Benha University
Faculty of Engineering (Shoubra)
Electronics and Communications Engineering

ECE 211
Electrical and Electronic Measurements
(2020-2021)

Lecture 5: Electromechanical Instruments Part 3 and Electro-Dynamic Instrument

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Chapter Outline:

1. Permanent Magnet Moving Coil (PMMC).
2. Galvanometer.
3. DC Ammeters
4. DC Voltmeters
5. Ohmmeters
6. AC Voltmeters
7. AC Ammeters
8. Electro-Dynamic Instrument

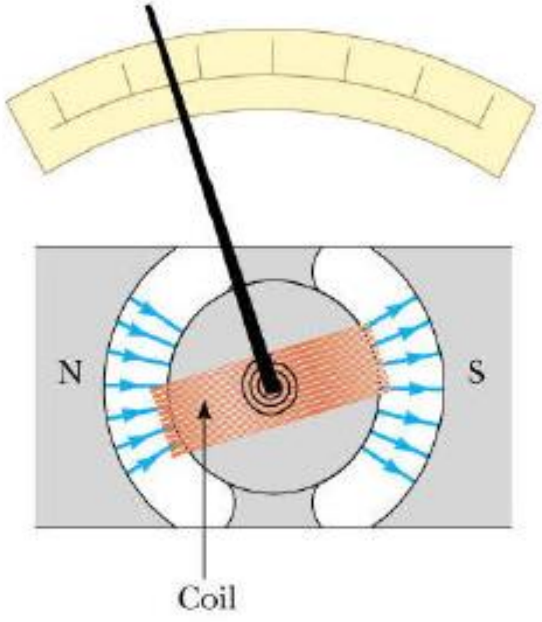
6. AC Voltmeters

3.6 AC Voltmeter:

Introduction:

PMMC as AC instrument:

- When an alternating current with **a very low frequency 0.1 Hz)** is passed through a PMMC, the **pointer will follow the instantaneous level** of the ac signal.
- Since the PMMC is polarized, **the pointer will move when ac goes positive only** and will stop when ac goes negative.
- With higher frequencies, the PMMC will **not be able to follow** the changing ac level **due to its damping force** and the pointer will stop on the average level (zero for pure sinusoidal wave).
- So, a modification has to be done on PMMC to measure alternating current and voltage.



Construction of PMMC

3.6 AC Voltmeter:
[1] Full-Wave Rectifier Voltmeter:

- Four diodes rectifiers are added to the PMMC to convert the AC signal into a series of uni-directional current pulses that pass through the PMMC instrument to cause positive deflection.
- **On positive half cycle:** Diodes **D1** and **D4** conduct and the current flows through the PMMC meter from top to bottom.
- **On negative half cycle**: Diodes **D2** and **D3** to conduct causing the current to flow again through the meter in the same direction.
- The multiplier resistance Rs is connected to allow higher voltage to the meter in the same way as in the case of DC voltmeter.

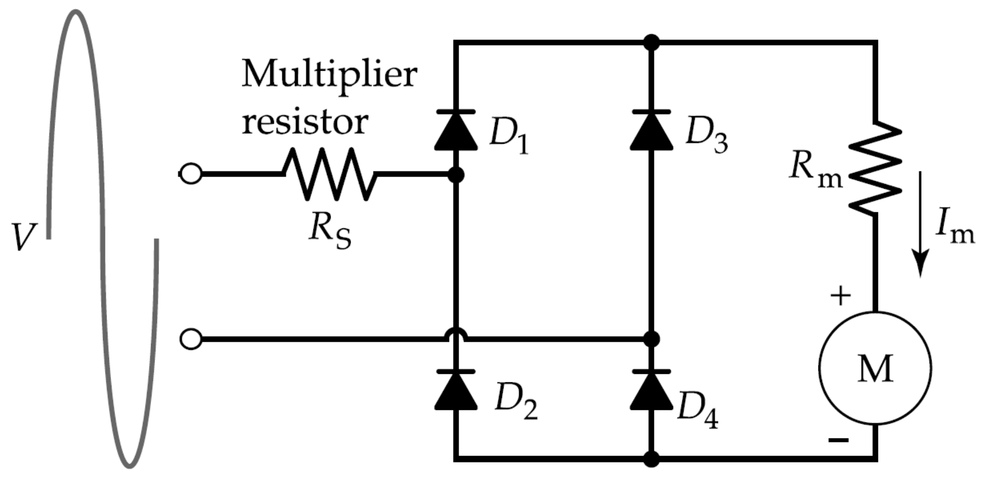
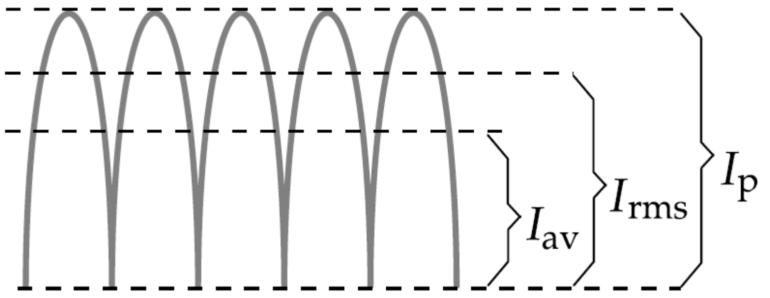


Figure 4-7 An ac voltmeter may be constructed of a PMMC instrument, a multiplier resistor, and a full-wave bridge rectifier.

3.6 AC Voltmeter:

[1] Full-Wave Rectifier Voltmeter:

- The rectifier meter will deflect in proportional to the average value of the current (0.637 peak current).
- However, the meter must indicate the RMS value, (that is, 0.707 peak value) of the voltage.
- Therefore, the linear scale of the meter can be calibrated accordingly to indicate the RMS value (1.11 average value).
- Limitation: The diodes drop will limit the measurement of low levels of AC signals.



Example 3.9

A PMMC instrument with FSD = 100 μA and R_m = 1 kΩ is to be employed as an ac voltmeter with FSD = 100 V (rms). Silicon diodes are used in the bridge rectifier circuit of Figure 3-17. Calculate the multiplier resistance value required.

Solution

At FSD, the average current flowing through the PMMC instrument is

$$I_{av} = 100\ \mu A$$

$$\text{peak current } I_m = \frac{I_{av}}{0.637} = \frac{100\ \mu A}{0.637} \simeq 157\ \mu A$$

$$I_m = \frac{(\text{applied peak voltage}) - (\text{rectifier volt drop})}{\text{total circuit resistance}}$$

$$\text{rectifier volt drops} = 2V_F \text{ (for } D_1 \text{ and } D_4 \text{ or } D_2 \text{ and } D_3)$$

$$\text{applied peak voltage} = 1.414V_{rms}$$

$$\text{total circuit resistance} = R_s + R_m$$

$$I_m = \frac{1.414V_{rms} - 2V_F}{R_s + R_m}$$

$$R_s = \frac{1.414V_{rms} - 2V_F}{I_m} - R_m$$

$$= \frac{(1.414 \times 100\ V) - (2 \times 0.7\ V)}{157\ \mu A} - 1\ k\Omega$$

$$= 890.7\ k\Omega$$

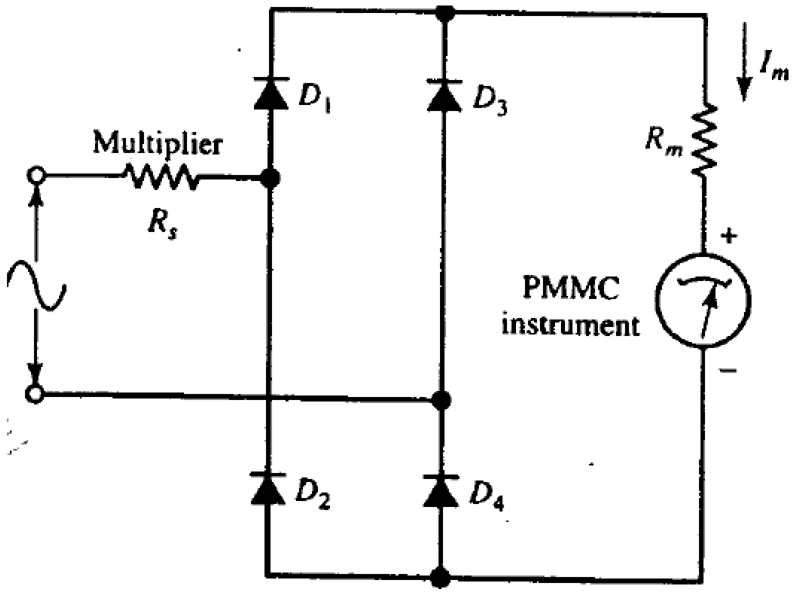


Fig. 3-17

Example 3.10:

- Calculate the pointer indications for the voltmeter in the previous example, when the rms input voltage is:

  (a) 75 V and (b) 50 V

Solution

(a)

$$I_{av} = 0.637 I_m = 0.637\left(\frac{1.414 V_{rms} - 2V_F}{R_s + R_m}\right)$$

$$= 0.637\left[\frac{(1.414 \times 75\ \text{V}) - (2 \times 0.7\ \text{V})}{890.7\ \text{k}\Omega + 1\ \text{k}\Omega}\right]$$

$$\simeq 75\ \mu\text{A} = 0.75\ \text{FSD}$$

(b)

$$I_{av} = 0.637\left[\frac{(1.414 \times 50\ \text{V}) - (2 \times 0.7\ \text{V})}{890.7\ \text{k}\Omega + 1\ \text{k}\Omega}\right]$$

$$\simeq 50\ \mu\text{A} = 0.5\ \text{FSD}$$

The previous two examples demonstrate that:

100V rms at Full scale, 75V rms at 0.75 FSD and 50V rms at 0.5 FSD.

Then, the instrument has a linear scale

3.6 AC Voltmeter:
[2] Half-Wave Rectifier Voltmeter:

- D1 is used to rectify the ac signal into the PMMC.
- On positive half cycle: Diodes D1 conducts and the current flows through the PMMC.
- On negative half cycle: Diodes D1 is OFF and no current flows.

- RSH is added in parallel to increase the current in diode D1 when a positive half-wave appears at the input (to operate in the linear region of the diode).
- D2 is added to protect the meter against any reverse voltages.
- The rectifier meter will deflect in proportional to the average value of the current (0.5 * 0.637 *peak current).

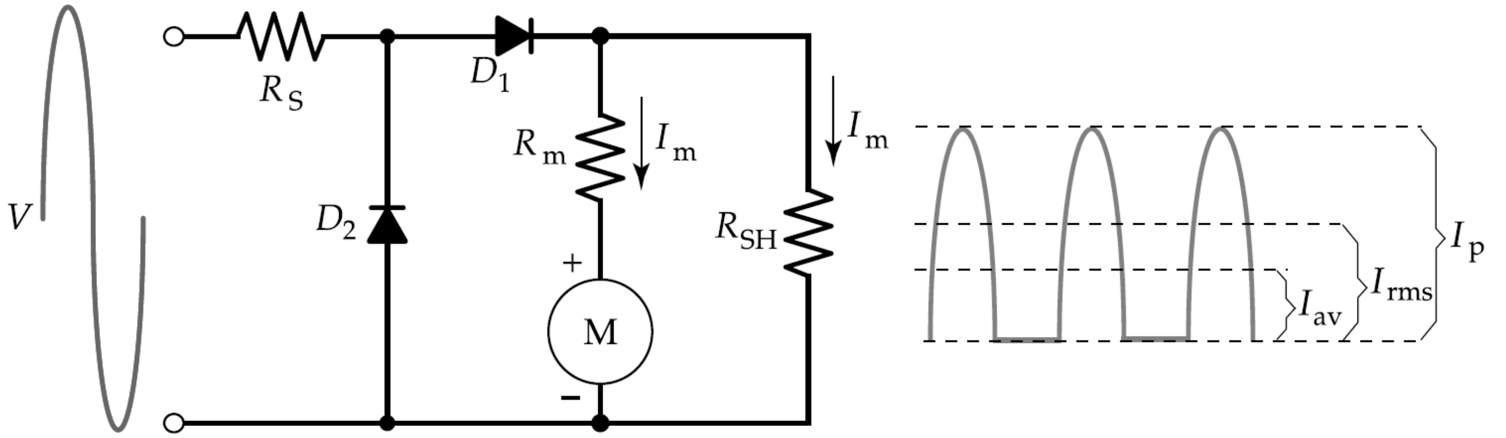


Figure 4-8 Half-wave rectification may be used with a PMMC instrument and a multiplier resistor for ac voltage measurements. A shunt resistor (R_{SH}) is included to ensure a satisfactory rectifier forward current level. The additional rectifier (D_2) minimizes reverse leakage current through D_1.

Example 3.11:

A PMMC instrument with FSD = 50 μA and R_m = 1700 Ω is used in the half-wave rectifier voltmeter circuit illustrated in Figure 3-18. The silicon diode (D_1) must have a minimum (peak) forward current of 100 μA when the measured voltage is 20% of FSD. The voltmeter is to indicate 50 V rms at full scale. Calculate the values of R_s and R_{SH}.

Solution At FSD, I_{av}=50 μA

Meter peak current: $\mathbf{I_m = \pi I_{av} = \pi(50\ \mu A) = 157\ \mu A}$

At 20% of FSD, *diode peak current* I_F *must be at least 100* μA; *therefore, at 100% of* FSD,

$$I_{F(peak)} = \frac{100\%}{20\%} \times 100\ \mu A = 500\ \mu A$$

$$I_{F(peak)} = I_m + I_{SH}$$

$$I_{SH(peak)} = I_{F(peak)} - I_m$$

$$= 500\ \mu A - 157\ \mu A = 343\ \mu A$$

$$V_{m(peak)} = I_m R_m = 157\ \mu A \times 1700\ \Omega$$

$$= 266.9\ mV$$

$$R_{SH} = \frac{V_{m(peak)}}{I_{SH(peak)}} = \frac{266.9\ mV}{343\ \mu A} = 778\ \Omega$$

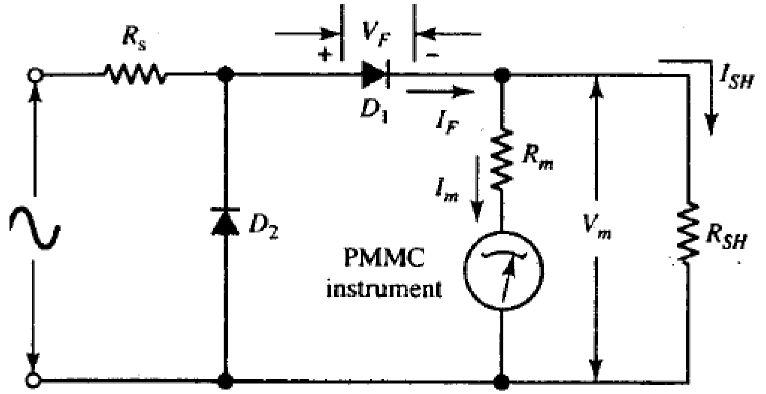


Fig. 3-18

Solution (Cont.)

$$I_{F(\text{peak})} = \frac{(\text{applied peak voltage}) - V_{m(\text{peak})} - V_F}{R_s}$$

$$I_{F(\text{peak})} = \frac{1.414V_{\text{rms}} - V_{m(\text{peak})} - V_F}{R_s}$$

$$R_s = \frac{1.414V_{\text{rms}} - V_{m(\text{peak})} - V_F}{I_{F(\text{peak})}}$$

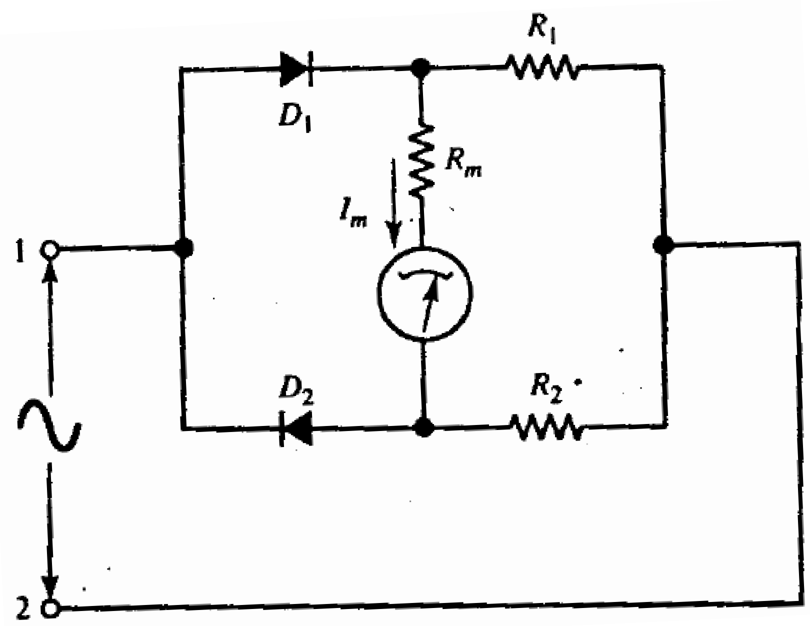
$$= \frac{(1.414 \times 50\ \text{V}) - 266.9\ \text{mV} - 0.7\ \text{V}}{500\ \mu\text{A}}$$

$$= 139.5\ \text{k}\Omega$$

3.6 AC Voltmeter:

[3] Half-bridge full-wave rectifier Voltmeter

- Two diodes and two resistors are used instead of the four diodes used in a full-wave bridge rectifier.
- During the positive half-cycle, D1 is forward and D2 is reverse. Current flows from terminal 1 through D1 and the meter, and then through R2 to terminal 2
- R1 is in parallel with the meter and R2.
- During the negative half-cycle, D2 is forward biased and D1 is reverse biased. Current now flows from terminal 2 through R1 and the meter, and through D2 to terminal 1.
- R2 is in parallel with the series-connected meter and R1.



7. AC Ammeters

3.7 AC Ammeter:

- The requirement of the AC ammeter is to have very low resistance which implies that a very low (typically less than 100 mV) voltage drop.
- Thus, a rectifier PMMC circuit is not suitable to directly measure AC currents.
- A step-up transformer is used to measure AC current:

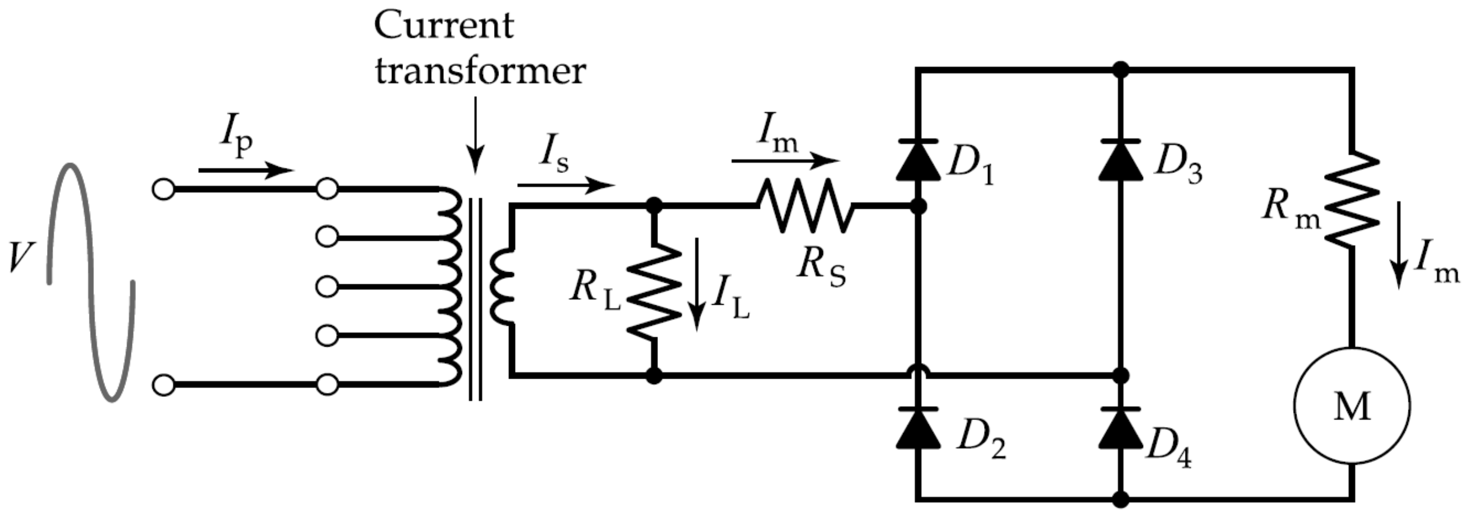
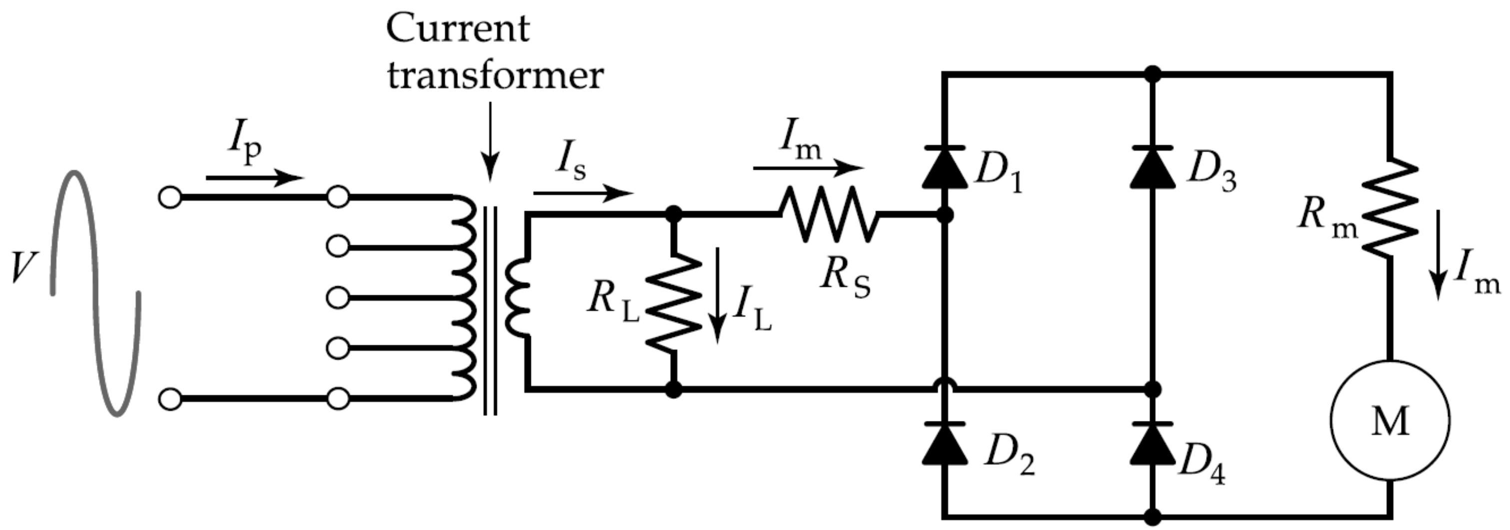


Figure 4-10 Ac ammeter circuit consisting of a current transformer, full-wave bridge rectifier, and a PMMC instrument.

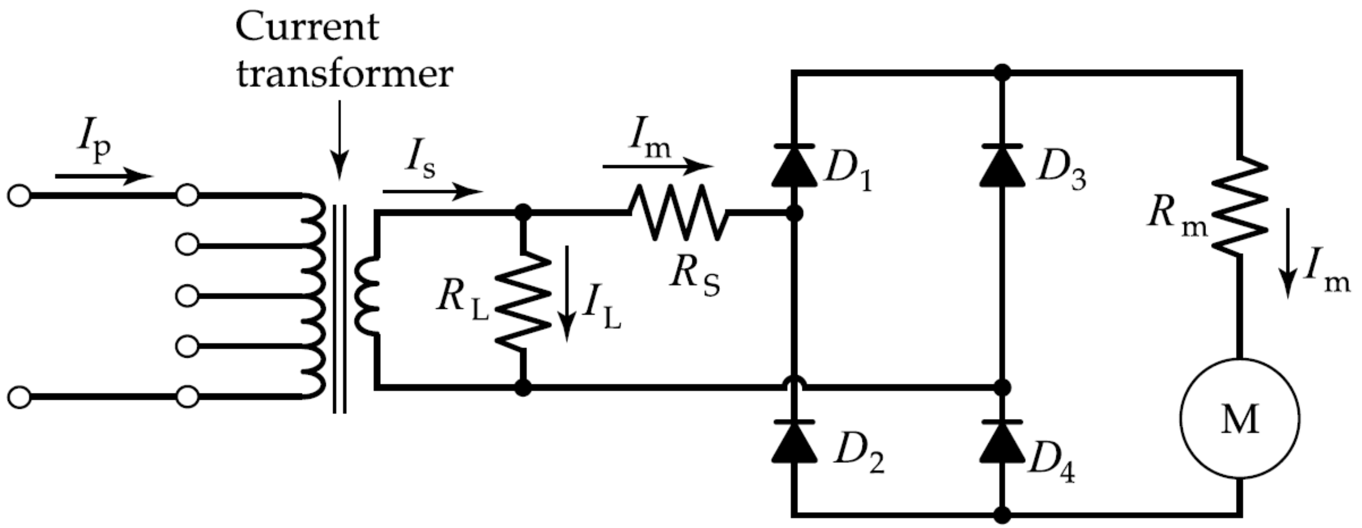
3.7 AC Ammeter:



- Using a current transformer with a rectifier instrument provides a very low terminal resistance and low voltage drop.
- In step-up transformer, the input voltage gets stepped up so that sufficient voltage can be provided for rectifier operation.
- Since the transformer is used in an ammeter circuit, the current transformation ratio $I_P/I_S = N_S/N_P$ is very important.
- A multi-range AC ammeter could be provided by changing the number of primary turns in the transformer or using different values of load resistance (R_L)

Example 3.12:

A rectifier ammeter with the circuit shown is to give FSD for a primary current of 250 mA (rms). The PMMC meter has FSD = I mA and R_m = 1700 Ω The current transformer has N_S = 500 and N_P = 4. The diodes each have V_F = 0.7 V, and the series resistance is R_S = 20 kΩ ***Calculate*** the required value of R_L.



Solution:

Peak meter current $I_m = \dfrac{I_{av}}{0.637} = \dfrac{1\text{ mA}}{0.637}$

$= 1.57\text{ mA}$

Transformer secondary peak voltage,

$E_m \doteq I_m(R_s + R_m) + 2V_F$

$= 1.57\text{ mA }(20\text{ k}\Omega + 1700\ \Omega) + 1.4\text{ V}$

$\simeq 35.5\text{ V}$

or secondary voltage $E_s = (0.707 \times 35.5\text{ V})\text{ rms}$

$\simeq 25.1\text{ V}$

and *rms meter current* $= 1.11\ I_{av}$

$= 1.11\text{ mA}$

Solution (Cont.)

Transformer rms secondary current,

$$I_s = I_p \frac{N_p}{N_s}$$

$$= 250 \text{ mA} \times \frac{4}{500} = 2 \text{ mA}$$

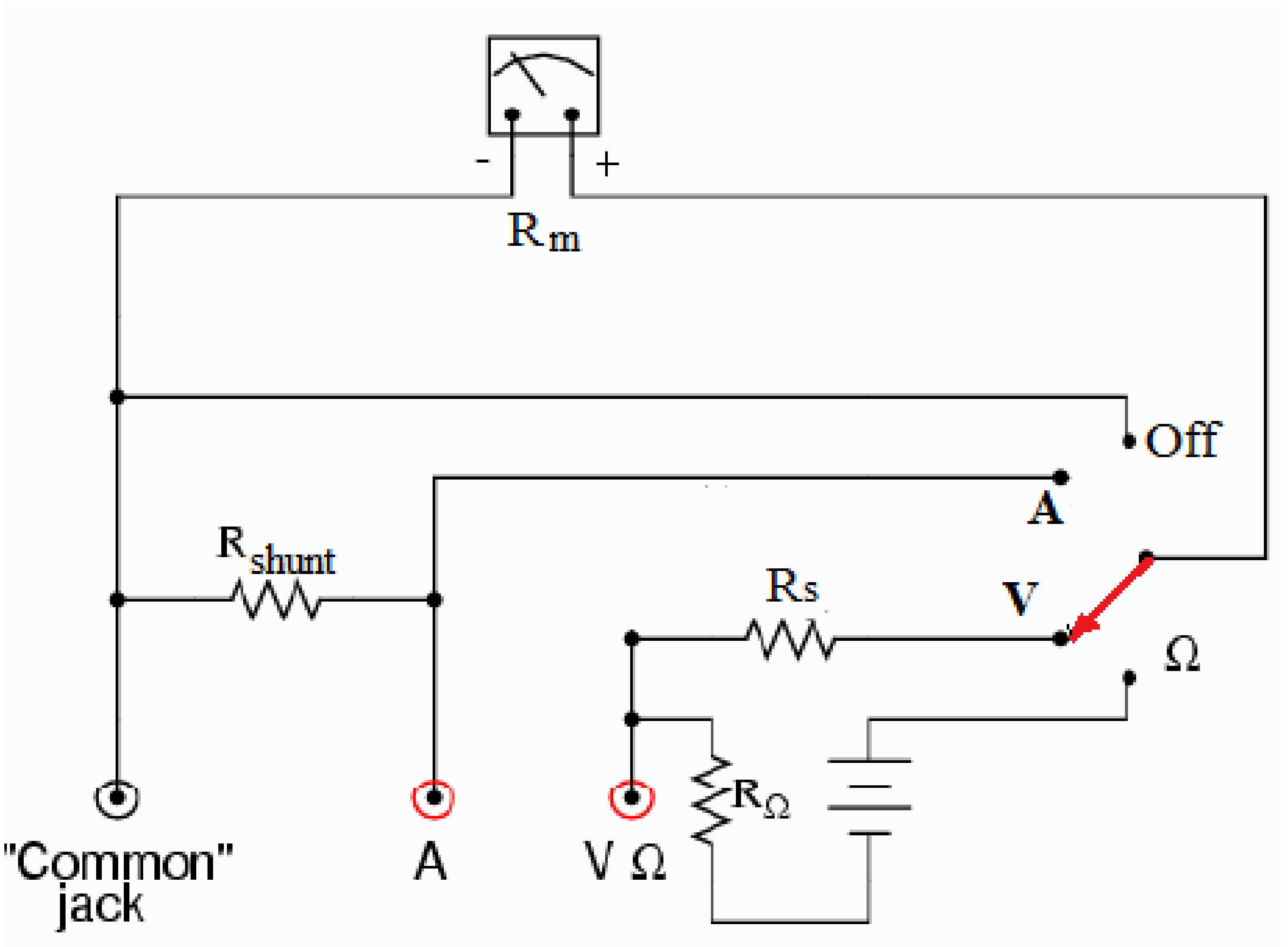
$$I_L = I_s - I_m$$

$$= 2 \text{ mA} - 1.11 \text{ mA} = 0.89 \text{ mA}$$

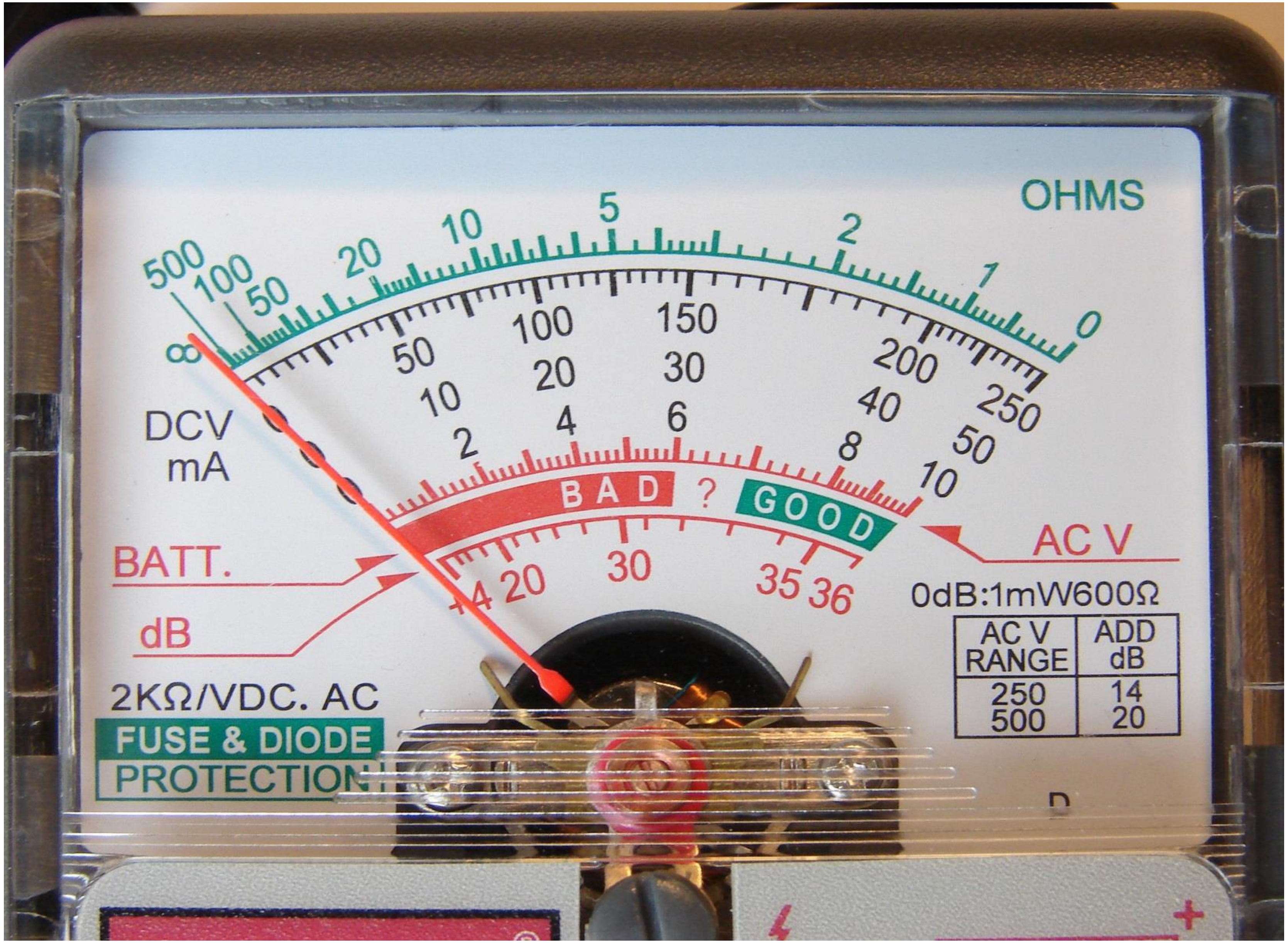
$$R_L = \frac{E_s}{I_L} = \frac{25.1 \text{ V}}{0.89 \text{ mA}}$$

$$= 28.2 \text{ k}\Omega$$

Analogue Multi-meter circuit



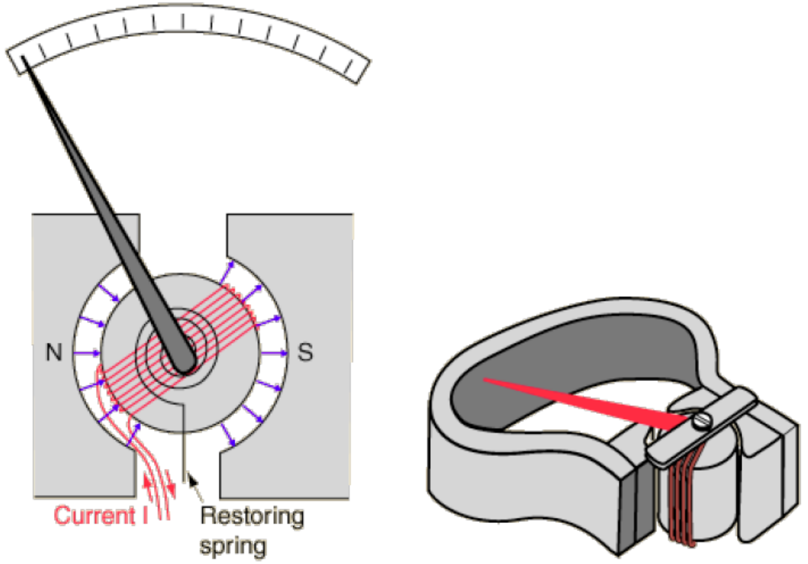
Scale of ohm, volt and ampere in analogue multi-meter



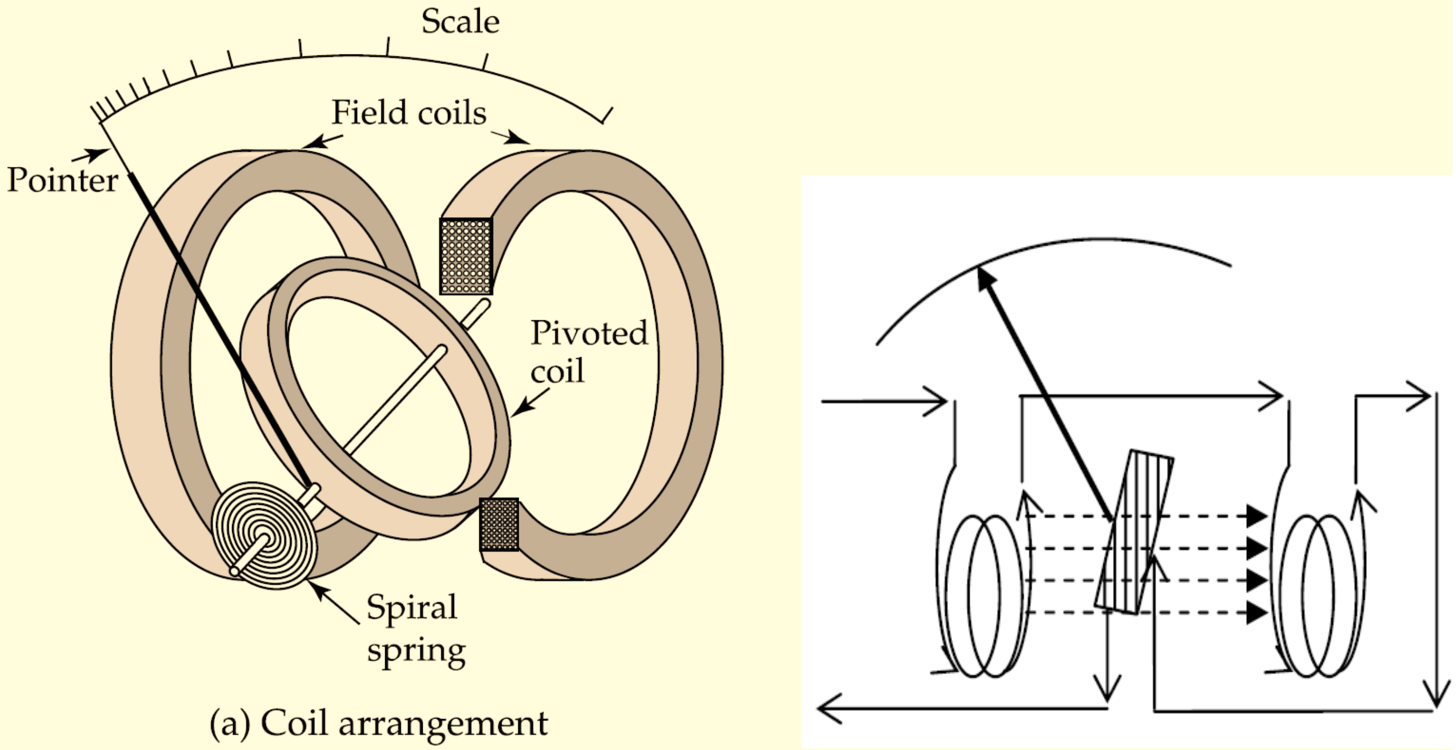
8. Electro-Dynamic Instrument

3.8 Electro-Dynamic Instrument

- **electrodynamic** or **dynamometer** instrument



PMMC meters



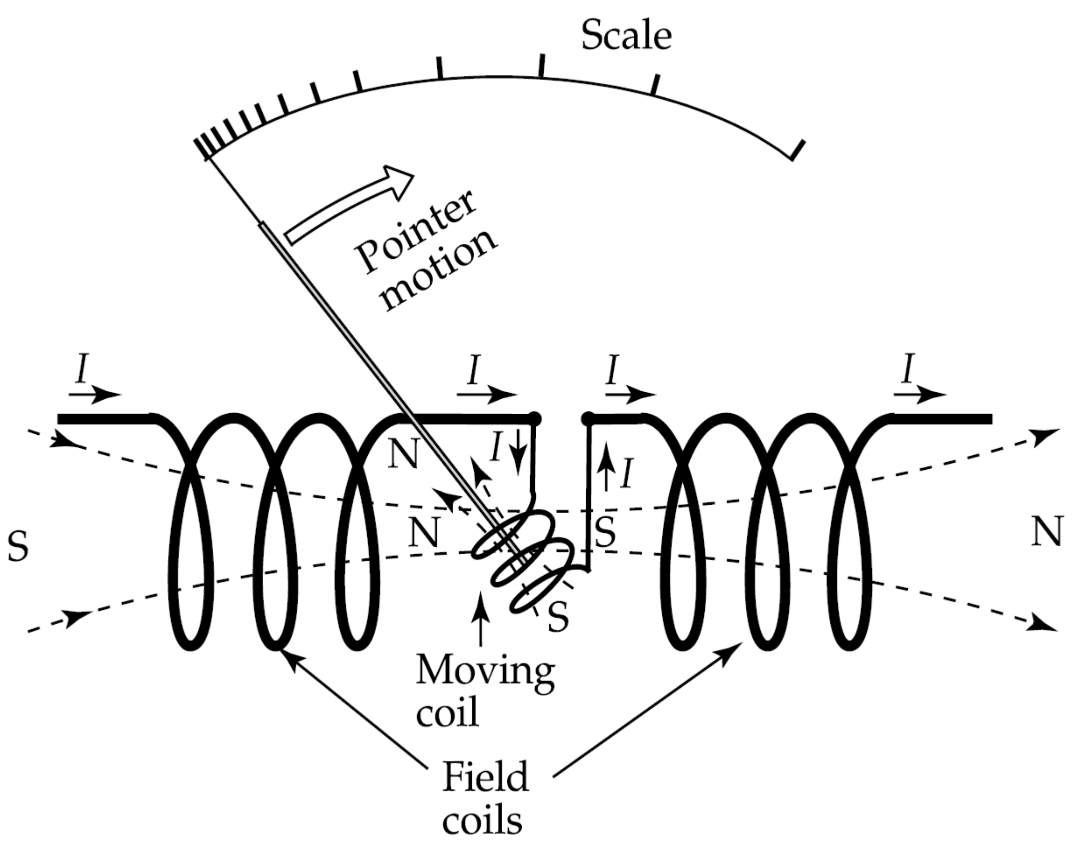
(a) Coil arrangement

Figure 3-9 An electrodynamic instrument has a moving coil, as in a PMMC instrument, but the magnetic field is produced by two current-carrying field coils instead of a magnet. Damping is provided by an enclosed vane.

3.8 Electro-Dynamic Instrument

Comparing with PMMC

- Permanent magnet➔ two magnetic field coils
- The magnetic field in which the moving coil is mounted is generated by passing a current through the stationary field coils.
- When a current flows through the moving coil, the two fluxes interact (as in the PMMC instrument), causing the coil and pointer to be deflected



(a) Current flow from left to right produces positive deflection

3.8 Electro-Dynamic Instrument

Comparing with PMMC (Cont.)

- the deflecting torque of an electrodynamic instrument is dependent on field flux, coil current, coil dimensions, and number of coil turns.
- Consequently, the deflecting torque is proportional to the product of the two currents:

$$T_D \propto I_{field\ coil} \times I_{moving\ coil}$$

- When the same current flows through field coils and moving coil, the deflecting torque is proportional to the square of the current:

$$T_D \propto I^2$$

- Deflection angle is:

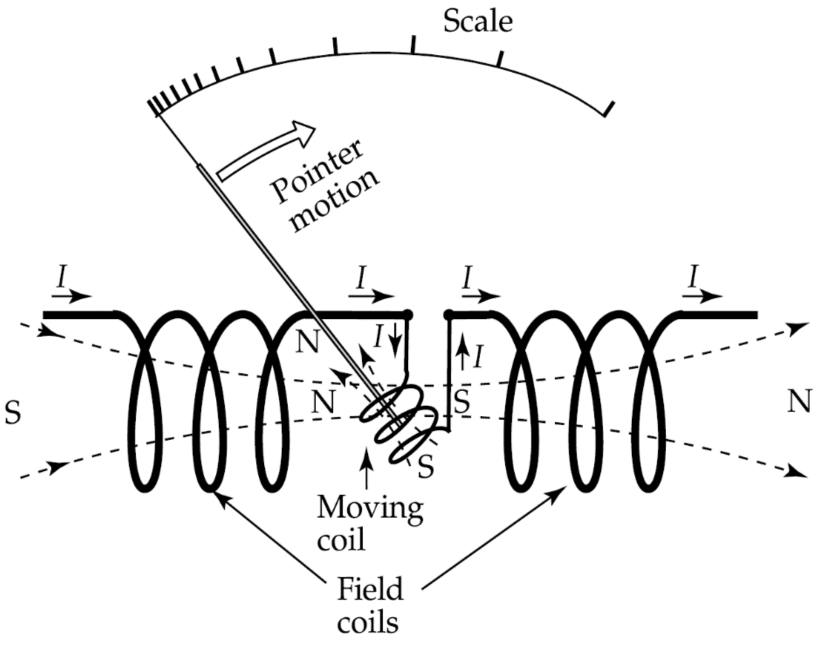
$$\theta = CI^2$$

- where C is a constant. Because the deflection is proportional to I^2, the scale of the instrument is nonlinear cramped at the low end and spaced out at the high end.

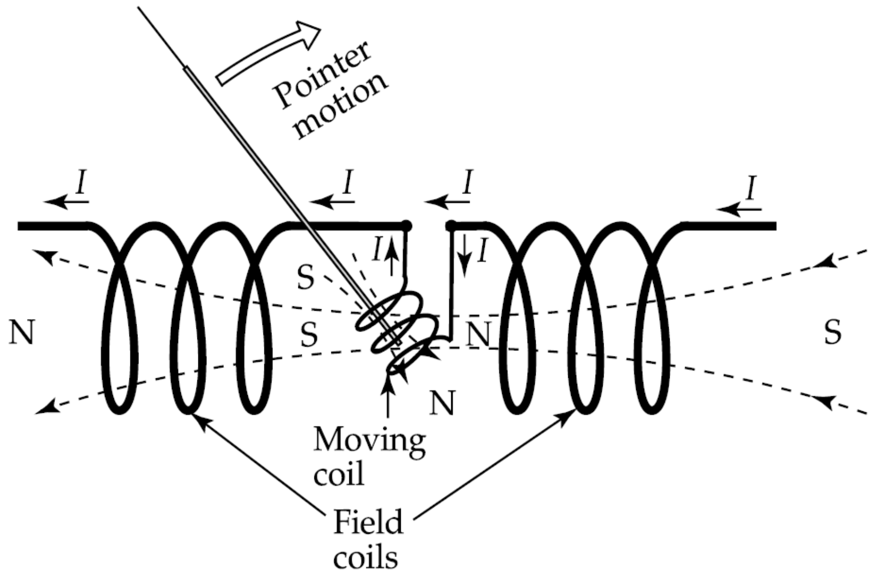
3.8 Electro-Dynamic Instrument

Comparing with PMMC (Cont.)

- Major disadvantages of an electrodynamoc instrument (compared to PMMC) are low sensitivity and nonlinear scale.
- Major advantage of electrodynamoc instrument is that it is not polarized. A positive deflection is obtained regardless the direction of the current in coils ➔ then, the instrument can be used to measure AC or DC



(a) Current flow from left to right produces positive deflection



(b) Current flow from right to left produces positive deflection

3.8 Electrodynamic Voltmeter and Ammeter

- Voltmeter must have a high resistance, all three coils are connected in series, and a multiplier resistor is included.
- The moving coil and its series-connected swamping resistance are connected in parallel with the ammeter shunt. The two field coils should be connected in series with the parallel arrangement of shunt and moving coil

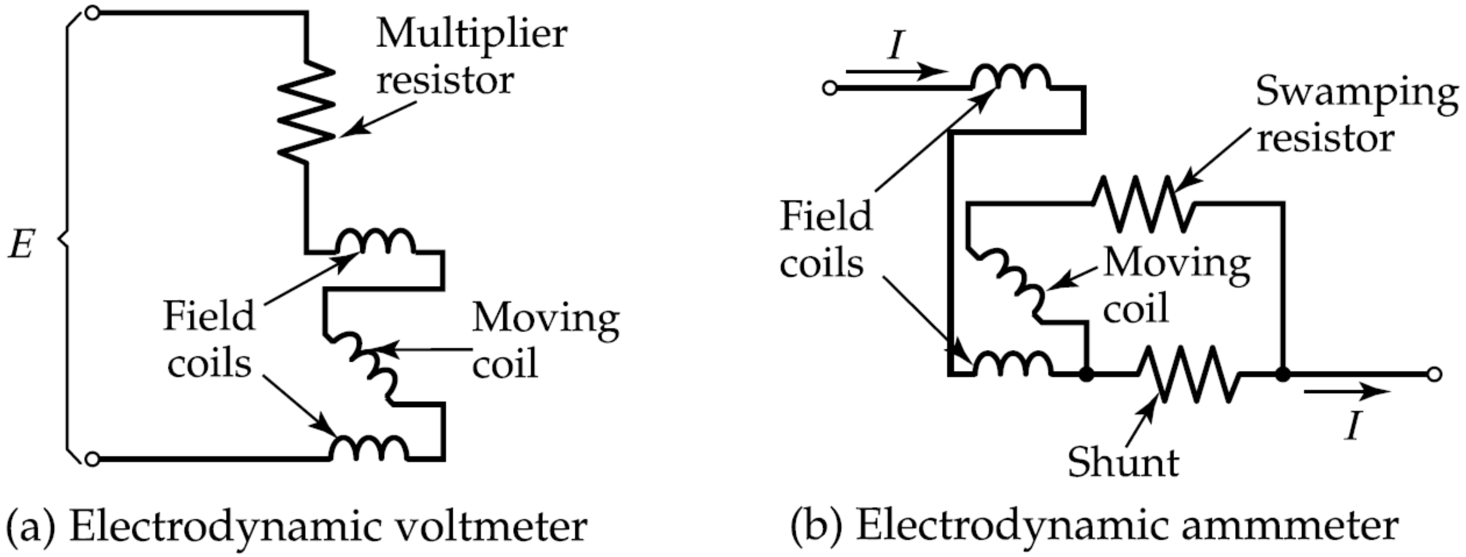


Figure 3-11 For use as a voltmeter, an electrodynamic instrument has the field coils, moving coil, and multiplier resistor all connected in series. For use as an ammeter, the field coils are connected in series with the parallel-connected shunt and moving-coil circuit.

End of Lecture

Best Wishes