Electrical Measurements and Instrumentation

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UNIT – I
INTRODUCTION TO MEASURING INSTRUMENTS

MEASURING INSTRUMENTS

"The device used for comparing the unknown quantity with the unit of measurement or standard quantity is called a Measuring Instrument."

OR

"An instrument may be defined as a machine or system which is designed to maintain functional relationship between prescribed properties of physical variables & could include means of communication to human observer."

CLASSIFICATION OF INSTRUMENTS

Electrical instruments may be divided into two categories, that are;

1. Absolute instruments,
2. Secondary instruments.

- Absolute instruments gives the quantity to be measured in term of instrument constant & its deflection.

- In Secondary instruments the deflection gives the magnitude of electrical quantity to be measured directly. These instruments are required to be calibrated by comparing with another standard instrument before putting into use.

CLASSIFICATION OF INSTRUMENTS

CLASSIFICATION OF INSTRUMENTS

Electrical measuring instruments may also be classified according to the kind of quantity, kind of current, principle of operation of moving system.

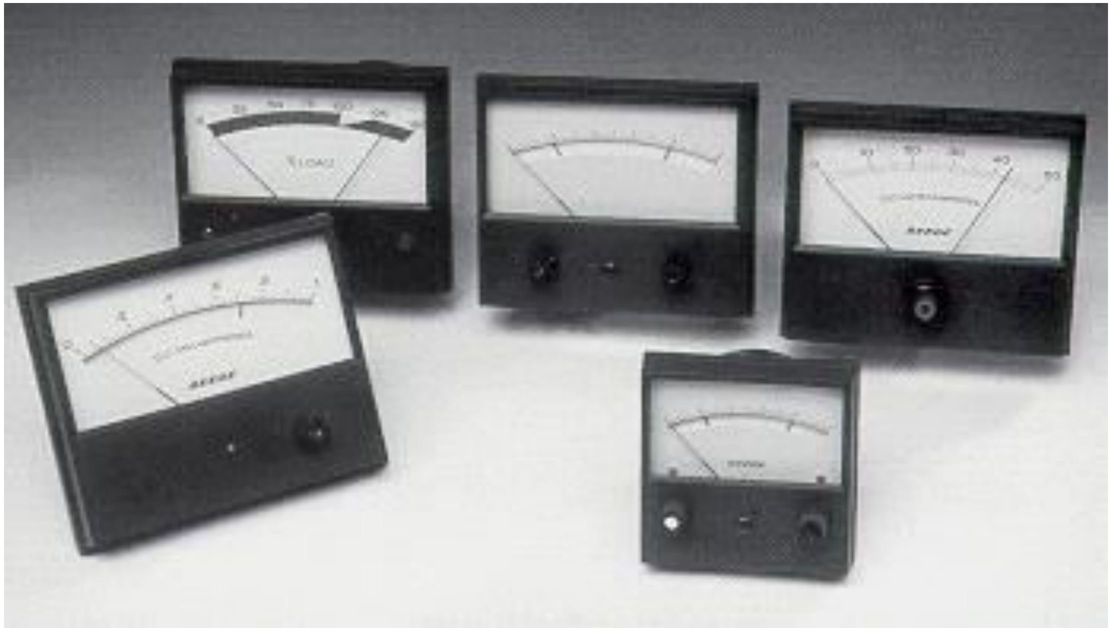
CLASSIFICATION OF SECONDARY INSTRUMENTS

- Secondary instruments can be classified into three types;
  - i. Indicating instruments;
  - ii. Recording instruments;
  - iii. Integrating instruments.

CLASSIFICATION OF SECONDARY INSTRUMENTS

- Indicating Instruments:

  It indicate the magnitude of an electrical quantity at the time when it is being measured. The indications are given by a pointer moving over a graduated dial.



CLASSIFICATION OF SECONDARY INSTRUMENTS

- Recording Instruments:

The instruments which keep a continuous record of the variations of the magnitude of an electrical quantity to be observed over a defined period of time.

CLASSIFICATION OF SECONDARY INSTRUMENTS

- Integrating Instruments:

  The instruments which measure the total amount of either quantity of electricity or electrical energy supplied over a period of time. For example energy meters.

ESSENTIALS OF INDICATING INSTRUMENTS

A defined above, indicating instruments are those which indicate the value of quantity that is being measured at the time at which it is measured. Such instruments consist essentially of a pointer which moves over a calibrated scale & which is attached to a moving system pivoted in bearing. The moving system is subjected to the following three torques:

1. A deflecting (or operating) torque;
2. A controlling (or restoring) torque;
3. A damping torque.

DEFLECTING TORQUE

- The deflecting torque is produced by making one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effect of current or voltage and cause the moving system of the instrument to move from its zero position.
- The method of producing this torque depends upon the type of instrument.

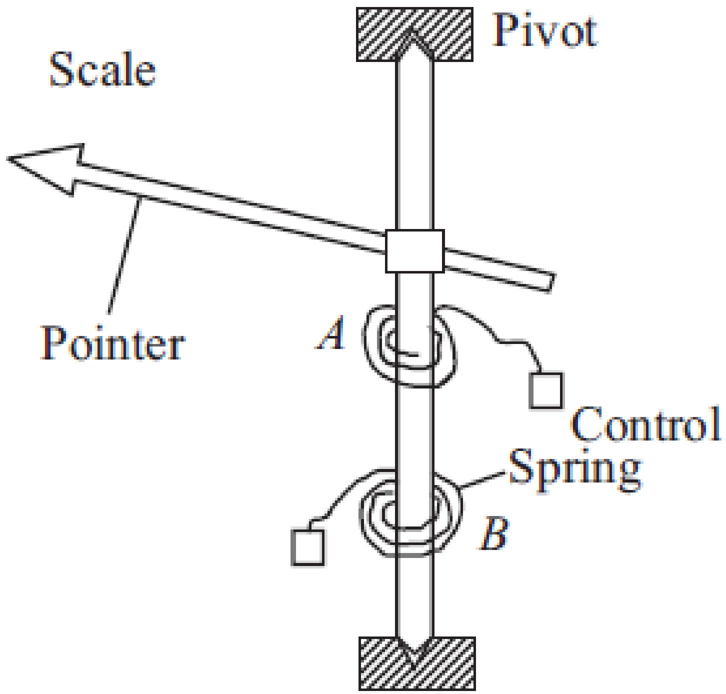
CONTROLLING TORQUE

- The magnitude of the moving system would be some what indefinite under the influence of deflecting torque, unless the controlling torque existed to oppose the deflecting torque.
- It increases with increase in deflection of moving system.
- Under the influence of controlling torque the pointer will return to its zero position on removing the source producing the deflecting torque.
- Without controlling torque the pointer will swing at its maximum position & will not return to zero after removing the source.

- Controlling torque is produced either by spring or gravity control.

Spring Control:

- When the pointer is deflected one spring unwinds itself while the other is twisted. This twist in the spring produces restoring (controlling) torque, which is proportional to the angle of deflection of the moving systems.



Spring Control

$$T_c \propto \theta$$

$$T_c = K_s\theta$$

$$T_d \propto I$$

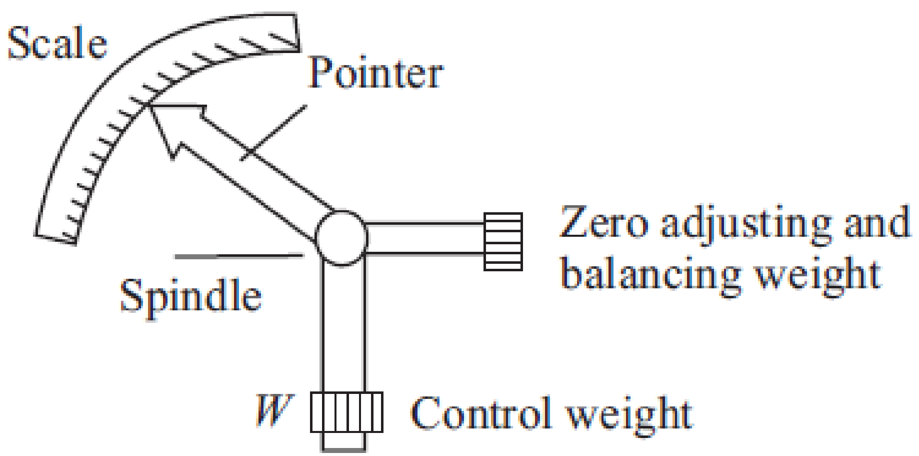
$$T_d = K_s I$$

$$T_c = T_d$$

$$\theta = I$$

Gravity Control

- In gravity controlled instruments, *a small adjustable weight is attached to the* spindle of the moving system such that the deflecting torque produced by the instrument has to act against the action of gravity.
- Thus a controlling torque is obtained. This weight is called the *control weight*. *Another adjustable weight is also attached is the moving system for zero adjustment and balancing* purpose. This weight is called *Balance weight*.



DAMPING TORQUE

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

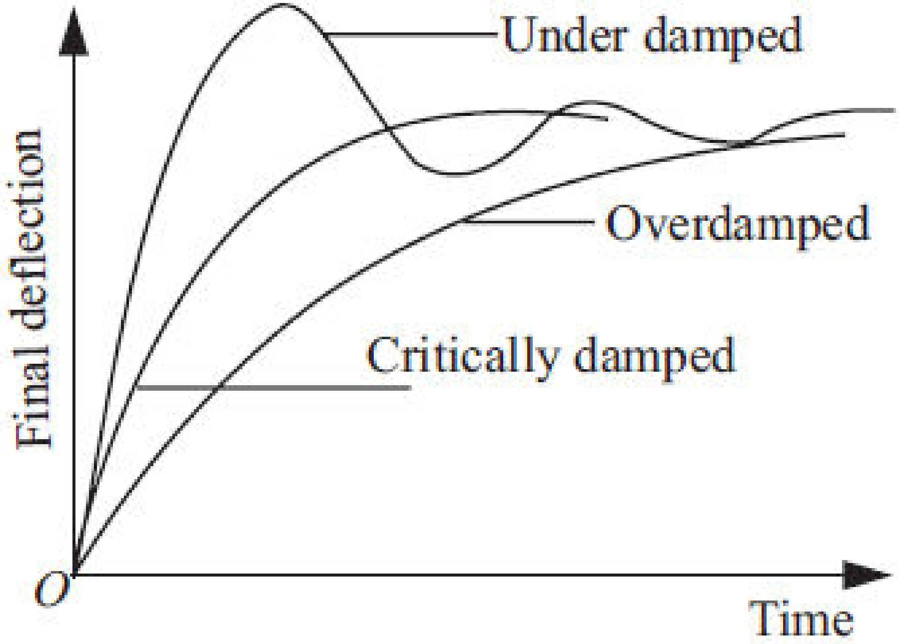
DAMPING TORQUE

- The damping torque is proportional to the speed of rotation of the moving system, that is

$$T_v = k_v \frac{d\theta}{dt}$$

where k_v = damping torque constant

$\frac{d\theta}{dt}$ = speed of rotation of the moving system



- Depending upon the degree of damping introduced in the moving system, the instrument may have any one of the following conditions as depicted in above graph.

DAMPING TORQUE

1. **Under damped condition:**

   The response is oscillatory

2. **Over damped condition:**

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

3. **Critically damped condition:**

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

The damping torque is produced by the following methods:

1.Air Friction Damping

2.Fluid Friction Damping

3.Eddy Current Damping

4.Electromagnetic Damping

TYPES OF AMMETERS & VOLTMETERS

1) **Moving Iron Type Meters (AC & DC);**
   - **a) Attraction type,**
   - **b) Repulsion type.**

2) **Moving Coil Type Meters (AC & DC);**
   - **a) Permanent Magnet type,**
   - **b) Electrodynamic or Dynamometer.**

3) **Hot Wire Type (AC & DC);**

4) **Induction Type (AC & DC);**
   - **a) Split phase,**
   - **b) Shaded Pole type.**

5) **Electrostatic Type for Voltmeters Only;**

Moving-iron instrument

- An attraction type of moving-iron instrument is shown diagrammatically in Figure. When current flows in the solenoid, a pivoted soft-iron disc is attracted towards the solenoid and the movement causes a pointer to move across a scale.

- In the repulsion type moving-iron instrument shown diagrammatically in Figure, two pieces of iron are placed inside the solenoid, one being fixed, and the other attached to the spindle carrying the pointer.

Moving-iron instrument

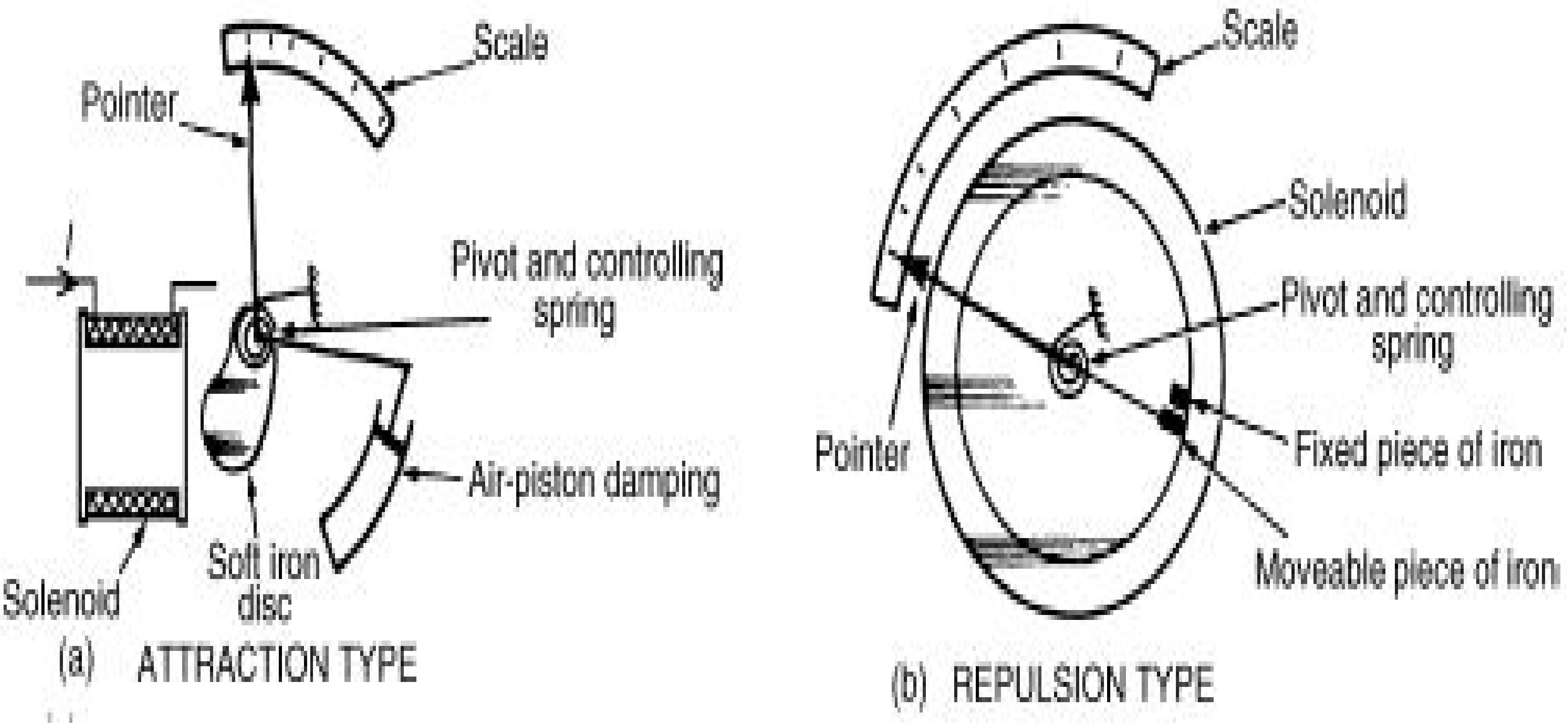


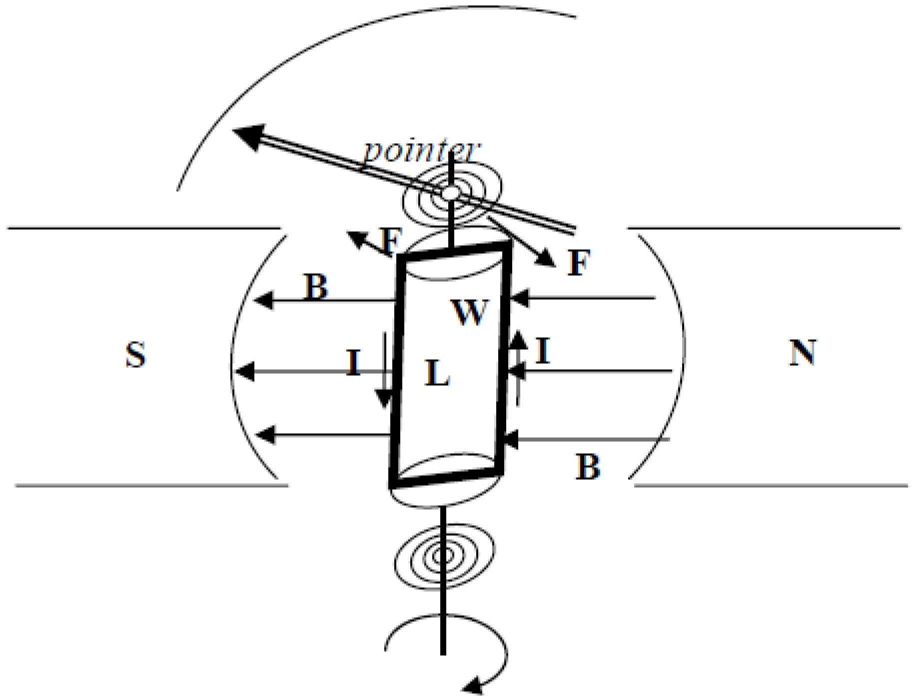
Figure 10.2

Moving-Coil instrument

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

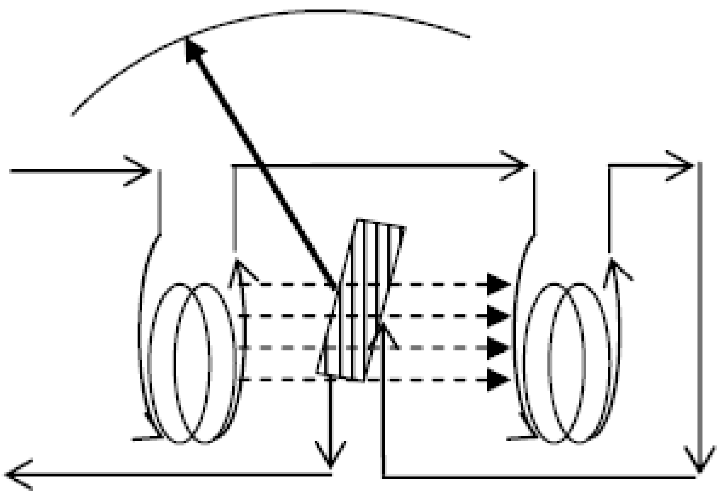
PERMANENT MAGNET MOVING COIL

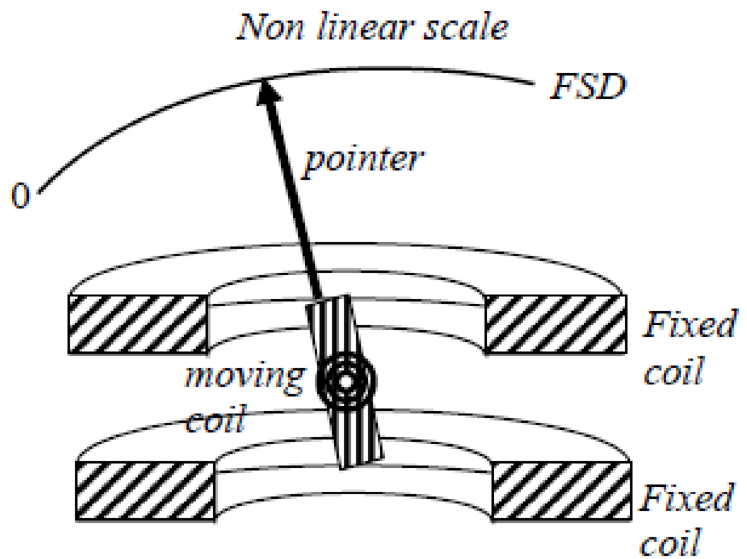
"The principle operation of PMMC is based upon the principle of current carrying conductor is placed in a magnetic field it is acted upon by force which tends to move it."



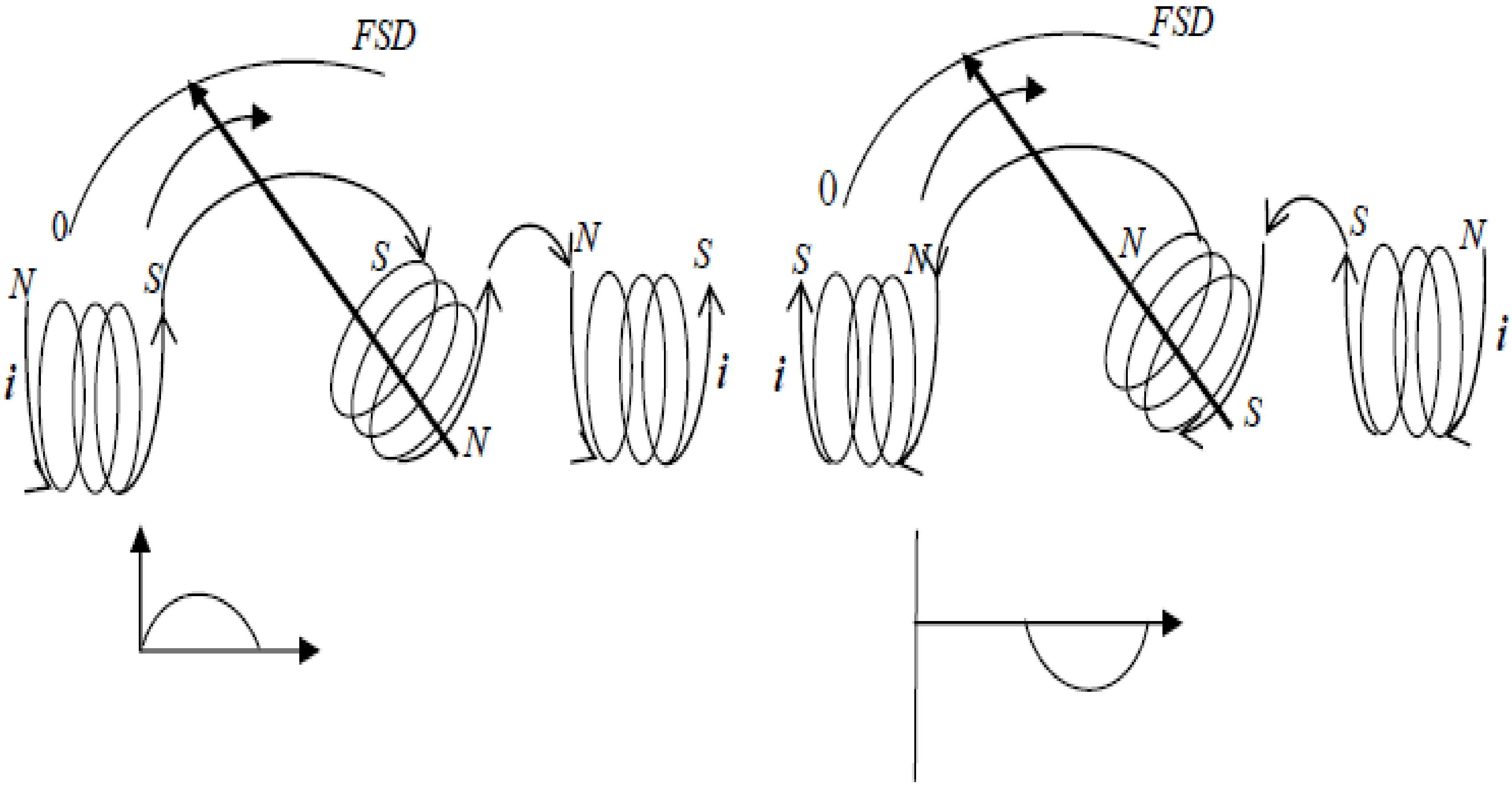
DYNAMOMETER

- This instrument is suitable for the measurement of direct and alternating current, voltage and power.
- The deflecting torque in dynamometer is relies by the interaction of magnetic field produced by a pair of fixed air cored coils and a third air cored coil capable of angular movement and suspended within the fixed coil.





DYNAMOMETER



HOT WIRE TYPE

- It is based on the heating effect of current.
- It consist of platinum-iridium (it can withstand oxidation at high temperatures) wire.
- When current is through wire, it expands according to I^2R formula.
- This produces sag in the wire and pointer is attached with this wire which in result deflects.

INDUCTION TYPE INSTRUMENT

- Such instruments are suitable for ac measurements only in these instruments the deflecting torque is produced by the eddy currents induced in an aluminum or copper disc or drum by the flux created by an electro-magnet.

- The main advantages of such instruments are that

  (i) a full scale deflection can be obtained giving long and open scale

  (ii) the effect of stray magnetic field is small;

  (iii) damping is easier and effective.

INDUCTION TYPE INSTRUMENT

- These instruments have got some serious disadvantages

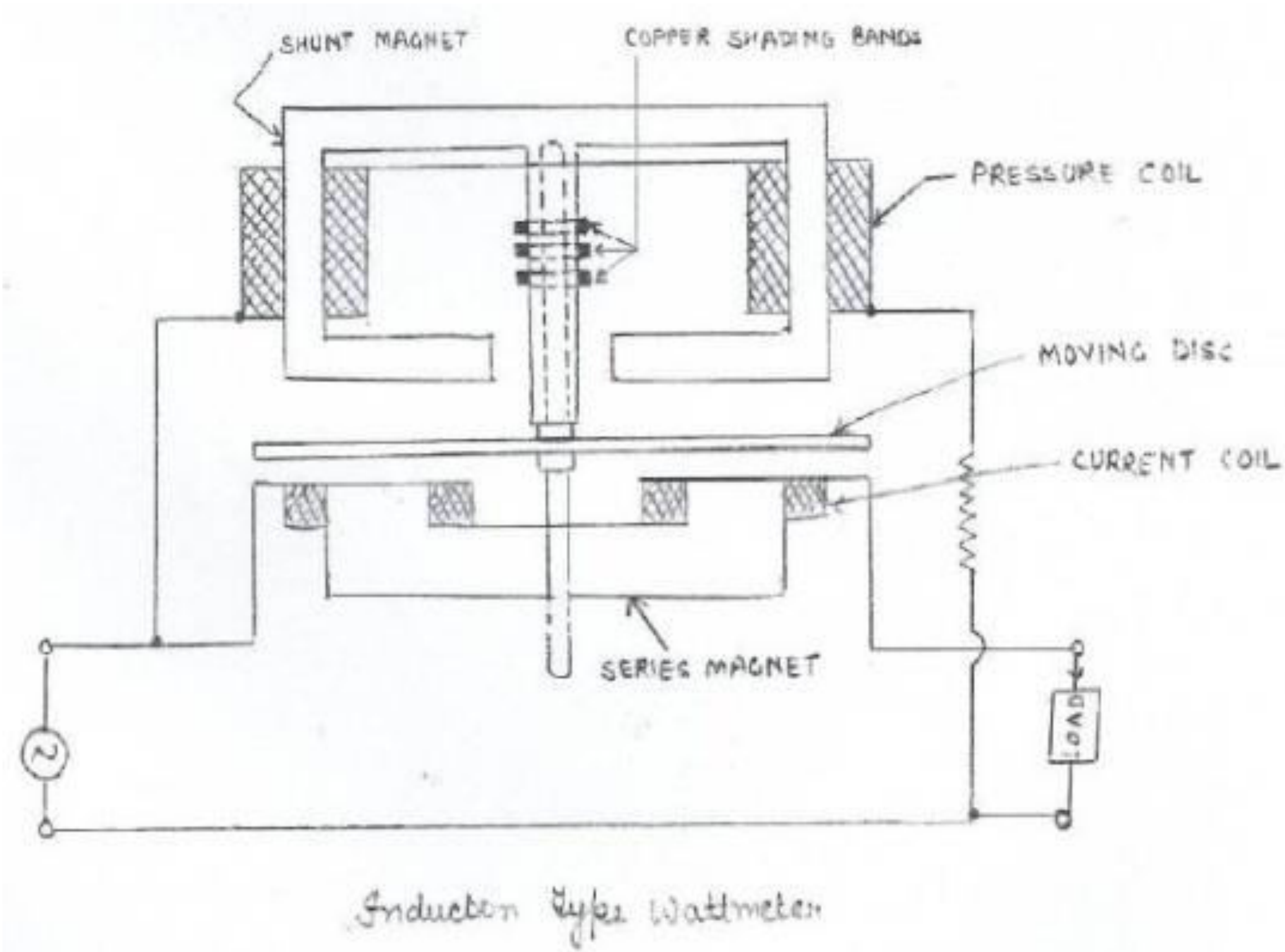
  (i) The greater deflection causes more stresses in the control springs.

  (ii) Variation in supply frequency and temperature may cause serious errors unless compensating device is employed.

  (iii) These instruments are costlier and consume more power

- Such instruments are mostly used as watt-meters or energy meters.

INDUCTION TYPE INSTRUMENT



INDUCTION TYPE INSTRUMENT

- Induction type wattmeter consists of two laminate electromagnets known as shunt electromagnet and series electromagnet respectively.
- Shunt magnet is excited by the current proportional to the voltage across load flowing through the pressure coil and series magnet is excited by the load current flowing through the current coil.
- A thin disc made of Cu or Al, pivoted at its centre, is placed between the shunt and series magnets so that it cuts the flux from both of the magnets.

INDUCTION TYPE INSTRUMENT

- The deflection torque is produced by interaction of eddy current induced in the disc and the inducing flux in order to cause the resultant flux in shunt magnet to lag in phase by exactly 90° behind the applied voltage.
- One or more copper rings, known as copper shading bond are provided on one limb at the shunt magnet.
- Correct disappointed between shunt and series magnet fluxes may be attained by adjusting the position of copper shading bonds. The pressure coil circuit of induction type instrument is made as inductive as possible so that the flux of the shunt magnet may lag by 90° behind the applied voltage.

UNIT – II

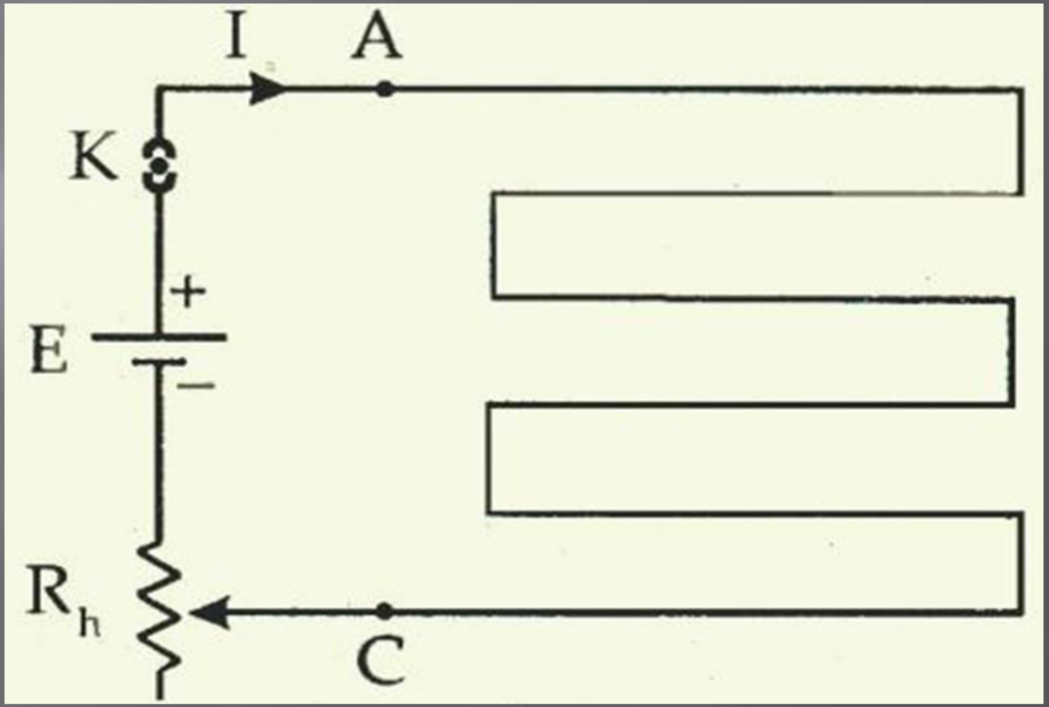
POTENTIOMETERS AND INSTRUMENT TRANSFORMERS

Potentiometer

- It is basically a long piece of uniform wire, sometimes a few meters in length across which a standard cell is connected.
- It is used to find emf of a primary cell, to compare emf's of two primary cells and to find internal resistance of a primary cell.

Constructi on

It consists of a resistance wire of uniform cross sectional area and of length 4m to 10 m. It is fixed on a **rectangular** wooden board between point A and point C in zigzag way.



A metre scale is fixed below the first wire so as to measure the length of null point. A cell of constant e.m.f. E called as lead cell, is connected between point A and point C. The positive terminal of cell is connected to point A through plug key K and negative terminal of cell is connected to point C through rheostat R_h.

Principle of Working

If the wire of potentiometer is of uniform cross section and a constant current flows through it, the potential between any two points of the wire is directly proportional to the length of wire between the points

$V(\ell) \alpha \ell$

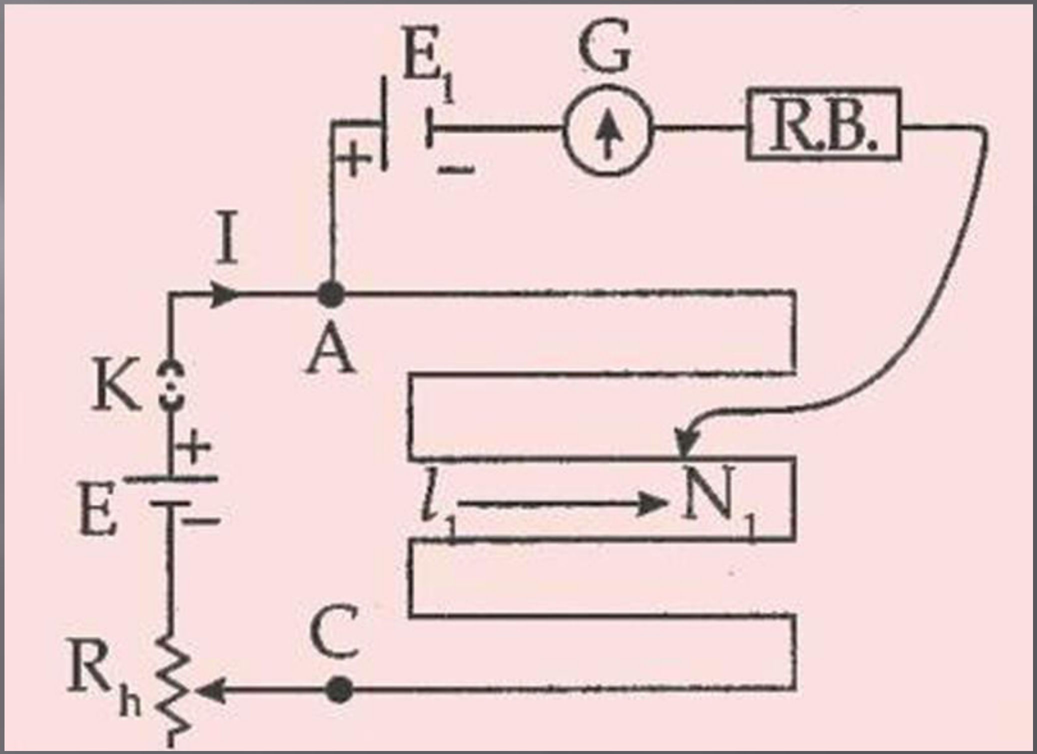
The potential per unit length of the wire is called potential gradient, denoted by ϕ and given by-

$\phi = V/L$

V is the potential across potentiometer wire and L is the length of the potentiometer wire.

1. To Measure emf of a cell

The positive terminal of cell is connected to point A and negative terminal is connected to jockey through galvanometer. Measure the length of null point N_1 from point A ($AN_1 = \ell_1$)



The emf of cell is balanced by the balancing length $AN_1 = \ell_1$.

By applying KVL in loop AE_1GN_1A, we have-

$-E_1 + 0 + \phi\ell_1 = 0$

or, $E_1 = \phi\ell_1$

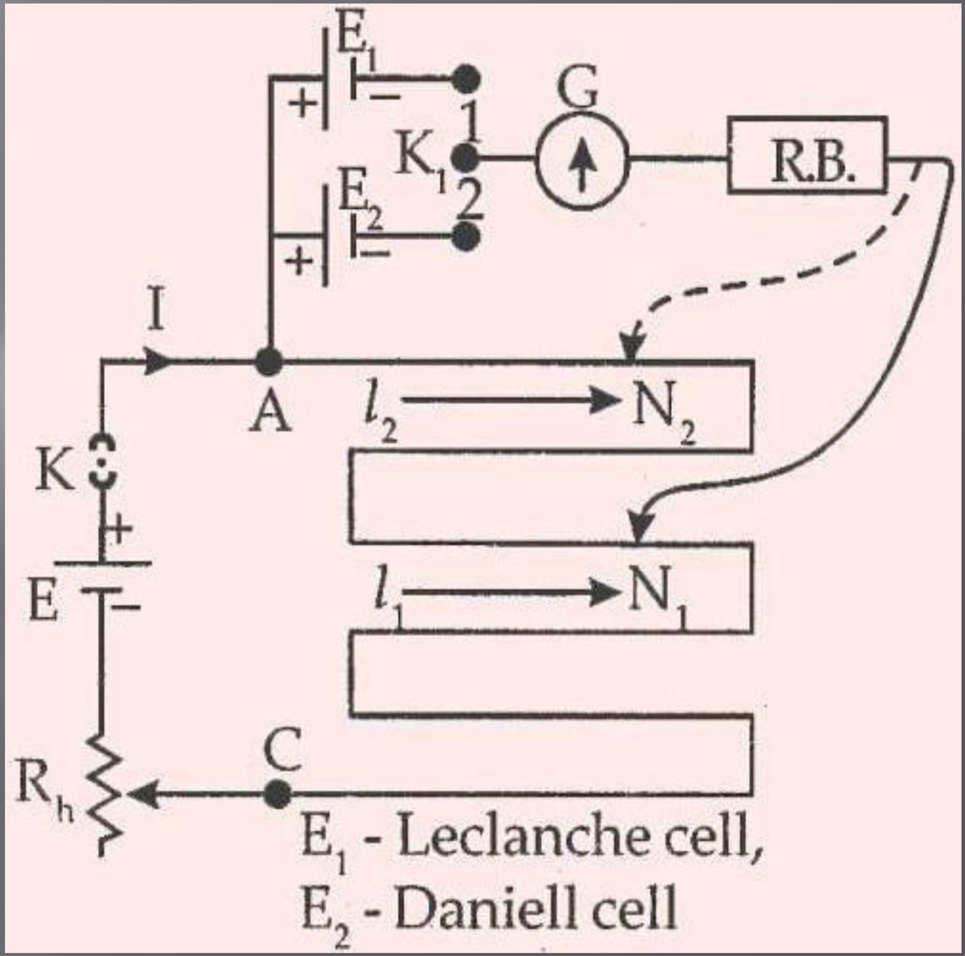
From this equation one can find emf of the cell.

2. To compare EMF of two cells

The two cells of e.m.f. E1 and E2 along with two way key K1 and galvanometer G is connected with the potentiometer.

When cell E1 is connected, at null point-

$E_1 = \phi \ell_1$ ……(1)



When cell E_2 is connected, at null point-

$E_2 = \phi \ell_2$ ……………..(2)

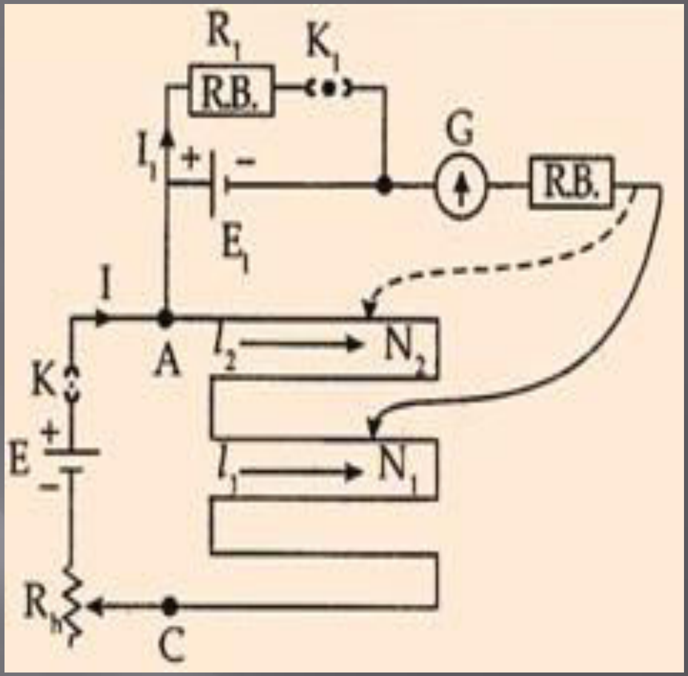
From equations (1) and (2)

$E_1 / E_2 = \ell_1 / \ell_2$

3.To determine internal resistance of a cell

A cell of e.m.f. E_1 and internal resistance

r1 is connected with potentiometer. The known resistance$R$1 from resistance box along with plug key K_1 is connected across a cell of emf E1. Initially plug key K is closed and K1 is kept open.



Now momentarily touch the jockey at different points and select a point N_1 at which galvanometer shows null deflection. Let $AN_1 = \ell_1$ be the balancing length for a cell of emf E_1. Hence by the principle of potentiometer, we have

$E_1 = \phi\ell_1$ ....(i)

Now close both the plug keys K and K_1 Take a suitable resistance R1 from resistance box. A cell of e.m.f. E_1 supplies current I_1 through R_1. Therefore, potential difference across R_1 is given by-

$V_1 = I_1R_1$ ....(ii)

This potential difference is balanced by balancing length $AN_2 = \ell_2$ which is determined by touching the jockey at different points and selecting point N_2 at which galvanometer shows null deflection. Hence by the principle of potentiometer, we have

$V_1 = \phi\ell_2$ ………….(iii)

Dividing equation (i) by (iii), we have,

$$\frac{E_1}{V_1} = \frac{l_1}{l_2} \qquad \text{..... (iv)}$$

The current supplied by a cell of e.m.f. E_1 is given by

$$I_1 = \frac{E_1}{R_1 + r_1} \qquad \text{..... (v)}$$

From equation (ii), we have,

$$I_1 = \frac{V_1}{R_1} \qquad \text{..... (vi)}$$

From equation (v) and (vi), we have,

$$\frac{E_1}{R_1 + r_1} = \frac{V_1}{R_1}$$

$$\frac{E_1}{V_1} = \frac{R_1 + r_1}{R_1} \qquad \text{..... (vii)}$$

From equation (vi) and (vii), we have,

$$\frac{R_1 + r_1}{R_1} = \frac{l_1}{l_2}$$

$$\therefore \qquad r_1 = R_1\left(\frac{l_1}{l_2} - 1\right) \qquad \text{..... (viii)}$$

Precautions

1. The +ve or -ve terminal of driving cell is connected to that terminal of potentiometer at which +ve or -ve terminal of the cell of unknown e.m.f. is connected.

2. The emf of driving cell is greater than the unknown emf's of other cells connected in the potentiometer circuit.

3. The wire of potentiometer should be of uniform cross sectional area.
4. The resistance of potentiometer wire should be large.

Advantages of potentiometer over voltmeter

1. Potentiometer is used to measure e.m.f. of a cell while voltmeter is used to measure terminal P.O. of a cell.
2. By increasing length of potentiometer potential drop can be made as small as possible therefore it is used to measure very small P.O.
3. Potentiometer is more accurate than voltmeter.
4. Potentiometer is used for the calibration of readings of ammeter and voltmeter. But voltmeter can't be used for the calibration purpose.

Disadvantages of potentiometer over voltmeter

1. Potentiometer is not portable but voltmeter is portable.
2. Potentiometer does not give direct readings but voltmeter gives direct readings.

Instrument Transformers

Instrument Transformers

What is an Instrument Transformer ?:

- It is a transformer that is used in conjunction with any measuring instrument (i.e., Ammeter, Voltmeter, Wattmeter, Watt-hour-meter, …etc.)or protective equipment (i.e., Relays).

- It utilizes the current-transformation and voltage transformation properties to measure high ac current and voltage.

Instrument Transformers

Types of instrument transformers :

These instrument transformers are of two types:-

1. Current transformers
2. Potential transformers

Instrument Transformers

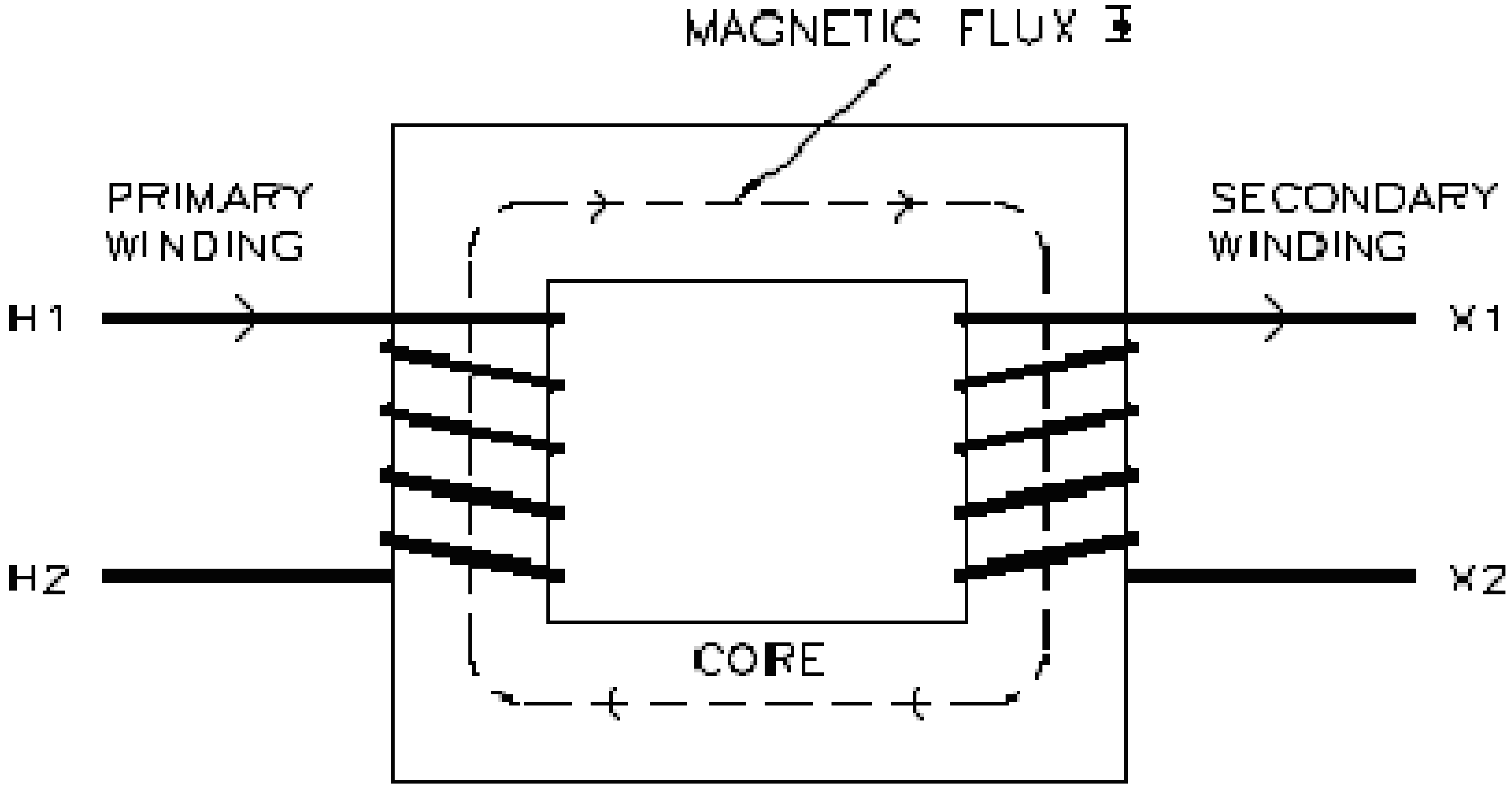
Applications of Instrument Transformers:

- For measurement of high ac current, it is usual to use low range ac ammeter with suitable shunt.
- For measurement of high ac voltage, low range ac voltmeters are used with high resistances connected in series.
- For measurement of very high ac current and voltage, we cannot use these methods. Instead, we use specially constructed HV instrument transformers to insulate the high voltage circuit from the measuring circuit in order to protect the measuring instruments from burning.

Instrument Transformers

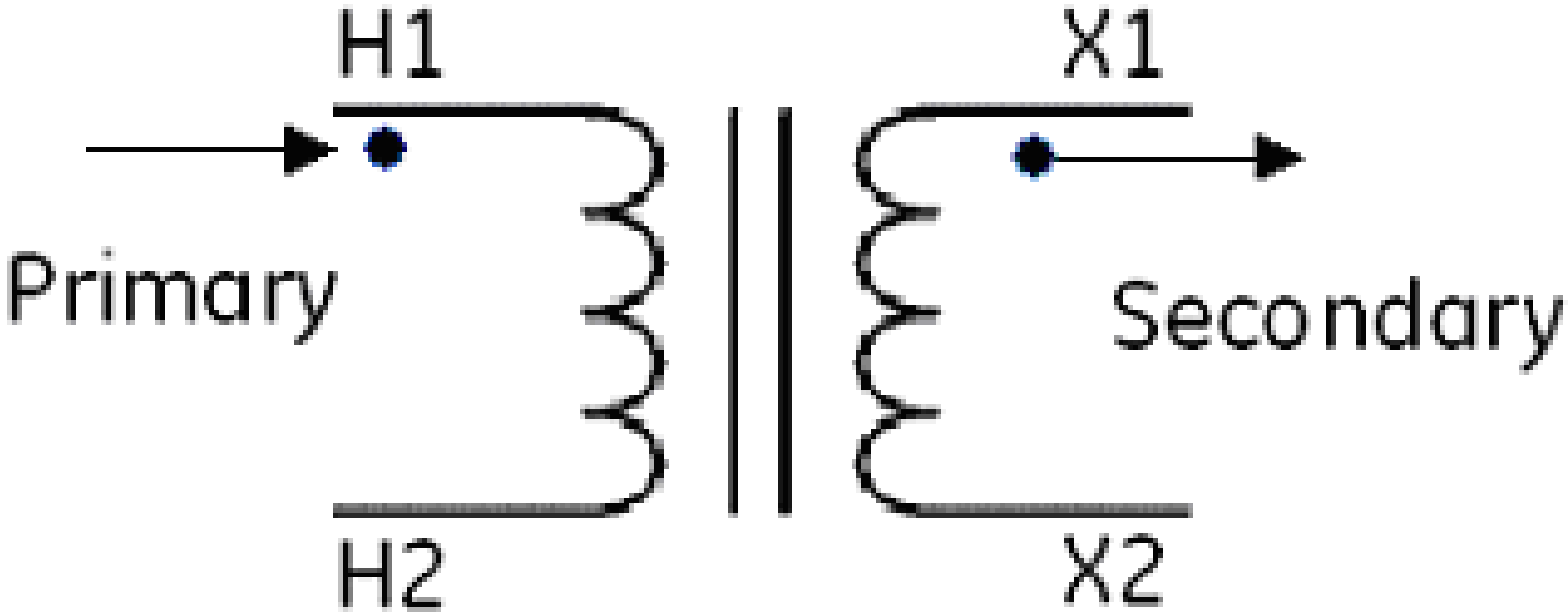
- Application of Instrumentation Transformers In dc circuits for current and voltage measurement, we use low range dc ammeters and voltmeters with rectifiers connected in their secondary circuits.
- The vast primary application of Instrument Transformers is for the protection and control of power system and power equipment of high and very high ratings.
- The working of these instrument transformers are similar to those of the ordinary transformers.

Instrument Transformers



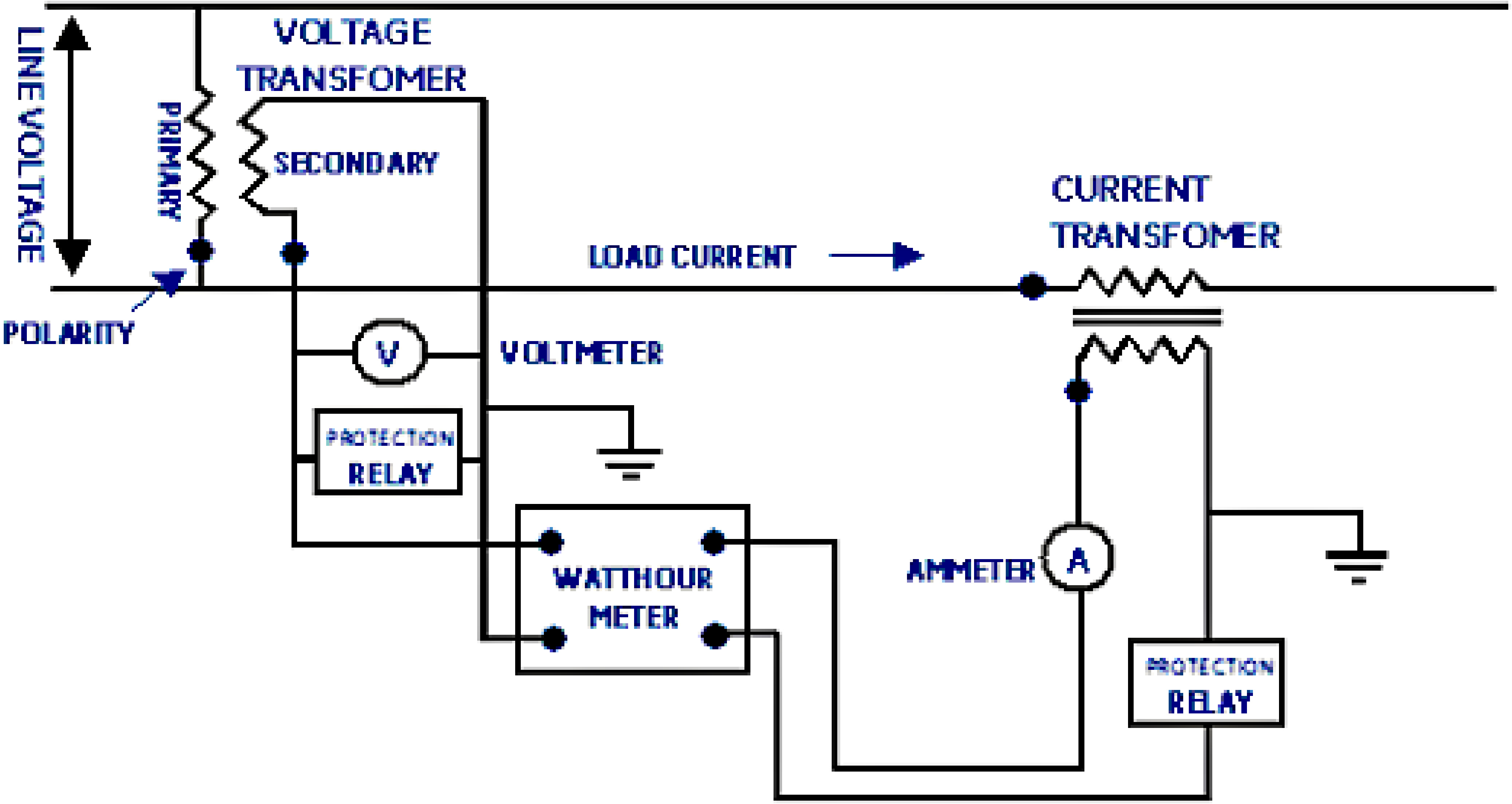
Basic Construction and Magnetic Circuit of Instrument Transformers

Instrument Transformers



Polarity of Instrument Transformers

Instrument Transformers



Common connections of instrument transformers

Current Transformers

What is current Transformer (CT)?:

- A current transformer is a transformer, which produces in its secondary winding low current, which is proportional to the high current flowing in its primary winding.
- The secondary current is usually much smaller in magnitude than the primary current.
- The design of CT depends on which type of instrument is connected to its secondary winding. **Measuring instrument** OR **Protective instrument**.

  -**Measuring instrument CT** is expected to give accurate results up to a maximum of 125% of its normal full-load rated current.

  -**Protective instrument CT** is expected to be accurate for up to 20 times of its normal full-load rated current (about 2000% of its full-load rated current!!..??).

- Based on the type of equipment for which the Ct is used for, its saturation point will vary. At the same time it is expected to be linear in the entire working range.

Current Transformers

Construction of C.T.:

- C.T. has a primary coil of one or more turns made of thick wire connected in series with the line whose current is to be measured.
- The secondary consists of a large number of turns made of fine wire and is connected across an ammeter or a relay’s terminals.

Construction Types of Current Transformers

Window-type

Bar-type

Current Transformers

Function of CT:

- The principal function of a CT is to produce a proportional current at a level of magnitude, which is suitable for the operation of low-range measuring or protective devices such as indicating or recording instruments and relays.
- The primary and secondary currents are expressed as a ratio such as 100/5 or 1000/5 .
- With a 100/5 ratio CT, 100A flowing in the primary winding will result in 5A flowing in the secondary winding, provided that the correct rated burden is connected to the secondary winding.

Current Transformers

“Class” of a CT:

- The extent to which the actual secondary current magnitude differs from the calculated value, expected by the virtue of the CT ratio, is defined as the accuracy “Class” of the CT.
- The greater the number used to define the class, the greater the permissible “current error” [the deviation in the actual secondary current from the calculated value].

Current Transformers

Specifications of CT:

CTs should be specified as follow:

RATIO : Input / output current ratio

VA: Total burden (rating) including pilot wires.

Common burden ratings are 2.5, 5, 10, 15 and 30 VA. For example:

- Moving iron ammeter is 1-2 VA
- Moving coil rectifier ammeter is 1-2.5 VA
- Electro-dynamic instrument is 2.5-5 VA
- Maximum demand ammeter is 3-6 VA
- Recording ammeter or transducer is 1-2.5 VA

Current Transformers

CLASS : The accuracy required for the operation

DIMENSIONS: Maximum & minimum limits. For example:

- 0.1 or 0.2 for precision measurements.
- 0.5 for high grade kilowatt hour meters and commercial grade kilowatt hour meters.
- 3 for general industrial measurements.
- 3 or 5 for approximate measurements.

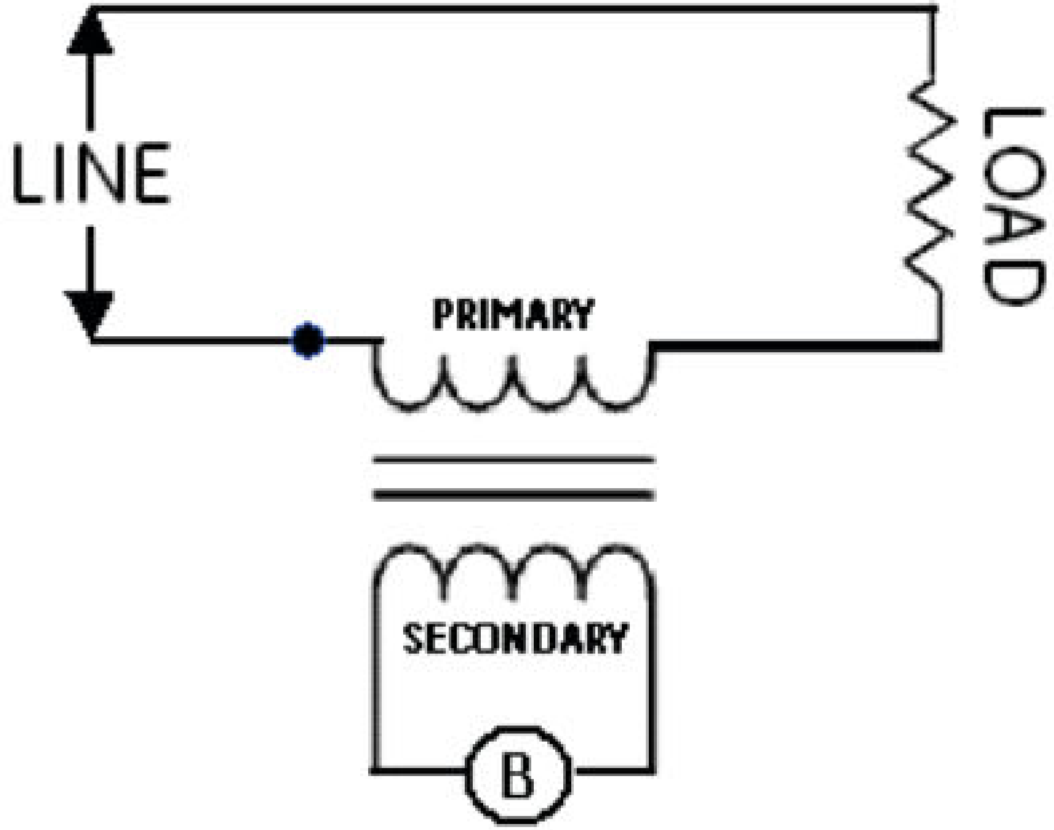
BURDEN (OHMIC): (Depending on pilot lead length)

Current Transformers

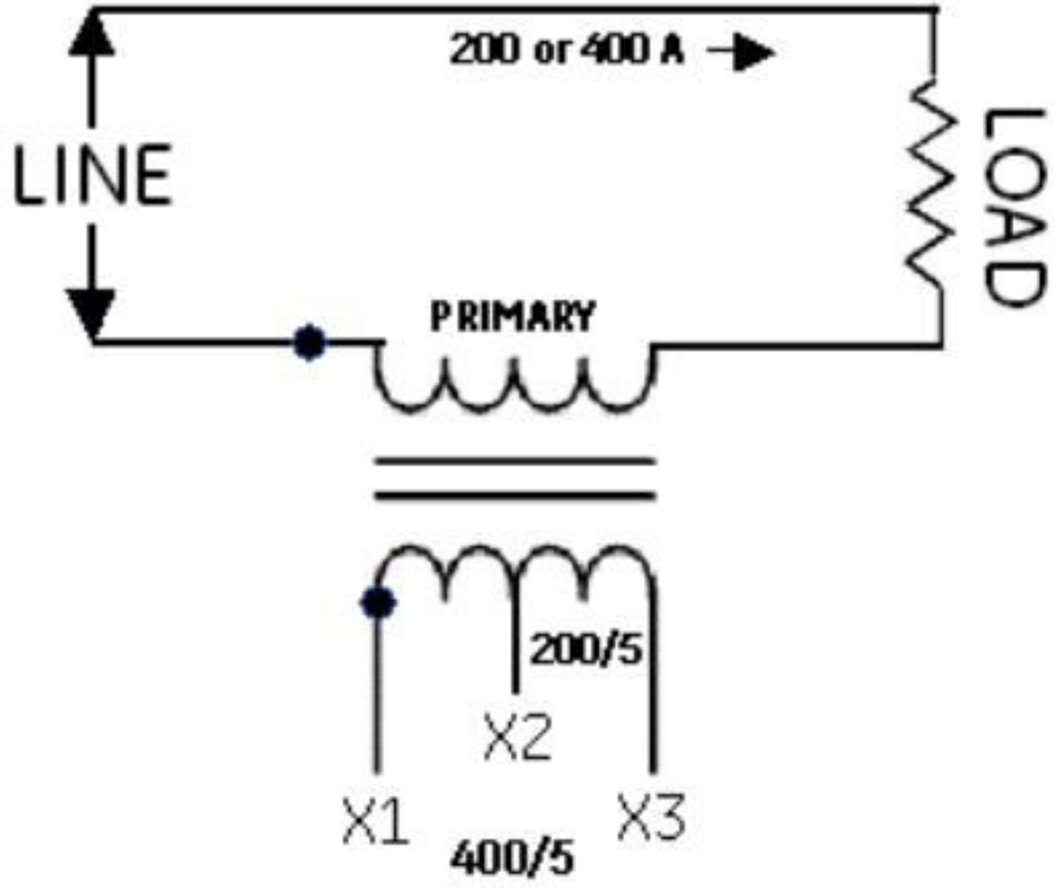
Current Transformers Stepping:

- These are used with low range ammeters to measure current in high voltage alternating circuits where it is not practical to connect instrument and meters directly to lines.
- They are step-up transformers (**voltage ratio**) because when we step-up the voltage the current decreases.
- The current is a step-down in a known ratio called the **current ratio** .

Connections of Current Transformers



Single-Ratio CT



Multi-Ratio CT

Multi-ratio CT:

- As indicated in the previous Figure, current transformers having a center tapped secondary are referred to as a dual ratio CT.
- Dual ratio CT are used in applications where it is necessary to have available two ratios of primary to secondary current from the same secondary winding of the CT.
- This may be accomplished by adding a tap in the secondary winding to get a second ratio.
- The ratio obtained by the tap is usually one-half the ratio obtained by the full secondary winding.
- A schematic example is previously shown with 200 amperes flowing in the primary, a connection X2 – X3 will produce 5 amperes out of the secondary. As the load grows to 400 amperes, the secondary circuit will be reconnected to X1 – X3 to still produce 5 amperes in the secondary circuit.

Current Transformers

Working (Measurement):

- If a current transformer has primary to secondary current ratio of 100:5 then it steps up the voltage 20 times and step down the current 1/20 times of its actual value.
- If we know the current ratio and the reading of an a.c. ammeter, the primary current can be calculated as:

$$\text{Primary Current} = \text{CT ratio} \times \text{ammeter reading}$$

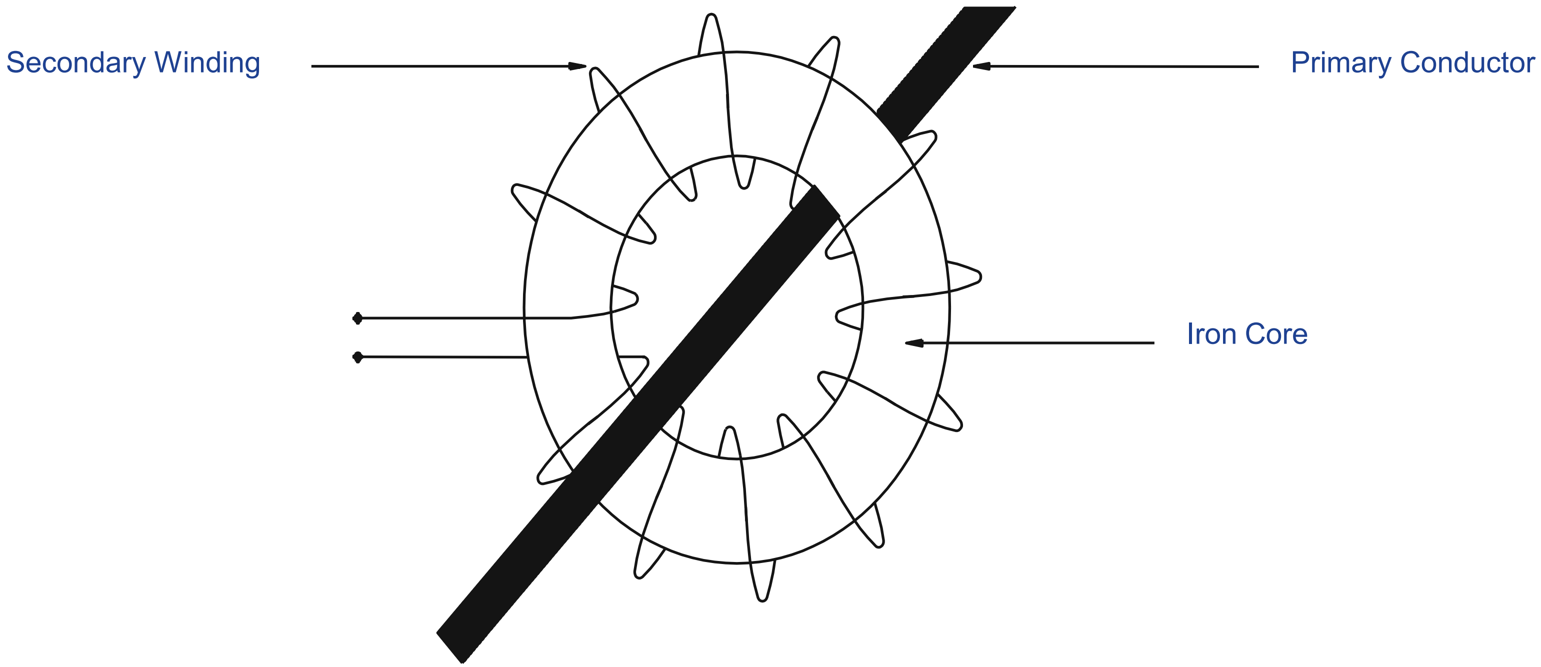
Current Transformers

Why CT secondary should never be open ?:

- Ammeter resistance is very low ,the current transformer normally works as a short-circuited instrument.
- If for any reason the ammeter is taken out of secondary winding then the secondary winding must be short-circuited with the help of a short-circuit switch.
- If this is not done, then a high m.m.f. (Ampere-turns IT) will set up a high flux in the magnetic core and it will produce excessive core loss which produce heat and high voltage across the secondary terminals .
- The high voltage can damage any electronic components in secondary side.
- Hence the secondary of any current transformer should never be left open.

Construction of the DOUGHNUT Type **C.T.** :

The most common type of C.T. construction is the **"DOUGHNUT"** type. It is constructed of an iron toroid, which forms the core of the transformer, and is wound with many secondary turns.



- The `doughnut' fits over the primary conductor, which constitutes one primary turn. If the toroid is wound with 240 secondary turns, then the ratio of the C.T. is 240 : 1 or 1200 : 5A
- The continuous rating of the secondary winding is normally 5 AMPS in North America, and 1 AMP or 0.5 AMP in many other parts of the world.
- This type of `doughnut' C.T. is most commonly used in circuit breakers and power transformers. The C.T. fits into the bushing, and the porcelain bushing fits through the centre of the `doughnut'.
- Up to four C.T.'s of this type can be installed around each bushing of an oil circuit breaker. This arrangement is shown in a following diagram.

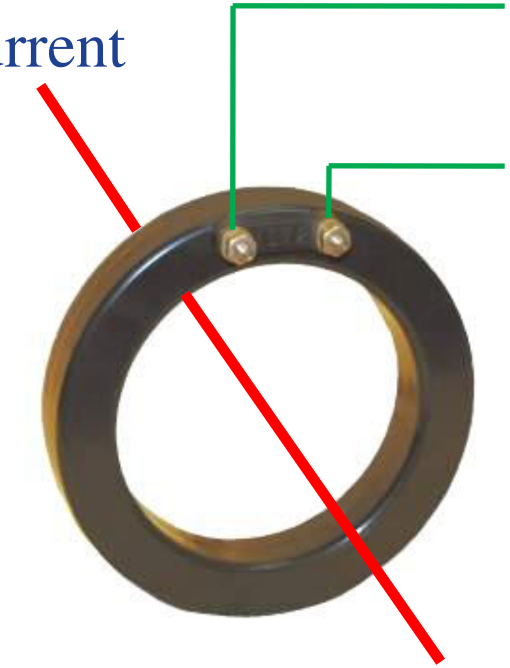
Substation Class Circuit Breakers' CTs

Polyester Taped Bushing CT on Outdoor Circuit Breaker

CT Turns-ratio (TR)

$$\text{Transformer Ratio} = \frac{\text{Primary Current}}{\text{Secondary Current}}$$

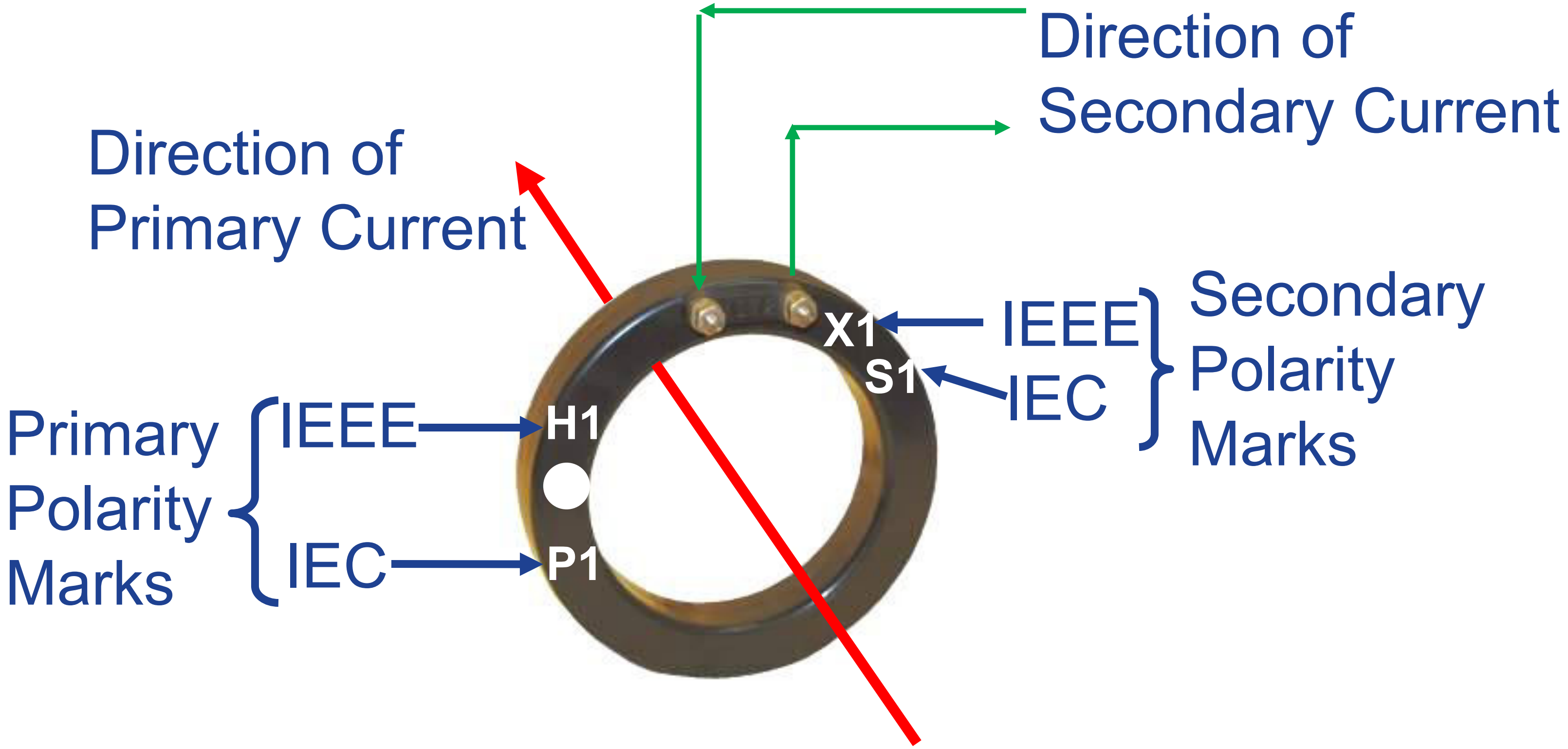
Primary Current
(100 amps)



Secondary Current
(5 amps)

$$\frac{100}{5} = 100{:}5 \text{ or } 20{:}1$$

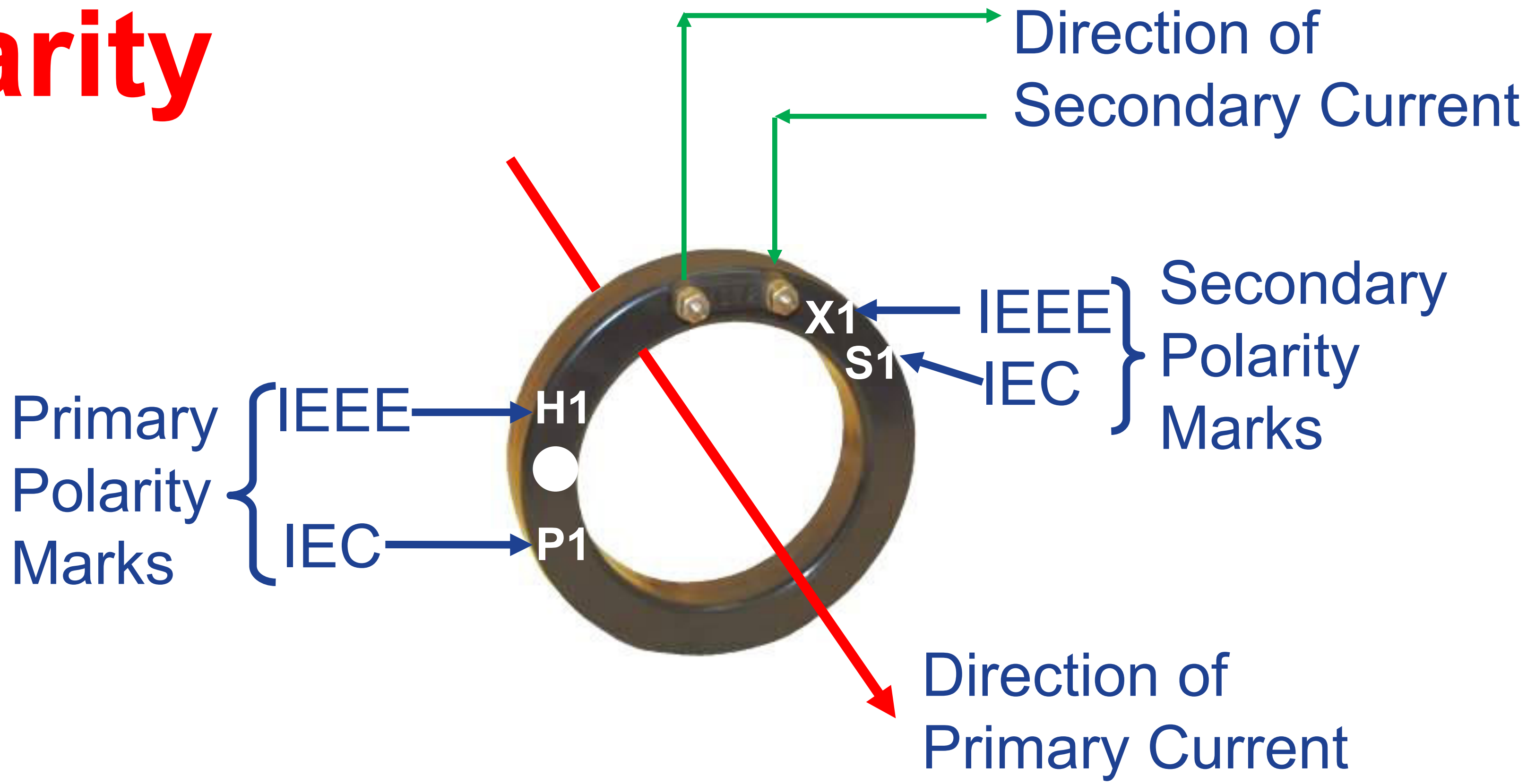
Polarity



Primary current into "polarity" forces

Secondary current out of "polarity"

Polarity



Primary current <u>into</u> “non-polarity” forces

Secondary current <u>out of</u> “non-polarity”

CT <u>Metering</u> Accuracy

Since actual secondary current ≠ **Rated** secondary current

Then:

The difference in % is known as the
“**Accuracy**” or “**Class**”
of the CT

Burden

Load connected to CT secondary

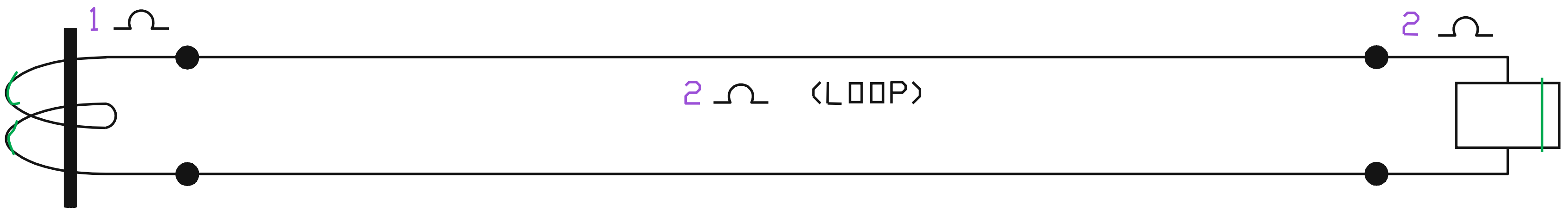
Includes devices & connecting leads

Expressed in ohms

Standard values = B0.1, B0.2, B0.5, B0.9, B1.8

E0.04, E0.2

CT accurate Burden Calculation



$$Z_T = R_{CT} + R_L + Z_B$$

Z_T = Total burden in ohms (vector summation of resistance and inductance components)

R_{CT} = CT secondary resistance in ohms @75 deg C

R_L = Resistance of leads in ohms (Total loop distance)

Z_B = Device impedance in ohms

CT Saturation

Factors Affecting Degree and Time to Saturation

1. High DC offset
2. High fault current Magnitude (symmetrical current)

Example:

- 100 to 5 CT@20 times= 2000 amps.
- Also @20,000 amps we have 200 times CT

3. Low CT Turns Ratios
4. High secondary burden
5. Low CT Accuracy (Class)
6. High reminance flux

- Can occur if current interrupted when core is saturated
- If DC flows in windings during testing
- Need a voltage above 60% of knee point to reduce the Reminance to less than 10% of saturation flux density.

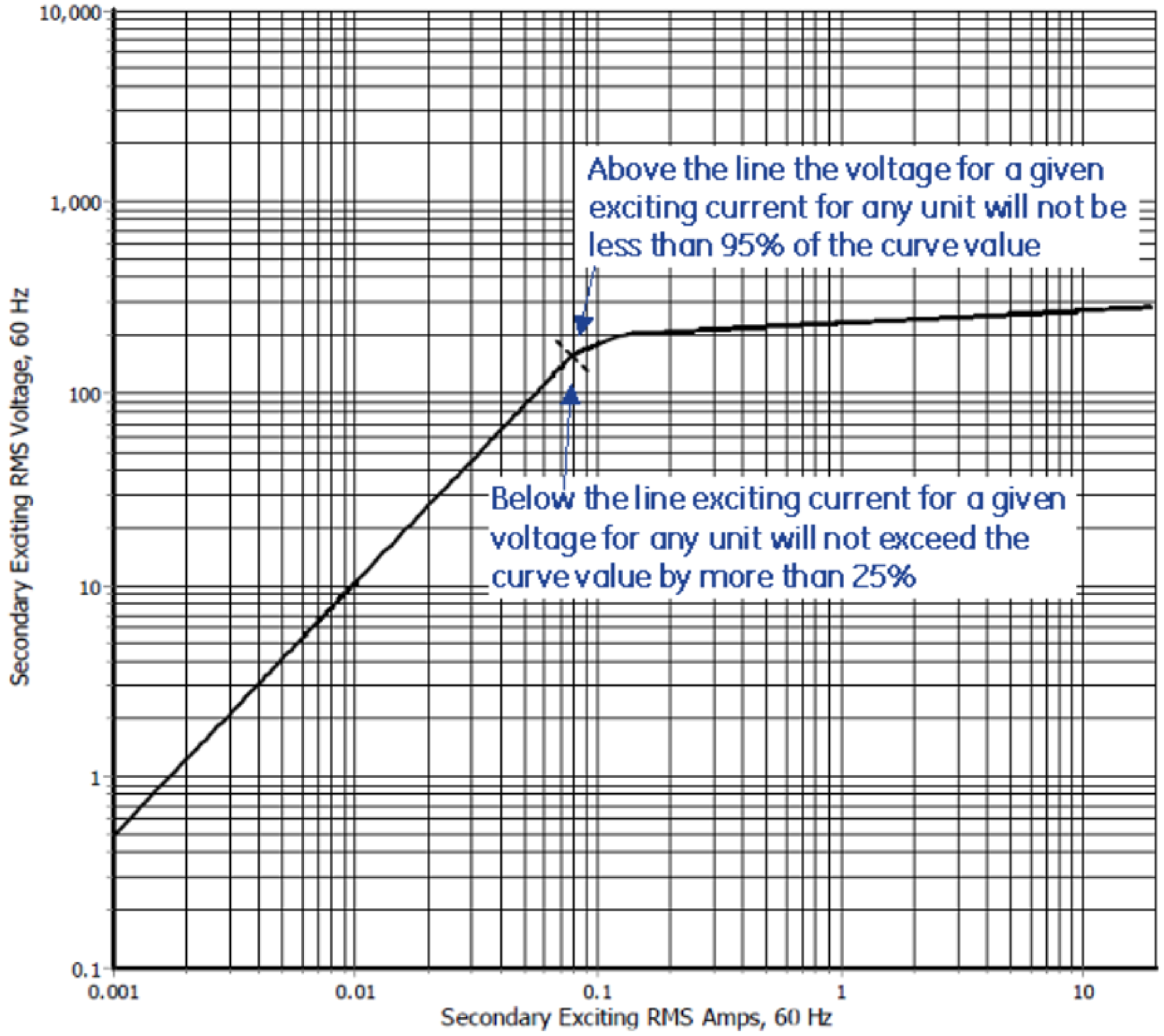
Tips for Avoiding CT Saturation

1. Use higher ratio CTs

2. Use separate set of high ratio CTs for high fault current tripping

3. Reduce secondary burden by:
   - Selecting low burden relays & meters
   - Distributing single phase burdens among phases
   - Increasing the size of secondary leads
   - Reducing the length of secondary leads
   - Using “step down” auxiliary CTs

Avoiding CT Saturation with Linear Operation (Knee limit of the Curve)

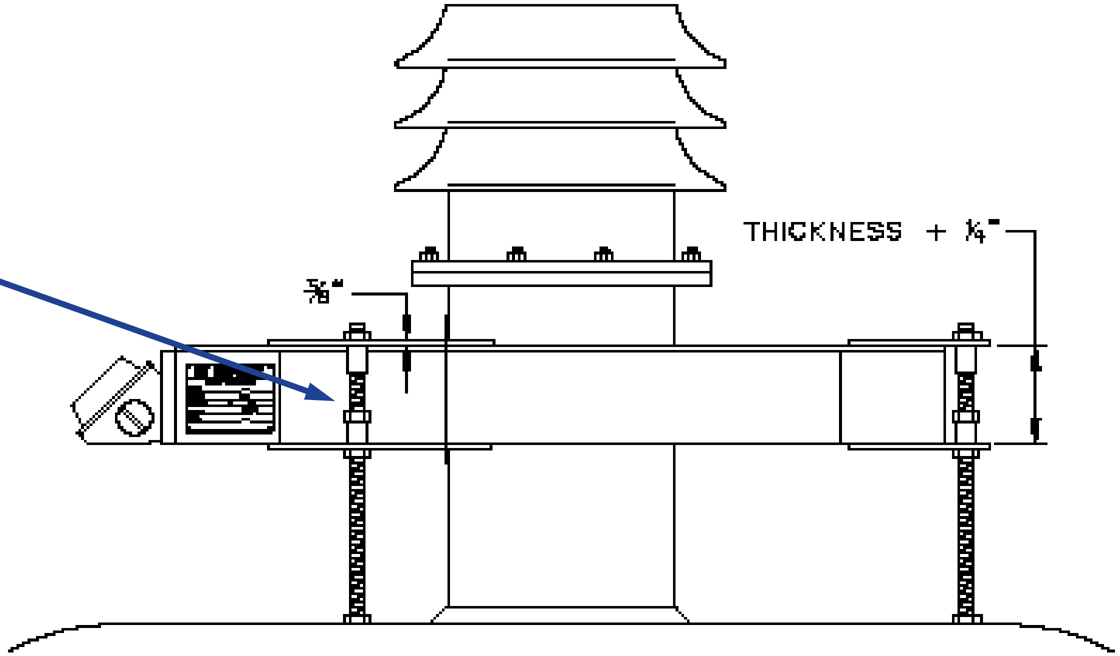


CT Actual Connections

Typical window CT

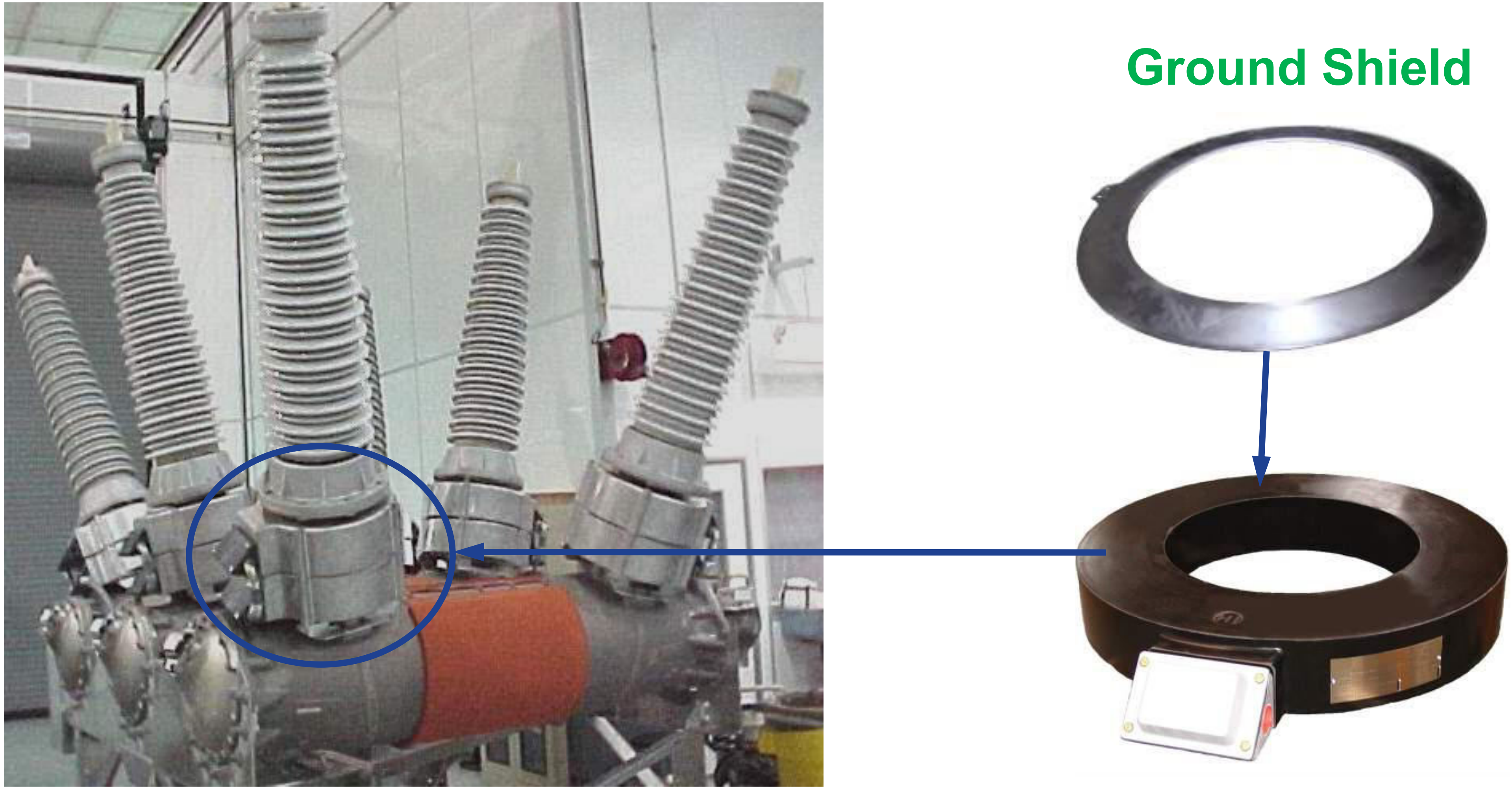
Power Transformers’ CT Connections

Slip over current transformer for installation over exterior of outdoor bushing



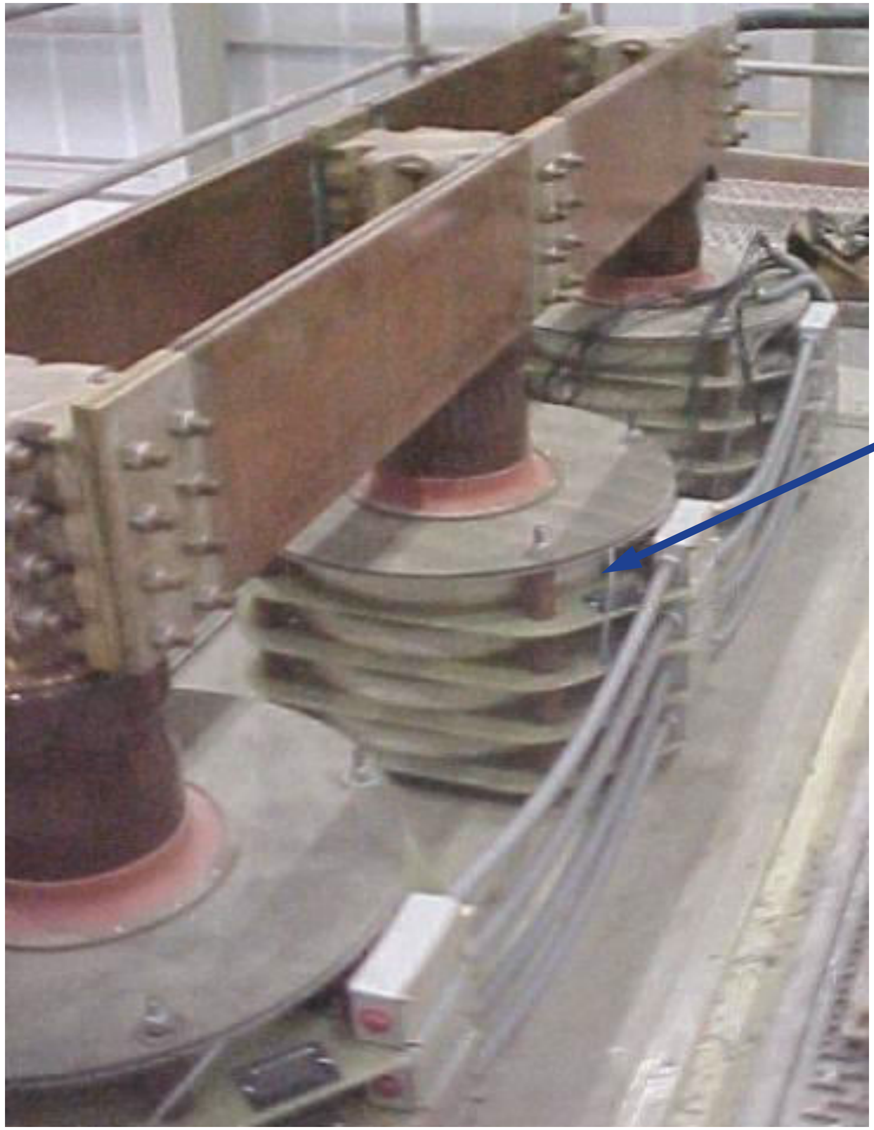
Outdoor Type BO7 for Retrofit

Substation Class Circuit Breakers' CT's



Outdoor BO7 - Replaces BCT's
in shielded aluminum housing

Generators CT Connections



Board Mounted Generator CT

Potential Transformers

What is a Potential Transformer (PT) or (VT)?:

- A PT or sometimes called VT is a step-down transformer having many primary turns but few secondary turns.
- In a step-down transformer the voltage decreases and the current increases, thus voltage can be easily measured by using a low-range voltmeter instrument.
- The voltage is stepped-down in a known ratio called the voltage ratio.

Potential Transformers

Construction and working of P.T.:

Construction

- A potential transformer has many primary winding turns but few number of secondary winding turns that makes it a step-down transformer.
- A Voltmeter is connected to the secondary winding is usually a voltmeter of 150 V.

Working (Measurement):

- Primary terminals are connected in parallel across the line to which the voltage is to be measured.
- The voltmeter reading gives the transformed value of the voltage across the secondary terminals.
- The deflection of the voltmeter when divided by the transformed ratio gives the actual voltage across the primary winding as:

The Line voltage = deflection / transformation-Ratio

Where transformation ratio = V2/V1

Potential Transformers

Precaution for P.T.:

- Since the secondary of a p.t. is connected to relays, their ratings are usually 40 to 100 Watts.

- For safety purpose the secondary should be completely insulated from the high voltage primary and should be in addition grounded.

Potential Transformers

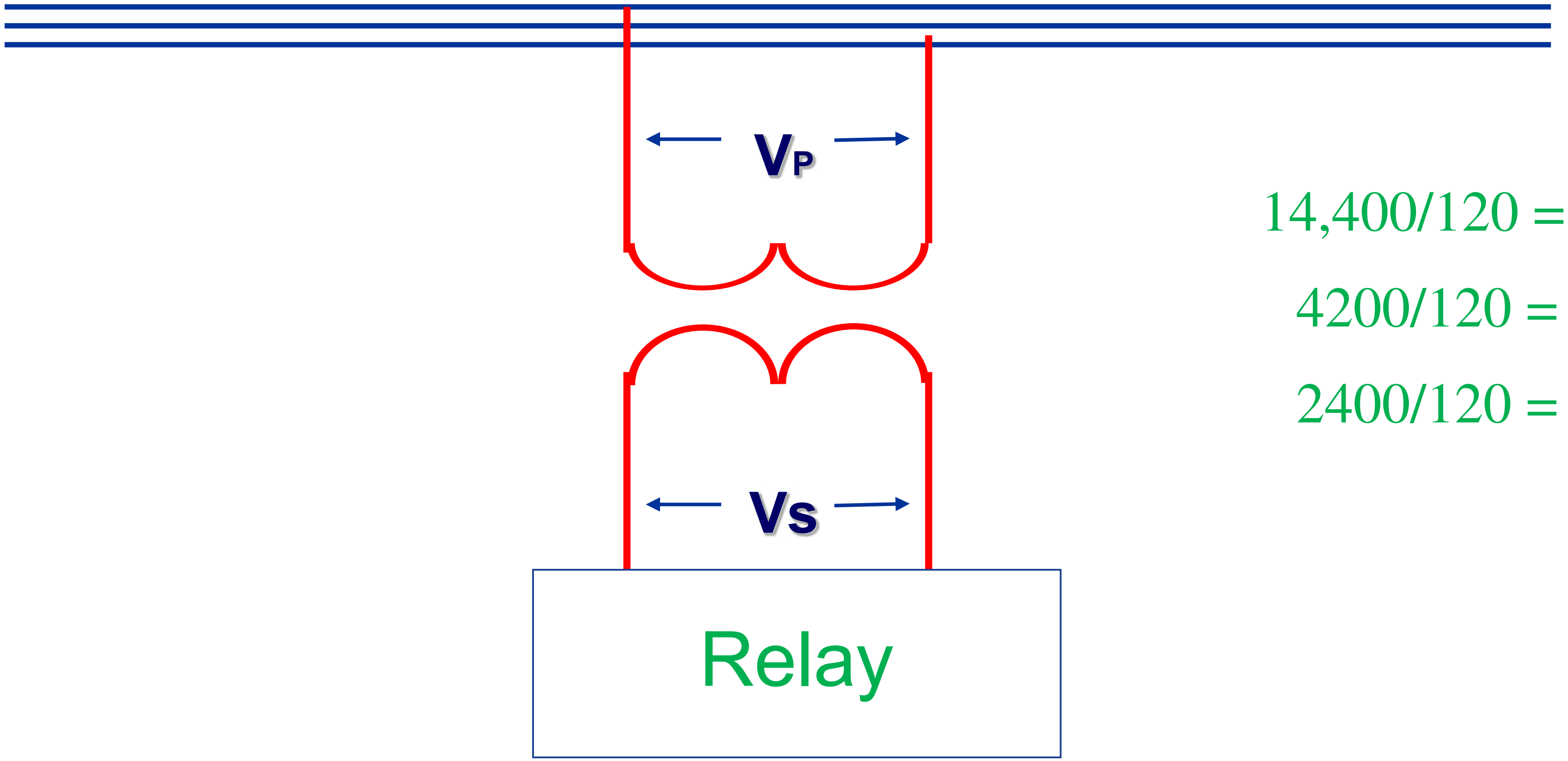
Types of P.T. :

Some types of p.t. are:

- Shell type
- Dry type
- Oil type

Rating	**Type**
1. Below 5000 v	Shell type
2. 5000-13800 v	Dry type and oil type
3. Above 13800 v	only oil type

Potential Transformer Common Ratios

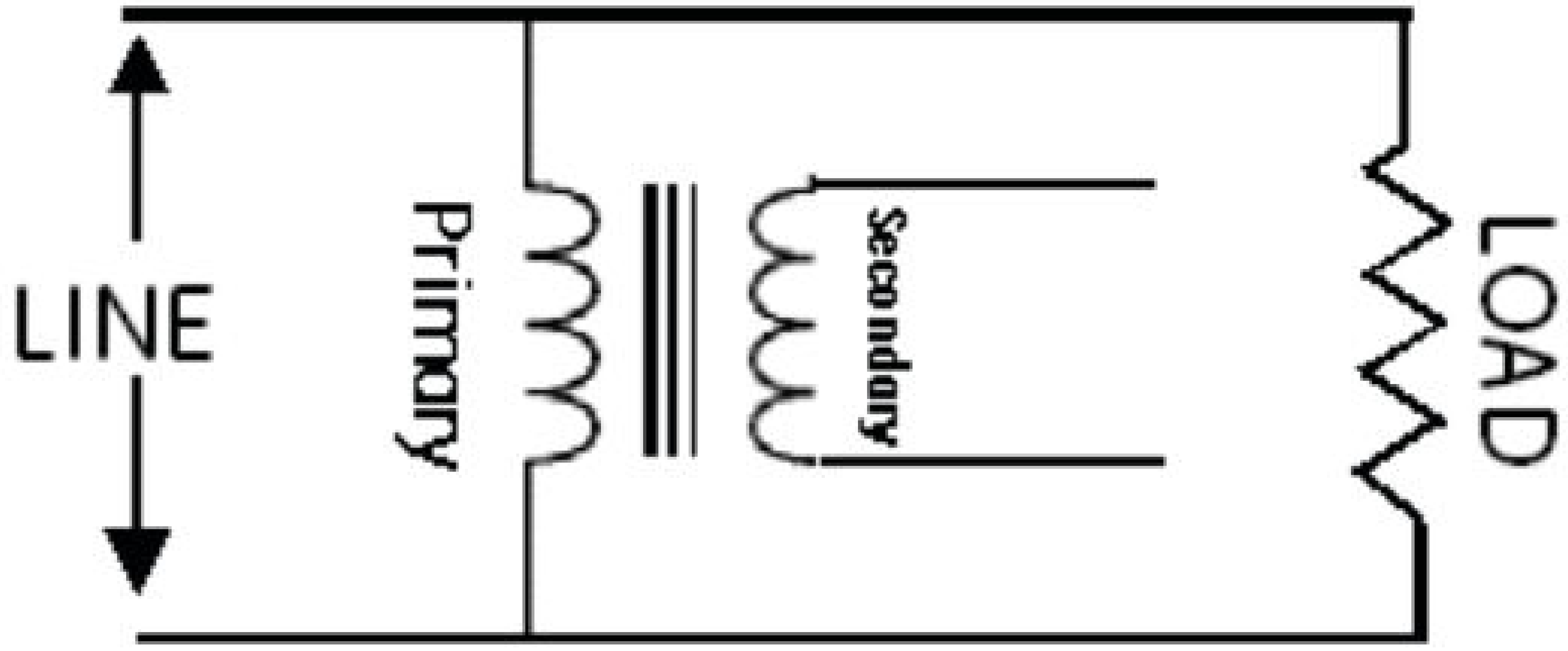


14,400/120 = 120/1

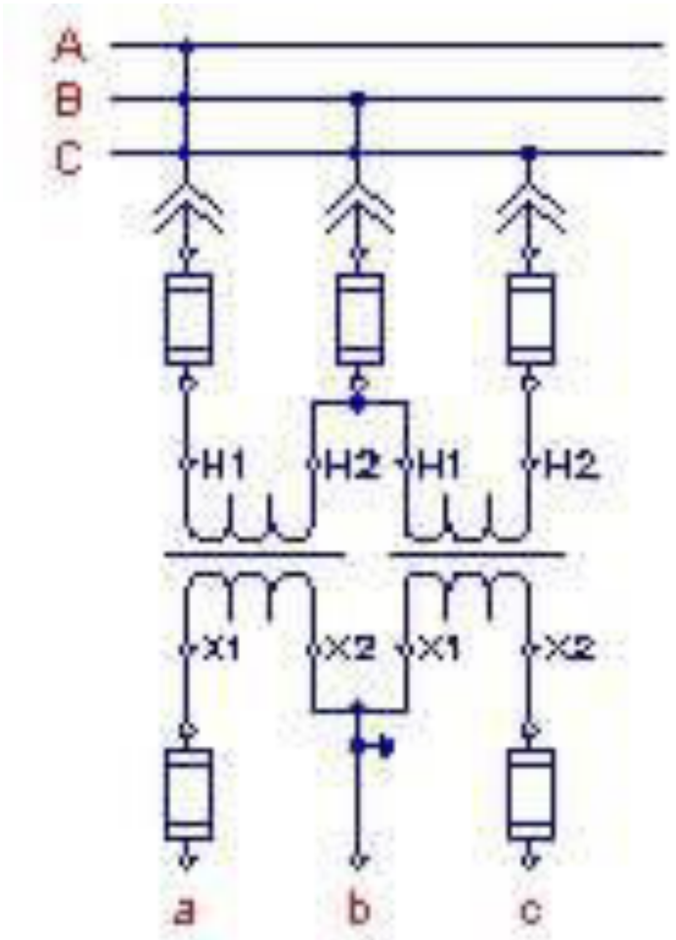
4200/120 = 35/1

2400/120 = 20/1

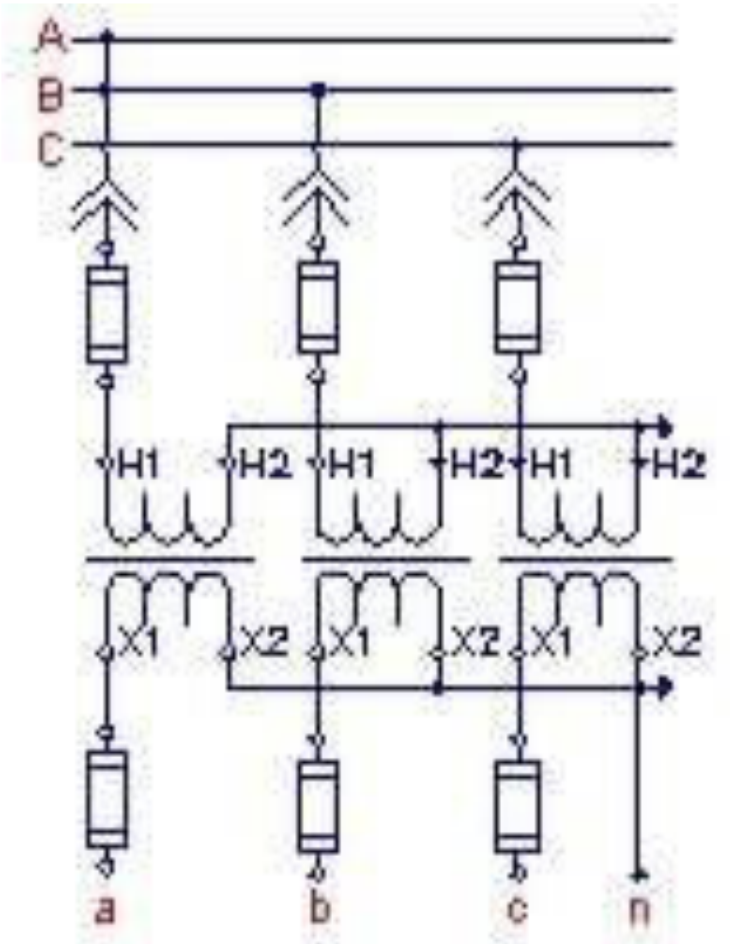
Connections of 1-Phase Potential Transformers



Other PT and 3-Phase Typical Connections

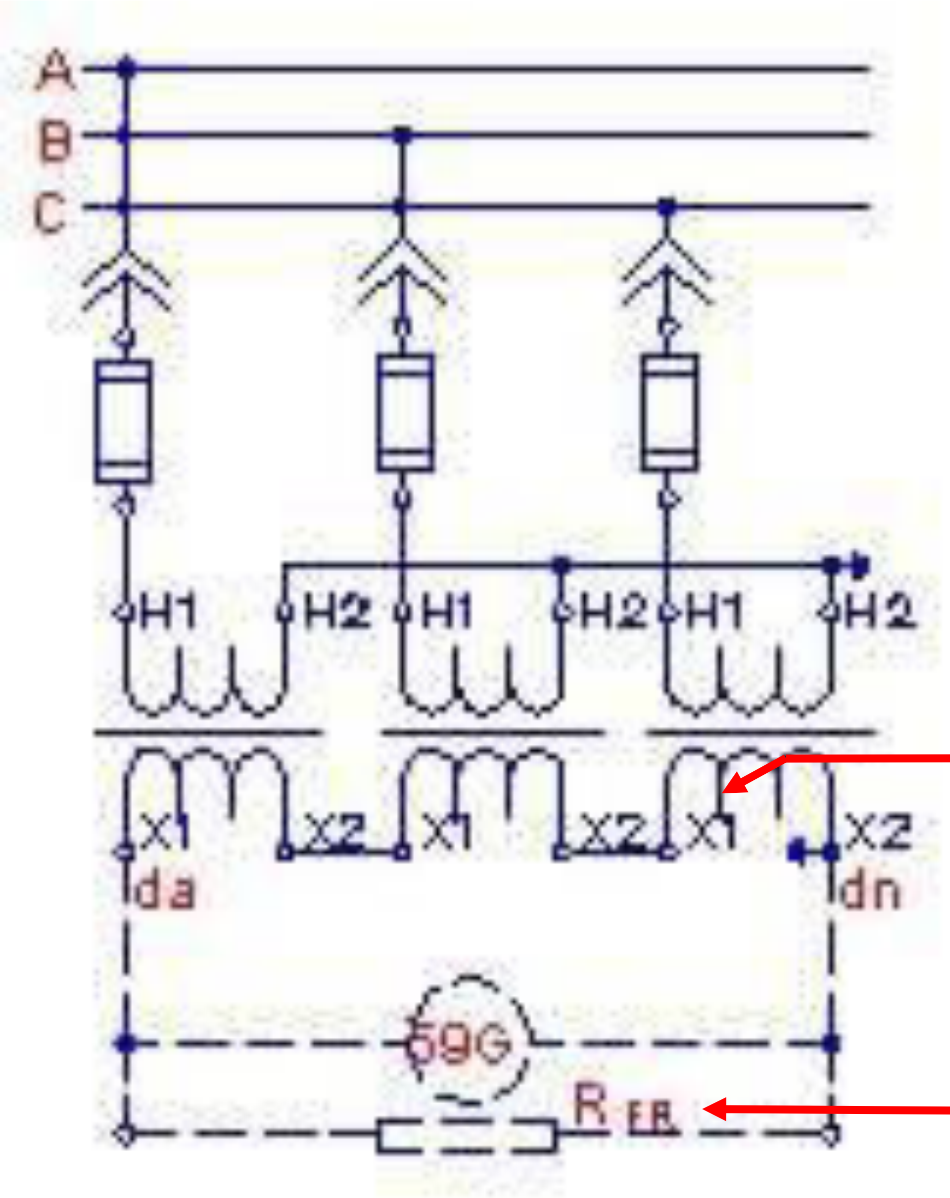


Open Delta Connection
(2) Double Bushing VTs



Y – Y Connection
(3) Single Bushing VTs

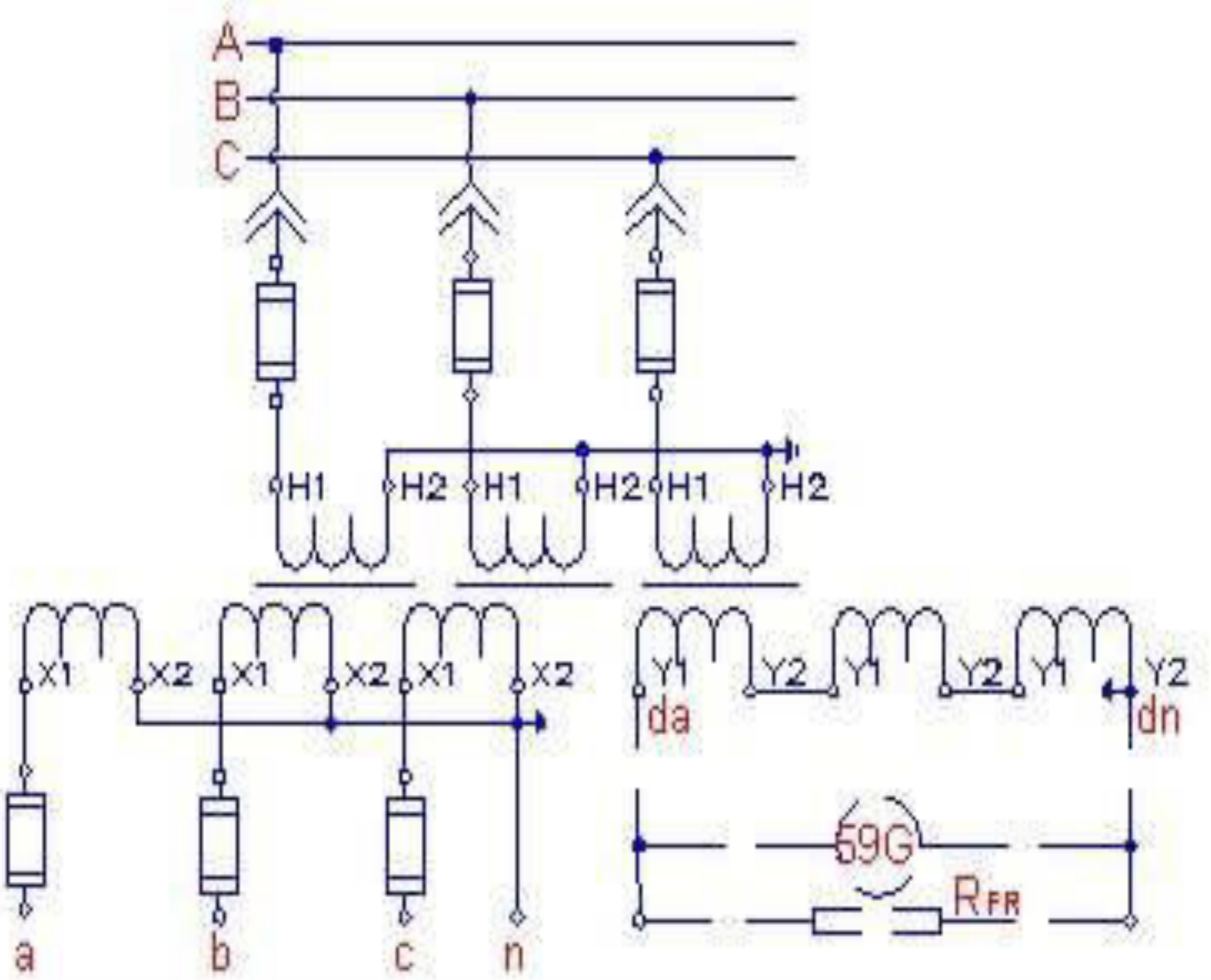
Other PT and 3-Phase Typical Connections



Y – Broken Corner Δ VT Connection

damping resistor R

Other PT and 3-Phase Typical Connections



Y-Y/Broken Corner Δ Connection

Basic important rules for Instrument Transformers

Rule # 1

<u>Never open circuit a current transformer secondary while the primary is energized</u>

CTs are intended to be proportional current devices. Very high voltages can result from open circuiting the secondary circuit of an energized CT. Even very small primary currents can cause damage.

Rule # 2

Never short circuit the secondary of an energized VT

VTs are intended to be used as proportional voltage devices. Damaging current will result from short circuiting the secondary circuit of an energized VT.

Rule # 3

CT secondary leads must be added to the CT burden

Electronic relays usually represent very little burden to the CT secondary circuit. In many cases the major burden is caused by the CT secondary leads.

Rule # 4

Never use a 60 Hz rated VT on a 50 Hz System

60 Hz VTs may saturate at lower frequencies and exceed temperature limitations. VT failure is likely…severe equipment damage is possible.

UNIT – III
MEASUREMENT OF POWER AND ENERGY

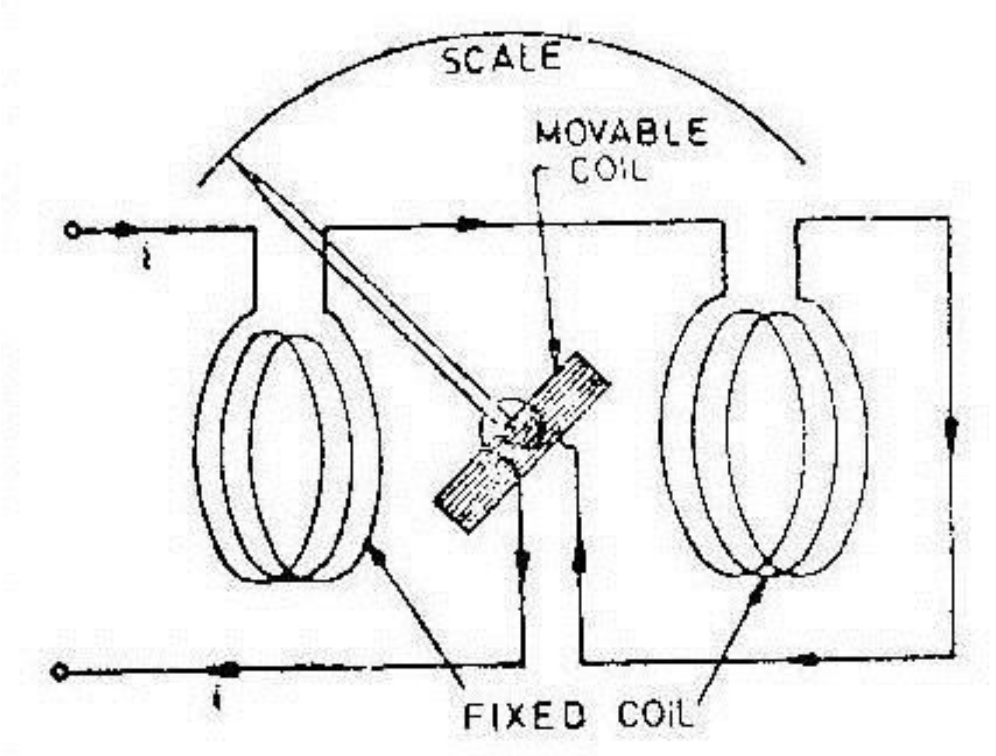
Operating Forces

- Deflecting Force.
- Controlling Force.
- Damping Force.

Supporting the moving element

- Suspension
- Taut Suspension
- Pivot and jewel bearings.

Electrodynamometer Type



Wattmeter

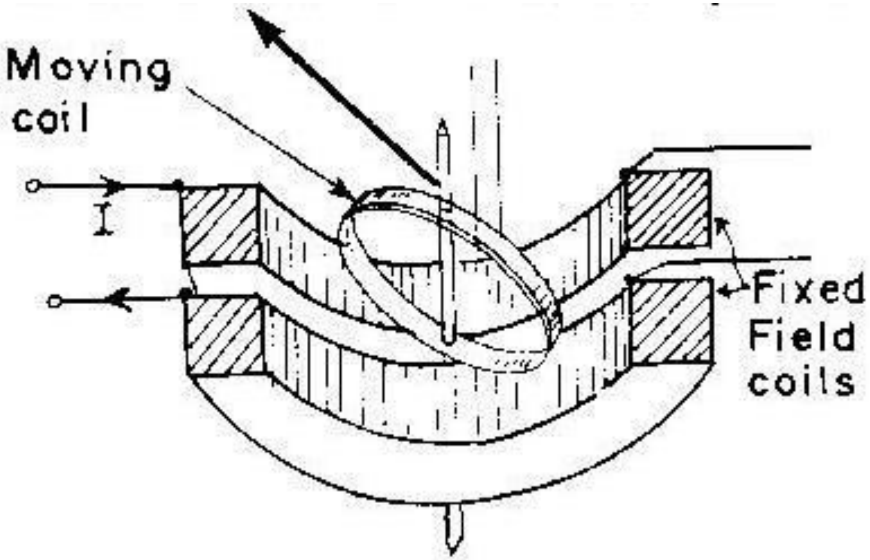


Fig. 11.2. Dynamometer wattmeter.

Power Measurement in 3 phase 3 wire system

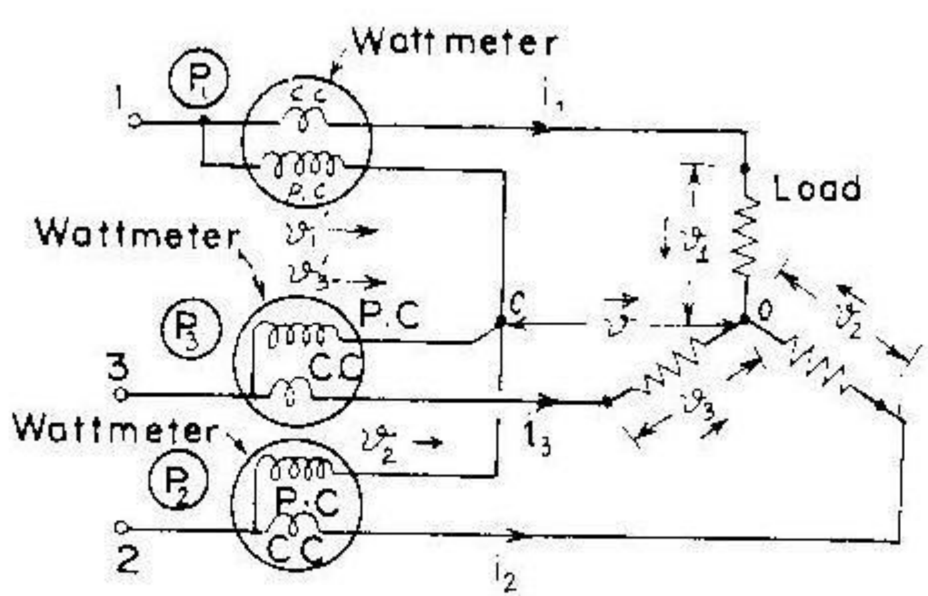


Fig. 11.23. Power measurement in a 3 phase 3 wire system.

Two wattmeter method

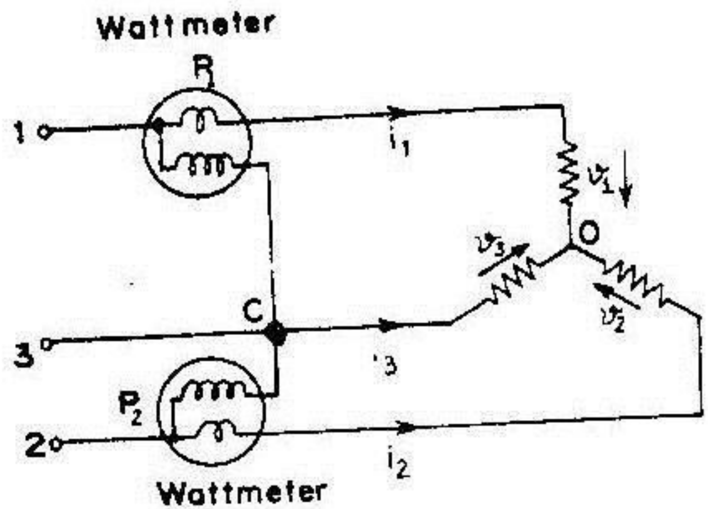


Fig. 11.25. Two wattmeter method (Star connection).

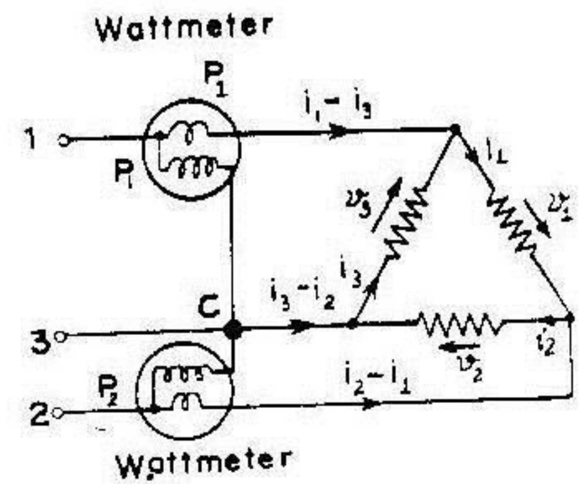
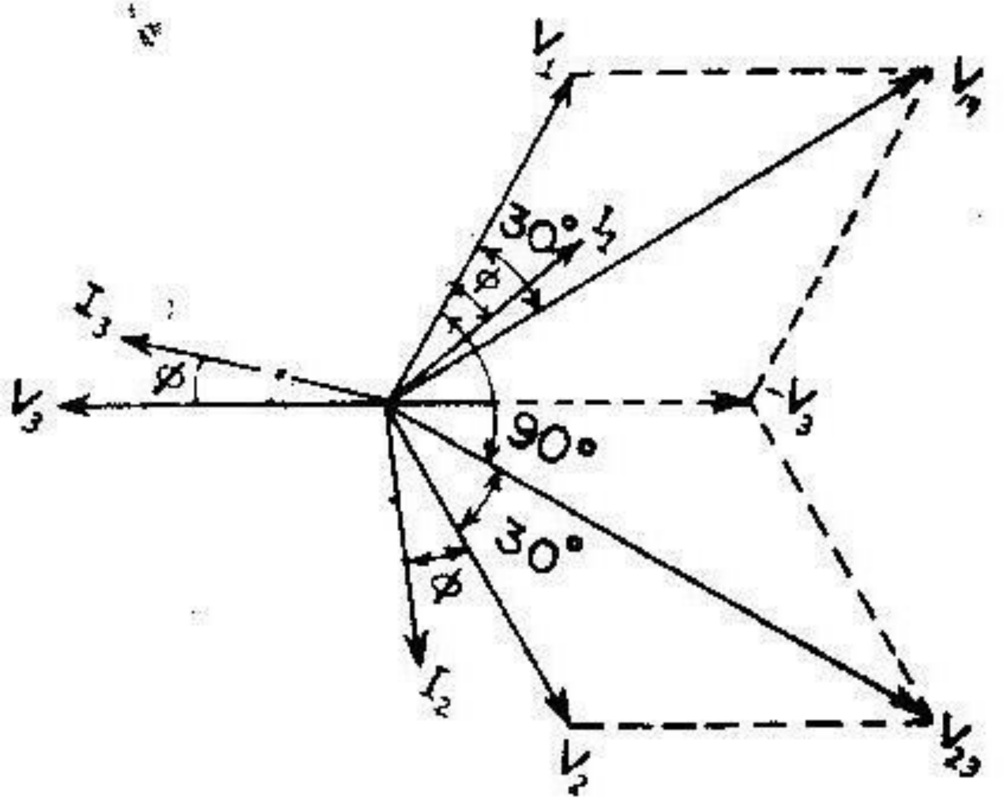
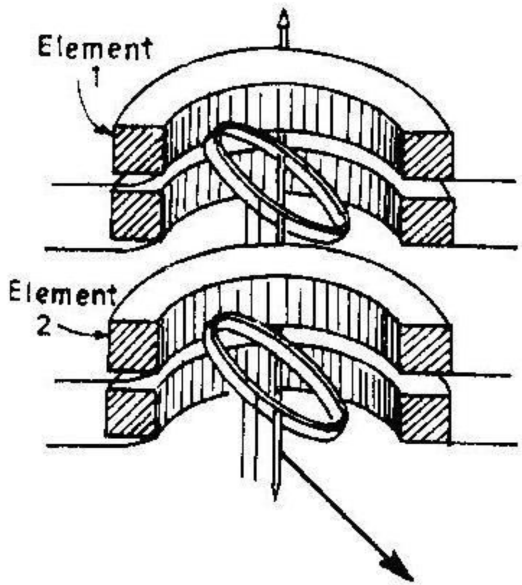


Fig. 11.26. Two wattmeter method (Delta connection)



V_1
V_{12}
30°
I_1
ϕ
I_3
ϕ
V_3
$-V_3$
90°
30°
ϕ
I_2
V_2
V_{23}

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



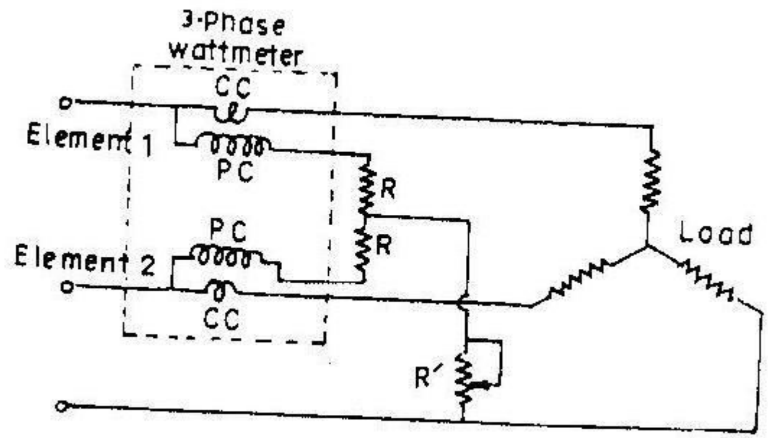


Fig. 11.30. Three phase two element wattmeter. **Fig. 11.31.** Compensation for mutual effects between two elements of a 3 phase wattmeter

Energy meters

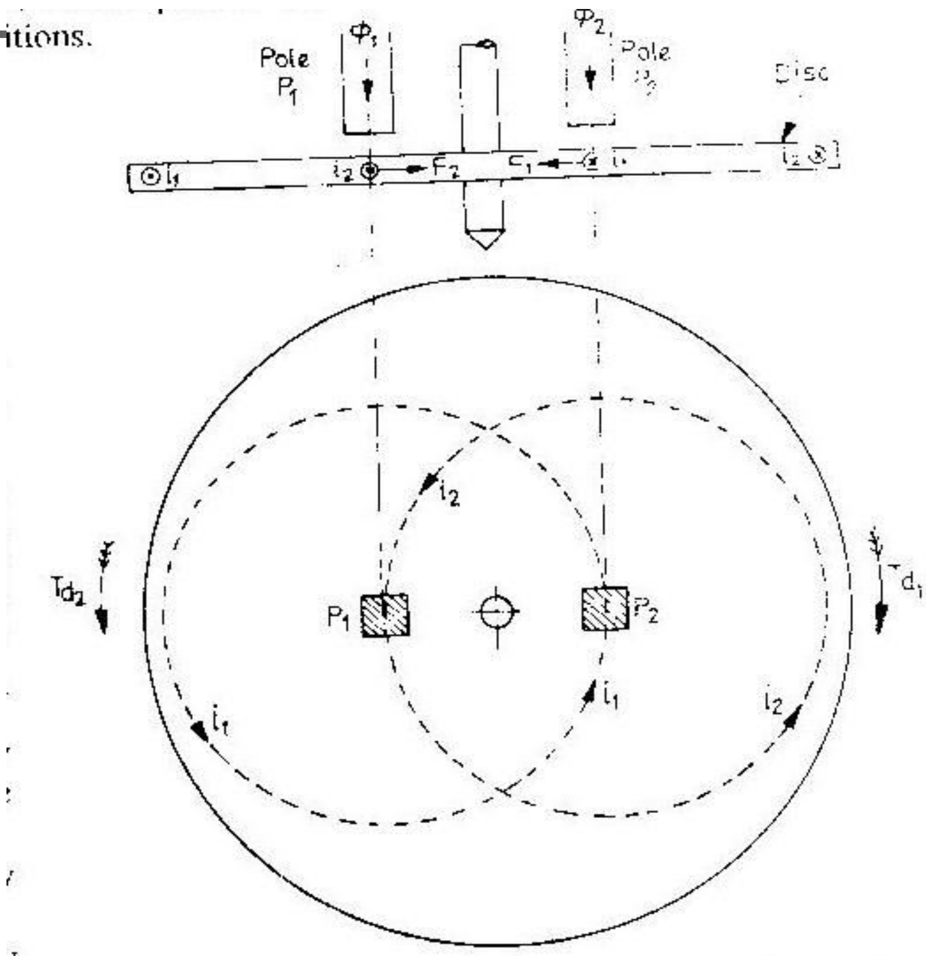


Fig. 12.1. Principle of working of an induction type instrument.

Single Phase Energy Meter

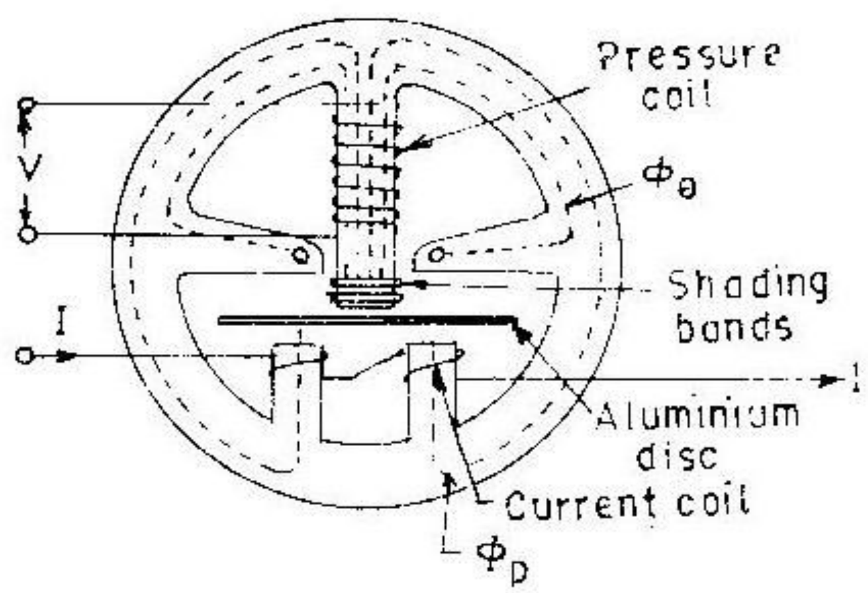


Fig. 12.3 Single phase energy meter.

Poly Phase Energy Meter

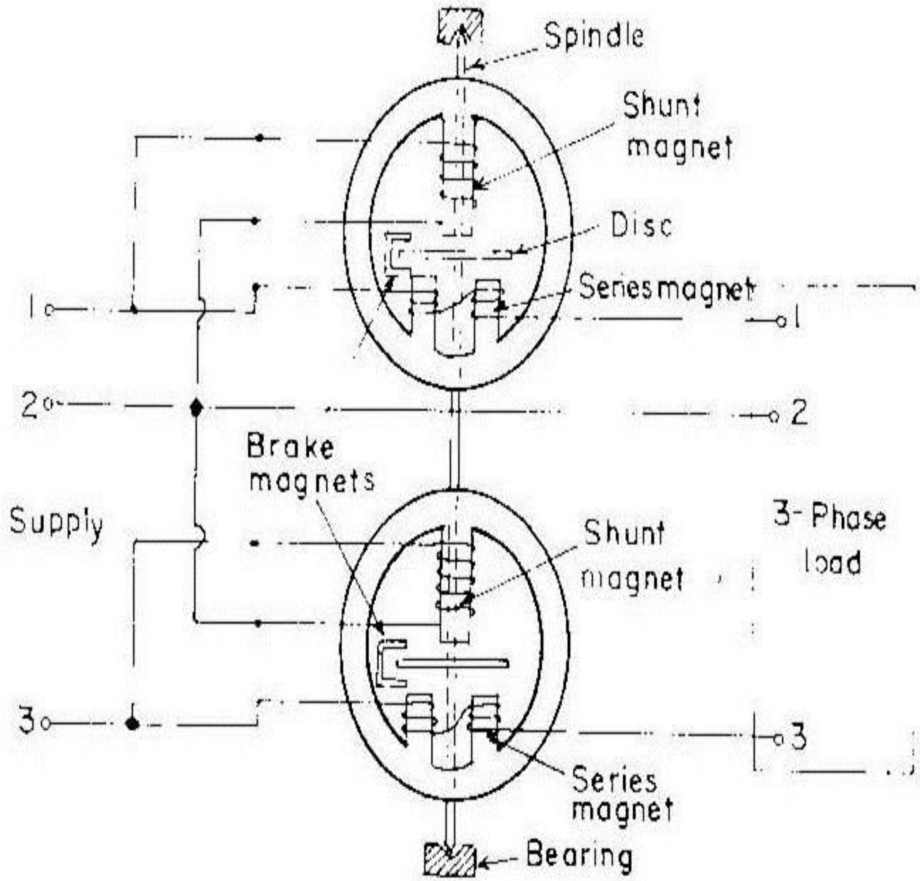
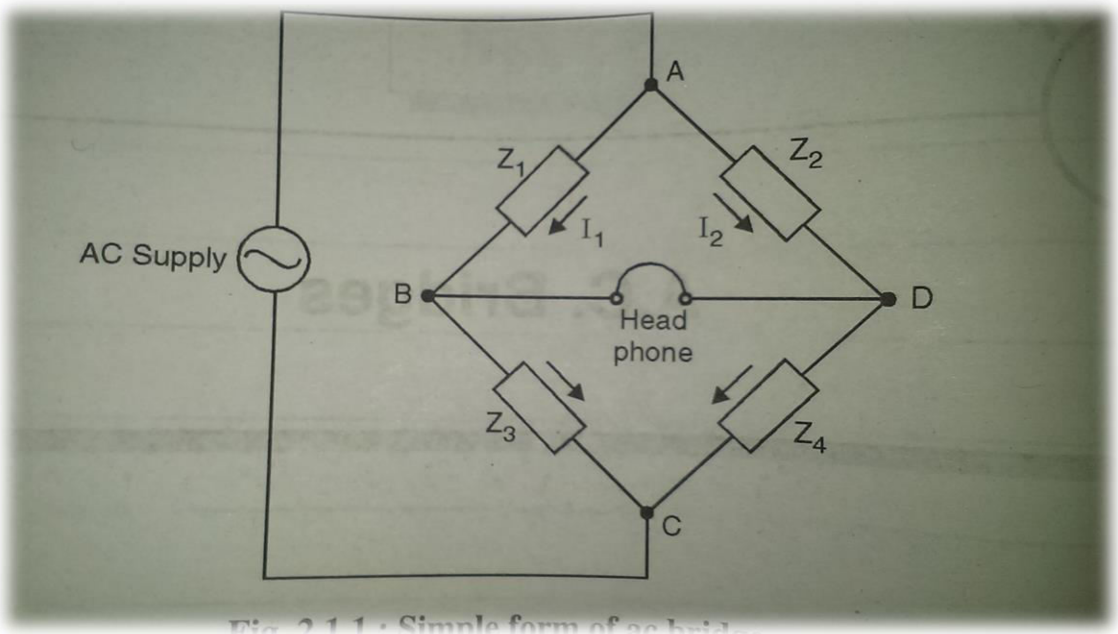


Fig. 12.13. Two element energy meter.

UNIT – IV
DC AND AC BRIDGES

2.1.1 Basic A.C.Bridge :

- As the name indicates ac bridges consists of an ac supply. This provides ac voltage at the required frequency. The null detector is used to give indication of unbalanced. This gives response to the unbalanced current in the bridge circuit. The simplest form of AC Bridge as shown in following fig.:



2.1.3 Hay's Bridge :

- The limitation of Maxwell's bridge is that it can be used for high Q values.The Hay's bridge is suitable for the coils having high Q values.
- The different in Maxwell's bridge and Hay's bridge is that the Hay's bridge consists of resistanceR_1 in series with the standard capacitor C_1 in one of the ratio arms. Hence for larger phase angles R_1needed is very low, which is practicable. Hence bridge can be used for coils with high Q values.

schematic.

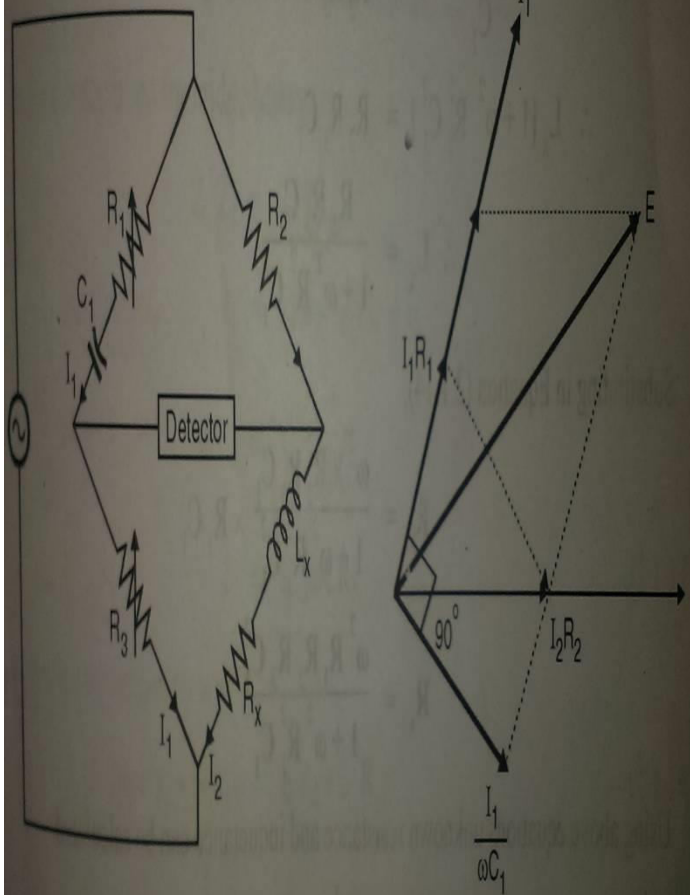


Fig. 2.1.3 : Hay's bridge

- **ADVANTAGES:**
- 1) It is best suitable for the measurement of inductance with high Q, typically greater than 10.
- 2) It gives very simple expression for Q factor in terms of elements in the bridge.
- It requires very low value resister R_1 to measure high Q inductance.
- **DISADVANTAGES:**
- 1) It is only suitable for measurement of high Q inductance. Consider expression for unknown inductance.

2.1.4 Anderson’s Bridge

- The Anderson’s bridge is a modification over the Maxwell’s bridge. In Anderson’sbridge, the self inductance is measured in terms of a standard capacitor.fig shows the schematic for Anderson’s bridge.
-

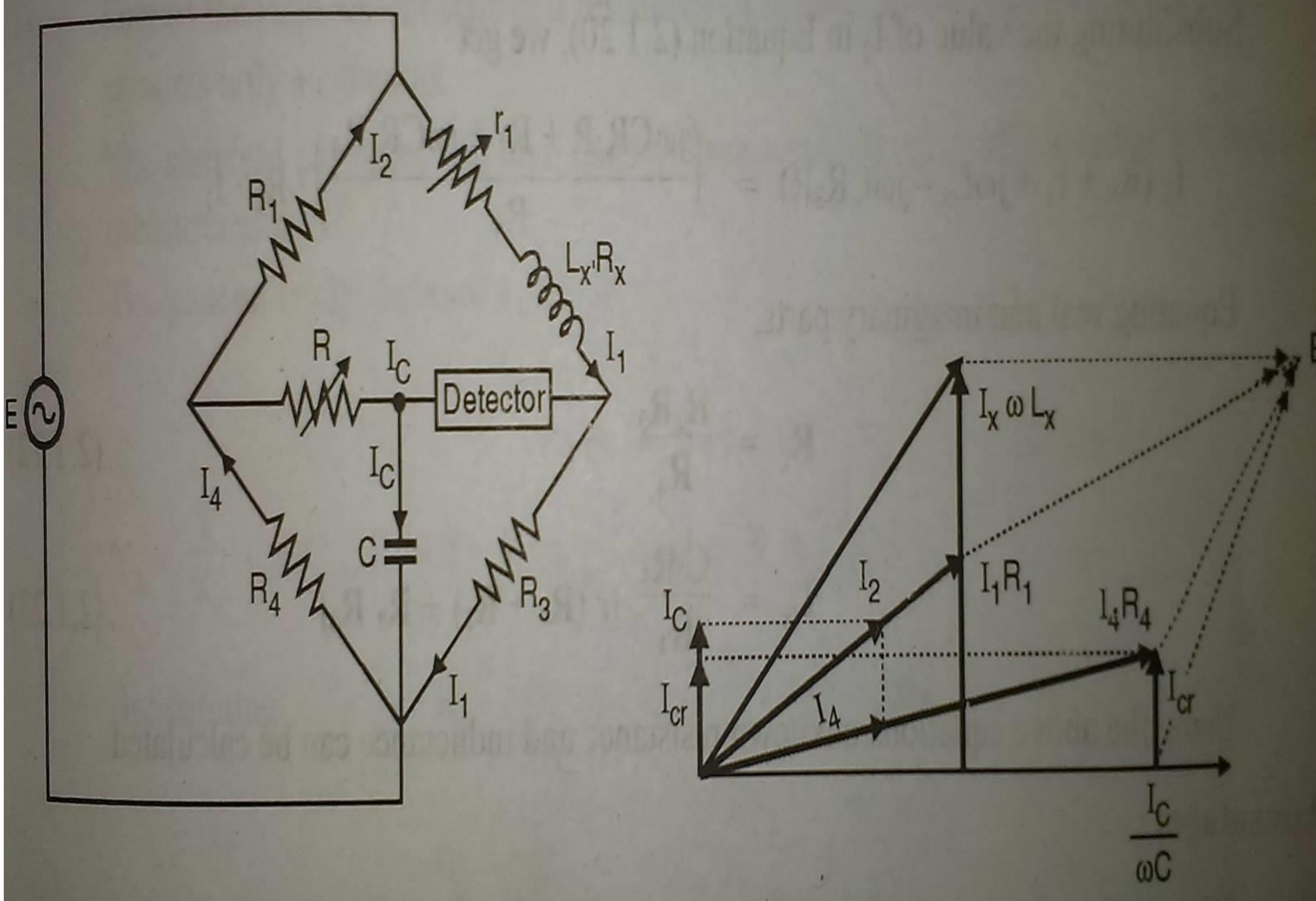


Fig. 2.1.4 : Anderson's bridge

Wien Bridge

- It is a bridge used for the measurement of frequency.
- Apart from this it has a variety of applications in the harmonic distortion analyzer where it is used as a notch filter,discriminating against a specific frequency in the audio and HF oscillators as frequency determining against a specific frequency in the audio and HF oscillators as frequency determining element.
- Fig.2.1.9 shows the circuit.

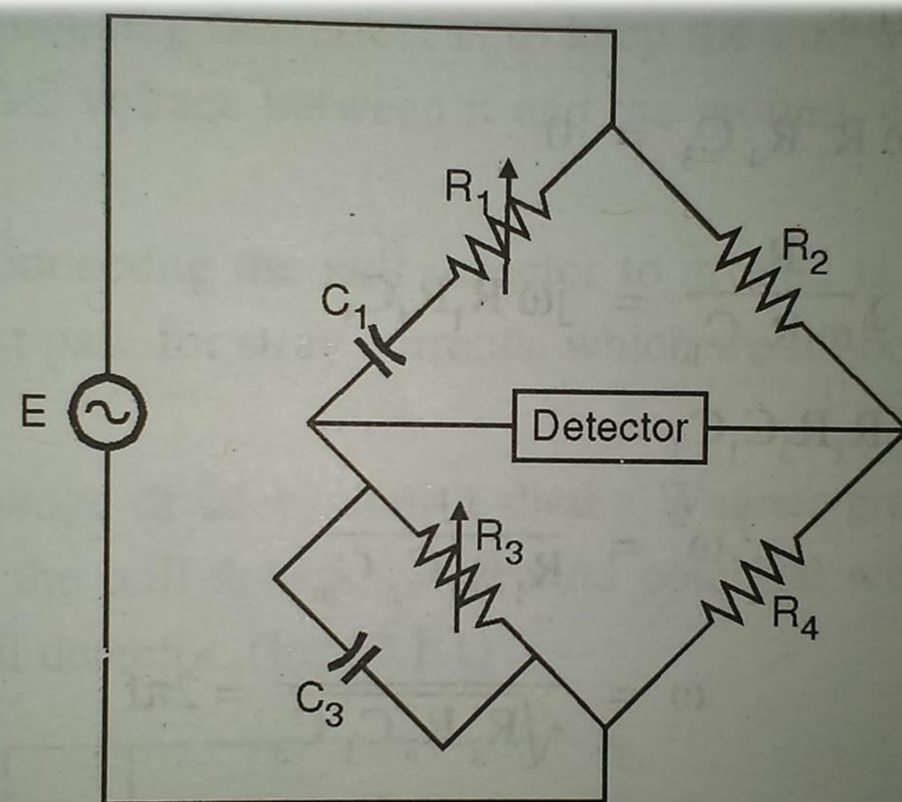
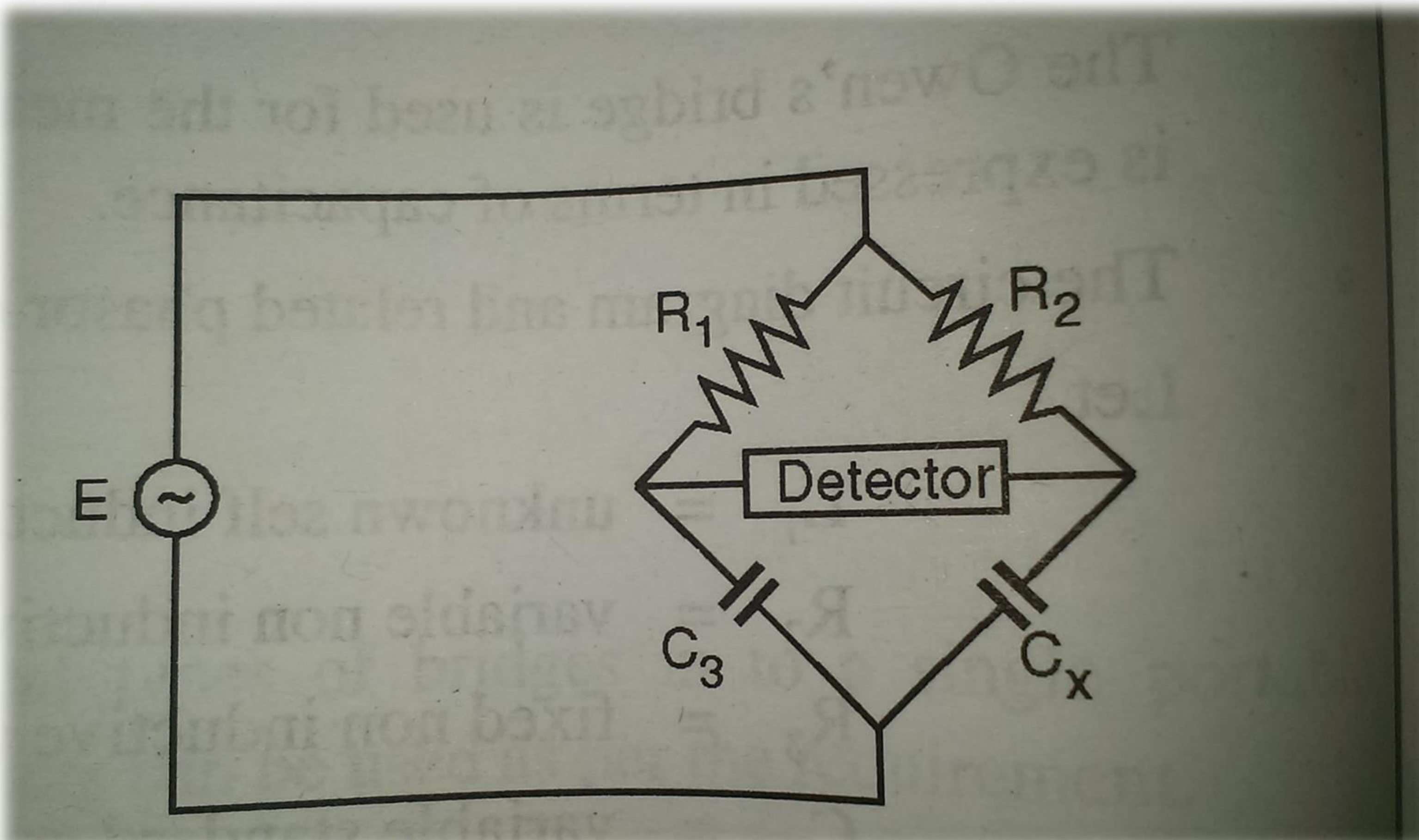


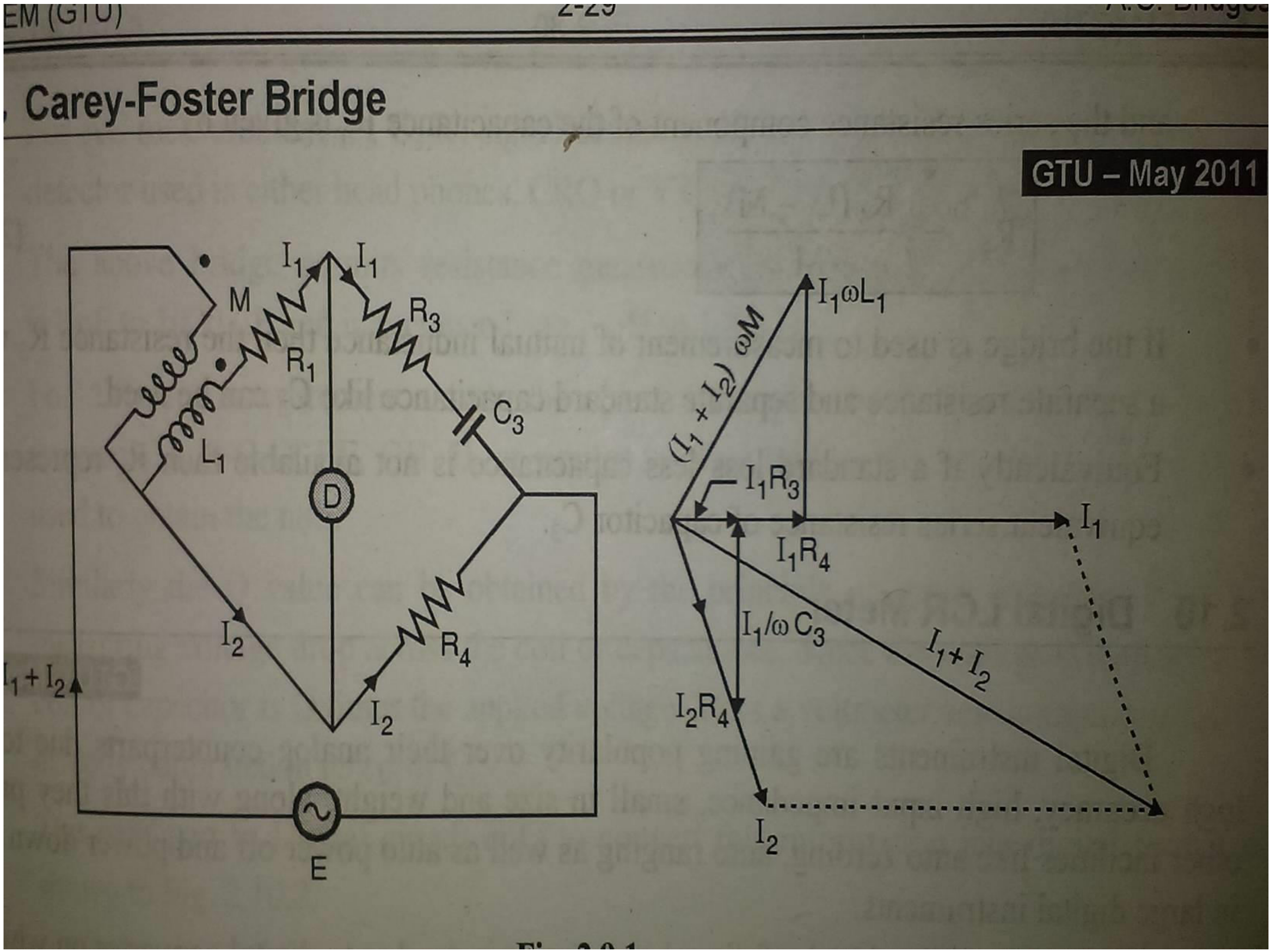
Fig. 2.1.9 : Frequency measurement with Wien bridge

De-Sauty’s Bridge :



- **ADVANTAGE:**
- 1. The bridge is simplest
- 2. It is economical
- **DISADVANTAGE:**
- 1. If both the capacitor are not free from dielectric loss, then it is not possible to achieve bridge balance. This method is only suitable for the measurement of lossless capacitor e.g. air capacitors.

Carey-Foster Bridge :



UNIT – V
TRANSDUCERS AND OSCILLOSCOPES

Introduction

- Basically transducer is defined as a device, which converts energy or information from one form to another. These are widely used in measurement work because not all quantities that need to be measured can be displayed as easily as others. A better measurement of a quantity can usually be made if it may be converted to another form, which is more conveniently or accurately displayed.

Introduction(cont'd)

- For example, the common *mercury thermometer* converts variations in temperature into variations in the length of a column of mercury. Since the variation in the length of the mercury column is rather simple to measure, the mercury thermometer becomes a convenient device for measuring temperature.

Introduction(cont'd)

- On the other hand, the actual temperature variation is not as easy to display directly. Another example is *manometer, which* detects pressure and indicates it directly on a scale calibrated in actual units of pressure.

Introduction(cont'd)

- Thus the transducer is a device, which provides a usable output in response to specific input measured, which may be physical or mechanical quantity, property or condition. The transducer may be mechanical, electrical, magnetic, optical, chemical, acoustic, thermal nuclear, or a combination of any two or more of these.

Mechanical transducers

- are simple and rugged in construction, cheaper in cost, accurate and operate without external power supplies but are not advantageous for many of the modern scientific experiments and process control instrumentation owing to their poor frequency response, requirement of large forces to overcome mechanical friction, in compatibility when remote control or indication is required, and a lot of other limitations. All these drawbacks have been overcome with the introduction of electrical transducers.

ELECTRICAL TRANSDUCERS

- Mostly quantities to be measured are non-electrical such as temperature, pressure, displacement, humidity, fluid flow, speed etc., but these quantities cannot be measured directly. Hence such quantities are required to be sensed and changed into some other form for easy measurement.
- Electrical quantities such as current, voltage, resistance. inductance and capacitance etc. can be conveniently measured, transferred and stored, and therefore, for measurement of non-electrical quantities these are to be converted into electrical quantities first and then measured.

ELECTRICAL TRANSDUCERS(cont'd)

- The function of converting non-electrical quantity into electrical one is accomplished by a device called the electrical transducer. Basically an electrical transducer is a sensing device by which a physical, mechanical or optical quantity to be measured is transformed directly, with a suitable mechanism, into an electrical signal (current, voltage or frequency). The production of these signals is based upon electrical effects which may be resistive, inductive, capacitive etc in nature.

ELECTRICAL TRANSDUCERS(cont'd)

- The input versus output energy relationship takes a definite reproducible function. The output to input and the output to time behavior is predictable to a known degree of accuracy, sensitivity and response, within the specified environmental conditions.

BASIC REQUIREMENTS OF A TRANSDUCER

- The main function of a transducer is to respond only for the measurement under specified limits for which it is designed. It is, therefore, necessary to know the relationship between the input and output quantities and it should be fixed. Transducers should meet the following basic requirements.

Basic Requirements Of a Transducer (cont'd)

- Ruggedness. It should be capable of withstanding overload and some safety arrangement should be provided for overload protection.
- Linearity. Its input-output characteristics should be linear and it should produce these characteristics in symmetrical way.
- Repeatability. It should reproduce same output signal when the same input signal is applied again and again under fixed environmental conditions e.g. temperature, pressure, humidity etc.

Basic Requirements Of a Transducer (cont'd)

- High Output Signal Quality. The quality of output signal should be good i.e. the ratio of the signal to the noise should be high and the amplitude of the output signal should be enough.
- High Reliability and Stability. It should give minimum error in measurement for temperature variations, vibrations and other various changes in surroundings.
- Good Dynamic Response. Its output should be faithful to input when taken as a function of time. The effect is analyzed as the frequency response.

Basic Requirements Of a Transducer (cont'd)

- No Hysteretic. It should not give any hysteretic during measurement while input signal is varied from its low value to high value and vice-versa.
- Residual Deformation. There should be no deformation on removal of local after long period of application.

Classification Of Transducers

- The transducers may be classified in various ways such as on the basis of electrical principles involved, methods of application, methods of energy conversion used, nature of output signal etc.

Classification Of Transducers(cont'd)

- ***Primary and Secondary Transducers:*** Transducers, on the basis of methods of applications, may be classified into primary and secondary transducers. When the input signal is directly sensed by the transducer and physical phenomenon is converted into the electrical form directly then such a transducer is called the primary transducer.

1-Primary and Secondary Transducers(cont'd)

- For example a thermistor used for the measurement of temperature fall in this category. The thermistor senses the temperature directly and causes the change in resistance with the change in temperature. When the input signal is sensed first by some detector or sensor and then its output being of some form other than input signals is given as input to a transducer for conversion into electrical form, then such a transducer falls in the category of secondary transducers.

Primary and Secondary Transducers(cont'd)

- For example, in case of pressure measurement, bourdon tube is a primary sensor which converts pressure first into displacement, and then the displacement is converted into an output voltage by an LVDT. In this case LVDT is secondary transducer.

2-Active and Passive Transducers.

- . Transducers, on the basis of methods of energy conversion used, may be classified into active and passive *transducers.Self-generating type transducers i.e. the transducers, which* develop *their* output *the form of electrical voltage* or *current without* any auxiliary *source,* are called the active transducers. Such transducers draw energy from the system under measurement. Normal such transducers give very small output and, therefore, use of amplifier becomes essential.

Active and Passive Transducers(cont'd)

- Transducers, in which electrical parameters i.e. resistance, inductance or capacitance changes with the change in input signal, are called the passive *transducers*. These transducers require external power source for energy conversion. In such transducer electrical parameters *i.e.* resistance, inductance or capacitance causes a change in voltages current or frequency of the external power source. These transducers may draw sour energy from the system under measurement. Resistive, inductive and capacitive transducer falls in this category.

3-*Analog and Digital Transducers*

- Transducers, on the basis of nature of output signal, may be classified into analog and digital transducers. Analog transducer converts input signal into output signal, which is a continuous function of time such as thermistor, strain gauge, LVDT, thermo-couple etc. Digital transducer converts input signal into the output signal of the form of pulse e.g. it gives discrete output.

Analog and Digital Transducers(cont'd)

- These transducers are becoming more and more popular now-a-days because of advantages associated with digital measuring instruments and also due to the effect that digital signals can be transmitted over a long distance without causing much distortion due to amplitude variation and phase shift. Sometimes an analog transducer combined with an ADC (analog-digital convector) is called a digital *transducer.*

Transducers and Inverse Transducers.

- Transducer, as already defined, is a device that converts a non-electrical quantity into an electrical quantity. Normally a transducer and associated circuit has a non-electrical input and an electrical output, for example a thermo-couple, photoconductive cell, pressure gauge, strain gauge etc. An inverse transducer is a device that converts an electrical quantity into a non-electrical quantity. It is a precision actuator having an electrical input and a low-power non-electrical output.

Transducers and Inverse Transducers(cont'd)

- For examples a piezoelectric crystal and transnational and angular moving-coil elements can be employed as inverse transducers. Many data-indicating and recording devices are basically inverse transducers. An ammeter or voltmeter converts electric current into mechanical movement and the characteristics of such an instrument placed at the output of a measuring system are important. A most useful application of inverse transducers is in feedback measuring systems.

Selection Of Transducers

- In a measurement system the transducer (or a combination of transducers) is the input element with the critical function of transforming some physical quantity to a proportional electrical signal. So selection of an appropriate transducer is most important for having accurate results.

Selection Of Transducers(cont'd)

- The first step in the selection procedure is to clearly define the nature of quantity under measurement (measurand) and know the range of magnitudes and frequencies that the measurand is expected to exhibit. Next step will be to examine the available transducer principles for measurement of desired quantity. The type of transducer selected must be compatible with the type and range of the quantity to be measured and the output device.

Selection Of Transducers(cont'd)

- In case one or more transducer principles are capable of generating a satisfactory signal, decision is to be taken whether to employ a commercially available transducer or build a suitable transducer. If the transducers are available in the market at a suitable price, the choice will probably be to purchase one of them, otherwise own transducer will have to be designed, built and calibrated.

Selection Of Transducers(cont'd)

- The points to be considered in determining a transducer suitable for a specific measurement are as follows:
- ***Range***. The range of the transducer should be large enough to encompass all the expected magnitudes of the measurand.
- ***Sensitivity***. The transducer should give a sufficient output signal per unit of measured input in order to yield meaningful data.
- ***Electrical Output Characteristics***. The electrical characteristics- the output impedance, the frequency response, and the response time of the transducer output signal should be compatible with the recording device and the rest of the measuring system equipment.

Selection Of Transducers(cont'd)

- ***Physical Environment***. The transducer selected should be able to withstand the environmental conditions to which it is likely to be subjected while carrying out measurements and tests.
- Such parameters are temperature, acceleration, shock and vibration, moisture, and corrosive chemicals might damage some transducers but not others.

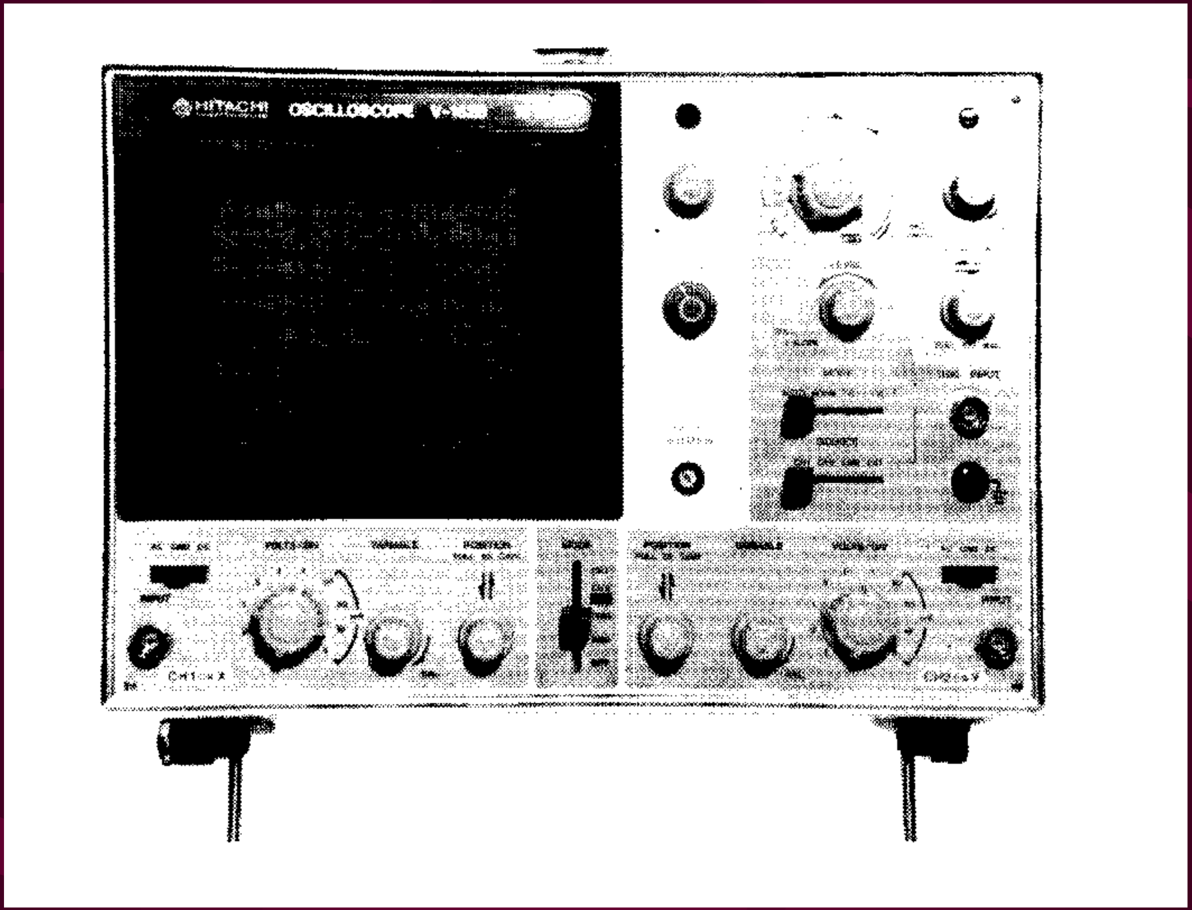
Selection Of Transducers(cont'd)

- ***Errors***. The errors inherent in the operation of the transducer itself, or those errors caused by environmental conditions of the measurement, should be small enough or controllable enough that they allow meaningful data to be taken.
- However the total measurement error in a transducer-activated system may be reduced to fall within the required accuracy range by adopting the following techniques.

Errors(cont'd)

- Calibrating the transducer output against some known standards while in use under actual test conditions. This calibration should be performed regularly as the measurement proceeds.
- Continuous monitoring of variations in the environmental conditions of the transducer and correcting the data accordingly.
- Controlling the measurement environment artificially in order to reduce possible transducer errors. Artificial environmental control includes the enclosing of the transducer in a temperature-controlled housing and isolating the device from external shocks and vibrations.

CATHODE RAY OSCILLOSCOPE



Functional Units

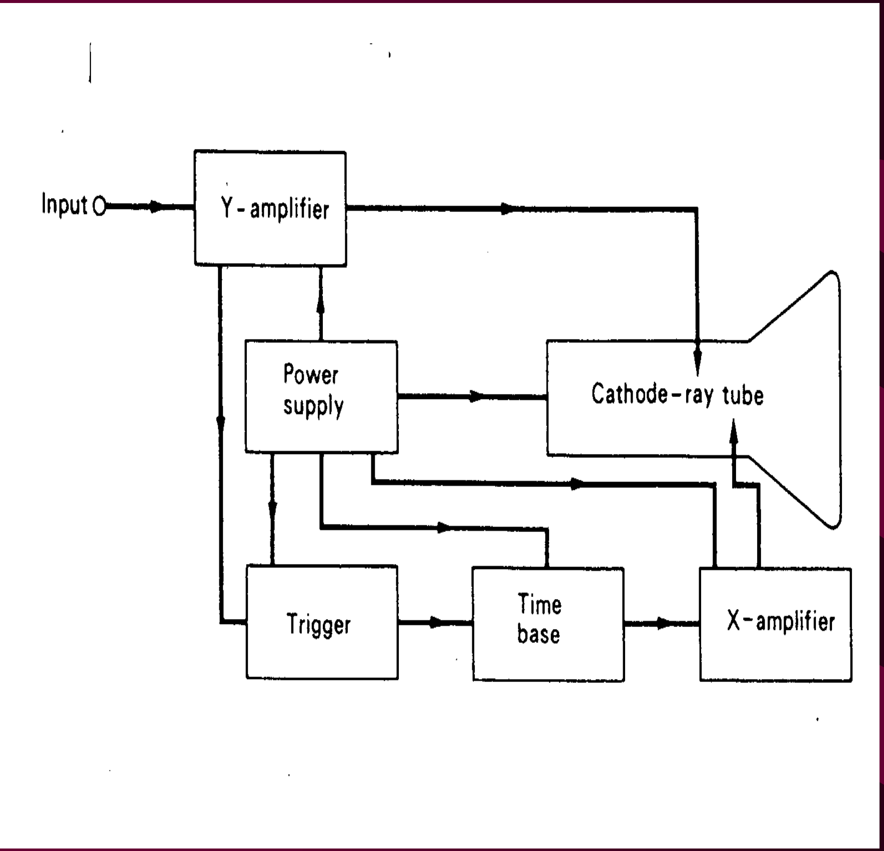
a) Electron Gun

b) Evacuated Tube

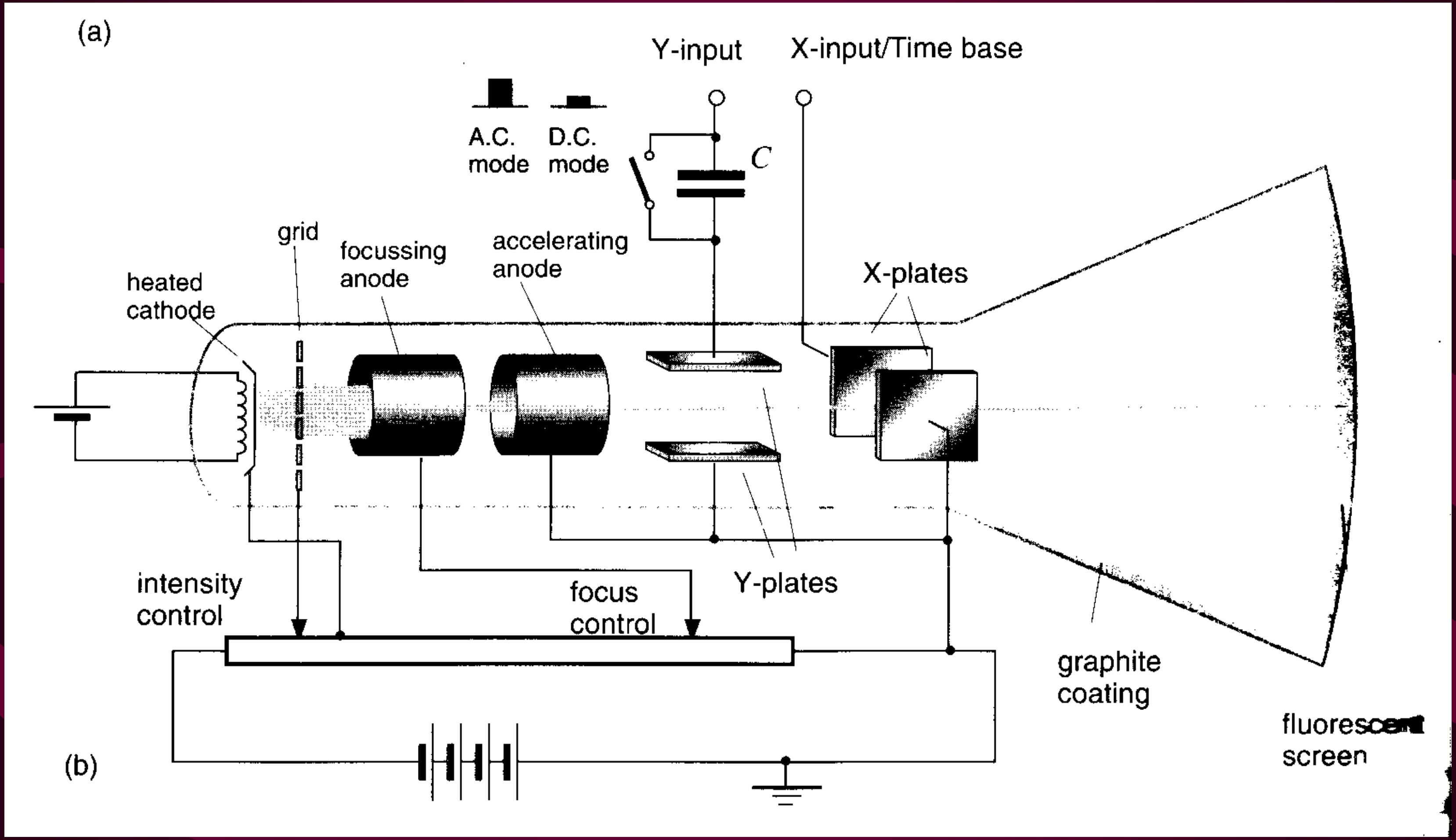
c) Deflecting System

d) Time Base

e) Trigger Circuit



Electron Gun



a) Heating Filament

b) Cathode

c) Grid

d) Electron lens

Return

Link to figure

Evacuated Tube

- Vacuum space
- Screen
- Graphite inner wall
- Shielded from electric and magnetic fields

Return

Link to figure

Deflecting System

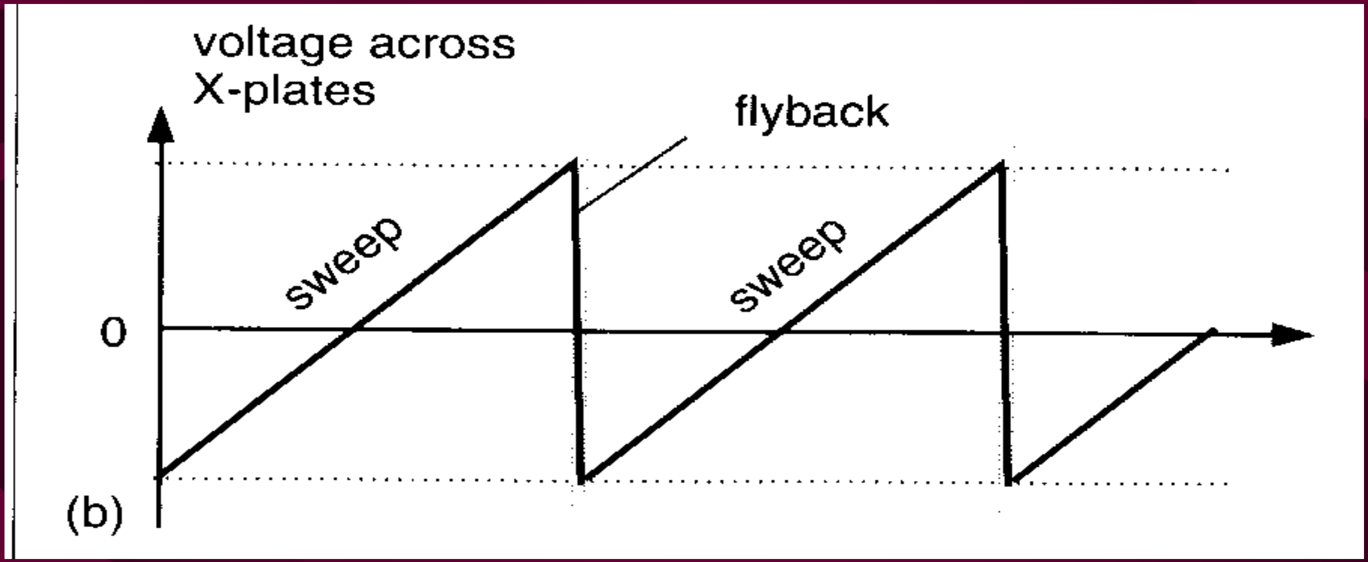
- X-plates
- Y-plates
- X and Y Deflection Amplifiers
- *X-shift Control*
- *Y-shift Control*
- *Sensitivity Control*

Return

Link to figure

Time Base

- Sawtooth potential difference
- Time period control



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Link to figure

Trigger Circuit

- Maintain a stable trace
- Trig level control
- Trigger time base
- automatic triggering

USES OF CRO

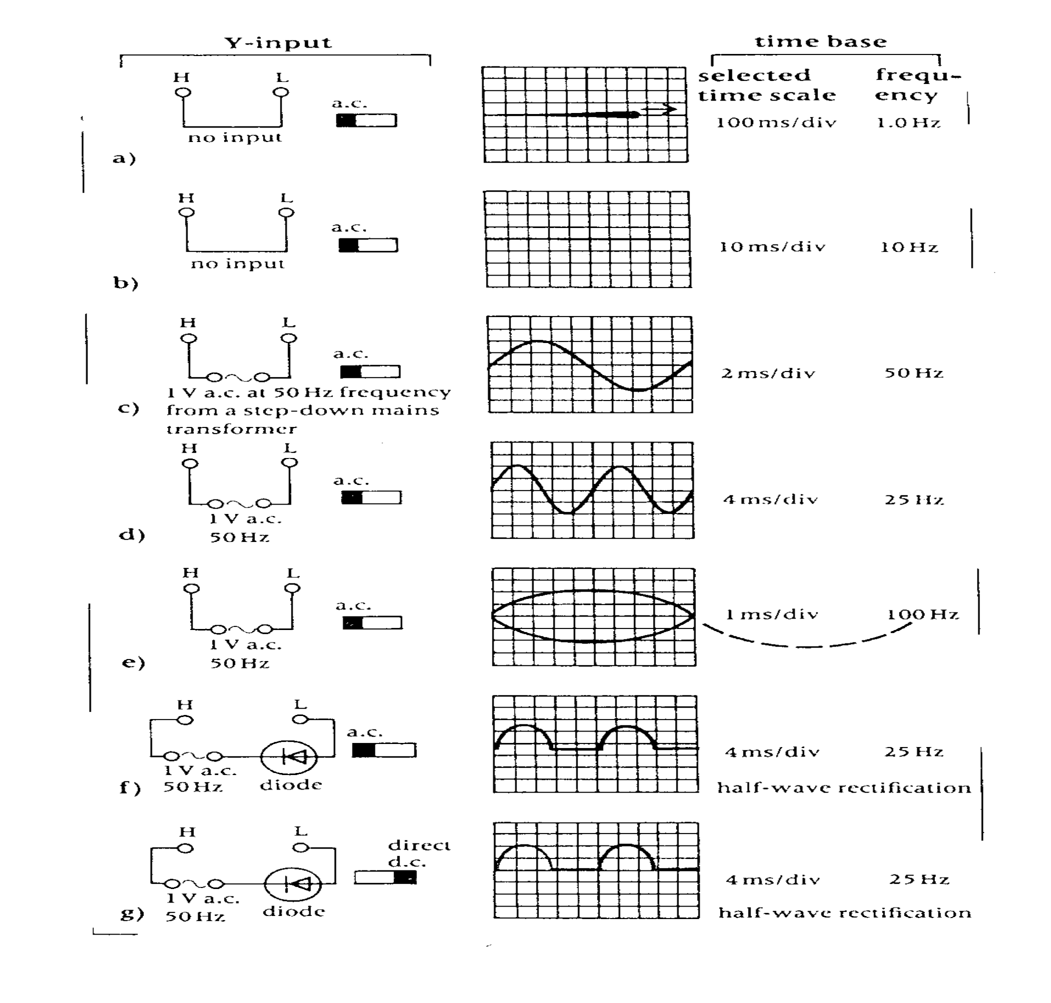
a) Voltmeter
b) Display of waveforms
c) Measurement of short time intervals
d) Measurement of frequency
e) Display of phase relationship
f) Comparison of frequencies

Voltmeter

- Calibration
- D.C. voltmeter
- A.C. voltmeter
- Advantages over moving-coil voltmeters

Return

Display of Waveforms



magnify

Return

Measurement of Short Time Intervals

- Calibrate for the time base
- Measure a very small time interval, e.g. measurement of sound speed in a metal rod

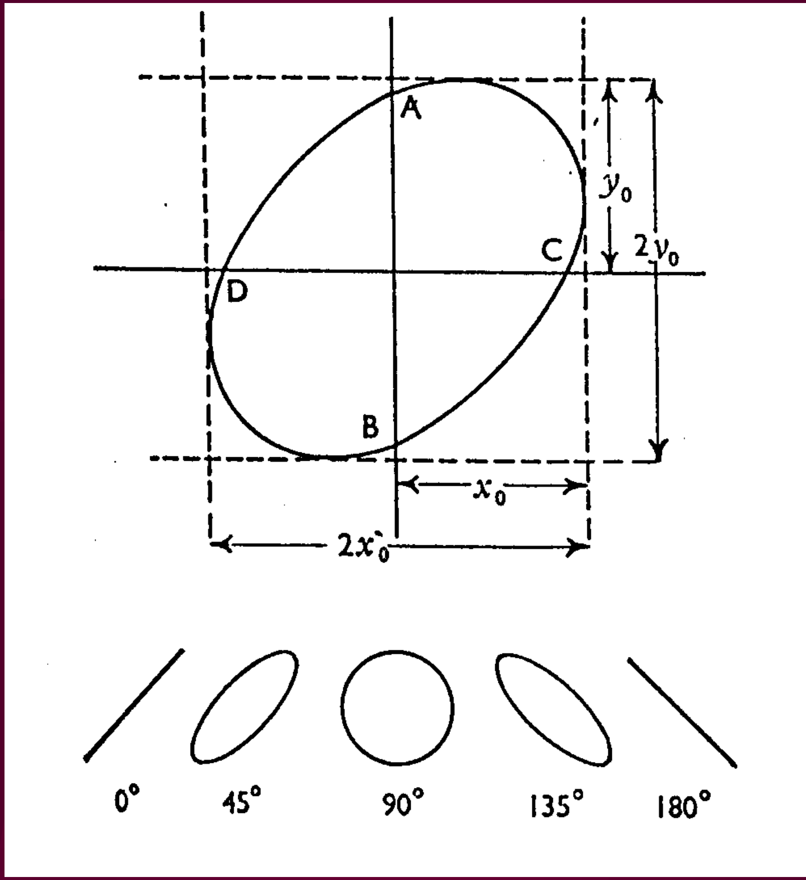
Return

Measurement of Frequency

- Signal applied to Y-plates
- ‘Lock’ the trace
- Choose a suitable time base
- Determine the period, T
- Calculate the frequency

Return

Display of Phase Relationships



Computer Simulation

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Comparison of Frequencies

- Lissajous' figures
- Frequency ratio