SRIMAAN COACHING CENTRE-TRICHY-TNPSC-CTSE- ELECTRICAL ENGINEERING / EEE – (DIPLOMA STANDARD) STUDY MATERIAL TO CONTACT: +91 8072230063.

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TNPSC CTSE

(DIPLOMA / ITI LEVEL)

Combined Technical Services Examination (Non-Interview Posts)

ELECTRICAL ENGINEERING / EEE (Diploma Standard)

UNIT-3- MEASUREMENTS AND INSRUMENTS

TNPSC-CTSE (DIPLOMA / ITI) STUDY MATERIALS

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Combined Technical Services Examination (Diploma / ITI Level)

ELECTRICAL ENGINEERING / ELECTRICAL AND ELECTRONICS ENGINEERING (Diploma Standard)

UNIT III: MEASUREMENTS AND INSRUMENTS

INTRODUCTION TO MEASURING INSTRUMENTS:

Definition of instruments

An instrument is a device in which we can determine the magnitude or value of the quantity to be measured. The measuring quantity can be voltage, current, power and energy etc. Generally instruments are classified in to two categories.

Instrument

AbsoluteInstrument **SecondaryInstrument**

Absoluteinstrument

An absolute instrument determines the magnitude of the quantity to be measured in terms of the instrument parameter. This instrument is really used, because each time the value of the measuring quantities varies. So we have to calculate the magnitude of the measuring quantity, analytically which is time consuming. These types of instruments are suitable for laboratory use. Example: Tangentgalvanometer.

Secondaryinstrument

This instrument determines the value of the quantity to be measured directly. Generally these instruments are calibrated by comparing with another standard secondary instrument.

Examples of such instruments are voltmeter, ammeter and wattmeter etc. Practically secondary instruments are suitable for measurement.

Secondary instruments

Indicatinginstruments Recording **Integrating** **Electromechanically**
Indicating instruments

Indicatinginstrument

This instrument uses a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity.

Recordinginstrument

This type of instruments records the magnitude of the quantity to be measured continuously over a specified period of time.

Integratinginstrument

This type of instrument gives the total amount of the quantity to be measured over a specified period of time.

Electromechanical indicatinginstrument

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

(a) Deflectingforce

(b) Controlling force

(c)Dampingforce

Deflectingforce

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. 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.

Magnitudeeffect

When a current passes through the coil , it produces a imaginary bar magnet. When a soft iron piece is brought near this coil it is magnetized. Depending upon the current direction the poles are produced in such a way that there will be a force of attraction between the coil and the soft iron piece. This principle is used in moving iron attraction typeinstrument.

If two soft iron pieces are place near a current carrying coil there will be a force of repulsion between the two soft iron pieces. This principle is utilized in the moving iron repulsion type instrument.

Force between a permanent magnet and a current carryingcoil

When a current carrying coil is placed under the influence of magnetic field produced by a permanent magnet and a force is produced between them. This principle is utilized in the moving coil type instrument.

Force between two current carryingcoil

When two current carrying coils are placed closer to each other there will be a force of repulsion between them. If one coil is movable and other is fixed, the movable coil will move away from the fixed one. This principle is utilized in electrodynamometer type instrument.

Controllingforce

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 is equal to controlling torque.

$$T_d = T_c$$

Springcontrol

Two springs are attached on either end of spindle .The spindle is placed in jewelled 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.

When a current is supply, the pointer deflects due to rotation of the spindle. While spindle is rotate, the spring attached with the spindle will oppose the movements of the pointer. The torque produced by the spring is directly proportional to the pointer deflectionθ. $T_C \propto \theta$

The deflecting torque produced T_d proportional to 'I'. When $T_C = T_d$, the pointer will come to a steady position.

Therefore $\theta \propto I$

Since, $\theta$and I are directly proportional to the scale of such instrument which uses spring controlled is uniform.

Dampingforce

The deflection torque and controlling torque produced by systems are electro mechanical. Due to inertia produced by this system, the pointer oscillates about it final steady position before coming to rest. The time required to take the measurement is more. To damp out the oscillation is quickly, a damping force is necessary. This force is produced by differentsystems.

(a) Air frictiondamping (b)
Fluid frictiondamping

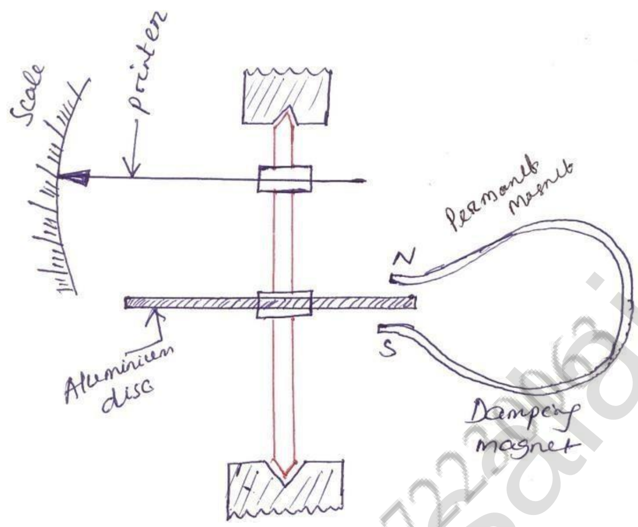
(c) Eddy currentdamping

Air frictiondamping

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 the pointer oscillates in clockwise direction, the piston goes inside and the cylinder gets compressed. The air pushes the piston upwards and the pointer tends to move in anticlockwise direction.

If the pointer oscillates in anticlockwise direction the piston moves away and the pressure of the air inside cylinder gets reduced. The external pressure is more than that of the internal pressure. Therefore the piston moves down wards. The pointer tends to move in clock wise direction.

Eddy currentdamping



Disc type

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.

Permanent Magnet Moving Coil (PMMC)instrument

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

Construction: A permanent magnet is used in this type instrument. Aluminum former is provided in the cylindrical in between two poles of the permanent magnet . Coils are wound on the aluminum former which is connected with the spindle. This spindle is supported with jeweled bearing. Two springs are attached on either end of the spindle. The terminals of the moving coils are connected to the spring. Therefore the current flows through spring 1, moving coil and spring 2.

Damping: Eddy current damping is used. This is produced by aluminum former. Control: Spring control is used.

Principle of operation

When D.C. supply is given to the moving coil, D.C. current flows through it. When the current carrying coil is kept in the magnetic field, it experiences a force. This force produces a torque and the former rotates. The pointer is attached with the spindle. When the former rotates, the pointer moves over the calibrated scale. When the polarity is reversed a torque is produced in the opposite direction. The mechanical stopper does not allow the deflection in the opposite direction. Therefore the polarity should be maintained with PMMCinstrument.

If A.C. is supplied, a reversing torque is produced. This cannot produce a continuous deflection. Therefore this instrument cannot be used in A.C.

Torque developed by PMMC

For N turns, $F = NBIL$

Torque produced $T_d = F \times \perp_r$ distance

$T_d = NBIL \times b = BINA$

$T_d = BANI$ $T_d \propto I$

Advantages

- ✓ Torque/weight ishigh
- ✓ Power consumption isless
- ✓ Scale isuniform
- ✓ Damping is veryeffective
- ✓ Since operating field is very strong, the effect of stray field isnegligible
- ✓ Range of instrument can beextended

Disadvantages

- ✓ Use only forD.C.
- ✓ Cost ishigh
- ✓ Error is produced due to ageing effect ofPMMC
- ✓ Friction and temperature error are present

Extension of range of PMMCinstrument Case- I:Shunt

A low shunt resistance connected in parrel with the ammeter to extent the range of current. Large current can be measured using low current rated ammeter by using a shunt. $\therefore V_m = V_{sh}$ $I_m R_m = I_{sh} R_{sh}$ I_m

Apply KCL at 'P' $I = I_m + I_{sh}$

$\frac{I}{I_m} = 1 + \frac{I_{sh}}{I_m}$

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

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

$\left(1 + \frac{R_m}{R_{sh}}\right)$ is called multiplication factor

Shunt resistance is made of manganin. This has least thermoelectric emf. The change is resistance, due to change in temperature is negligible.

Case (II): Multiplier

A large resistance is connected in series with voltmeter is called multiplier. A large voltage can be measured using a voltmeter of small rating with a multiplier.

$$\frac{V_m}{V_{se}} = \frac{R_m}{R_{se}}$$

$$\therefore \frac{V_{se}}{V_m} = \frac{R_{se}}{R_m}$$

Apply KVL, $V = V_m + V_{se}$

Eq^n (1.19) $\div V_m$

$$\frac{V}{V_m} = 1 + \frac{V_{se}}{V_m} = 1 + \left(\frac{R_{se}}{R_m}\right)$$

$$\therefore V = V_m\left(1 + \frac{R_{se}}{R_m}\right)$$

$\left(1 + \frac{R_{se}}{R_m}\right) \rightarrow$ Multiplication factor

Moving Iron (MI)instruments

One of the most accurate instrument used for both AC and DC measurement is moving iron instrument. There are two types of moving iron instrument.

- Attractiontype
- Repulsiontype

Attraction type M.I.instrument

Construction:The moving iron fixed to the spindle is kept near the hollow fixed coil. The pointer and balance weight are attached to the spindle, which is supported with jeweled bearing. Here air friction damping is used.

Principle of operation

The current to be measured is passed through the fixed coil. As the current is flow through the fixed coil, a magnetic field is produced. By magnetic induction the moving iron gets magnetized. The north pole of moving coil is attracted by the south pole of fixed coil. Thus the deflecting force is produced due to force of attraction. Since the moving iron is attached with the spindle, the spindle rotates and the pointer moves over the calibrated scale. But the force of attraction depends on the current flowing through the coil.

Torque developed by M.I

Let 'θ' be the deflection corresponding to a current of 'i' amp Let the current increases by di, the corresponding deflection is 'θ+dθ'

There is change in inductance since the position of moving iron change w.r.t the fixed electromagnets.

Let the new inductance value be 'L+dL'. The current change by 'di' is dt seconds. Let the emf induced in the coil be 'e' volt.

$$e = \frac{d}{dt}(Li) = L\frac{di}{dt} + i\frac{dL}{dt}$$

Multiplying by 'idt' in equation (1.22)

$$e \times idt = L\frac{di}{dt} \times idt + i\frac{dL}{dt} \times idt$$

$$e \times idt = Lidi + i^2 dL$$

Change in energy stored=Final energy-initial energy stored

$$= \frac{1}{2}(L+dL)(i+di)^2 - \frac{1}{2}Li^2$$

$$= \frac{1}{2}\{(L+dL)(i^2+di^2+2idi) - Li^2\}$$

$$= \frac{1}{2}\{(L+dL)(i^2+2idi) - Li^2\}$$

$$= \frac{1}{2}\{Li^2 + 2Lidi + i^2dL + 2ididL - Li^2\}$$

$$= \frac{1}{2}\{2Lidi + i^2dL\}$$

$$= Lidi + \frac{1}{2}i^2dL$$

Mechanical work to move the pointer by $d\theta = T_d\, d\theta$

By law of conservation of energy,

Electrical energy supplied=Increase in stored energy+ mechanical work done.

Input energy= Energy stored + Mechanical energy

$$Lidi + i^2dL = Lidi + \frac{1}{2}i^2dL + T_d\, d\theta$$

Advantages

- ✓ MI can be used in AC andDC
- ✓ It ischeap
- ✓ Supply is given to a fixed coil, not in movingcoil.
- ✓ Simpleconstruction
- ✓ Less frictionerror.

Disadvantages

- ✓ It suffers from eddy current and hysteresiserror
- ✓ Scale is notuniform
- ✓ It consumed morepower
- ✓ Calibration is different for AC and DCoperation

Repulsion type moving ironinstrument

Construction: The repulsion type instrument has a hollow fixed iron attached to it. The moving iron is connected to the spindle. The pointer is also attached to the spindle in supported with jeweled bearing.

Principle of operation: When the current flows through the coil, a magnetic field is produced by it. So both fixed iron and moving iron are magnetized with the same polarity, since they are kept in the same magnetic field. Similar poles of fixed and moving iron get repelled. Thus the deflecting torque is produced due to magnetic repulsion. Since moving iron is attached to spindle, the spindle will move. So that pointer moves over the calibratedscale.

Damping: Air friction damping is used to reduce the oscillation.

Control: Spring control is used.

This instrument can be used for the measurement of voltage, current and power. The difference between the PMMC and dynamometer type instrument is that the permanent magnet is replaced by an electromagnet.

Construction:A fixed coil is divided in to two equal half. The moving coil is placed between the two half of the fixed coil. Both the fixed and moving coils are air cored. So that the hysteresis effect will be zero. The pointer is attached with the spindle. In a non metallic former the moving coil is wounded.

Control: Spring control is used.

Damping: Air friction damping is used.

Principle of operation:

When the current flows through the fixed coil, it produced a magnetic field, whose flux density is proportional to the current through the fixed coil. The moving coil is kept in between the fixed coil. When the current passes through the moving coil, a magnetic field is produced by this coil.

The magnetic poles are produced in such a way that the torque produced on the moving coil deflects the pointer over the calibrated scale. This instrument works on AC and DC. When AC voltage is applied, alternating current flows through the fixed coil and moving coil. When the current in the fixed coil reverses, the current in the moving coil also reverses. Torque remains in the same direction. Since the current i_1 and i_2 reverse simultaneously. This is because the fixed and moving coils are either connected in series or parallel.

Torque developed by EMMC

Let

L_1=Self inductance of fixed coil L_2=

Self inductance of moving coil

M=mutual inductance between fixed coil and moving coil

i_1=current through fixed coil

i_2=current through moving coil

Total inductance of system,

$$L_{total} = L_1 + L_2 + 2M$$

But we know that in case of M.I

$$T_d = \frac{1}{2} i^2 \frac{d(L)}{d\theta}$$

$$T_d = \frac{1}{2} i^2 \frac{d}{d\theta}(L_1 + L_2 + 2M)$$

The value of L_1 and L_2 are independent of 'θ' but 'M' varies with θ

$$T_d = \frac{1}{2} i^2 \times 2 \frac{dM}{d\theta}$$

$$T_d = i^2 \frac{dM}{d\theta}$$

If the coils are not connected in series $i_1 \neq i_2$

$$\therefore T_d = \frac{dM}{d\theta} i_1 i_2$$

$$T_C = T_d$$

$$\therefore \theta = \frac{i_1 i_2}{K} \frac{dM}{d\theta}$$

Hence the deflection of pointer is proportional to the current passing through fixed coil and moving coil.

Extension of EMMCinstrument Case-I Ammeterconnection

Fixed coil and moving coil are connected in parallel for ammeter connection. The coils are designed such that the resistance of each branch is same.

Therefore $I_1 = I_2 = I$

$$\text{Or} \therefore T_d = I^2 \frac{dM}{d\theta}$$

$$T_C = K\theta$$

$$\theta = \frac{I^2}{K} \frac{dM}{d\theta}$$

To extend the range of current a shunt may be connected in parallel with the meter. The value R_{sh} is designed such that equal current flows through moving coil and fixed coil.

$\therefore T_d = I_1 I_2$

Case-II Voltmeter connection

Fixed coil and moving coil are connected in series for voltmeter connection. A multiplier may be connected in series to extent the range of voltmeter.

$$I_1 = \frac{V_1}{Z_1}, \quad I_2 = \frac{V_2}{Z_2}$$

$$T_d = \frac{V_1}{Z_1} \times \frac{V_2}{Z_2} \times \frac{dM}{d\theta}$$

$$T_d = \frac{K_1 V}{Z_1} \times \frac{K_2 V}{Z_2} \times \frac{dM}{d\theta}$$

$$T_d = \frac{KV^2}{Z_1 Z_2} \times \frac{dM}{d\theta}$$

$$T_d \propto V^2$$

$$\therefore \theta \propto V^2 \quad \text{(Scale innotuniform)}$$

Case-III As **wattmeter**

When the two coils are connected to parallel, the instrument can be used as a wattmeter. Fixed coil is connected in series with the load. Moving coil is connected in parallel with the load. The moving coil is known as voltage coil or pressure coil and fixed coil is known as current coil.

Assume that the supply voltage is sinusoidal. If the impedance of the coil is neglected in comparison with the resistance 'R'. The current,

$$I_2 = \frac{v_m \sin wt}{R}$$

Let the phase difference between the currents I_1 and I_2 is ϕ

$$I_1 = I_m \sin(wt - \phi)$$

$$T_d = I_1 I_2 \frac{dM}{d\theta}$$

$$T_d = I_m \sin(wt-\phi) \times \frac{V_m \sin wt}{R} \frac{dM}{d\theta}$$

$$T_d = \frac{1}{R}(I_m V_m \sin wt \sin(wt-\phi)) \frac{dM}{d\theta}$$

$$T_d = \frac{1}{R} I_m V_m \sin wt . \sin(wt-\phi) \frac{dM}{d\theta}$$

$(T_d)_{avg} \propto KVI\cos\phi$

$T_C \propto \theta \quad \theta \propto KVI\cos\phi \quad \theta \propto VI\cos\phi$

Advantages

- ✓ It can be used for voltmeter, ammeter andwattmeter
- ✓ Hysteresis error isnill
- ✓ Eddy current error isnill
- ✓ Damping iseffective
- ✓ It can be measure correctively and accurately the rms value of thevoltage

Disadvantages

- ✓ Scale is notuniform
- ✓ Power consumption is high(because of high resistance)
- ✓ Cost ismore
- ✓ Error is produced due to frequency, temperature and strayfield.
- ✓ Torque/weight is low.(Because field strength is verylow)

Errors in PMMC

- ✓ The permanent magnet produced error due to ageing effect. By heat treatment, this error can beeliminated.
- ✓ The spring produces error due to ageing effect. By heat treating the spring the error can beeliminated.
- ✓ When the temperature changes, the resistance of the coil vary and the spring also produces error in deflection. This error can be minimized by using a spring whose temperature co-efficient is verylow.

Difference between attraction and repulsion typeinstrument

An attraction type instrument will usually have a lower inductance, compare to repulsion type instrument. But in other hand, repulsion type instruments are more suitable for economical production in manufacture and nearly uniform scale is more easily obtained. They are therefore much more common than attraction type.

Characteristics of meter Full scale deflection current(I_{FSD})

The current required to bring the pointer to full-scale or extreme right side of the instrument is called full scale deflection current. It must be as small as possible. Typical value is between 2 μA to 30mA.

Resistance of the coil(R_m)

This is ohmic resistance of the moving coil. It is due to ρ, L and A. For an ammeter this should be as small as possible.

Sensitivity of themeter(S)

$$S = \frac{1}{I_{FSD}} (\Omega / volt), \uparrow S = \frac{Z\uparrow}{V}$$

It is also called ohms/volt rating of the instrument. Larger the sensitivity of an instrument, more accurate is the instrument. It is measured in Ω/volt. When the sensitivity is high, the impedance of meter is high. Hence it draws less current and loading affect is negligible. It is also defend as one over full scale deflectioncurrent.

Error in M.Iinstrument

Temperature error

Due to temperature variation, the resistance of the coil varies. This affects the deflection of the instrument. The coil should be made of manganin, so that the resistance is almost constant.

Hysteresiserror

Due to hysteresis affect the reading of the instrument will not be correct. When the current is decreasing, the flux produced will not decrease suddenly. Due to this the meter reads a higher value of current. Similarly when the current increases the meter reads a lower value of current. This produces error in deflection. This error can be eliminated using small iron parts with narrow hysteresis loop so that the demagnetization takes place very quickly.

Eddy currenterror

The eddy currents induced in the moving iron affect the deflection. This error can be reduced by increasing the resistance of the iron.

Stray fielderror

Since the operating field is weak, the effect of stray field is more. Due to this, error is produced in deflection. This can be eliminated by shielding the parts of theinstrument.

Frequencyerror

When the frequency changes the reactance of the coil changes.

$$Z = \sqrt{(R_m + R_S)^2 + X_L^2}$$

$$I = \frac{V}{Z} = \frac{V}{\sqrt{(R_m + R_S)^2 + X_L^2}}$$

Deflection of moving iron voltmeter depends upon the current through the coil. Therefore, deflection for a given voltage will be less at higher frequency than at low frequency. A capacitor is connected in parallel with multiplier resistance. The net reactance, $(X_L - X_C)$ is very small, when compared to the series resistance. Thus the circuit impedance is made independent of frequency. This is because of the circuit is almost resistive.

$$C = 0.41 \frac{L}{(R_S)^2}$$

Electrostaticinstrument

In multi cellular construction several vans and quadrants are provided. The voltage is to be measured is applied between the vanes and quadrant. The force of attraction between the vanes and quadrant produces a deflecting torque. Controlling torque is produced by spring control. Air friction damping is used.

The instrument is generally used for measuring medium and high voltage. The voltage is reduced to low value by using capacitor potential divider. The force of attraction is proportional to the square of the voltage.

Torque develop by electrostatic instrument V=Voltage applied between vane and quadrant C=capacitance between vane and quadrant

Energy stored= $\frac{1}{2}CV^2$

Let ' θ' be the deflection corresponding to a voltage V.

Let the voltage increases by dv, the corresponding deflection is'$\theta+d\theta$'

When the voltage is being increased, a capacitive current flows

$i=\frac{dq}{dt}=\frac{d(CV)}{dt}=V\frac{dC}{dt}+C\frac{dV}{dt}$ $V\times dt$ multiply on both side of equation

At steady state condition, $T_d=T_C$

$$K\theta=\frac{1}{2}V^2\left(\frac{dC}{d\theta}\right)$$

$$\theta=\frac{1}{2K}V^2\left(\frac{dC}{d\theta}\right)$$

Advantages

- ✓ It is used in both AC andDC.
- ✓ There is no frequencyerror.
- ✓ There is no hysteresiserror.
- ✓ There is no stray magnetic field error. Because the instrument works on electrostatic principle.
- ✓ It is used for highvoltage
- ✓ Power consumption isnegligible.

Disadvantages

- ✓ Scale is notuniform
- ✓ Large insize
- ✓ Cost ismore

Multi rangeAmmeter : When the switch is connected to position (1), the supplied current I_1

$R_1 = R_{sh1} - R_{sh2}$, R_2

$= R_{sh2} - R_{sh3}$, R_3

$= R_{sh3} - R_{sh4}$, R_4

$= R_{sh4}$

Multi range D.C.voltmeter

$R_{s1} = R_m\ (m_1 - 1)$

$R_{s2} = R_m\ (m_2 - 1)$

$R_{s3} = R_m\ (m_3 - 1)$

We can obtain different Voltage ranges by connecting different value of multiplier resistor in series with the meter. The number of these resistors is equal to the number of ranges required.

Potential dividerarrangement

The resistance R_1, R_2, R_3 and R_4 is connected in series to obtained the ranges V_1, V_2, V_3 and V_4

$R_1 = (m_1 - 1)R_m$

For V2, $(R_2 + R_1 + R_m)I_m = V_2 \Rightarrow R_2 =$

$$R_2 = \left(\frac{V_2}{V_m}\right)R_m - (m_1 - 1)R_m - R_m$$

$R_2 = m_2R_m - R_m - (m_1 - 1)R_m$

$= R_m(m_2 - 1 - m_1 + 1)$

$R_2 = (m_2 - m_1)R_m$

For V3 $(R_3 + R_2 + R_1 + R_m)I_m = V_3$

$$R_3 = \frac{V_3}{I_m} - R_2 - R_1 - R_m$$

$$= \frac{V_3}{V_m}R_m - (m_2 - m_1)R_m - (m_1 - 1)R_m - R_m$$

$= m_3R_m - (m_2 - m_1)R_m - (m_1 - 1)R_m - R_m$

$R_3 = (m_3 - m_2)R_m$

For V4 $(R_4 + R_3 + R_2 + R_1 + R_m)I_m = V_4$ $R = R_4$

$= R_m[m_4 - m_3 + m_2 - m_2 + m_1 - m_1 + 1 - 1]$

$R_4 = (m_4 - m_3)R_m$

The pointer of a moving coil instrument gives full scale deflection of 20mA. The potential difference across the meter when carrying 20mA is 400mV.The instrument to be used is 200A for full scale deflection. Find the shunt resistance required to achieve this, if the instrument to be used as a voltmeter for full scale reading with 1000V. Find the series resistance to be connected it?

Solution: Case-1

$V_m = 400mV$ $I_m = 20mA$ I=200A

$R_m = \frac{V_m}{I_m} = \frac{400}{20} = 20\Omega$

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

$200 = 20\times10^{-3}\left[1+\frac{20}{R_{sh}}\right]$

$R_{sh} = 2\times10^{-3}\Omega$

Case-II

V=1000V

$V = V_m\left(1+\frac{R_{se}}{R_m}\right)$

$4000 = 400\times10^{-3}\left(1+\frac{R_{se}}{20}\right)$

$R_{se} = 49.98k\Omega$

Example:

A 150 v moving iron voltmeter is intended for 50HZ, has a resistance of 3kΩ. Find the series resistance required to extent the range of instrument to 300v. If the 300V instrument is used to measure a d.c. voltage of 200V. Find the voltage across the meter?

Solution:

$R_m = 3k\Omega, V_m = 150V, V = 300V$

$\therefore V_m = 100V$

Example:

What is the value of series resistance to be used to extent '0'to 200V range of 20,000Ω/volt voltmeter to 0 to 2000 volt?

Solution:

$V_{se} = V - V_i = 1800$ $I_{FSD} =$

$= R_{se} \times i_{FSD}$

$\Rightarrow R_{se} = 36M\Omega$

Example:

A 250V M.I. voltmeter has coil resistance of 500Ω, coil inductance 0f 1.04 H and series resistance of 2kΩ. The meter reads correctively at 250V D.C. What will be the value of capacitance to be used for shunting the series resistance to make the meter read correctly at 50HZ? What is the reading of voltmeter on A.C. without capacitance?

Solution: $C = 0.41$

$$= 0.41 \times \frac{1.04}{(2\times10^3)^2} = 0.1\mu F$$

For A.C $Z = \sqrt{(R_m + R_{Se})^2 + X_L^2}$

$$Z = \sqrt{(500+2000)^2 + (314)^2} = 2520\Omega$$

With D.C

$R_{total} = 2500\Omega$

For 2500Ω → 250V

$1\Omega \rightarrow \frac{250}{2500}$

$$2520\Omega \rightarrow \frac{250}{2500} \times 2520 = 248V$$

Example:

The relationship between inductance of moving iron ammeter, the current and the position of pointer is as follows:

Reading (A)	1.2	1.4	1.6	1.8
Deflection (degree)	36.5	49.5	61.5	74.5
Inductance (μH)	575.2	576.5	577.8	578.8

Calculate the deflecting torque and the spring constant when the current is 1.5A?

Solution: $\frac{dL}{d\theta} = \frac{577.65 - 576.5}{60 - 49.5} = 0.11\mu H / \text{degree} = 6.3\mu H / rad$

Deflecting torque , $T_d = \frac{1}{2} I^2 \frac{dL}{d\theta} = \frac{1}{2}(1.5)^2 \times 6.3\times10^{-6} = 7.09\times10^{-6} N-m$

Spring constant, $K = \frac{T_d}{\theta} = \frac{7.09\times10^{-6}}{0.968} = 7.319\times10^{-6} N-m/rad$

MEASURMENT OF POWER & ENERGY

Dynamometer type wattmeter works on very simple principle and this principle can be stated as when any current carrying conductor is placed inside a magnetic field, it experiences a mechanical force and due to this mechanical force deflection of conductor takes place.

Construction and Working Principle of Electrodynamometer Type Wattmeter

Now let us look at constructional details of electrodynamometer. It consists of following parts. Moving Coil

Moving coil moves the pointer with the help of spring control instrument. Limited of current flows through the moving coil so as to avoid heating. So in order to limit the current we have connected the high value resistorin series with the moving coil. The moving is air cored and is mounted on a pivoted spindle and can move freely.

In **electrodynamometer type wattmeter**, moving coil works as pressure coil. Hence moving coil is connected across the voltageand thus the current flowing through this coil is always proportional to the voltage

Fixed Coil

The fixed coil is divided into two equal parts and these are connected in series with the load, therefore the load current will flow through these coils. Now the reason is very obvious of using two fixed coils instead of one, so that it can be constructed to carry considerable amount of electric current. These coils are called the current coils of **electrodynamometer type wattmeter**. Earlier these fixed coils are designed to carry the current of about 100 amperes but now the modern wattmeter are designed to carry current of about 20 amperes in order to save power. **Control System** Out of two controlling systems i.e.

1. Gravitycontrol
2. Spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will be appreciable amount oferrors.

Damping System Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may leads to error. **Scale** There is uniform scale which is used in these types of instrument as moving coil moves linearly over a range of 40 degrees to 50 degrees on either side. Now let us derive the expressions for the controlling torque and deflecting torques. In order to derive these expressions let us consider the circuit diagram givenbelow:

$$T = I_1 \times I_2 \times \frac{dM}{dx}$$

$$I_2 = \sqrt{2} \times \frac{V sin\omega t}{R_p}$$

$$T_d = deflecting\ torque = \frac{VI}{R_p} cos\phi \times \frac{dM}{dx}$$

Advantages of Electrodynamometer Type Wattmeter

Following are the **advantages of electrodynamometer type wattmeter** and they are written as follows:

1. Scale is uniform upto a certainlimit.
2. They can be used for both to measure ac as well dc quantities as scale is calibrated forboth.

Errors in Electrodynamometer Type Wattmeter

Following are the errors in the electrodynamometer type watt meters:

1. Errors in the pressure coilinductance.
2. Errors may be due to pressure coilcapacitance.
3. Errors may be due to mutual inductanceeffects.

Thus the net field is due to the current I only. Hence by this way error caused by pressure coil can beneutralised.

(2) We require compensating coil in the circuit in order to make the low power factor meter. It is the second modification that we have discussed indetailabove.

(3) Now the third point deals with the compensation of the inductanceof pressure coil, which can be achieved by

$$b = tan^{-1}\frac{W_l}{R + r_p}$$

$$\frac{VIcos(C)\frac{dM}{dx}}{K + R_p}........(1)$$

Where, R_p is (r_p+R) and x is angle. If we ignore the effect of inductance of pressure i.e putting b = 0 we have expression for true power as

$$\frac{VIcos(A)\frac{dM}{dx}}{K \cdot R_p}........(2)$$

On taking ratio of equations (2) and (1) we have expression for correction factor as written below:

$$\frac{cos(A)}{cos(b)cos(A-b)}$$

$$Error = \{1 - (correction\ factor)\} \times (actual\ reading\ of\ the\ voltmeter)$$

This final modified circuit so obtained is called **low power factor meter**. A modern low power factor meter is designed such that it gives high accuracy while measuring power factors even lower than 0.1.

TWO-ELEMENT WATTMETER FOR THREE-PHASE SYSTEM

two single-phase wattmeters were used to measure the power in a three-phase, three-wire sys- tem. The two single-phase wattmeters can be combined into a single instrument

The scale of this instrument indicates the sum or difference of the power values indicated by the separate meters. To make the single wattmeter, two sets of potential coils are mounted on a single shaft. Also, two sets of field coils are mounted on the instrument frame so that they have the proper relationship to the armature coils. In this way, each of two power measuring mechanisms develops a torque that is proportional to the power in the circuit to which it is connected. These torque values are added to obtain the total power in the three-phase, three wire circuit. If the power factor of the system is less than 0.5, the torque of one mechanism opposes that of the second mechanism. The difference between the torque values is the powerindication.

A wattmeter containing two dynamometer mechanisms is called a *two-element wattmeter*.