WATTMETER

Electrodynamometer Wattmeter

- These instruments are similar in design and construction to electrodynamometer type ammeters and voltmeters.
- The two coils are connected in different circuits for measurement of power.
- The fixed coils or "field coils" arc connected in series with the load and so carry the current in the circuit.
- The fixed coils, therefore, form the current coil or simply C.C. of the wattmeter.
- The moving coil is connected across the voltage and, therefore, carries a current proportional to the voltage.
- A high non-inductive resistance is connected in series with the moving coil to limit the current to a small value.
- Since the moving coil carries a current proportional to the voltage, it is called the"" pressure coil"" or "voltage coil" or simply called P.C. of the wattmeter.

Construction of Electrodynamometer Wattmeter Fixed Coils

- The fixed coils carry the current of the circuit. They are divided into two halves.
- The reason for using fixed coils as current coils is that they can be made more massive and can be easily constructed to carry considerable current since they present no problem of leading the current in or out.
- The fixed coils are wound with heavy wire. This wire is stranded or laminated especially when carrying heavy currents in order to avoid eddy current losses in conductors. The fixed coils of earlier wattmeter's were designed to carry a current of 100 A but modem designs usually limit the maximum current ranges of wattmeter's to about 20 A. For power measurements involving large load currents, it is usually better to use a 5 A wattmeter in conjunction with a current transformer of suitable range.

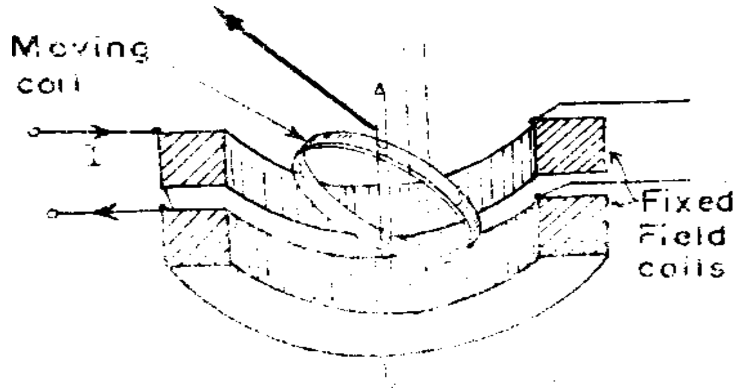


Fig 2.28 Dynamometer wattmeter

Damping:

- Air friction damping is used.
- The moving system carries a light aluminium vane which moves in a sector shaped box.

Electromagnetic or eddy current damping is not used as introduction of a permanent magnet (for damping purposes) will greatly distort the weak operating magnetic field.

Scales and Pointers:

They are equipped with mirror type scales and knife edge pointers to remove reading errors due to parallax.

Theory of Electrodynamometer Watt-meters

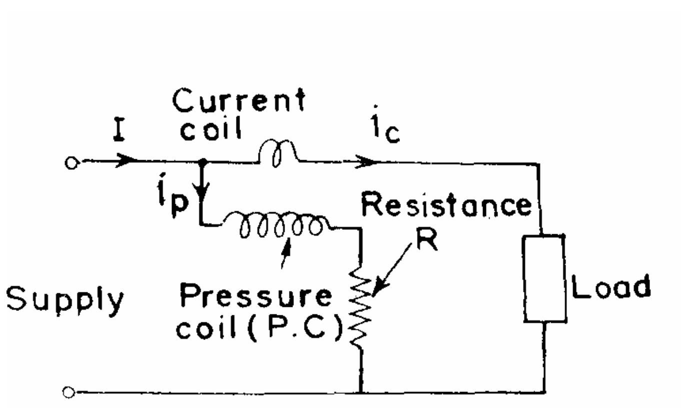


Fig 2.29 circuit of electrodynamometer

It is clear from above that there is a component of power which varies as twice the frequency of current and voltage (mark the term containing 2Åt).

Average deflecting torque

$$T_d = \frac{1}{T}\int_0^T T_i\, d(\omega t) = \frac{1}{T}\int_0^T I_p\, I\, [\cos\phi - \cos(2\omega t - \phi)]\, \frac{dM}{d\theta}\, .\, d(\omega t)$$

$$= I_p\, I \cos\phi\, .\, dM/d\theta$$

$$= (VI/R_p) \cos\phi\, .\, dM/d\theta$$

Controlling torque exerted by springs Tc= Kș

Where, K = spring constant; ș= final steady deflection.

Errors in electrodynamometer

i) Errors due to inductance effects

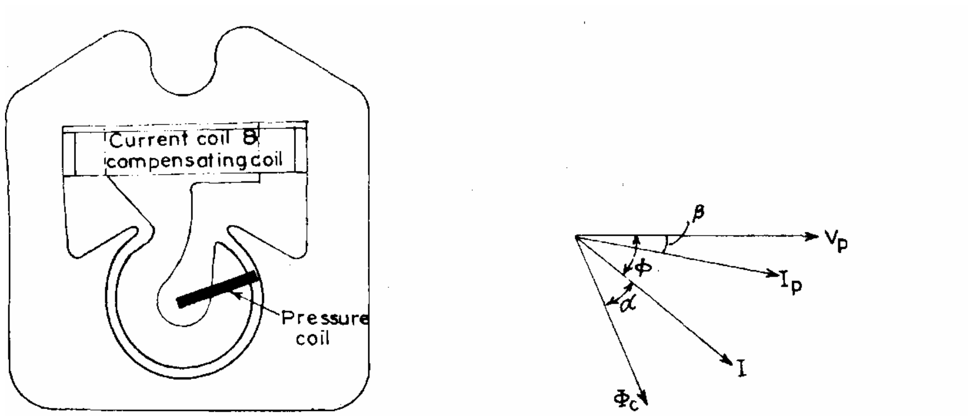
ii) Stray magnetic field errors

iii) Eddy current errors

iv) Temperature error

Ferro dynamic Wattmeter's

- The operating torque can be considerably increased by using iron cores for the coils Ferro
- dynamic wattmeter's employ cores of low loss iron so that there is a large increase in the flux density and consequently an increase in operating torque with little loss in accuracy.
- The fixed coil is wound on a laminated core having pole pieces designed to give a uniform radial field throughout the air gap.
- The moving coil is asymmetrically pivoted and is placed over a hook shaped pole piece.
- This type of construction permits the use of a long scale up to about 270° and gives a deflecting torque which is almost proportional to the average power.
- With this construction there is a tendency on the part of the pressure coil to creep (move further on the hook) when only the pressure coil is energized.
- This is due to the fact that a coil tries to take up a position where it links with maximum flux. The creep causes errors and a compensating coil is put to compensate for this voltage creep.

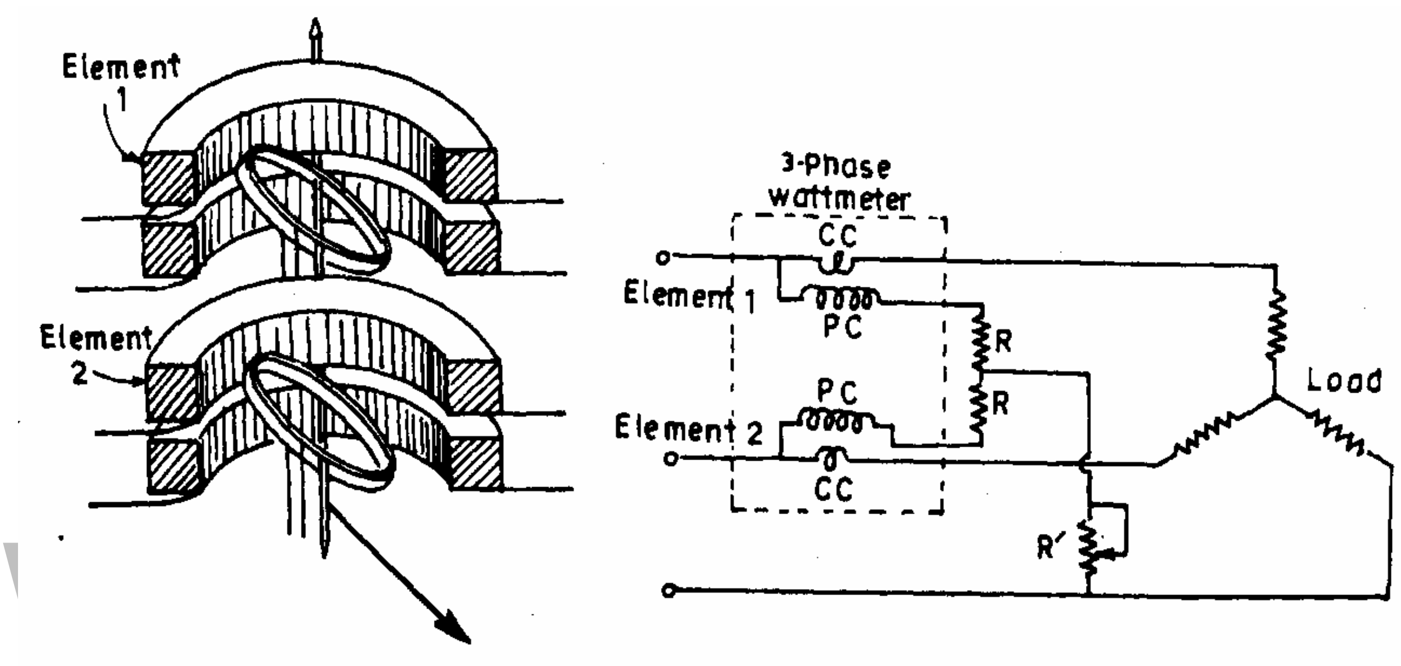


- The use of ferromagnetic core makes it possible to employ a robust construction for the moving element.
- Also the Instrument is less sensitive to external magnetic fields. On the other hand, this construction introduces non-linearity of magnetization curve and introduction of large eddy current & hysteresis losses in the core.

Three Phase Wattmeter's

- A dynamometer type three-phase wattmeter consists of two separate wattmeter movements mounted together in one case with the two moving coils mounted on the same spindle.
- The arrangement is shown in Fig.
- There are two current coils and two pressure coils.
- A current coil together with its pressure coil is known as an element.
- Therefore, a three phase wattmeter has two elements. The connections of two elements of a 3 phase wattmeter are the same as that for two wattmeter method using two single phase wattmeter.
- The torque on each element is proportional to the power being measured by it. The total torque deflecting the moving system is the sum of the deflecting torque of" the two elements. Hence the total deflecting torque on the moving system is proportional to the total Power. In order that a 3 phase wattmeter read correctly, there should not be any mutual interference between the two elements.

- A laminated iron shield may be placed between the two elements to eliminate the mutual effects.



Dynamometer (or) Electromagnetic moving coil instrument (EMMC)

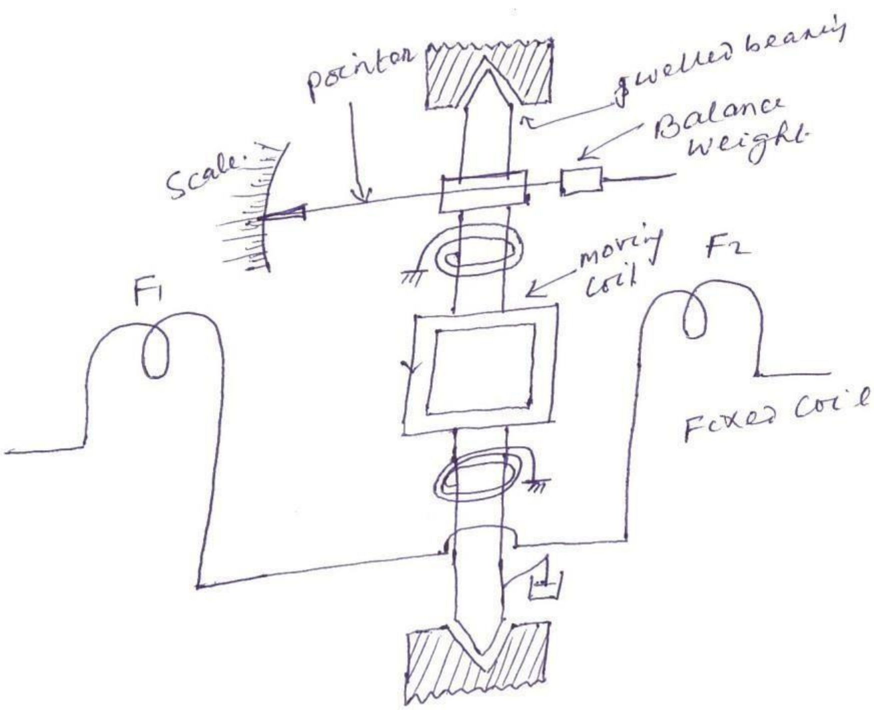


Fig. 2.13 Dynamometer (or) Electromagnetic moving coil instrument (EMMC)

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 i1 and i2 reverse simultaneously. This is because the fixed and moving coils are either connected in series or parallel.

Extension of range of PMMC instrument

Case-I: Shunt

A low shunt resistance connected in parallel with the ammeter to extent the range of current. Largecurrent can be measured using low current rated ammeter by using a shunt

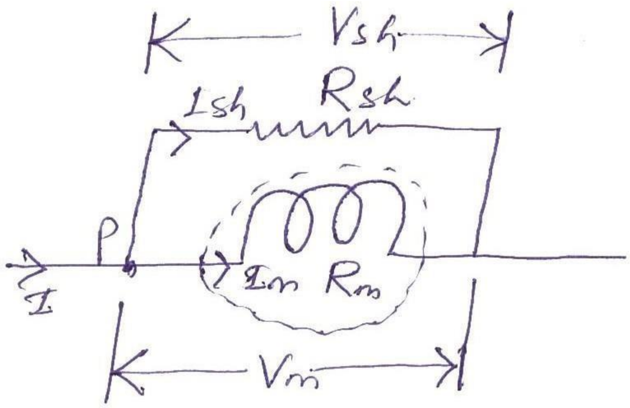
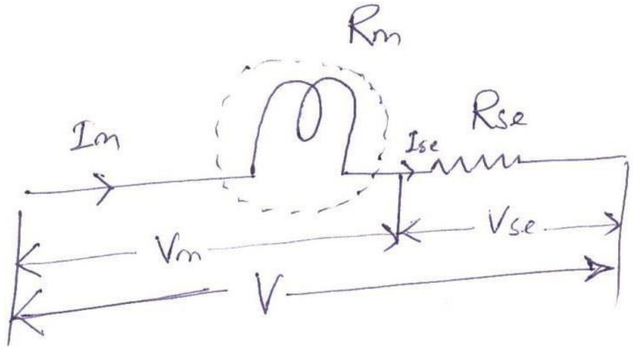


Fig. 2.8 Extension of range of PMMC instrument - Shunt

Shunt resistance is made of manganic. 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 (Fig. 2.9). A large voltage can be measured using a voltmeter of small rating with a multiplier.



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.

- Attraction type
- Repulsion type

Attraction type M.I. instrument

Construction: The moving iron fixed to the spindle is kept near the hollow fixed coil (Fig. 2.10). 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 „$\theta + d\theta$ "

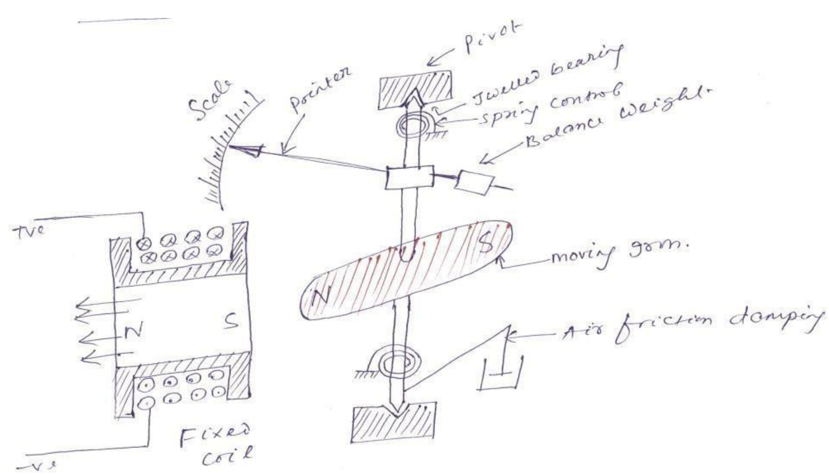


Fig. 2.10 2.8Moving Iron (MI) instruments- Attraction type

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‟ isdt seconds.Let the emf induced in the coil be „e‟ volt.

$$e = \frac{d}{dt}(Li) = L\frac{di}{dt} + i\frac{dL}{dt} \qquad (2.22)$$

Multiplying by „idt‟ in equation (2.22)

$$e \times idt = L\frac{di}{dt} \times idt + i\frac{dL}{dt} \times idt \qquad (2.23)$$

$$e \times idt = Lidi + i^2 dL \qquad (2.24)$$

Eq^n (2.24) gives the energy is used in to two forms. Part of energy is stored in the inductance. Remaining energy is converted in to mechanical energy which produces deflection.

Fig. 2.11Energyused

Change in energy stored=Final energy-initial energy stored

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

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

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

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

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

$$= Lidi + \frac{1}{2}i^2dL \tag{2.25}$$

Mechanical work to move the pointer by $d\theta$

$$= T_d d\theta \tag{2.26}$$

By law of conservation of energy,

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

Input energy= Energy stored + Mechanical energy (2.27)

$$Lidi + i^2dL = Lidi + \frac{1}{2}i^2dL + T_d d\theta \tag{2.28}$$

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

$$T_d = \frac{1}{2}i^2\frac{dL}{d\theta} \tag{2.29}$$

At steady state condition $T_d = T_C$

$$\frac{1}{2}i^2\frac{dL}{d\theta} = K\theta \tag{2.30}$$

$$\theta = \frac{1}{2K}i^2\frac{dL}{d\theta} \tag{2.31}$$

$$\theta \propto i^2$$

(2.32)

When the instruments measure AC, $\theta \propto i^2_{rms}$

Scale of the instrument is non uniform.

Advantages

- MI can be used in AC and DC
- It is cheap
- Supplyis given to a fixed coil, not in moving coil.
- Simple construction
- Lessfrictionerror.

Disadvantages

- It suffers from eddycurrent and hysteresis error
- Scale is not uniform
- It consumed more power
- Calibration is different for AC and DC operation

Repulsion type moving iron instrument

Construction: The repulsion type instrument has a hollow fixed iron attached to it (Fig. 2.12). 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 calibrated scale.

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

Control: Spring control is used.

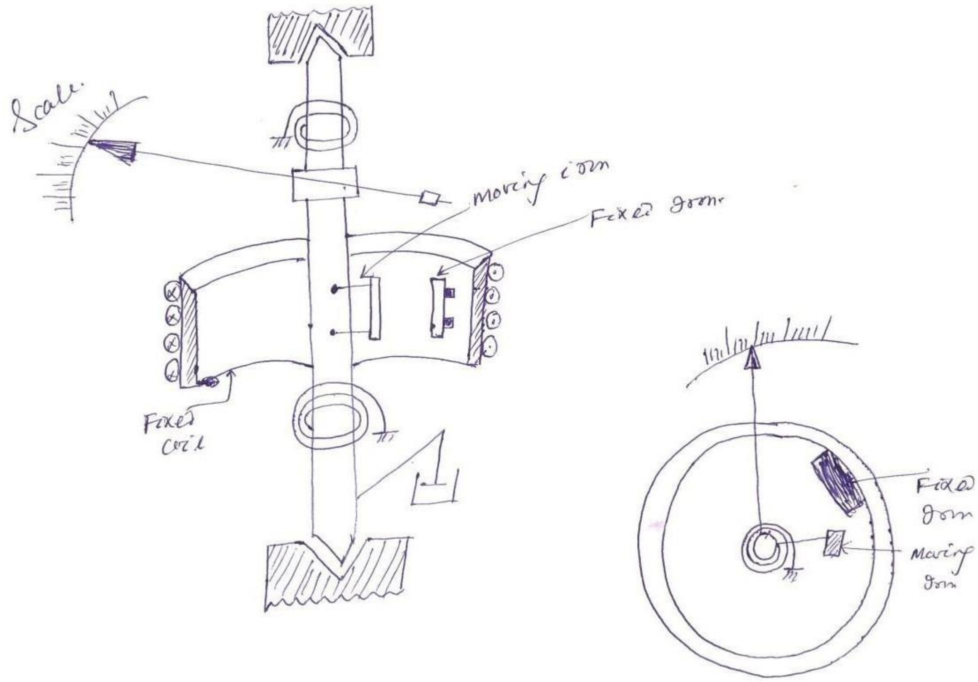


Fig. 2.12 Moving Iron (MI) instruments- Repulsion type

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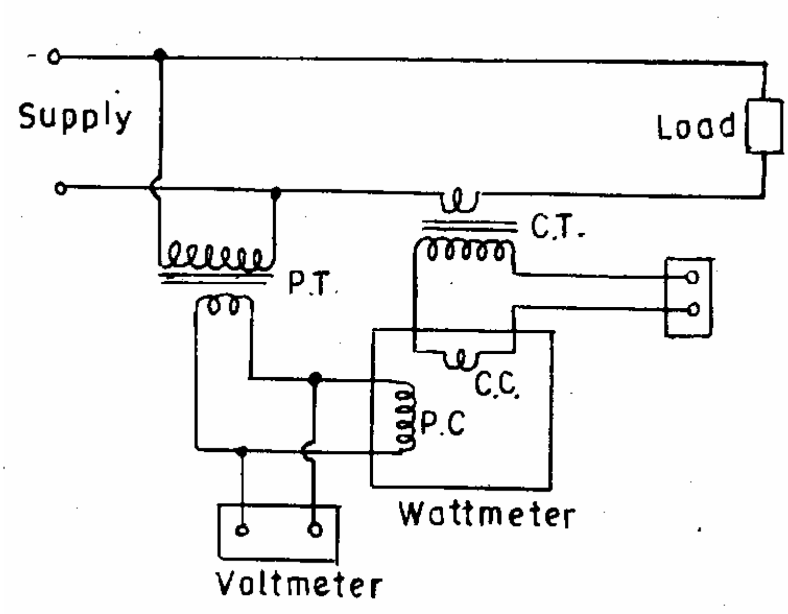
Instrument Transformers

- Power measurements are made in high voltage circuits connecting the wattmeter to the circuit through current and potential transformers as shown.
- The primary winding of the C.T. is connected in series with the load and the secondary winding is connected in series with an ammeter and the current coil of a wattmeter.
- The primary winding of the potential transformer is connected across the supply lines and a voltmeter and the potential coil circuit of the wattmeter are connected in parallel with the secondary winding of the transformer. One secondary terminal of each transformer and the casings are earthed.
- The errors in good modem instrument transformers are small and may be ignored for many purposes.
- However, they must be considered in precision work. Also in some power measurements these errors, if not taken into account, may lead to very inaccurate results.
- Voltmeters and ammeters are affected by only ratio errors while wattmeter's are influenced in addition by phase angle errors. Corrections can be made for these errors if test information is available about the instrument transformers and their burdens.



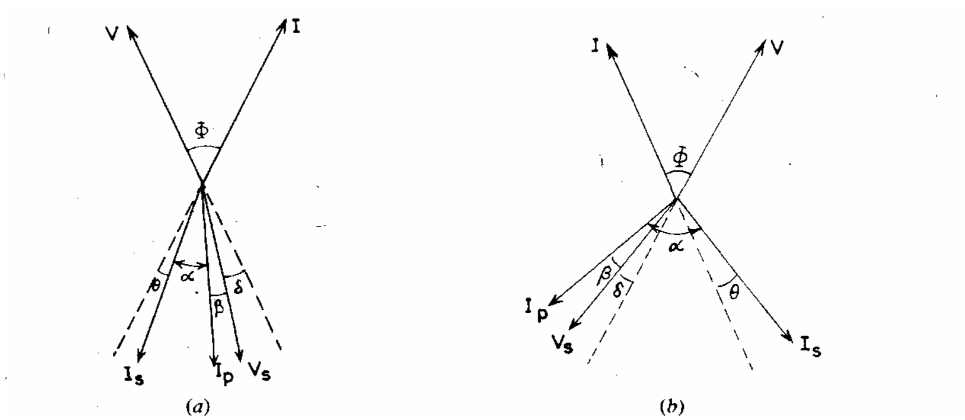


Fig 2.33Phasor diagrams for the current and voltages of load, and in the wattmeter coils.

Measurements of flux and flux density (Method of reversal)

D.C. voltage is applied to the electromagnet through a variable resistance R1 and a reversing switch. The voltage applied to the toroid can be reversed by changing the switch from position 2 to position „1". Let the switch be in position „2" initially. A constant current flows through the toroid and a constant flux is established in the core of the magnet.

A search coil of few turns is provided on the toroid. The B.G. is connected to the search coil through a currentlimitingresistance.Whenitisrequiredtomeasuretheflux,theswitchischangedfromposition„2" to position „1". Hence the flux reduced to zero and it starts increasing in the reverse direction. The flux goes from + ϕ to - ϕ, in time „t" second. An emf is induced in

The search coil, science the flux changes with time. This emf circulates a current through R2 and B.G. The meter deflects. The switch is normally closed. It is opened when it is required to take the reading.

Plotting the BH curve

The curve drawn with the current on the X-axis and the flux on the Y-axis, is called magnetization characteristics. The shape of B-H curve is similar to shape of magnetization characteristics. The residual magnetism present in the specimen can be removed as follows.

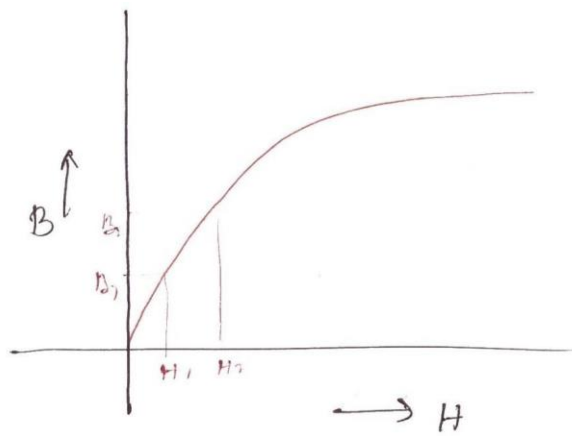


Fig 2.34 BH curve

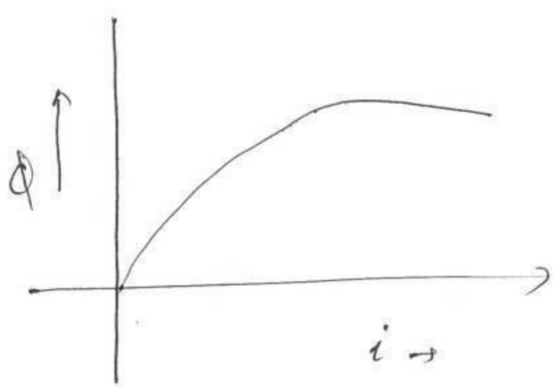


Fig 2.35 Magnetization characteristics

Close the switch „S2‟ to protect the galvanometer, from high current. Change the switch S1 from position „1‟ to „2‟ and vice versa for several times.

To start with the resistance „R1‟ is kept at maximum resistance position. For a particular value of current, the deflection of B.G. is noted. This process is repeated for various value of current. For each deflection flux can be calculated.(B ▯ ▯) _ A

Magnetic field intensity value for various current can be calculated.().The B-H curve can be plotted by using the value of „B‟ and „H‟.

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

Absolute Instrument **Secondary Instrument**

Absolute instrument

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: Tangent galvanometer.

Secondary instrument

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

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

Indicating instrument:

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

Recording instrument:

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

Integrating instrument:

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

Electromechanical indicating instrument

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

(a) Deflecting force

(b) Controlling force

(c)Damping force

Deflecting force

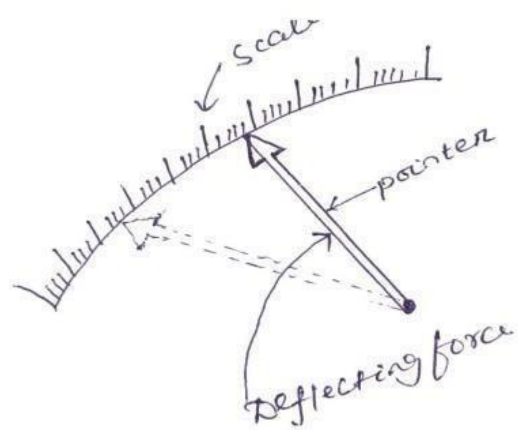


Fig. 2.1 Pointer scale

Magnitude effect

When a current passes through the coil (Fig.2.2), 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 type instrument.

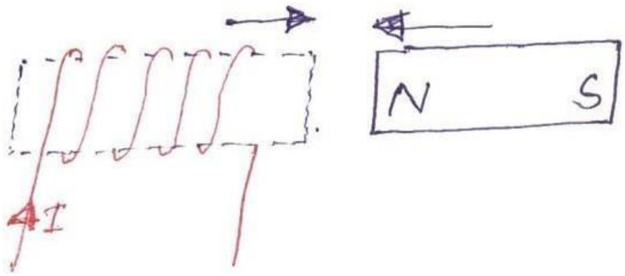


Fig. 2.2 Magnitude effect due to current

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 carrying coil

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

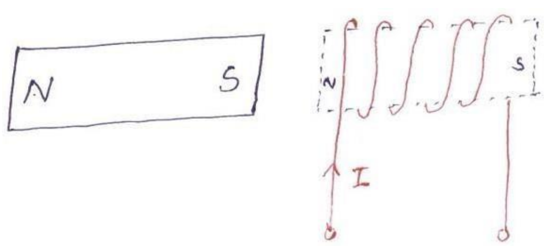


Fig. 2.3 Force between a permanent magnet and a current carrying coil

Force between two current carrying coils:

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.

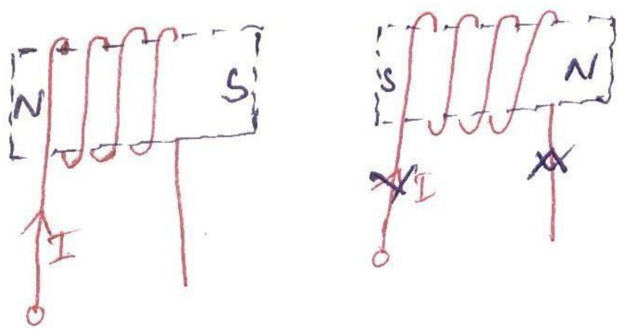


Fig. 2.4 Force between two current carrying coil

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 is equal to controlling torque.

$$T_d = T_c$$

Spring control:

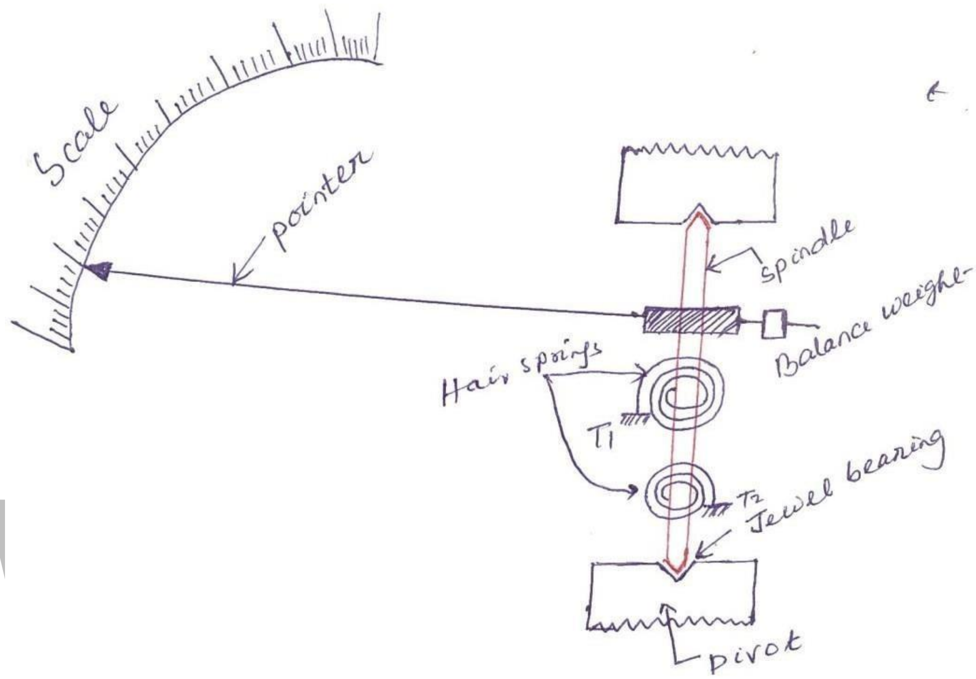
Two springs are attached on either end of spindle (Fig. 2.5).The spindle is placed in jewelled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze.

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 deflection

$T_C \propto \theta$.

The deflecting torque produced Td proportional to „I‟. 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.

Damping force:

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 different systems.

(a) Air friction damping
(b) Fluid friction damping
(c) Eddy current damping

Air friction damping:

The piston is mechanically connected to a spindle through the connecting rod (Fig. 2.6). 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.

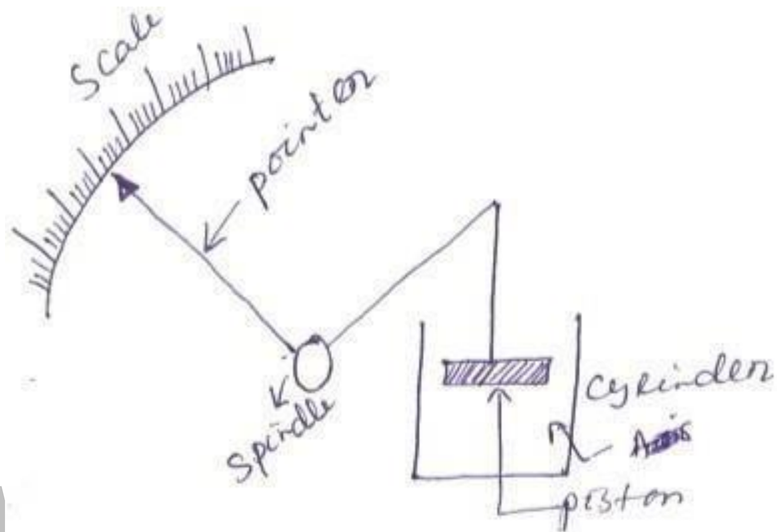


Fig. 2.6 Air friction damping

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 current damping:

An aluminum circular disc is fixed to the spindle (Fig. 2.6). 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.

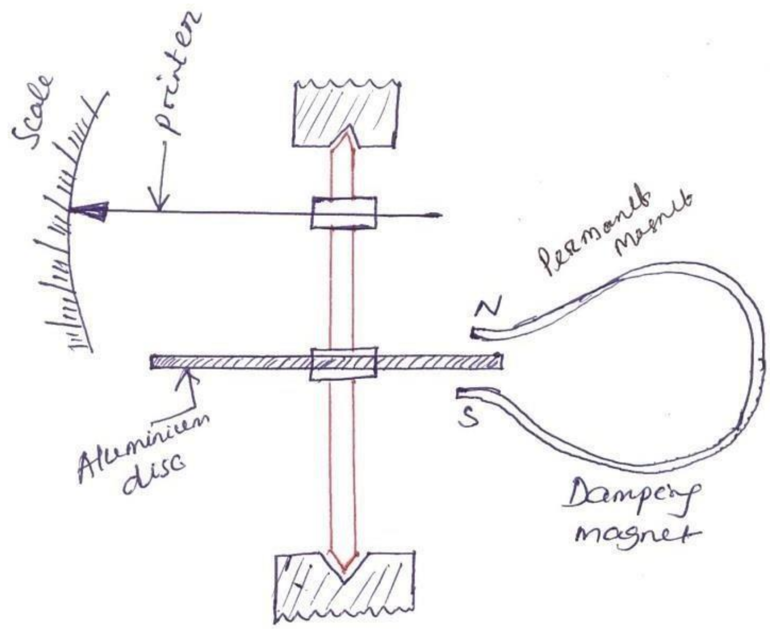
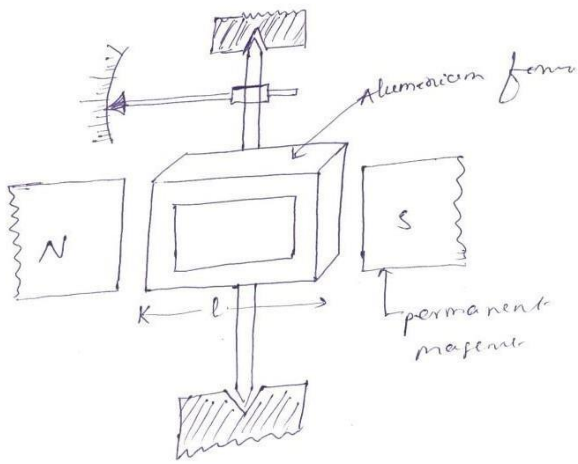


Fig. 2.6 Disc type

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 (Fig. 2.7). 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.

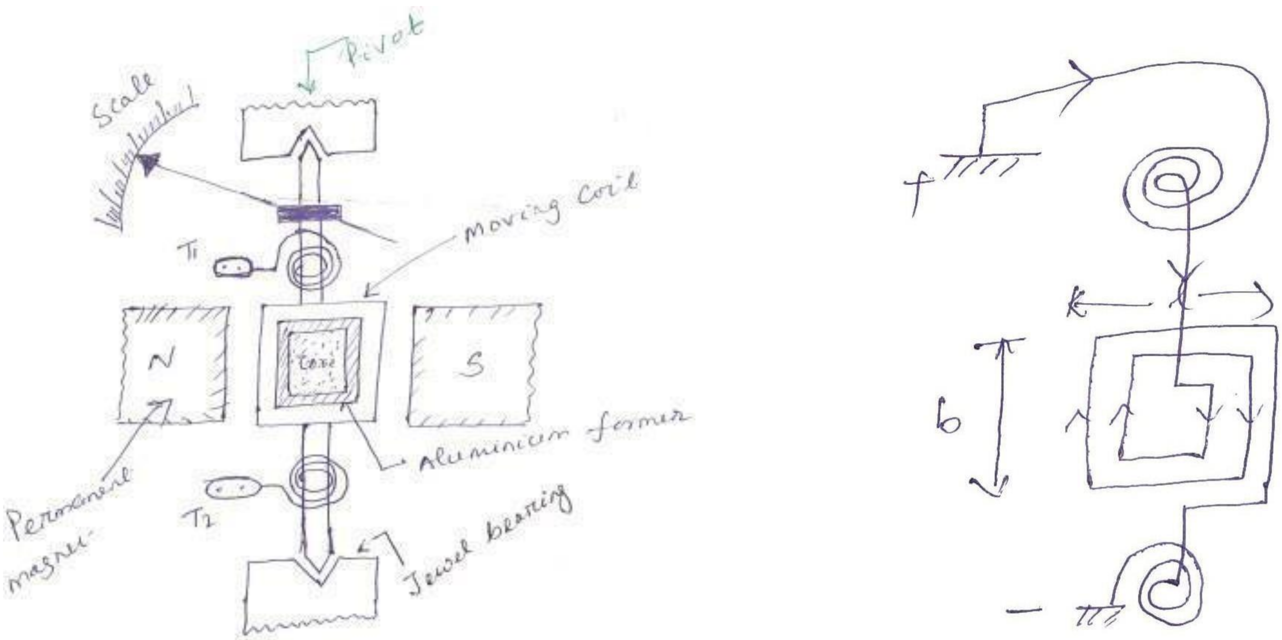


Fig. 2.7 **Permanent Magnet Moving Coil (PMMC) instrument**

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 PMMC instrument.

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

Let T_d =deflecting torque

T_C = controlling torque

θ = angle of deflection

K=spring

constant

b=widthof the

coil

l=height of the coil or length of coilN=No. of turns I=current

B=Flux density

A=area of the coil

The force produced in the coil is given by

$F = BIL\sin\theta$ (2.4)

$\theta = 90^\circ$

When

For N turns, $F = NBIL$ (2.5)

Torque produced $T_d = F \times \perp_r$ distance (2.6)

$T_d = NBIL \times b = BINA$ (2.7)

$T_d = BANI$

$T_d \propto I$

Advantages

- Torque/weight is high
- Power consumption is less
- Scale is uniform
- Damping is very effective
- sinceoperatingfieldisverystrong,theeffectofstrayfield isnegligible
- Range of instrument can be extended

Disadvantages

- Use only for D.C.
- Cost is high
- Error is produced due to ageing effect of PMMC
- Friction and temperature error are present.