Module 1

Different types of Electrical measuring instruments and their operations.

Electrical measuring instruments

Instruments which are designed to measure the various electrical quantities like electrical power factor, power, voltage and current etc.

These instruments basically have a sensor, operating and display unit.

Important properties of a measuring instrument:-

1. The measuring instrument should not change the characteristics of a circuit.

2. The measuring instrument should consume only low power.

3. Should have high accuracy.

Methods of measurement.

1.Direct Method – The unknown quantity is directly compared against a standard quantity.

2.Indirect Method – Where direct measurement is not possible. Measurement of resistance of conductor via ohm's law.

Classification of measuring instruments

1. Absolute and Secondary Measuring Instruments

2. Analog and Digital Measuring Instruments

3. Mechanical, Electrical and Electronics Measuring Instruments

4. Deflection Type and Null Type Measuring Instruments

1.Absolute and Secondary Measuring Instruments

Absolute Measuring Instruments

These instruments give output in terms of physical constant of the instruments. For example Rayleigh's current balance and Tangent galvanometer are absolute instruments.

Secondary Measuring Instruments

These instruments give the values directly. These instruments are constructed with the help of absolute instruments. Secondary instruments are calibrated by comparison with absolute instruments. These are more frequently used in measurement of the quantities.

Eg:- Voltmeter, Ammeter, Wattmeter.

Secondary instruments are classified as three,

1. Indicating instruments - Gives instantaneous values. Eg:-Ammeter, Voltmeter.

2. Recording instruments - Continuous records the measurement over a period of time. Eg:-ECG, CRO.

3. Integrating instruments – Measures the total amount of quantity for a period of time. Eg:- Energy Meter, Watt-hour meter.

2. Analog and Digital Measuring Instruments

Analog Measuring Instruments

The instrument whose output varies continuously is known as the analogue instrument.

Eg:- Wrist watch, Fuel gauge, Speedometer.

Digital Measuring Instruments

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**.**

3. Mechanical, Electrical and Electronics Measuring Instruments

Mechanical measuring instruments – To measure physical quantities.

Electrical measuring instruments – Pointer deflected due to electrical activity.

Electronics measuring instruments – Pointer deflected due to the movement of electrons.

4. Deflection Type and Null Type Measuring Instruments

Deflection Type Measuring Instruments

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.

Null Type Measuring Instruments

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 use. 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 and in galvanometer for obtaining the null point.

Types of torques in indicating instruments

Needs of torque:-

1. To move the pointer.

2. To stop a pointer at a point

3. To remove the oscillations in the pointer.

There are 3 types of torques

1. Deflecting Torque (T_d)
2. Controlling Torque (T_c)
3. Damping Torque

Deflecting Torque:

This torque produce the required amount of force in the pointer to move from its `zero' position, when the instrument is connected to the supply.

To obtain this force in an instrument, different effects of electric current use such as magnetic effect, heating effect, chemical effect etc.

Without deflecting torque pointer of an instrument cannot be move for any value.

Controlling Torque:

Controlling torque is essential to control the movement of the pointer and to ensure that the magnitude of the deflection of the pointer is always the same as given value of the quantity to be measured.

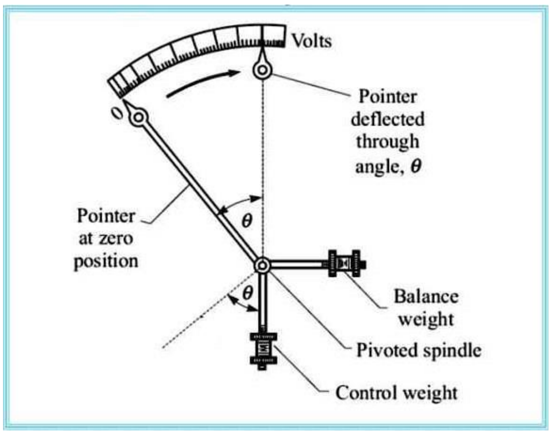
The controlling force is always acts in opposite direction to the deflecting force. And also return the pointer to its initial zero position when the instrument is disconnected from the supply.

The controlling force could be produced by any one of the following method.

- Gravity control
- Spring control

Gravity control:

In this method, small adjustable weights are attached to the opposite extension of the pointer as shown in figure.



When the instrument is disconnected from the supply, the control weight and the balance weight attached to the opposite end of the pointer make the pointer to be at zero position.

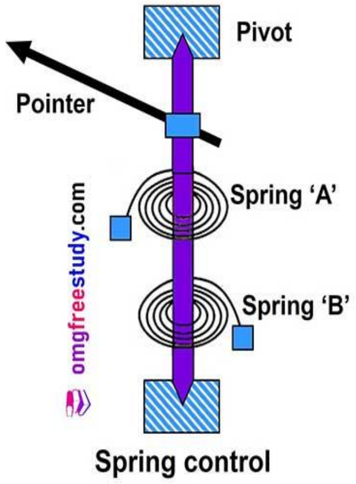
When the instrument is connected to the supply, the pointer moves in a clockwise direction, thereby displacing the weights shown in figure.

Due to the gravitational pull, the weights will try to come back to its original position.

Spring control:

The most common arrangement of two spring control utilizes. Which is made up of phosphor-bronze or beryllium copper spiral hair-springs A and B, the inner ends of which are attached to the spindle.

Both springs A and B are wound in opposite directions so that when pointer is deflecting, one spring winds up while the other unwinds. Therefore the controlling force is produce due to the combined torsions of the springs.



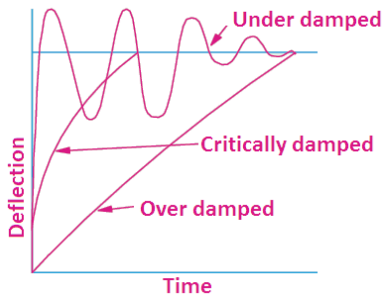
Spring controlled instruments have the following advantages over the gravity controlled instruments.

- The instruments can be used in any position
- Control springs help in leading in and out the current to the moving coil of the instruments.

Damping Torque:

This torque is necessary to bring the pointer to rest quickly. If there is no damping torque, then the pointer will oscillates about its final deflected position for some time before coming to rest, due to the inertia.

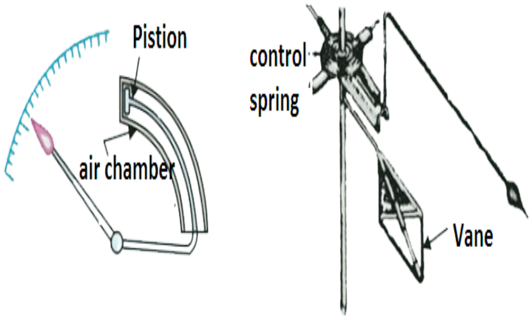
Under-damped condition - the pointer will oscillate about the final position for some time before coming to rest.
Over-damped condition, the pointer will become slow and lethargic.



Critically damped condition - the degree of damping is adjusted to such a value that the pointer comes up to the correct reading quickly without oscillating about it, the instrument is said to be.
Types of Damping Torque,

- Air friction damping.
- Fluid friction damping.
- Eddy current damping.

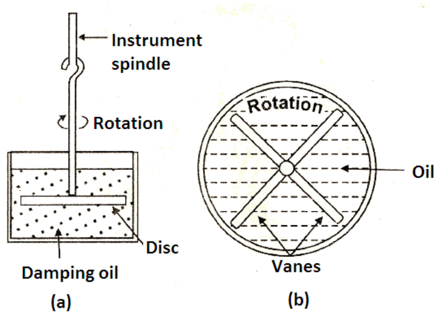
Air Friction Damping



A light aluminium piston is attached to the spindle that carries the pointer and moves with a very little clearance in a rectangular or circular air chamber closed at one end. The cushioning action of the air on the piston damps out any tendency of the pointer to oscillate about the final deflected position.

In this method, one or two light aluminium vanes are attached to the same spindle that carries the pointer. As the pointer moves, the vanes swing and compress the air. The pressure of compressed air on the vanes provides the necessary damping force to reduce the tendency of the pointer to oscillate.

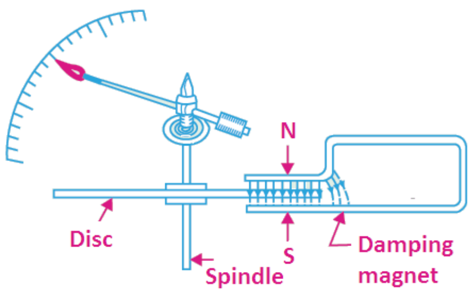
Fluid Friction Damping



Fluid friction damping

Discs or vanes attached to the spindle of the moving system are kept immersed in a pot containing oil of high viscosity. As the pointer moves, the friction between the oil and vanes opposes the motion of the pointer and thus necessary damping is provided.

Eddy Current Damping

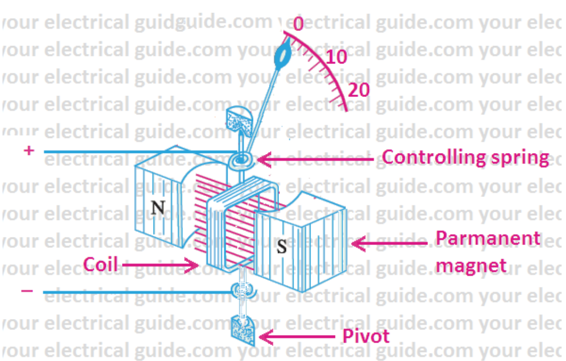


A thin aluminium or copper disc is attached to the moving system is allowed to pass between the poles of a permanent magnet. As the pointer moves, the disc cuts across the magnetic field and eddy currents are induced in the disc.

These eddy currents react with the field of the magnet to produce a force which opposes the motion according to Lenz's Law. In this way, eddy current damping torque reduces the oscillations of the pointer.

Permanent Magnet Moving Coil Instrument

It consists of a powerful permanent shoe magnet. A light rectangular coil of many turns of fine wire is wound on a light aluminium former. An iron core is inserted inside the coil to reduce reluctance for the magnetic lines of force. The coil is mounted on the spindle and acts as the moving element.



Two phosphor bronze spiral hairsprings are attached to the spindle. The springs provide the controlling torque as well as they act as incoming and outgoing leads for the current. Eddy current damping is provided by the aluminium former.

PMMC Construction

A PMMC meter (or D'Arsonval meters) is constructed of 5 main components:

- Stationary Part or Magnet System
- Moving Coil
- Control System
- Damping System
- Meter

Stationary Part or Magnet System

In the present time we use magnets of high field intensities, high coercive force instead of using U shaped permanent magnet having soft iron pole pieces. The magnets which we are using nowadays are made up of materials like alcomax and alnico which provide high field strength.

Moving Coil

The moving coil can freely moves between the two permanent magnets as shown in the figure given below. The coil is wound with many turns of copper wire and is placed on rectangular aluminium which is pivoted on jeweled bearings.

Control System

The spring generally acts as control system for PMMC instruments. The spring also serves another important function by providing the path to lead current in and out of the coil.

Damping System

The damping force hence torque is provided by movement of aluminium former in the magnetic field created by the permanent magnets.

Meter

Meter of these instruments consists of light weight pointer to have free movement and scale which is linear or uniform and varies with angle.

Moving Coil Instrument Working Principle

The basic moving coil instrument working principle is that when a current carrying conductor is placed in a magnetic field, a mechanical force is exerted on the conductor, thus a deflecting torque is developed. By the production of deflecting torque, the pointer deflects over the scale. Controlling torque is provided by the spring control and damping is provided by eddy current damping.

If the current in the coil is reversed, the direction of deflecting torque will be reversed because of the field produced by the permanent magnets remains the same. This will give a wrong direction of rotation thus the instrument cannot be used on AC, permanent magnet moving coil instruments can be used for the measurement of DC only.

$T_d \, \alpha \, I$

$T_c \, \alpha \, \theta$ at equilibrium $T_d = T_c$, $I \, \alpha \, \theta$.

Advantages and Disadvantages Moving Coil Instruments

Advantages:

- The scale of permanent magnet moving coil instrument is uniform.
- Very effective and reliable.
- Eddy current damping is used, no hysteresis loss as the former is of aluminum.
- Low power consumption because driving power is small.
- No effect of the stray magnetic field as working field provided by the permanent magnets is very strong.
- High torque/weight ratio, therefore, such instruments require small operating current.
- Very accurate and reliable.

Disadvantages:

- These instruments cannot be used for AC measurements.
- These are costlier in comparison of moving iron instruments.
- Friction and temperature might introduce some errors.
- Some errors are also caused due to the ageing of control springs and the permanent magnets.

Errors in Moving Coil Instruments

The main sources of errors in moving coil instruments are due to:

- Weakening of permanent magnets due to aging at temperature effects.
- Weakening of springs due to aging and temperature effects.
- Change of resistance of the moving coil with temperature.

Moving Iron Instrument

Moving iron Instrument or Moving iron meter is used to measure the current and voltage of AC and DC. They are non-directional. The working principle depends upon the movement of iron attracted by the magnetic field towards it and repulsion between them. The magnetic field is produced by the current in the coil.

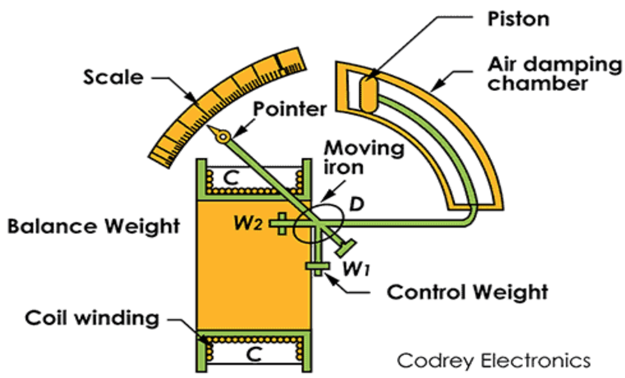
This instrument can be used as an ammeter, voltmeter, and wattmeter. The coil has less number of turns if the instrument is ammeter and more turns if the instrument is a voltmeter. The moving iron type supports both AC and DC.

The construction of moving iron instrument is divided into two types :

1. Attraction iron meter (Uses single iron)
2. Repulsion type moving iron meter(Uses double iron)

Attraction Type

Attraction type moving iron meter consists of a moving system which has soft iron. The current is passed through a coil placed near it. The moving iron is attracted to the coil which produces a magnetic field when a current flow through the coil.



Attraction Type Moving Iron

It consists of a fixed coil wounded by a copper wire. Soft iron is free to move on the spindle and a pointer is also attached to the spindle.

Working:-

The working of the Attraction type iron meter is When the current flows through the coil, the moving iron attracted to the coil which causes the pointer to move. The pointer will come to zero position where deflecting torque is zero.

When the current in the coil is changed, the direction of the magnetic field also changed and the moving iron will get magnetize in such a way that it is pulled inwards. Hence these types of instruments can be used for both AC and DC currents.

Here the air friction damping is provided by the air chamber because the magnets can affect the deflection of the pointer and the readings can be changed. Controlling torque is provided by the gravity control method.

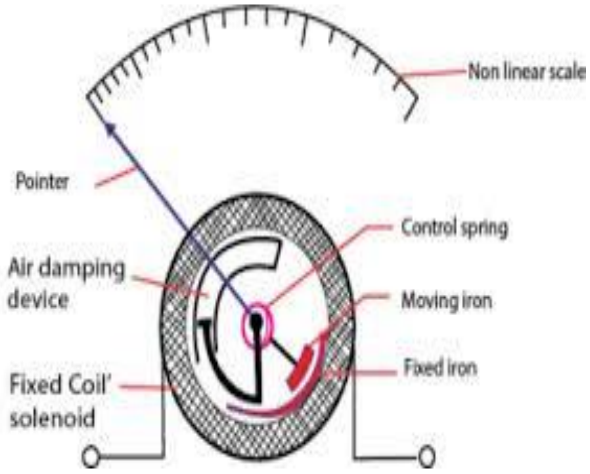
T_d α strength of magnetic field(H_f) x strength of magnetization of iron bar(H_i)

$T_d \alpha H^2$, $H \alpha I$, $T_d \alpha I^2$

$T_c \alpha \theta$, at equilibrium $T_d = T_c$, $I^2 \alpha \theta$

Repulsion Type

The repulsion type moving iron instrument consists of soft iron in the form of the vane as the moving element of the meter. It also has a fixed iron vane. A shaft is attached to the moving iron. A cylindrical stationary coil is used to produce the magnetic field when there is a flow of current through it. A pointer is fixed on the shaft which gets deflected shows the reading on a non-uniform scale. The strength of the magnetic field increases or decreases with the magnitude of the current flows through it.



Working:-

The moving iron and fixed iron magnetize with the same polarity due to which the two irons repel each other (when the same type of magnetic materials is placed in a magnetic field they will get magnetized uniformly and they repel each other). Therefore the movable piece moves away from the fixed piece. Thus the pointer attached to the spindle deflects over the calibrated scale.

The controlling torque is exerted by the spiral spring made of phosphor bronze which is connected to the shaft. An air chamber is provided for air friction damping because the magnets can affect the deflection of the pointer and affect the reading. The deflection torque makes the pointer to move away from the zero.

T_d α strength of of magnetization of fixed iron (H_f) x strength of magnetization of moving iron (H_m)

$T_d \alpha H^2$, $H \alpha I$, $T_d \alpha I^2$

$T_c \alpha \theta$, at equilibrium $T_d = T_c$, $I^2 \alpha \theta$

Advantages:

- This type of instrument is simple and cheap in construction.
- It is non-directional hence can be used in both AC and DC circuits.
- Because of the current-carrying part is stationary and has lighter moving parts, the torque weight ratio is high.
- Due to the high torque weight ratio, the frictional error is very less.

Disadvantages:

- Accuracy is less because of the instrument is non-directional.
- It cannot be calibrated with a high degree of precision for DC on account of the effect of hysteresis in the iron vanes.
- High power consumption.

Range Extension

Extension of range is a concept to measure the higher value of the current or voltage than the rating of the instruments by adding some external Resistance/Impedance of suitable value in series or parallel.

Common devices used for extending the range of the instruments are

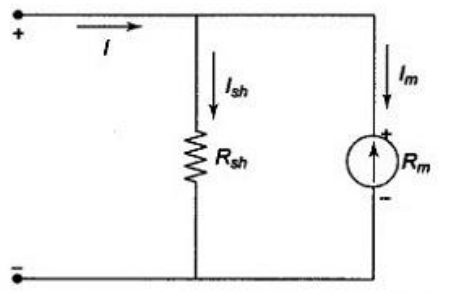
a. Shunts

b. Multipliers

Range Extension of Ammeter

The range of an ammeter can be extended by connecting a low resistance, called shunt resistance, connected in parallel with ammeter. So, the current will be distributed between the two branches in such a way that an appropriate (i.e., safe) amount would go through the ammeter, and the over range (i.e., extra) current would be bypassed through the shunt resistance.

The current required to be allowed through the shunt resistance is I_{sh}. I, is the total full scale deflection current required to be measured. I_m is the current the basic meter can measure. The shunt resistance is connected in parallel (in shunt) with the basic meter. Hence irrespective of the currents flowing through the shunt resistance and the meter (with internal resistance R_m) the voltage drop across the two is the same.



Method of connecting Shunt Resistance

Therefore

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

We know that $I_{sh} = I – I_m$

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

Substituting the value of I_{sh}

$R_{sh} = R_m.I_m/(I - I_m)$

Dividing the Nr and Dr on the right hand side by I_m

$R_{sh} = R_m/([I/I_m]-1)$

$I/I_m = N$, the number of times we increase the range.

N can be termed the multiplication factor. Hence the value of shunt resistance is:

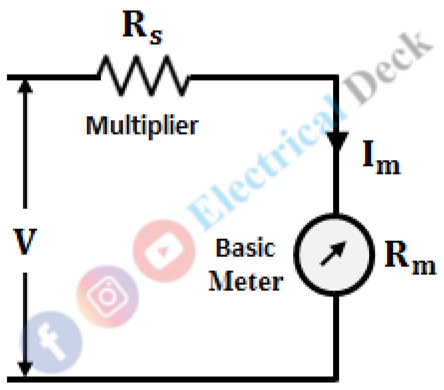
$R_{sh} = \{R_m/ (N - 1)\}\Omega$

Essential Requirements of Shunt resistance :

1. The temperature coefficient of the shunt resistance must be low.
2. The value of shunt resistance should not vary with time.
3. When carrying the current the shunt resistance should not have excessive temperature rise.
4. The thermal electromotive force must be low.

Extension of Range of Voltmeter Using Multiplier :

A multiplier is basically a resistor connected in series with the voltmeter as shown below. The main function of the multiplier is to limit the flow of current through the voltmeter in such a way that the deflection of the pointer should not exceed the full-scale deflection.



It must ensure that the voltmeter should be connected in parallel or across two points, to measure the potential difference.

Let,

- R_m = Internal resistance of the meter
- R_s = Resistance of multiplier
- I_m = Full-scale deflection current of meter
- V = Voltage being measured
- V_m = Full deflection voltage of the meter

From the above figure,

$$V = I_m(R_m + R_s)$$

$$V = I_m R_m + I_m R_s$$

$$I_m R_s = V - I_m R_m$$

$$\therefore R_s = \frac{V}{I_m} - R_m$$

The multiplying factor of the multiplier is the ratio of extended voltage range to be measured V to the actual sustainable voltage by the voltmeter V_m. If the sustainable voltage drop of the meter $V_m = I_m R_m$. Then multiplying factor m is,

$$m = \frac{V}{V_m} = \frac{I_m(R_m + R_s)}{I_m R_m}$$

$$m = 1 + \frac{R_s}{R_m}$$

$$R_s = (m - 1)R_m$$

Hence, to extend a voltmeter range for m times. The resistance of the multiplier required is (m-1) × resistance of the meter.

Essential Requirements of Multipliers :

The construction of multiplier should meet the following requirements,

- The resistance of the multiplier should be time-invariant.
- The temperature coefficient of resistance should be small.
- They should be non-inductively wound for ac meters.

In practice, the multipliers are made up of materials that have negligible temperature coefficients like manganin and constantan. These also reduce the errors due to temperature changes.