflection instrument, the one known and one unknown quantity is used. When the value of the known and the unknown measuring quantities are equal, the pointer shows the zero or null deflection. The null deflection instrument is used in the potentiometer.

Deflection Type Instrument:-The instrument in which the value of measuring quantity is determined through the deflection of the pointer is known as the deflection type instrument. The measuring quantity deflects the pointer of the moving system of the instrument which is fixed on the calibrated scale. Thus, the magnitude of the measured quantity is known.

The deflection type instrument is further sub-classified into three types.

Indicating Instrument – The instrument which indicates the magnitude of the measured quantity is known as the indicating instrument**.** The voltmeter, ammeter, power factor meter are the examples of the indicating instrument.

Integrating Instrument – The instrument totalize events over a specified period of time. The summation, which they give is the product of time and an electrical quantity. The watt-hour meter and ampere hour meter are the examples.

Recording Instrument – The instrument records the circuit condition at a particular interval of time is known as the recording instrument. The moving system of the recording instrument carries a pen which lightly touches on the paper sheet. The movement of the coil is traced on the paper sheet. The curve drawn on the paper shows the variation in the measurement of the electrical quantities.Example: ECG

Operating Forces in measuring instruments

For satisfactory operation of indicating instrument, three forces are necessary. They are

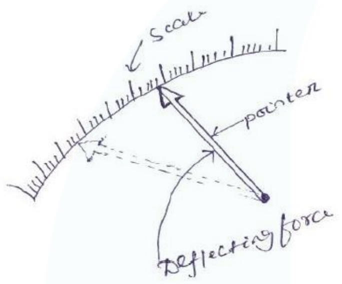
(a) Deflecting force

(b) Controlling force

(c)Damping force

Deflecting force

When there is no input signal to the instrument, the pointer will be at its zero position. To deflect the pointer from its zero position, a force is necessary which is known as deflecting force. The deflecting force is produced by magnetic, thermal, electrostatic ,induction or hall effect. A system which produces the deflecting force is known as a deflecting system. Generally a deflecting system converts an electrical signal to a mechanical force.



Controlling force

To make the measurement indicated by the pointer definite (constant) a force is necessary which will be acting in the opposite direction to the deflecting force. This force is known as controlling force. A system which produces this force is known as a controlled system. When the external signal to be measured by the instrument is removed, the pointer should return back to the zero position. This is possibly due to the controlling force and the pointer will be indicating a steady value when the deflecting torque (T_d) is equal to controlling torque (T_c) .

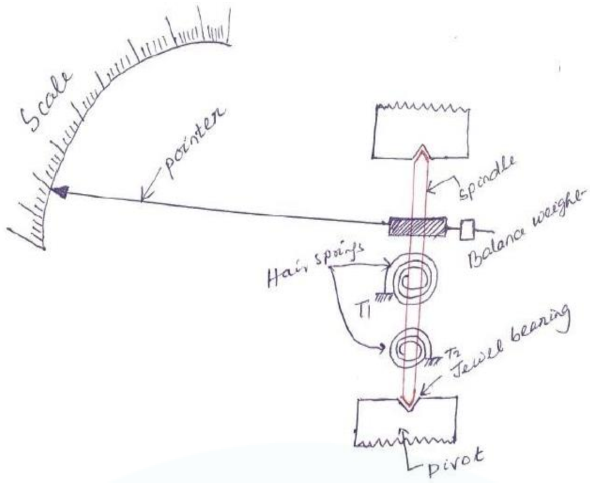
The controlling torque serves two functions.

- The pointer stops moving beyond the final deflection
- The pointer comes back to its zero position when the instrument is disconnected

In indicating instruments, the controlling torque is obtained by two methods

1) Spring control:

Two springs are attached on either end of spindle. The spindle is placed in jeweled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze. The deflecting torque produced T_d proportional to 'I' and $T_c \propto \theta$. When $T_C = T_d$ the pointer will come to a steady position. Therefore $\theta \propto I$. Since, θ and I are directly proportional to the scale of such instrument which uses spring controlled is uniform



Advantages of spring control method

1. The instrument can be placed in any position i.e., horizontal as well as vertical.

2. This method does not increase the weight of the instrument as springs are light.

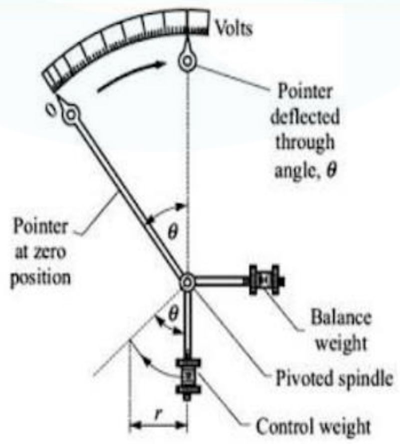
3. Scale is uniform in this method.

Disadvantages of spring control method

1. Temperature variations can affect the length and design of the spring and hence also changes the controlling torque.
2. Springs get deterioted with the time and hence its accuracy is also lost.

2) Gravity control

In this method, natural downward pull due to gravity is employed. A small weight “W” is placed on the arm attached to the moving system.At the zero position of the pointer, the control weight W is in the vertical position and therefore no controlling torque is produced. However, under the action of the deflecting force, the pointer deflects by an angle “θ” from its zero position.As shown in the figure below, as pointer moves weight will also move.



But due to gravity, the control weight would try to come back to its original vertical position and hence produces the necessary controlling torque. There are two components of the control weight Wsinθ and Wcosθ. Only the component Wsinθ will provide the necessary controlling torque and helps to retain the original position. Thus, T_c = Wsinθ. It is seen from above equation that controlling torque is directly proportional to the sine of the deflected angle.Then for position of rest,$T_d = T_c$ Or I ∝ Sin θ.Hence in gravity control instruments, the scales are not uniform but are cramped or crowded at their lower ends

Advantages of gravity control method

1. It is simple and cheap method.

2. Not affected by temperature variations.

Disadvantages of gravity control method

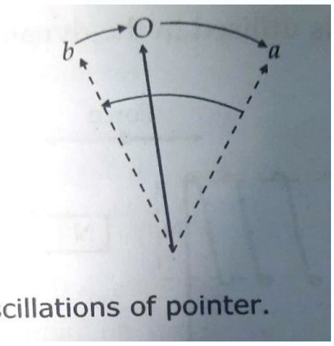
1. Have non-uniform scale and thus reading become difficult.

2. It increases the weight of the system.

3. The instrument should be placed in the always in the vertical position.

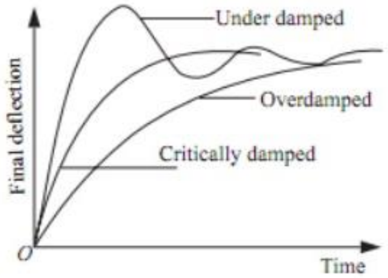
Damping force:

The moving system of the instrument will tend to move under the action of the deflecting torque. But on account of the control torque, it will try to occupy a position of rest when the two torques are equal and opposite. However, due to inertia of the moving system, the pointer will not come to rest immediately but oscillate about its final deflected position and takes appreciable time to come to steady state. To overcome this difficulty a damping torque is to be developed by using a damping device attached to the moving system.



Oscillations of pointer.

Depending upon the degree of damping introduced in the moving system, the instrument may have any one of the following conditions as shown in Fig.



Dynamic response of a measuring instrument

Under damped condition: The response is oscillatory

Over damped condition: The response is sluggish and it rises very slowly from its zero position to final position.

Critically damped condition: When the response settles quickly without any oscillation, the system is said to be critically damped.

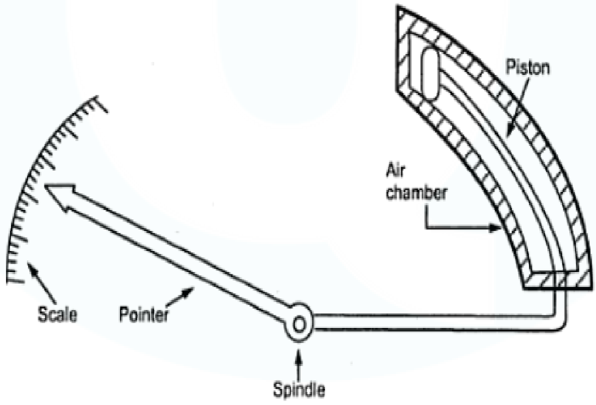
In practice, the best response is slightly obtained when the damping is below the critical value i.e., the instrument is slightly under damped.

The damping torque is produced by the following methods

- (a) Air friction damping
- (b) Fluid friction damping
- (c) Eddy current damping
- (d) Electromagnetic damping

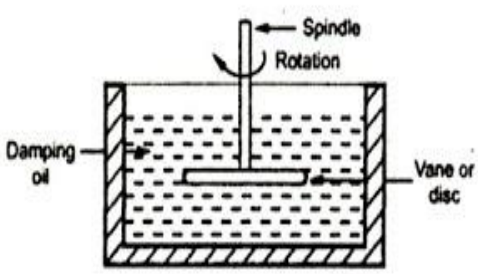
1. Air friction damping

The piston is mechanically connected to a spindle through the connecting rod . The pointer is fixed to the spindle moves over a calibrated dial. When there are oscillations the piston moves into and out of air chamber. When the piston moves inside the chamber, the air inside is compressed and pressure of air, thus builds up, opposes the motion of piston and hence the whole moving system. When the piston moves out of the air chamber, pressure in the closed space falls, and the pressure on the open side of piston is greater than on the other side. Thus there is again an opposition to motion.



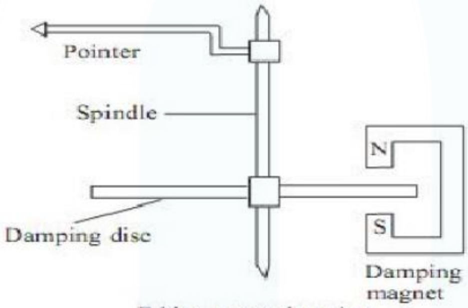
2. Fluid Friction damping

This form of damping is similar to air friction damping. Oil is used in place of air and as the viscosity of oil is greater, the damping force is correspondingly greater. A disc is attached to the moving system as shown in the figure, this disc dips into an oil pot and is completely submerged in oil. When the moving system moves, the disc moves in oil and a frictional drag is produced. This frictional drag always opposes the motion.



3) Eddy current damping

An aluminum circular disc is fixed to the spindle. This disc is made to move in the magnetic field produced by a permanent magnet. When the disc oscillates it cuts the magnetic flux produced by damping magnet. An emf is induced in the circular disc by faradays law. Eddy currents are established in the disc since it has several closed paths. By Lenz's law, the current carrying disc produced a force in a direction opposite to oscillating force. The damping force can be varied by varying the projection of the magnet over the circular disc.



Eddy current damping

4) **Electromagnetic Damping**

The movement of a coil in a magnetic field produces a current in the coil which interacts with the magnetic field to produce a torque. This torque opposes the movement of the coil and slows the response.

Comparison of types of damping torques:

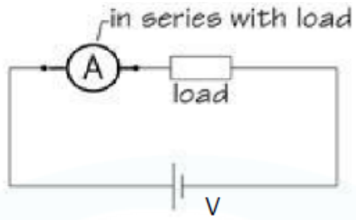
Air friction damping provides a very simple and cheap method of damping. Care must be taken to see that the piston is not bent or twisted otherwise it will touch the walls of the air chamber thereby causing serious errors due to solid friction. It does not require the use of a permanent magnet whose introduction may lead to distortion of the operating field.

Fluid friction damping has the advantage that the oil which is required for damping, can be used for insulation purposes in some forms of instruments which are submerged in oil. Due to more viscosity of fluid, more damping is provided. Due to upthrust of oil, the load on the bearings are reduced, thus reducing the frictional errors. Disadvantages of fluid friction damping is that it is used only for instruments in vertical position. Due to oil leakage, the instruments cannot be kept clean.

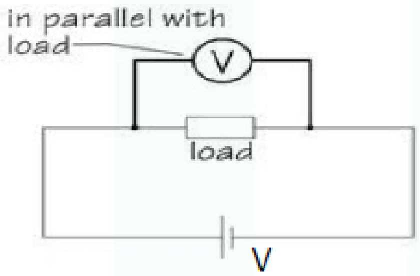
Eddy current damping is the most efficient form of damping. It is very convenient to use in instruments where a metallic disc or a former and a permanent magnet already form part of the operating system.

Ammeters and Voltmeters

Ammeters: Ammeters are used to measure current in amperes and are connected in series with the circuit whose current is to be measured. The power loss in an ammeter is I^2R_a where I is the current to be measured and R_a is the resistance of the ammeter. Ammeters have low electrical resistance so that they cause small voltage drop and consequently absorb small power. The ideal ammeter will have zero resistance so as not to disturb the circuit.



Voltmeters: Voltmeters are used to measure voltage in volts and are connected in parallel with the circuit whose voltage is to be measured. The power loss in a voltmeter is (V^2/R_v), where V is the voltage to be measured and R_v is the resistance of the voltmeter. Therefore voltmeters have a very high electrical resistance, in order that the current drawn by them is small and consequently the power consumed is small. An ideal voltmeter will have infinite resistance.



Permanent Magnet Moving Coil (PMMC) instrument

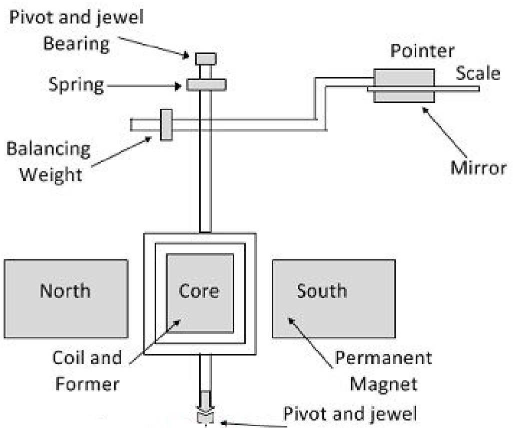
One of the most accurate type of instrument used for D.C. measurements is PMMC instrument.

Construction: The moving coil and permanent magnet are the main part of the PMMC instrument. The moving coil is the current carrying part of the instruments which is freely moved between the stationary field of the permanent magnet. The current passes through the coil deflects it due to which the magnitude of the current or voltage is determined. The coil is mounted on the rectangular former which is made up of aluminium. The former increases the radial and uniform magnetic field between the air gap of the poles. The coil is wound with the silk cover copper wire between the poles of a magnet.

Damping: Eddy current damping is used. This is produced by aluminium former.

Control: Spring control is used.

The pointer is linked with the moving coil. The pointer is made of the lightweight material, and hence it is easily deflected with the movement of the coil. Sometimes the parallax error occurs in the instrument which is easily reduced by providing the mirror.



Torque developed by PMMC instruments

Force produced in the coil

F = $N\ B\ I\ l$

N–Number of turns of coil
B–flux density in the air gap
l, b – the vertical and horizontal length of the side.
I – current through the coil.

T_d= Force * Distance

$T_d = N\ B\ I\ l*b = N\ B\ I\ A$

$T_d \alpha I$ i.e $T_d = G\ I$

$T_c = K\ \Theta$

Where K = Spring constant

Θ = Angular movement of coil.

At steady state condition, deflecting and controlling torque shall be equal,

$T_d = T_c$ $\Rightarrow GI = K\Theta$

$\Rightarrow \boldsymbol{\Theta = (G / K)\ I}$

Advantages:

1) Scale is uniform

2) Power consumption is less

3) Damping is very effective

4) Torque/weight is high

5) Since operating field is very strong, the effect of stray field is negligible

6) Range of instrument can be extended

Disadvantages:

1) Use only for D.C.

2) Cost is high

3) Error is produced due to ageing effect of PMMC

4) Friction and temperature error are present

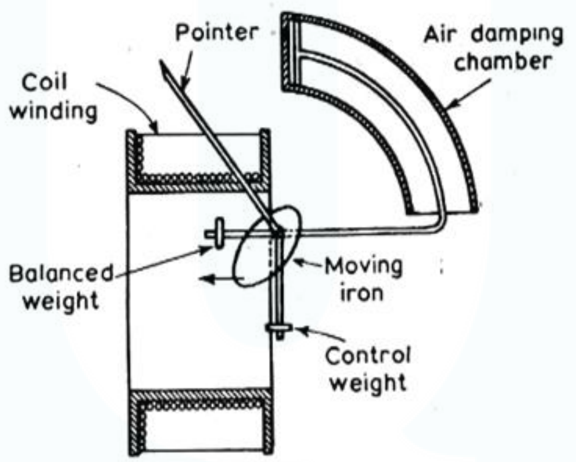
Moving Iron Instruments (MI Instruments)

This type of instrument is principally used for the measurement of alternating currents and voltages. This can also be used for DC measurements. There are two types of moving iron instruments

1)Attraction type in which a single soft iron vane(moving iron) is mounted on the spindle and is attracted **towards the coil when operating current flows through it.**

2)Repulsion type in which two soft iron vanes are used, one fixed while the other is movable (moving iron) and mounted on the spindle of the instrument.

1)Attraction Type Moving Iron Instrument



Construction

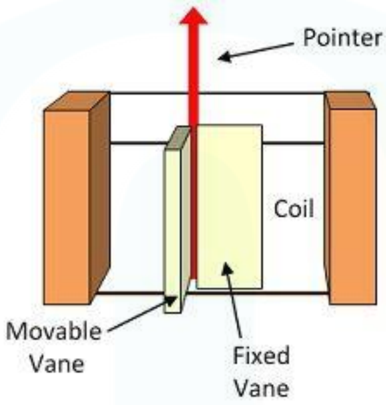
It consists of a coil wound on a hollow cylindrical bobbin. A small piece of soft iron is eccentrically pivoted just outside the coil. A pointer is attached to the spindle so that it is deflected with the motion of the soft iron piece. The spindle is pivoted to jewel bearings. Air friction damping is used .A piston, attached to the spindle, moves inside an air chamber and gives the necessary damping. The attraction type instruments use spring, which provided the controlling torque.

Working

When the instrument is connected in the circuit to measure current or voltage, the operating current flows through the coil and the coil behaves like a magnet and attracts the soft iron piece towards it. The result is that the pointer attached to the moving system moves from zero position. The pointer will come to rest at a position where deflecting torque is equal to the controlling torque. If current in the coil is reversed, the direction of magnetic field also reverses and so does the magnetism produced in the soft iron piece. Hence the direction of the deflecting torque remains unchanged. For this reason, such instruments can be used for both ac and dc measurements.

Repulsion Type Instruments

The repulsion type instrument has two vanes or iron plates. One is fixed, and the other one is movable. The vanes become magnetised when the current passes through the stationary coil and the force of repulsion occur between them. Because of a repulsive force, the moving coil starts moving away from the fixed vane. The spring provides the controlling torque. The air friction induces the damping torque, which opposes the movement of the coil.



Torque Equation of Moving Iron Instruments

Suppose that, at any instant of time current flowing in the coil is I.

Thus the energy stored in the coil in the form of magnetic field = $(1/2)LI^2$.

As soon as the current changes to (I+dI), deflection in the pointer becomes dΘ resulting into change in inductance of coil from L to (L+dL).

Let this deflection in pointer is due to deflection torque T_d.

Thus mechanical work done = $T_d * d\Theta$ ………………..(1)

Energy stored in Coil = $(1/2)(L+dL)(I+dI)^2$

Change in stored energy of coil = Final Stored Energy – Initial Stored Energy

$$= (1/2)(L+dL)(I+dI)^2 - (1/2)LI^2$$

$$= (1/2)[\ (L+dL)(I+dI)^2 - I^2L]$$

$$= (1/2)[\ (L+dL)(I^2+2IdI+(dI)^2 - I^2L]$$

$$= (1/2)[\ LI^2+2LIdI+L(dI)^2 + dLI^2+2IdIdL+dL(dI)^2 - I^2L]$$

Neglecting second order and higher terms of differential quantities i.e. $L(dI)^2$, 2IdIdL and $dL(dI)^2$

$$= (1/2)[\ 2LIdI+dLI^2]$$

$= LIdI + (1/2)dLI^2$ ……………………(2)

Again, just think, when there is a change of current from I to (I+dI), this change of current must be accompanied by change in emf of coil. Thus we can write as

$e = d(LI) / dt$

$= IdL/dt + LdI/dt$

Electrical energy supplied by the source = eIdt

$= (IdL + LdI)\ I$

$= I^2dL + LIdI$

According to law of conservation of energy, this electrical energy supplied by the source is converted into stored energy in the coil and mechanical work done for deflection of needle of Moving Iron Instruments.

Hence, $I^2dL + LIdI$ = Change in stored energy + Work done

$\Rightarrow I^2dL + LIdI = LIdI + (1/2)dL\,I^2 + T_d * d\Theta$ ….[from (1) and (2)]

$\Rightarrow T_d * d\Theta = (1/2)dLI^2$

$\Rightarrow \boldsymbol{T_d = (1/2)I^2(dL/d\Theta)}$

Thus deflecting torque in Moving iron Instruments is given as

$$\boldsymbol{T_d = (1/2)I^2(dL/d\Theta)}$$

From the above torque equation, we observe that the deflecting torque is dependent on the rate of change of inductance with the angular position and square of rms current flowing through the coil.In moving iron instruments, the controlling torque is provided by spring. Controlling torque due to spring is given as

$T_c = K\Theta$

Where K = Spring constant

Θ = Deflection in the needle

In equilibrium state, deflecting and controlling torque shall be equal.

Deflecting Torque = Controlling Torque

$\Rightarrow T_d = T_c$

$\Rightarrow (1/2)I^2(dL/d\Theta) = K\Theta$

$\Rightarrow \Theta = (1/2)(I^2/K)(dL/d\Theta)$

From the above torque equation, we observe that the angular deflection of needle of moving iron instruments is square of rms current flowing through the coil. Therefore, the deflection of moving iron instruments is independent of direction of current.

Errors in MI instrument

There are two types of errors which occur in moving iron instruments:

- Errors with both AC and DC.
- Errors with AC only.

Errors with both AC and DC

Error due to hysteresis: This error occurs as value of flux density is different for same current for ascending and descending values. The hysteresis error is considerably reduced by using materials which have negligible hysteresis loss.

Error due to stray magnetic fields: Since the operating magnetic field of the moving iron instruments in comparatively weak, therefore, stray fields (fields other than the operating magnetic field) affect these instruments considerably. These errors can be minimized by using an iron case or a thin iron shield over the working parts.

Error due to temperature: With the change in temperature stiffness of the spring varies which causes errors.

Errors with AC only

Error in moving iron instruments due to change in frequency: The change in frequency produces a change in impedance of the coil and change in magnitude of eddy currents.

Advantages of the MI Instruments

The following are the advantages of the moving iron instruments.

Universal use – The MI instrument is independent of the direction of current and hence used for both AC and DC.

Less Friction Error – The friction error is very less in the moving iron instrument because their torque weight ratio is high. The torque weight ratio is high because their current carrying part is stationary and the moving parts are lighter in weight.

Cheapness – The MI instruments require less number of turns as compared to PMMC instrument. Thus, it is cheaper.

Robustness – The instrument is robust because of their simple construction. And also because their current carrying part is stationary.

Disadvantages of Moving Iron Instruments.

The following are the disadvantages of Moving Iron Instrument.

Accuracy – The scale of the moving iron instruments is not uniform, and hence the accurate result is not possible.

Errors – Some serious error occurs in the instruments because of the hysteresis, frequency and stray magnetic field.

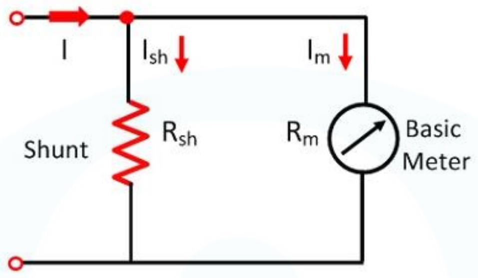
Waveform Error – Moving iron instruments may be seriously affected by waveform. It affects on both account of the change in the form of flux waveform

Difference between AC and DC calibration – The calibration of the AC and DC are differed because of the effect of the inductance of meter and the eddy current which is used on AC. The AC is calibrated on the frequency at which they use.

Shunts and Multipliers-Extension of range of Meters(PMMC)

Shunts: Extension of ammeter range

A low shunt resistance is connected in parallel with the ammeter to extent the range of current measurement which is shown in the fig.



Basic Ammeter Circuit

Large current can be measured by using an ammeter of small rating by using a shunt

Let *Rm=Resistance of meter,*

Rsh=Resistance of shunt,

Im= Current through meter,

Ish=current through shunt,

I= current to be measured

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

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

The shunt current is

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

Therefore the equation of shunt resistance is given as,

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

$$\frac{I}{I_m} - 1 = \frac{R_m}{R_{sh}}$$

$$\frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}$$

The multiplying power is given as,

$$m = 1 + \frac{R_m}{R_{sh}}$$

$$R_{sh} = \frac{R_m}{m-1}$$

The following are the requirements of the shunt.

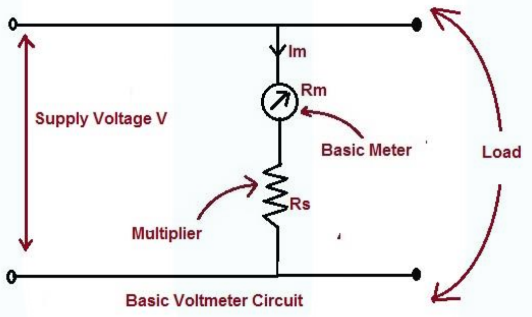
The resistance of the shunt remains constant with time.

The temperature of the material remains same even though substantial current flows through the circuit.

Manganin and Coustantan are used for making the shunt in the DC and AC instruments respectively.

Multipliers: Extension of voltmeter range

A large resistance is connected in series with the voltmeter to extent the range of voltage measurement and is called a multiplier which is shown in the fig.



Large voltage can be measured by using a voltmeter of small rating with a multiplier

Let *Rm=resistance of meter, Rs=resistance of multiplier Vm=Voltage across meter*

Vs= Voltage across series resistance

V= voltage to be measured

$V_m = I_m R_m$ ……………….(1)

and $V = Im(R_m + R_s)$ …………(2)

Dividing equation (2) by (1) we get,

$V/Vm = 1 + R_s/R_m$

Thus,

m = Multiplying Factor = $1 + R_s/R_m$

The essential requirements of voltmeter multiplier is

Their resistance should not change with time.

Q1) A 1mA meter with an internal resistance of 100 ohm is to be converted into a 0-100 mA ammeter. Calculate the shunt resistance required.

$$R_{sh} = \frac{I_m R_m}{(I - I_m)} = \frac{1\times10^{-3} \times 100}{(100\times10^{-3} - 1\times10^{-3})} = \underline{\underline{1.01\,\Omega}}$$

$I_m = 1\,mA = 1\times10^{-3}\,A$

$R_m = 100\,\Omega$

$I = 100\,mA = 100\times10^{-3}\,A$

Q2) Find the multiplying power of a shunt of 200 ohm resistance used with a galvanometer of 1000 ohm resistance. Determine the value of shunt resistance to give a multiplying power of 50.

Multiplying Power, $m = 1 + \frac{R_m}{R_{sh}}$

$R_m = 1000\,\Omega$

$R_{sh} = 200\,\Omega$ $\quad \therefore m = \underline{\underline{6}}$

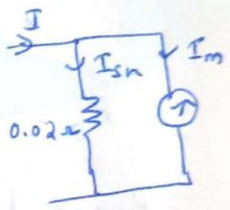
$$R_{sh} = \frac{R_m}{m-1} = \frac{1000}{50-1} = \underline{\underline{20.4\,\Omega}}$$

Q3) A moving coil ammeter has a fixed shunt of 0.02 ohm. With a coil resistance of R= 1000 ohm and a potential difference of 500 mV across it , full scale deflection is obtained:

a) To what shunted current does this correspond.

b) Calculate the value of R to give full scale deflection when shunted current I is 10A

a) $I_{sh} = \frac{500\times10^{-3}}{0.02} = 25\,A$



$I_m = \frac{500\times10^{-3}}{1000} = \underline{\underline{0.5\times10^{-3}\,A}}$

b) $I_{sh} = 10\,A$

Voltage across shunt $= 10\times.02 = 0.2\,V$

Resistance of the meter $= \frac{0.2}{0.5\times10^{-3}} = 400\,\Omega$