(UNIT-1)

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Contents

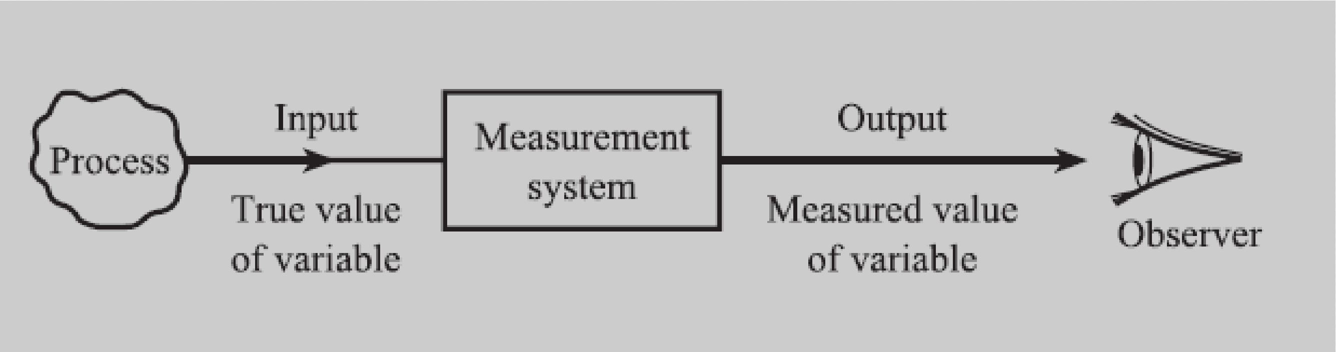
Definition

- Measurement
  - A method to obtain information regarding the physical values of the variable.
- Instrumentation
  - Devices used in measurement system

Terminologies

- Physical quantity: variable such as pressure, temperature, mass, length, etc.
- Data: Information obtained from the instrumentation/measurement system as a result of the measurements made of the physical quantities
- Information: Data that has a calibrated numeric relationship to the physical quantity.
- Parameter: Physical quantity within defined (numeric) limits.

Purpose of a measurement system



measurand

Sensor, signal conditioning, display

Man, tracking control etc

Terminology

- Measurand: Physical quantity being measured.
- Calibration: Implies that there is a numeric relationship throughout the whole instrumentation system and that it is directly related to an approved national or international standard.
- Test instrumentation: It is a branch of instrumentation and most closely associated with the task of gathering data during various development phases encountered in engineering, e.g. flight test instrumentation for testing and approving aircraft.

Terminologies

- Transducer: A device that converts one form of energy to another.
- Electronic transducer: It has an input or output that is electrical in nature (e.g., voltage, current or resistance).
- Sensor: Electronic transducer that converts physical quantity into an electrical signal.
- Actuator: Electronic transducer that converts electrical energy into mechanical energy.

Why measurement?

- In the case of process industries and industrial manufacturing…
  - To improve the quality of the product
  - To improve the efficiency of production
  - To maintain the proper operation.

Why instrumentation?

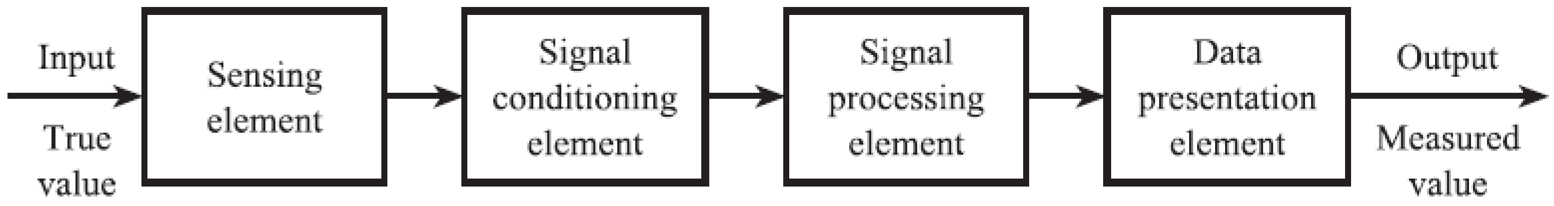
- To acquire data or information (hence data acquisition) about parameters, in terms of:
  - putting the numerical values to the physical quantities
  - making measurements otherwise inaccessible.
  - producing data agreeable to analysis (mostly in electrical form)

- Data Acquisition Software (DAS) – data is acquired by the instrumentation system.

Types of measurements

- Direct comparison
  - Easy to do but… less accurate
    - e.g. to measure a steel bar
- Indirect comparison
  - Calibrated system; consists of several devices to convert, process (amplification or filtering) and display the output
    - e.g. to measure force from strain gages located in a structure

Generalised measuring system



General Structure of Measuring System

- Stage 1: A detection-transducer or sensor-transducer, stage; e.g. *Bourdon tube*
- Stage 2: A signal conditioning stage; e.g. *gearing, filters, bridges*
- Stage 3: A terminating or readout-recording stage; e.g. *printers, oscilloscope*

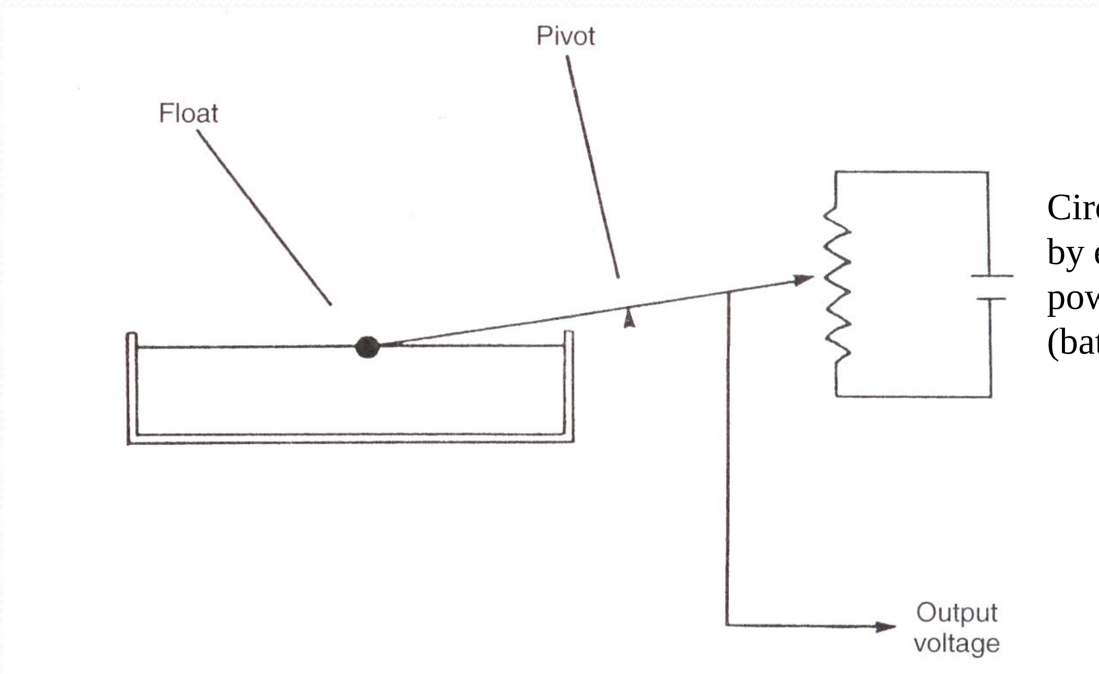
Types of instruments in measurements

- Active Instruments
  - the quantity being measured simply modulates (adapts to) the magnitude of some external power source.
- Passive Instruments
  - the instrument output is entirely produced by the quantity being measured

- Difference between active & passive instruments is the level of measurement resolution that can be obtained.

Active Instruments

- e.g. Float-type petrol tank level indicator



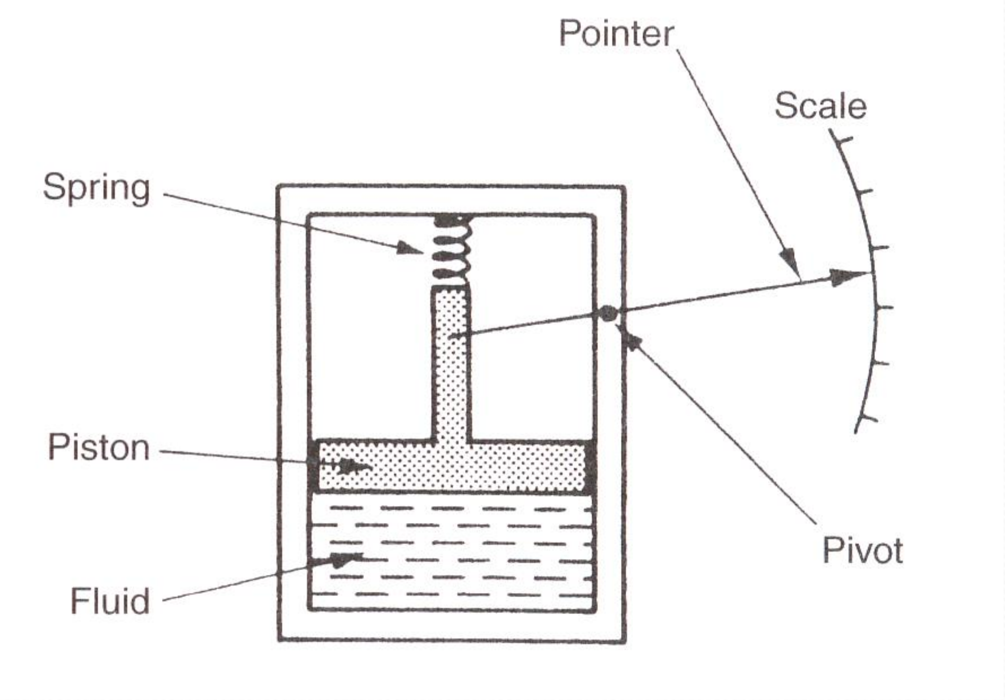
Circuit excited by external power source (battery)

Petrol tank level indicator

- The change in petrol level moves a potentiometer arm, and the output signal consists of a proportion of the external voltage source applied across the two ends of the potentiometer.
- The energy in the output signal comes from the external power source: the primary transducer float system is merely modulating the value of the voltage from this external power source.

Passive Instruments

- e.g. Pressure-measuring device



Passive pressure gauge

- The pressure of the fluid is translated into a movement of a pointer against scale.
- The energy expanded in moving the pointer is derived entirely from the change in pressure measured: there are no other energy inputs to the system.

Analogue Instruments

- An analogue instrument gives an output that varies continuously as the quantity being measured; e.g. Deflection-type of pressure gauge

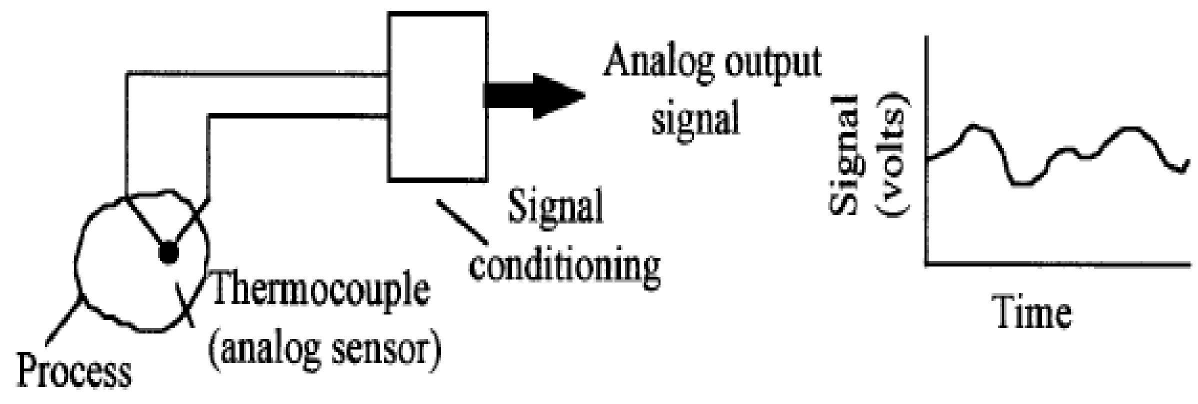


FIGURE 2.5 A thermocouple provides an analog signal for processing.

Digital Instruments

- A digital instrument has an output that varies in discrete steps and only have a finite number of values; e.g. Revolution counter

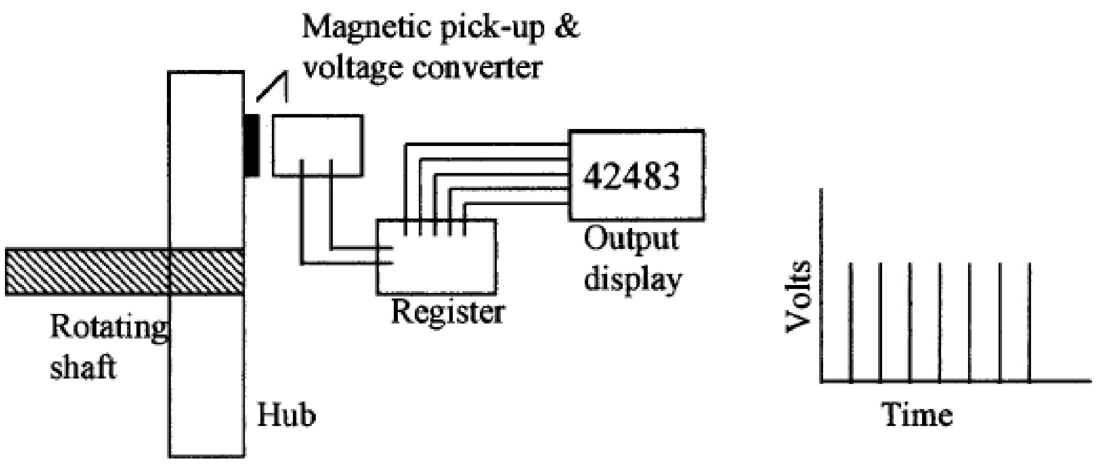


FIGURE 2.6 A rotating shaft with a revolution counter produces a digital signal.

Units Of Measurement

- To define physical quantities in type and magnitude
- Units of measurement may be defined as the standard measure of each kind of physical quantity.
- Efforts were made to standardise systems of measurement so that instrument professionals and specialist in other disciplines could communicate among themselves.

Fundamental Units & Derived Units

- Two types of units are used in science and engineering
  - Fundamental units (or quantities)
    - E.g. meter (length), kilogram (mass), second (time)
  - Derived units (or quantities); i.e. All units which can be expressed in terms of fundamental units
    - E.g. The volume of a substance is proportional to its length (l), breadth (b) and height (h), or $V = l \times b \times h$.
    - So, the derived unit of volume (V) is cube of meter (m^3).

International System (SI) Of Units

Quantity	Unit	Unit Symbol
Fundamental (Basic) Units		
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Luminous intensity	Candela	cd
Quantity of substance	Mole	mol
Supplementary Units		
Plane angle	Radian	rad
Solid angle	Steradian	sr
Derived Units		
Area	Square meter	m^2
Volume	Cubic meter	m^3
Velocity	Meter per second	m/s

English Systems Of Units

- Foot-pound-second (F.P.S.) used for:
  - Length
  - Mass
  - Time

Standard Of Measurement

- As a physical representation of a unit of measurement
- It is used for obtaining the values of the physical properties of other equipment by comparison methods; e.g.
  - The fundamental unit of mass in the SI system is the kilogram, defined as the mass of a cubic decimeter of water at its temperature of maximum density of 4°C.

Examples of Standard Bodies

- International Organization for Standardization (ISO)
- International Electrotechnical Commission (IEC)
- American National Standards Institute (ANSI)
- Standards Council of Canada (SCC)
- British Standards (BS)

Calibration

Calibration consists of comparing the output of the instrument or sensor under test against the output of an instrument of known accuracy (higher accuracy) when the same input (the measured quantity is applied to both instrument)

The procedure is carried out for a range of inputs covering the whole measurement range of the instrument or sensor Ensures that the measuring accuracy of all instruments and sensors used in a measurement system is known over the whole measurement range, provided that the calibrated instruments and sensors are used in environmental conditions that are the same as those under which they were calibrated

Calibration involve a comparison of an instrument with either:

1. A primary standard
2. A secondary standard
3. A known input

Example:

Weighing instrument → Standard weight measurement facility (for example: NIST)

Weighing instrument → Another weighing instrument of higher accuracy

Weighing instrument → Mass standard

Calibration

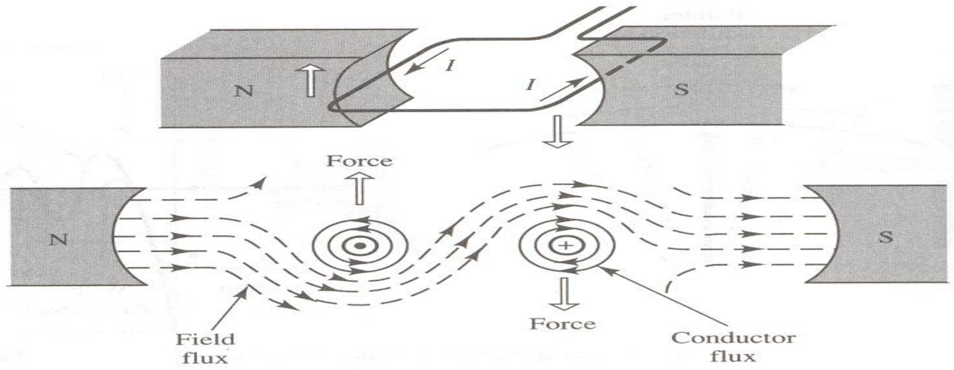
- The method and apparatus for performing measurement instrumentation calibrations vary widely.
- A rule that should be followed is that the calibration standard should be at least 10 times as accurate as the instrument being calibrated.
- By holding some inputs constant, varying others and recording the output(s) develop the desired static input-output relations. Many trial and runs are needed.

Application

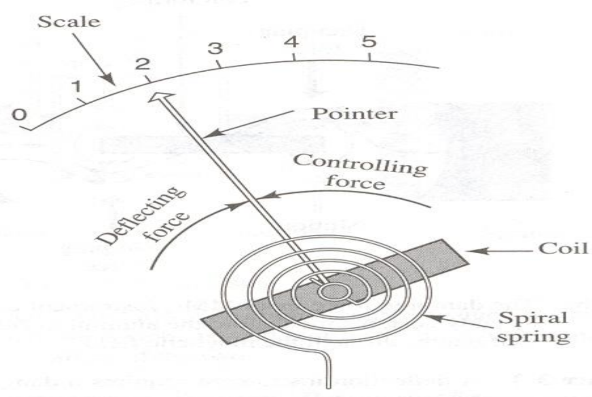
- Home
  - Thermometer
  - Barometer
  - Watch
- Road vehicles
  - speedometer
  - fuel gauge
- Industry
  - Automation
  - Process control
  - Boiler control

Chapter 3 Electromechanical Instruments

- Permanent-Magnet Moving-Coil Instruments
  - Deflection Instrument Fundamentals
    - Deflecting force
      - causes the pointer to move from its zero position when a current flows
      - is magnetic force; the current sets up a magnetic field that interacts with the field of the permanent magnet (see Figure 3.1 (a))



(a) The deflecting force in a PMMC instrument is provided by a current-carrying coil pivoted in a magnetic field.



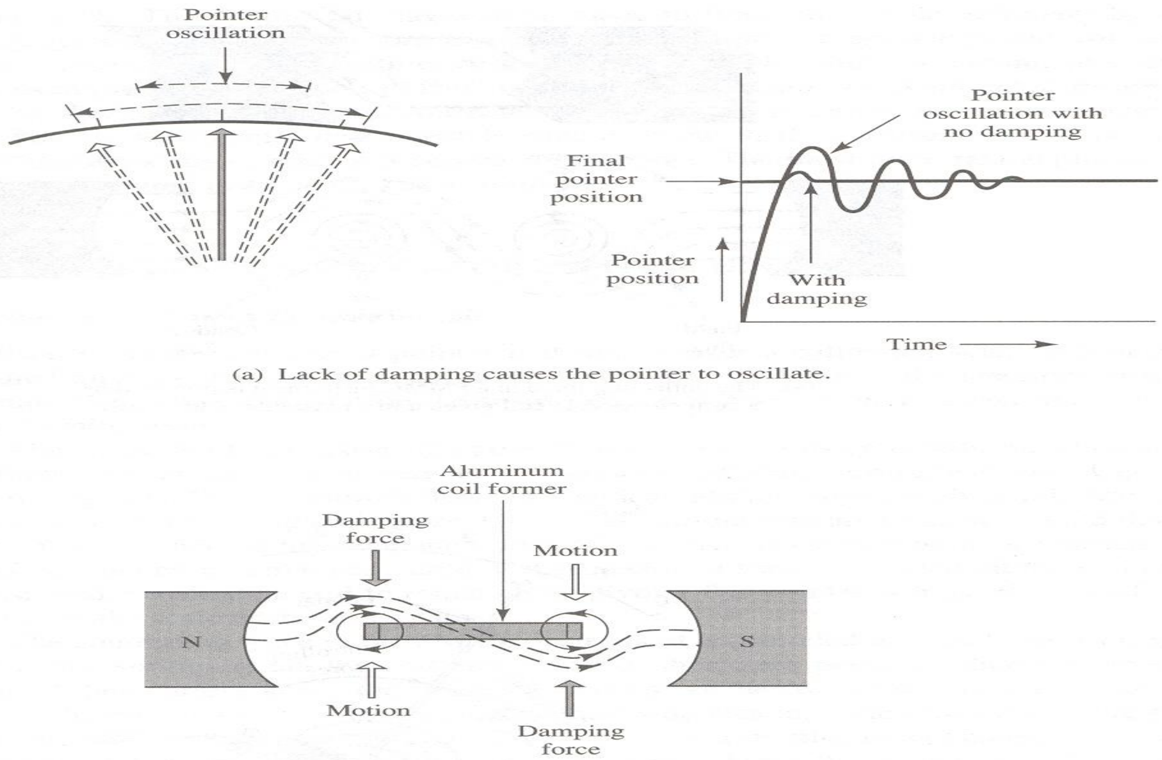
(b) The controlling force from the springs balances the deflecting force.

Figure 3-1 The deflecting force in a PMMC instrument is produced by the current in the moving coil. The controlling force is provided by spiral springs. The two forces are equal when the pointer is stationary.

- Controlling force
  - is provided by spiral springs (Figure 3.1 (b))
  - retain the coil and pointer at their zero position when no current is flowing
  - When current flows, the springs wind up as the coil rotates, and the force they exert on the coil increases
  - The coil and pointer stop rotating when the controlling force becomes equal to the deflecting force.
  - The spring material must be nonmagnetic to avoid any magnetic field influence on the controlling force.

- Since the springs are used to make electrical connection to the coil, they must have a low resistance.

- Damping force
  - is required to minimize (or damp out) the oscillations
  - must be present only when the coil is in motion, thus it must be generated by the rotation of the coil
  - In PMMC instruments, the damping force is normally provided by eddy currents.



(a) Lack of damping causes the pointer to oscillate.

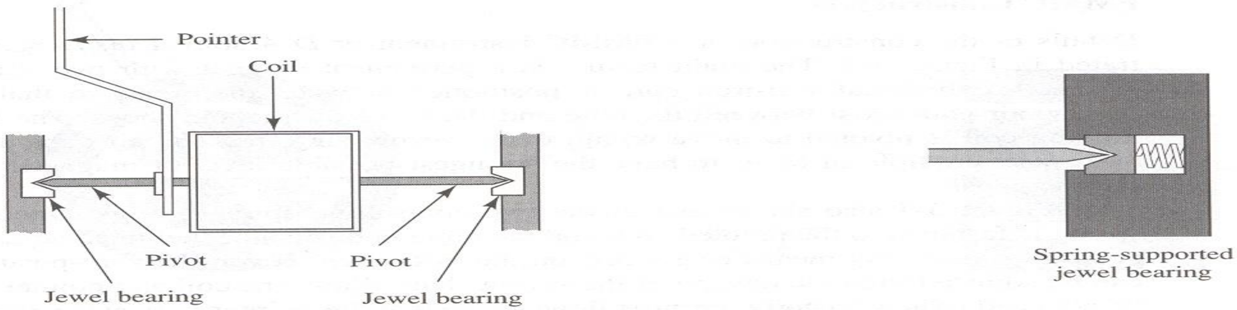
(b) The damping force in a PMMC instrument is provided by eddy currents induced in the aluminum coil former as it moves through the magnetic field.

Figure 3-2 A deflection instrument requires a damping force to stop the pointer oscillating about the indicated reading. The damping force is usually produced by eddy currents in a nonmagnetic coil former. These exist only when the coil is in motion.

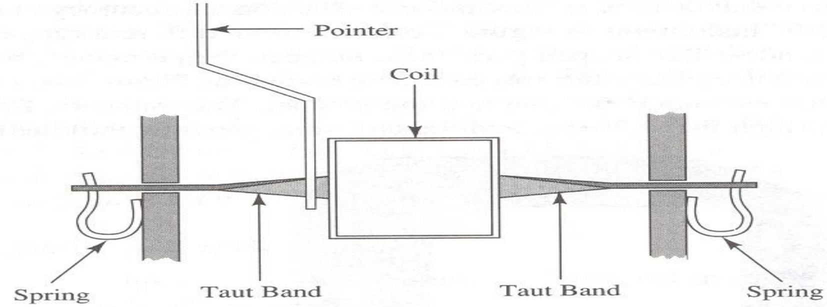
- Eddy currents induced in the coil former set up a magnetic flux that opposes the coil motion, thus damping the oscillations of the coil (see Figure 3.2 (b)).

- Two methods of supporting the moving system of a deflection instrument
  - Jeweled-bearing suspension
    - Cone-shaped cuts in jeweled ends of pivots
    - Least possible friction
    - Shock of an instrument spring supported to absorb such shocks ⇒
  - Taut-band method
    - Much tougher than jeweled-bearing
    - Two flat metal ribbons (phosphor bronze or platinum alloy) are held under tension by spring to support the coil

- Because of the spring, the metal ribbons behave like rubber under tension.
- The ribbons also exert a controlling force as they twist, and they can be used as electrical connections to the moving coil.
- Much more sensitive than the jeweled-bearing type because there is less friction
- Extremely rugged, not easily be shattered.



(a) Pivot and jewel-bearing suspension



(b) Taut-band suspension

Figure 3-3 The moving coil in a PMMC instrument may be supported by pivots in jeweled bearings, or by two flat metal ribbons held taut by springs. Taut-band suspension is the toughest and the most sensitive of the two.

- PMMC Construction
  - D'Arsonval or horseshoe magnet
  - Core-magnet

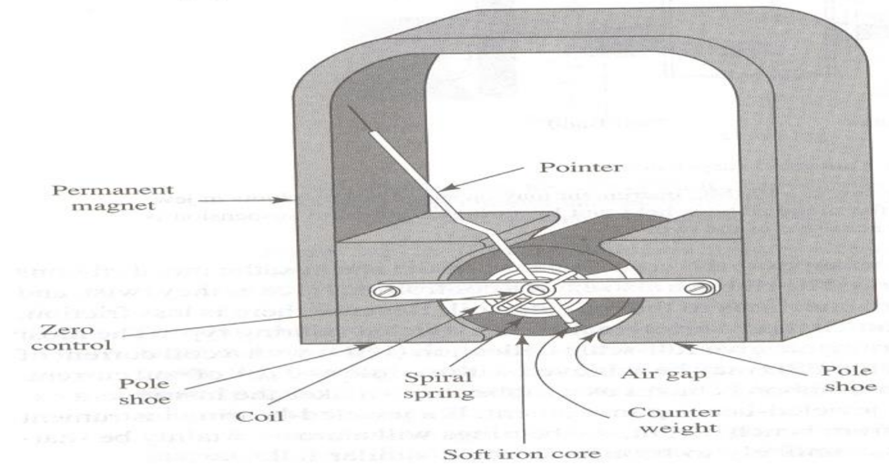


Figure 3-4 A typical PMMC instrument is constructed of a *horseshoe* magnet, soft-iron pole shoes, a soft-iron core, and a suspended coil that moves in the air gap between the core and the pole shoes.

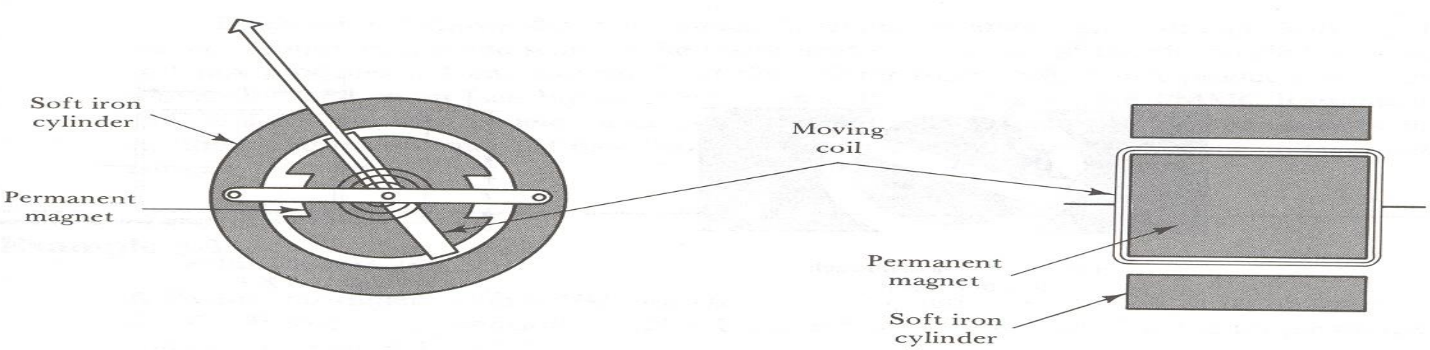
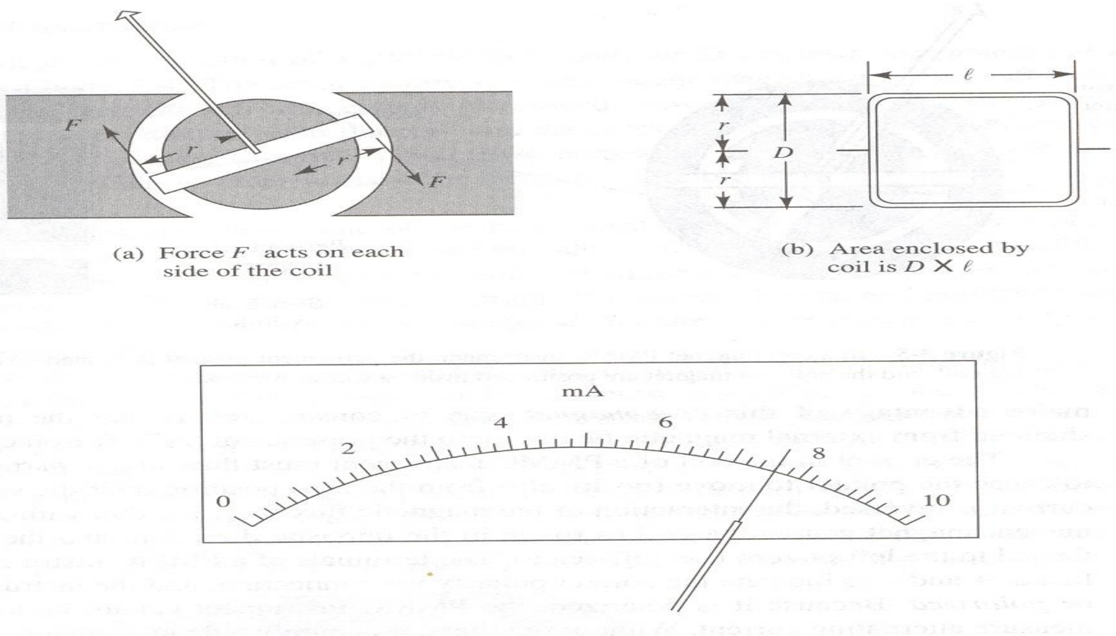


Figure 3-5 In a core-magnet PMMC instrument, the permanent magnet is located inside the moving coil, and the coil and magnet are positioned inside a soft-iron cylinder.

- Torque Equation and Scale
  - When a current I flows through a one-turn coil situated in a magnetic field, a force F is exerted on each side of the coil

$$F = BIl \quad newtons$$



(a) Force F acts on each side of the coil

(b) Area enclosed by coil is $D \times \ell$

(c) Linear scale on a PMMC instrument

Figure 3-6 The deflecting torque on the coil of a PMMC instrument is directly proportional to the magnetic flux density, the coil dimensions, and the coil current. This gives the instrument a linear scale.

- Since the force acts on each side of the coil, the total force for a coil of N turns is

$$F = 2BIlN$$

- The force on each side acts at a radius r, producing a deflecting torque:

$$\begin{aligned} T_D &= 2BlINr = BlIN(2r) \\ &= BlIND \\ &= BAIN \end{aligned}$$

- The controlling torque exerted by the spiral springs is directly proportional to the deformation or windup of the springs. Thus, the controlling torque is proportional to the actual angle of deflection of the pointer.

$$T_C = K\theta \quad \text{where } K \text{ is a constant}$$

- For a given deflection, the controlling and deflecting torque are equal:

$$K\theta = BlIND$$

$$\theta = CI \quad where\ C\ is\ a\ constant$$

Example 3.1 A PMMC instrument with a 100-turn coil has a magnetic flux density in its air gaps of B = 0.2 T. The coil dimension are D = 1 cm and l = 1.5 cm. Calculate the torque on the coil for a current of 1 mA.

Solution

$$T_d = BlIND = (0.2T)(1.5\times10^{-2})(1\times10^{-3})(100)(1\times10^{-2})$$

$$= 3\times10^{-6}\ Nm$$

Permanent Magnet Moving Coil

Moving Coil Instruments:

There are two types of moving coil instruments namely, permanent magnet moving coil type which can only be used for direct current, voltage measurements and the dynamometer type which can be used on either direct or alternating current, voltage measurements.

Permanent Magnet Moving Coil Mechanism (PMMC):

In PMMC meter or (D'Arsonval) meter or galvanometer all are the same instrument, a coil of fine wire is suspended in a magnetic field produced by permanent magnet. According to the fundamental law of electromagnetic force, the coil will rotate in the magnetic field when it carries an electric current by electromagnetic (EM) torque effect. A pointer which attached the movable coil will deflect according to the amount of current to be measured which applied to the coil. The (EM) torque is counterbalance by the mechanical torque of control springs attached to the movable coil also.

When the torques are balanced the moving coil will stopped and its angular deflection represent the amount of electrical current to be measured against a fixed reference, called a scale. If the permanent magnet field is uniform and the spring linear, then the pointer deflection is also linear.

Mathematical Representation of PMMC Mechanism

Assume there are (N) turns of wire and the coil is (L) in long by (W) in wide. The force (F) acting perpendicular to both the direction of the current flow and the direction of magnetic field is given by:

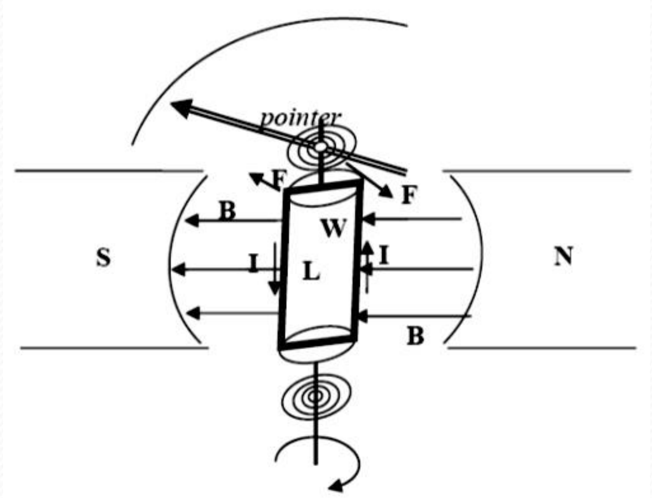
$F = N \cdot B \cdot I \cdot L$

where N: turns of wire on the coil

I: current in the movable coil

B: flux density in the air gap

L: vertical length of the coil



Electromagnetic torque is equal to the multiplication of force with distance to the point of suspension

$$T_{I1} = NBIL\frac{W}{2}$$ in one side of cylinder $$T_{I2} = NBIL\frac{W}{2}$$ in the other side of cylinder

The total torque for the two cylinder sides

$$T_I = 2\left(NBIL\frac{W}{2}\right) = NBILW = NBIA$$ where A: effective coil area

This torque will cause the coil to rotate until an equilibrium position is reached at an angle θ with its original orientation. At this position

Electromagnetic torque = control spring torque

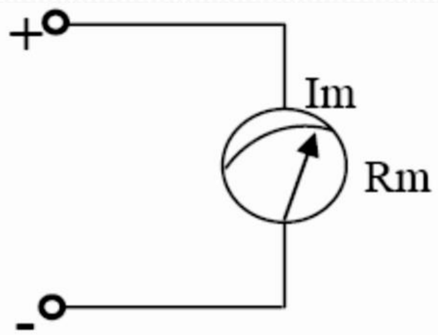
$$T_I = Ts$$

Since $Ts = K\theta$

So $\theta = \frac{NBA}{K}I$ where $C = \frac{NBA}{K}$ Thus $\theta = CI$

The angular deflection proportional linearly with applied current

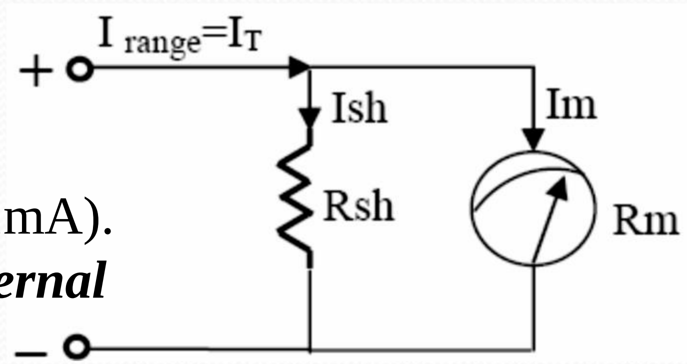
1- *D.C Ammeter:*



An Ammeter is always connected in series with a circuit branch and measures the current flowing in it. Most d.c ammeters employ a d'Arsonval movement, an ideal ammeter would be capable of performing the measurement without changing or distributing the current in the branch but real ammeters would possess some internal resistance.

Extension of Ammeter Range:

Since the coil winding in PMMC meter is *small and light*, they can carry only small currents (μA-1mA). Measurement of large current requires ***a shunt external resistor*** to connect with the meter movement, so only a fraction of the total current will passes through the meter.



$$Vm = Vsh$$

$$\text{Im}\,Rm = Ish\,Rsh$$

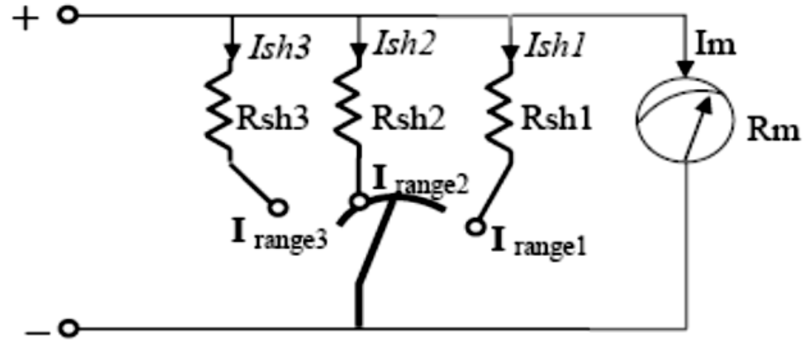
$$Ish = I_T - \text{Im}$$

$$\boxed{Rsh = \frac{\text{Im}\,Rm}{I_T - \text{Im}}}$$

a) *Direct D.c Ammeter Method (Ayrton Shunt):*

The current range of d.c ammeter can be further extended by a number of shunts selected by a range switch; such ammeter is called a multirange ammeter.

$$Rsh_* = \frac{Im\,Rm}{Ir_* - Im}$$

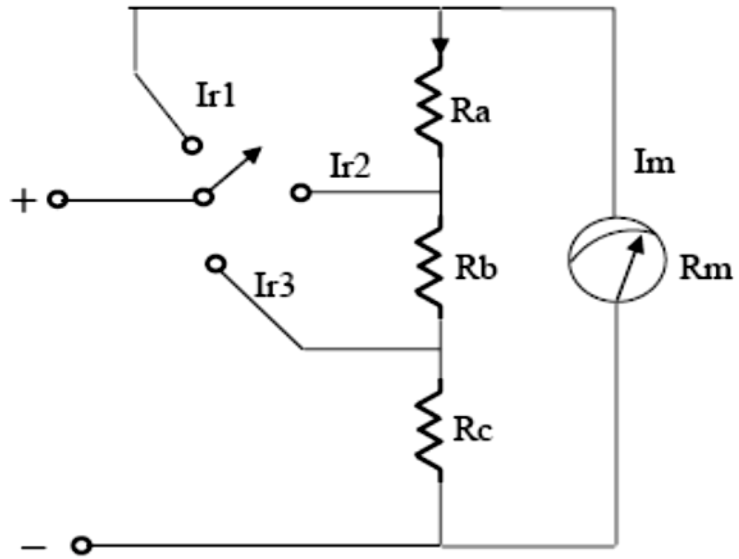


b) *Indirect D.C Ammeter Method:*

$$\frac{Ir_*}{Im} = \frac{Rm + R}{r_*}$$

Where R=Ra+ Rb+ Rc

And r = parallel resistors branch with the meter



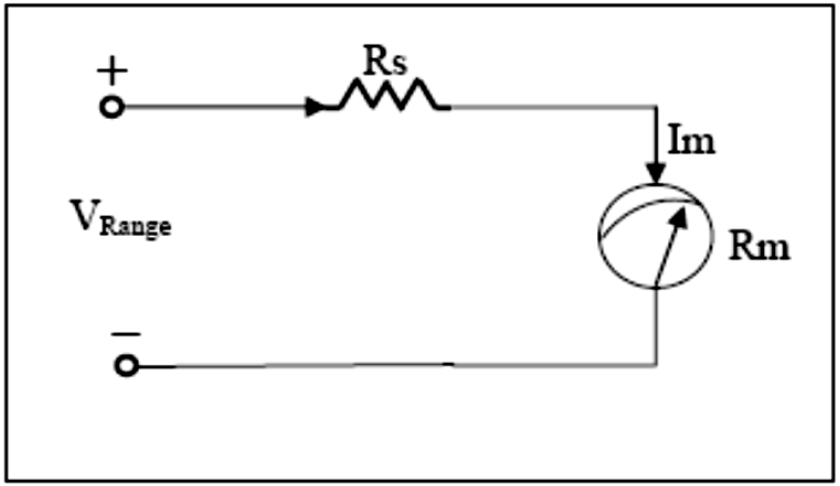
2- D.C Voltmeter:

A voltmeter is always connect in parallel with the element being measured, and measures the voltage between the points across which its' connected. Most d.c voltmeter employ PMMC meter with series resistor as shown. The series resistance should be much larger than the impedance of the circuit being measured, and they are usually much larger than Rm.

$$Rs = R_T - Rm$$

$$Rs = \frac{V_{range}}{\text{Im}} - Rm$$

$Im = I_{FSD}$



The ohm/volt sensitivity of a voltmeter
Is given by:

$$S_v = \frac{Rm}{V_{FSD}} = \frac{1}{I_{FSD}} = \frac{\Omega}{V} rating$$

$$S_{Range} = \frac{Rm + Rs}{V_{Range}} = \frac{1}{I_{Range}} = \frac{\Omega}{V}$$

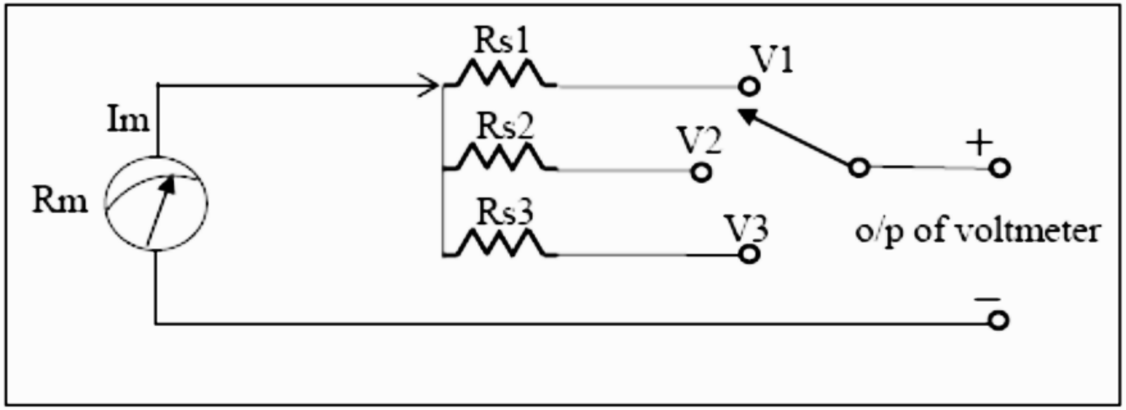
So the internal resistance of voltmeter or the input resistance of voltmeter is

$$Rv = V_{FSD} \text{ x sensitivity}$$

a) *Direct D.c Voltmeter Method:*

In this method each series resistance of multirange voltmeter is connected in direct with PMMC meter to give the desired range.

$$Rs_* = \frac{V_*}{Im} - Rm$$



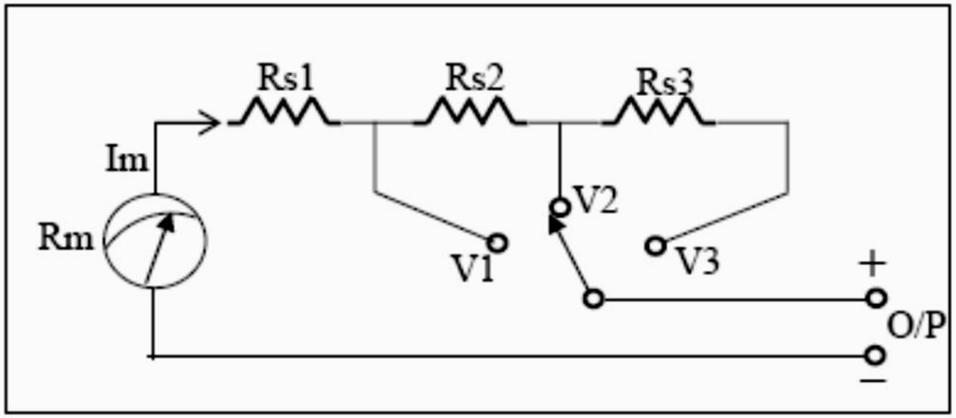
b) *Indirect D.c Voltmeter Method:*

In this method one or more series resistances of multirange voltmeter is connected with PMMC meter to give the desired range.

$$Rs1 = \frac{V1}{Im} - Rm$$

$$Rs2 = \frac{V2 - V1}{Im}$$

$$Rs3 = \frac{V3 - V2}{Im}$$



3- *Ohmmeter and Resistance measurement:*

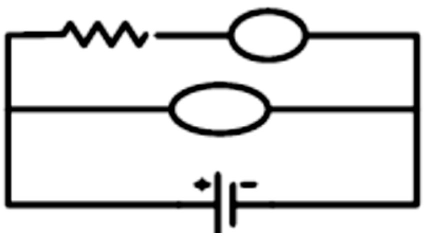
When a current of 1A flows through a circuit which has an impressed voltage of 1volt, the circuit has a resistance of 1Ω.

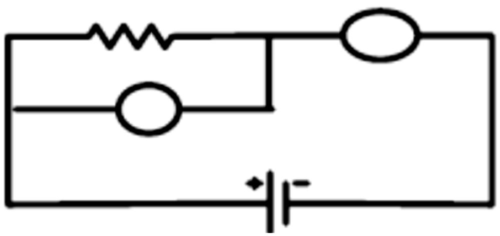
$$R = \frac{V}{I}$$

There are several methods used to measure unknown resistance:

a) *Indirect method by ammeter and voltmeter.*

This method is inaccurate unless the ammeter has a small resistance and voltmeter have a high resistance.





b) *Series Ohmmeter:*

Rx is the unknown resistor to be measured, R2 is variable adjusted resistance so that the pointer read zero at short circuit test. The scale of series ohmmeter is nonlinear with zero at the right and infinity at extreme left. Series ohmmeter is the most generally used meter for resistance measurement.