Lecture 9B – The Moving Coil Machine

Generator principle. Motor (or meter) principle.

Generator Principle

A simple generator consists of a rectangular coil (N_1 turns, radius r_1, area A_1) wound on a soft iron cylindrical core (the rotor). The pole faces are shaped so that the air gap is uniform and the gap flux density, B_g, is perpendicular to the pole faces. The rotor (and therefore the coil) is driven at constant angular speed ω_1 by a "prime mover" – such as a steam turbine or a diesel motor.

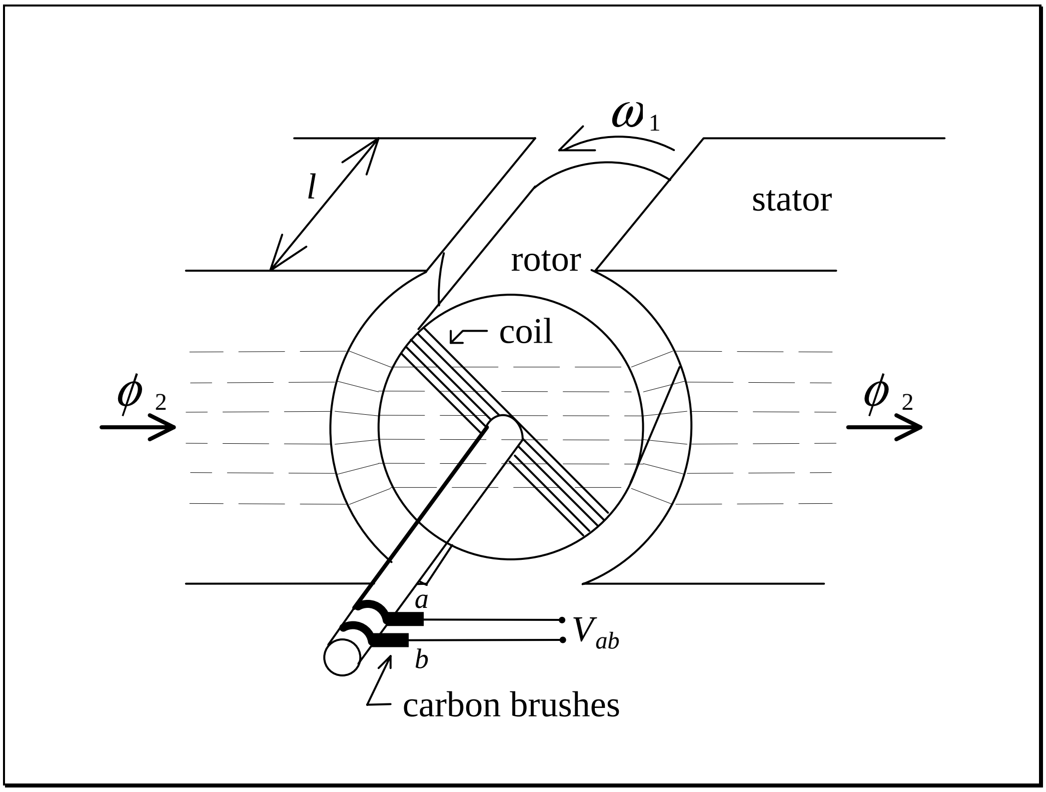

Figure 9B.1

9B.2

The coil rotation is equivalent to a conductor of length l moving with velocity $\mathbf{v}$ in a magnetic field of density B_g, as shown below:

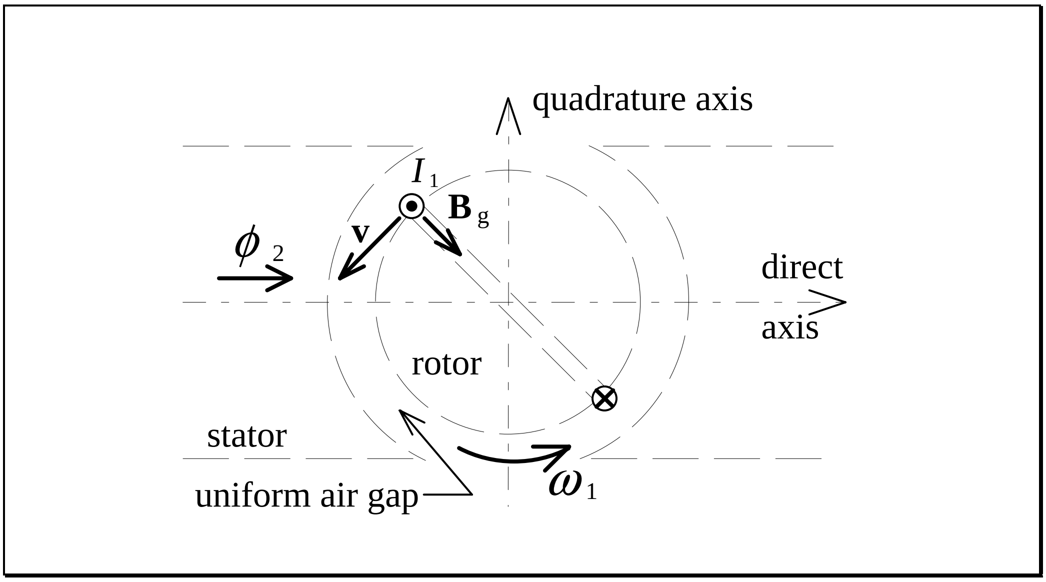

Figure 9B.2

We can apply the Lorentz force to a free charge in the conductor, and then calculate the potential difference between the brushes:

$$\mathbf{E} = -(\mathbf{v} \times \mathbf{B}), \qquad V_{ab} = -\int_b^a \mathbf{E} \cdot d\mathbf{l}$$

$$\begin{aligned} V_{ab} &= N_1 \int_a^b (\mathbf{v} \times \mathbf{B}) \cdot d\mathbf{l} \\ &= N_1 \omega_1 r_1 B_g 2l \\ &= B_g A_1 N_1 \omega_1 \end{aligned} \tag{9B.1}$$

A pulsating emf V_{ab} results. A DC output can be obtained by connecting leads a and b to a commutator which switches the output "positive" terminal to the other slip ring when the polarity changes.

To create the magnetic field, we can use permanent magnets or a coil.

Assuming we have a good core, the mmf required to produce the magnetic field in the air gap is given by:

$$N_2 I_2 \approx \mathcal{R}_g \phi_g = \frac{2l_g}{\mu_0 A_g} B_g A_g = K B_g \tag{9B.2}$$

The mmf does not depend upon the radius of the machine. It depends upon the length.

The electrical power output from the generator is limited by factors such as:

- Overheating of windings. To compensate for overheating, windings are distributed over the periphery of the rotor for better heat dissipation.
- The number of conductors that can be accommodated (and therefore the current) is proportional to the radius.
- The output voltage is limited by saturation in the iron (ϕ_2 controls B_g).

The output power of the machine is given by:

$$VI = KA_1 \omega_1 r_1 = K' \omega_1 \times (\text{machine volume}) \tag{9B.3}$$

Power station generators therefore tend to be large. With these large machines, the large currents are unsuitable for brush contacts. In these machines, the field and rotor windings are reversed so that the brushes carry the field current. The field supply is either by battery or rectified AC.

Advantage of AC Generation

Alternating current and voltage are easily transformed (the transformer is simple and very efficient – 98%).

Generation of Sinusoidal Voltages

The pole faces are shaped to give a sinusoidal B_g or the windings are distributed so that the mmf is sinusoidal.

Electrical Equivalent Circuit

The electrical equivalent circuit for a machine is:

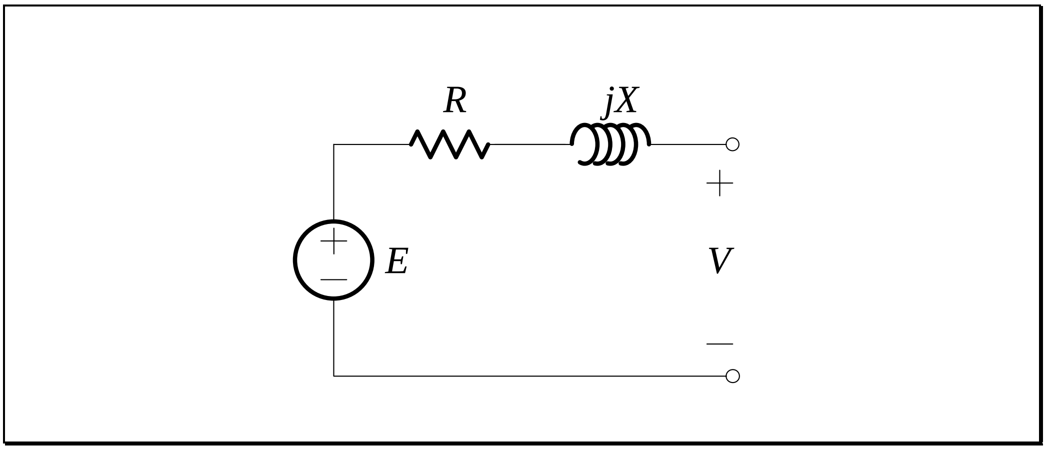

Figure 9B.3

Motor (or Meter) Principle

To use the machine as a motor, we apply a voltage V_{ab} to terminals a and b. There is a current I_1 as shown:

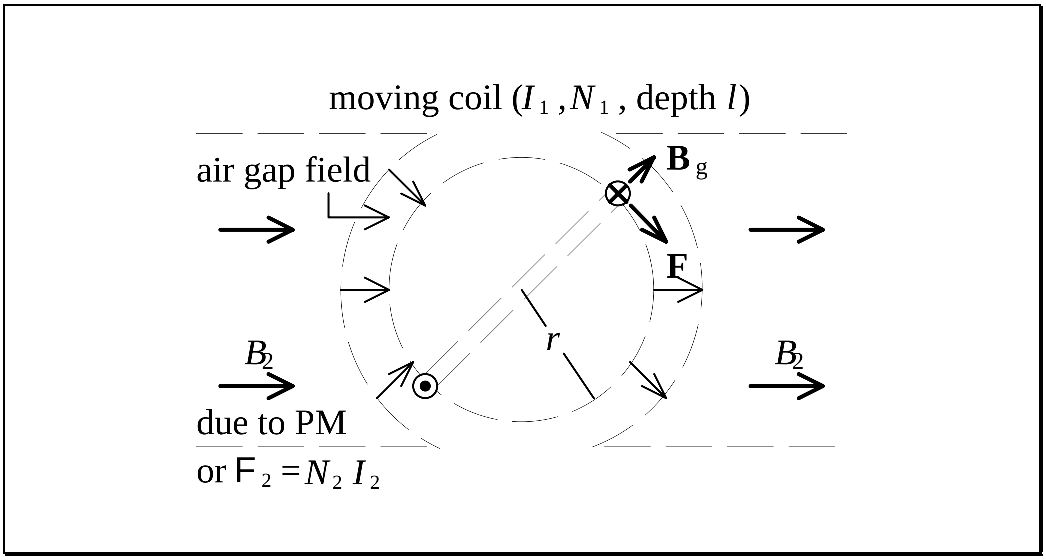

Figure 9B.4

The force and torque experienced by an element *dl* of coil 1 (the moving coil) is:

$$d\mathbf{F} = I_1\left(d\mathbf{l} \times \mathbf{B}_g\right) = I_1 dl B_g$$

$$T = r\int_b^a dF = B_g A_1 N_1 I_1 \tag{9B.4}$$

The moving coil moves clockwise until $T = 0$ is reached. To operate the machine as a motor, an AC source is needed to produce continuous motion – in a DC machine the voltage is switched via the commutator on the rotor.

Moving Coil Meter

The moving coil is free to rotate in the air gap field. The magnetic field is produced by a permanent magnet. The current to be measured (I_1) is fed via the control springs:

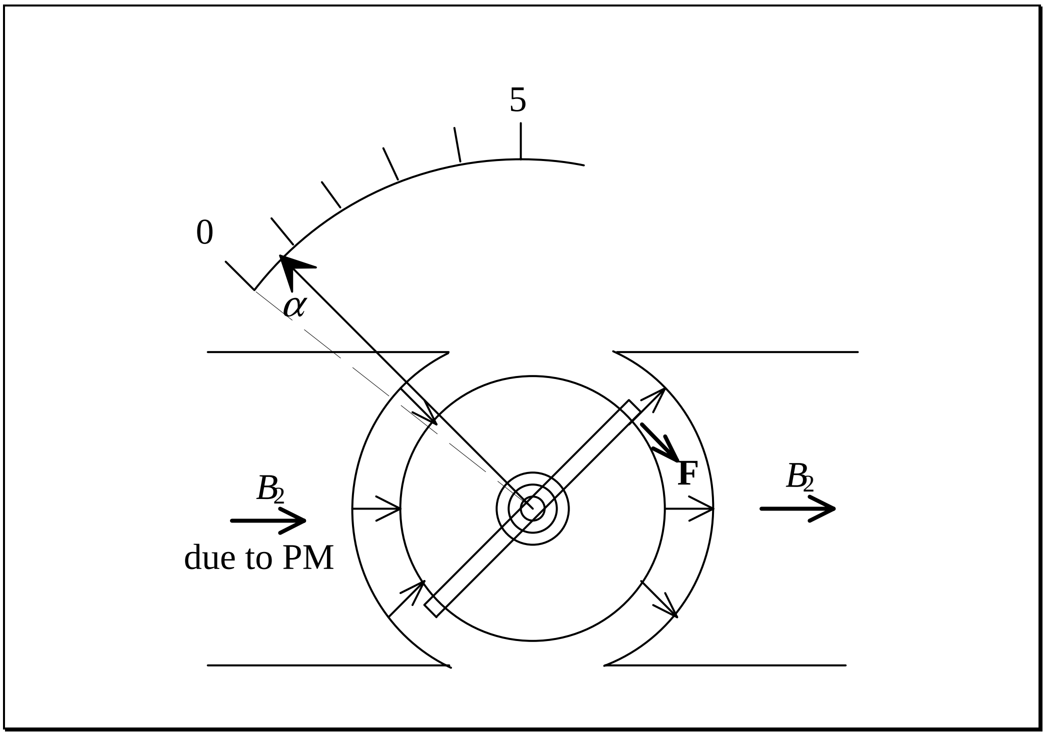

Figure 9B.5

The electric deflecting torque T_d (due to I_1 and B_g) causes rotation of the moving coil (and the attached pointer) against the restoring torque of the spring (T_r).

9B.6

If B_g is constant, then:

$$\begin{aligned} T_d &= K_d I_1 \qquad K_d = B_g A_1 N_1 \\ T_r &= K_r \alpha \qquad K_r = \text{spring constant} \end{aligned} \tag{9B.5}$$

At balance:

$$T_d = T_r \tag{9B.6}$$

and the deflection of the pointer is:

$$\alpha = KI_1 \tag{9B.7}$$

The scale of a moving coil meter is therefore linear (uniformly divided).

For time varying currents, the pointer will respond to the average deflecting torque (due to the inertia of the coil):

$$\begin{aligned} T_{d_{AV}} &= \frac{1}{T}\int_0^T T_d dt = K_d \frac{1}{T}\int_0^T i_1 dt = K_d I_{1_{AV}} \\ \alpha &= KI_{1_{AV}} \end{aligned} \tag{9B.8}$$

If we apply a sinusoidal current, then:

$$\begin{aligned} i_1 &= \hat{I}_1 \cos \omega t \\ I_{1_{AV}} &= 0 \end{aligned} \tag{9B.9}$$

To obtain a reading, i_1 is rectified.

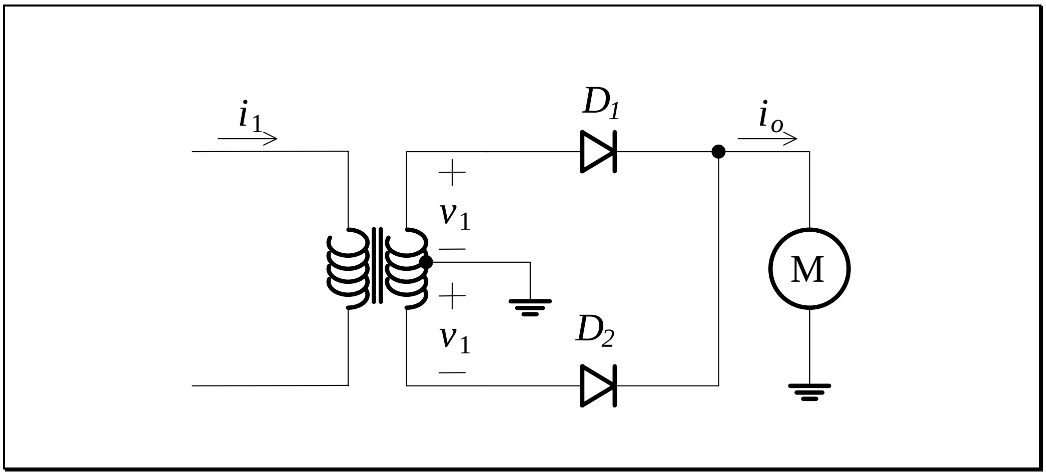

Figure 9B.6

For a full wave rectified (FWR) sine wave:

$$I_{AV} = \frac{2}{\pi}\hat{I}$$

$$I_{RMS} = \frac{\hat{I}}{\sqrt{2}} = \frac{\pi}{2\sqrt{2}} I_{AV} = 1.11 I_{AV} \quad \text{(9B.10)}$$

The scale may therefore be calibrated in RMS values (average x 1.11).

The moving coil meter responds to the average value, so AC moving coil meters use a FWR to read sine wave RMS values.

References

Slemon, G. and Straughen, A.: *Electric Machines*, Addison-Wesley Publishing Company, Inc., Sydney, 1982.