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Name of the course— B.Sc. (H) Physics

Semester- IV

Name of the paper—Electrical circuits and Network Skills

Paper code-32223903

Lecture timings: 10:40 to 12:40 AM

Topics to be covered:

Name of the unit: Electric motors

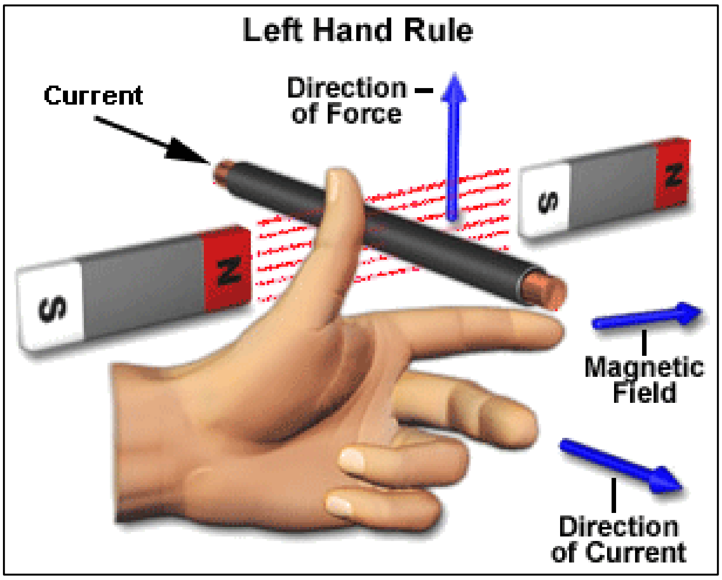
- *DC motor (Basic idea)*
- *Control or interfacing Dc motors using various circuits*

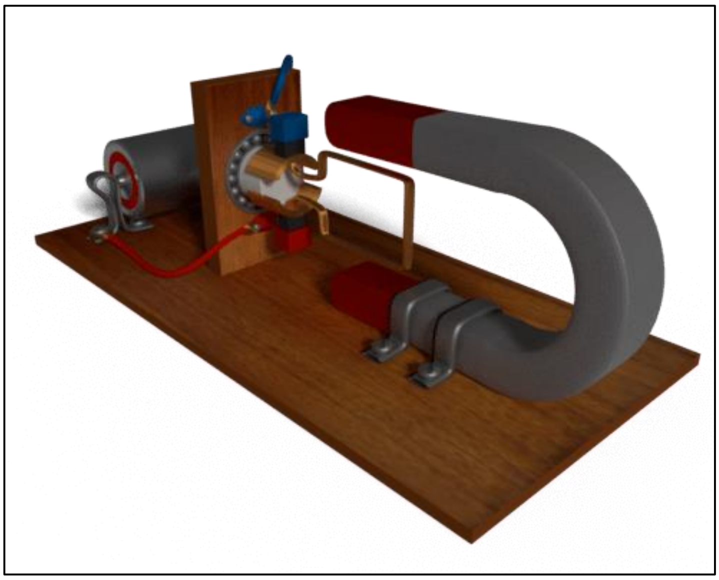
What is DC Motor?

The electric motor operated by dc is called **dc motor**. This is a device that converts DC electrical energy into a mechanical energy.

Principle of DC Motor

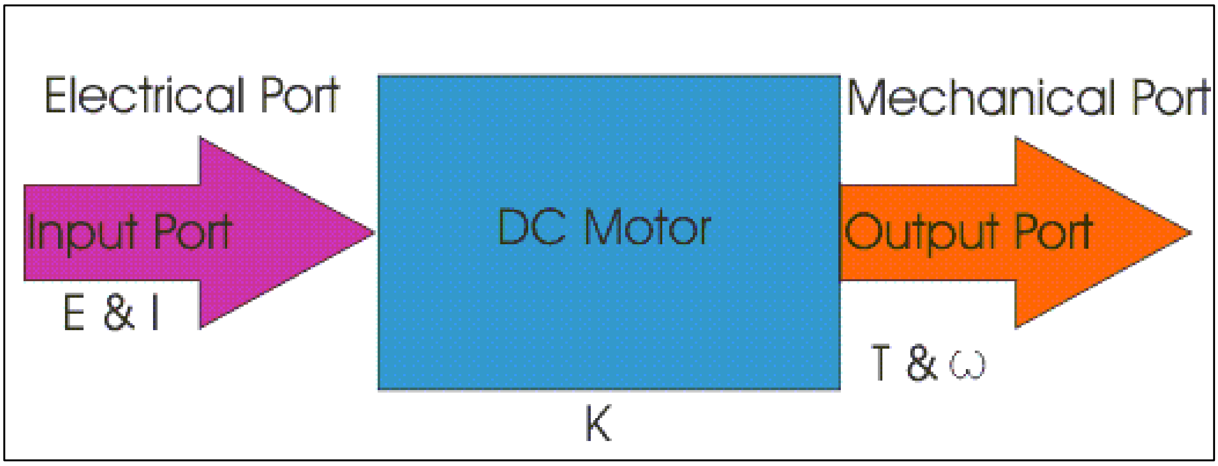
When a current carrying conductor is placed in a magnetic field, it experiences a torque and has a tendency to move. In other words, when a magnetic field and an electric field interact, a mechanical force is produced. The **DC motor** or **direct current motor** works on that principal. This is known as motoring action.





The direction of rotation of a this motor is given by Fleming's left hand rule, which states that if the index finger, middle finger, and thumb of your left hand are extended mutually perpendicular to each other and if the index finger represents the direction of magnetic field, middle finger indicates the direction of current, then the thumb represents the direction in which force is experienced by the shaft of the **DC motor**.

Structurally and construction wise a direct current motor is exactly similar to a DC generator, but electrically it is just the opposite. Here we unlike a generator we supply electrical energy to the input port and derive mechanical energy from the output port. We can represent it by the block diagram shown below.



Here in a DC motor, the supply voltage E and current I is given to the electrical port or the input port and we derive the mechanical output i.e. torque T and speed ω from the mechanical port or output port.

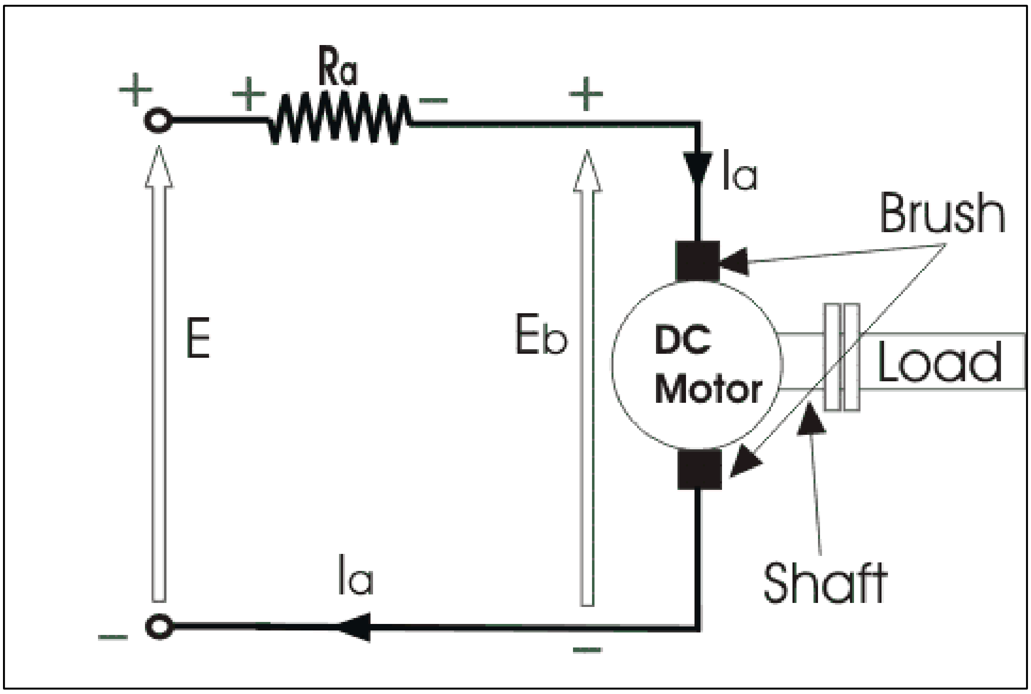
The parameter K relates the input and output port variables of the **direct current motor**.

$T = KI \; and \; E = K\omega$

So from the picture above, we can well understand that motor is just the opposite phenomena of a DC generator, and we can derive both motoring and generating operation from the same machine by simply reversing the ports.

Detailed Description of a DC Motor

To understand the DC motor in details let’s consider the diagram below,



The circle in the center represents the direct current motor. On the circle, we draw the brushes. On the brushes, we connect the external terminals, through which we give the supply voltage. On the mechanical terminal, we have a shaft coming out from the center of the armature, and the shaft couples to the mechanical load. On the supply terminals, we represent the armature resistance R_a in series.

Now, let the input voltage E, is applied across the brushes. Electric current which flows through the rotor armature via brushes, in presence of the magnetic field, produces a torque T_g. Due to this torque T_g the dc motor armature rotates. As the armature conductors are carrying currents and the armature rotates inside the stator magnetic field, it also produces an emf E_b in the manner very similar to that of a generator. The generated Emf E_b is directed opposite to the supplied voltage and is known as the back Emf, as it counters the forward voltage. The back emf like in case of a generator is represented by

$$E_b = \frac{P.\varphi.Z.N}{60.A} \text{..........................} (1)$$

Where, P = no of poles

φ = flux per pole

Z= No. of conductors

A = No. of parallel paths

and N is the speed of the DC Motor.

So, from the above equation, we can see E_b is proportional to speed 'N.' i.e. whenever a direct current motor rotates; it results in the generation of back Emf. Now let's represent the rotor speed by ω in rad/sec.

So E_b is proportional to ω.

So, when the application of load reduces the speed of the motor, E_b decreases. Thus the voltage difference between supply voltage and back emf increases that means $E - E_b$ increases. Due to this increased voltage difference, the armature current will increase and therefore torque and hence speed increases. Thus a DC Motor is capable of maintaining the same speed under variable load.

Now armature current I_a is represented by

$$I_a = \frac{E - E_b}{R_a}$$

Now at starting,speed ω = 0 so at starting $E_b = 0$.

$$\therefore\ I_a = \frac{E}{R_a}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Now since the armature winding electrical resistance R_a is small, this motor has a very high starting current in the absence of back Emf. As a result we need to use a starter for starting a DC Motor.

Now as the motor continues to rotate, the back emf starts being generated and gradually the current decreases as the motor picks up speed.

Types of DC Motors

Direct motors are named according to the connection o the field winding with the armature. There are 3 types:

1. Shunt wound DC motor
2. Series wound DC motor
3. Compound wound DC motor

8.4 CONTROL OF DC MOTORS

Control of dc motors is accomplished by using SCRs to modulate the input voltages to the armature and/or the field circuit of the motor. For an ac source, phase-controlled rectifiers are employed; for a dc source, choppers. But before we discuss these, it is worthwhile to consider the analysis of some passive RL-circuits involving diodes or SCRs.

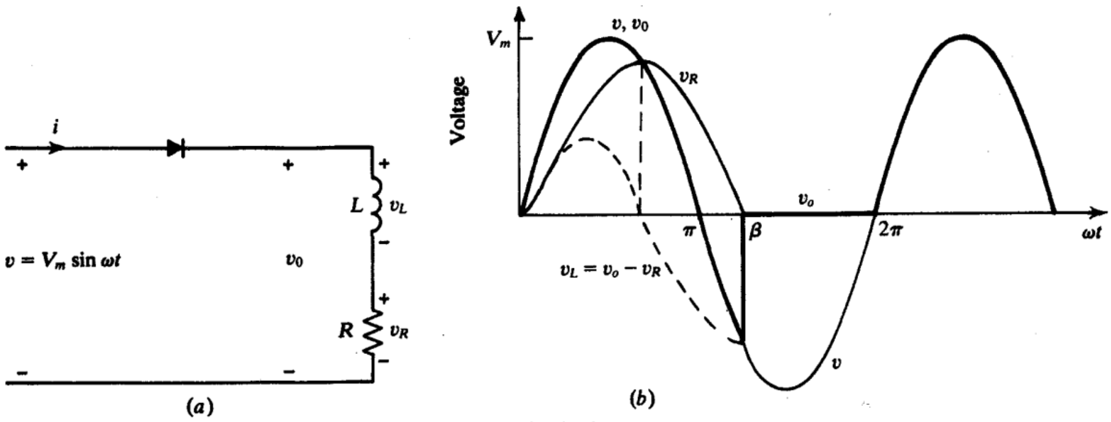


Fig. 8-10

1. *Half-wave rectifier with RL-load.* A half-wave rectifier with *RL*-load is indicated in Fig. 8-10(*a*). It may be shown (see Problem 8.23) that the current during one period of the applied voltage $v = V_m \sin \omega t$ is given by

$$i = \begin{cases} \dfrac{V_m}{Z}\left[\sin(\omega t - \phi) + e^{-(R/L)t}\sin\phi\right] & 0 < \omega t < \beta \\ 0 & \beta < \omega t < 2\pi \end{cases} \qquad (8.5)$$

where

$$Z = \sqrt{R^2 + (\omega L)^2} \qquad \tan \phi = \frac{\omega L}{R}$$

The *extinction time* (the time at which the diode stopped conducting) is β/ω; and β can be found from the condition that i be continuous at the extinction time. Thus:

$$\sin (\beta - \phi) + e^{-\beta \cot \phi} \sin \phi \pm 0 \tag{8.6}$$

a transcendental equation for β. The average value of $i(t)$ over a period $2\pi/\omega$ is (see Problem 8.2)

$$I_{avg} = \frac{V_m}{2\pi R} (1 - \cos \beta) \tag{8.7}$$

Because the average voltage across the inductor is zero, the average voltage across the load is given by

$$V_{o\,avg} = V_{R\,avg} = RI_{avg} = \frac{V_m}{2\pi} (1 - \cos \beta) \tag{8.8}$$

The four voltage waveforms are shown in Fig. 8-10(*b*)

2. *Half-wave rectifier with dc-motor load.* The circuit is shown in Fig. 8-11(*a*), where R and L are respectively the armature-circuit resistance and inductance, and e' is the motor back emf, assumed constant. The circuit analysis leads to the following expression for the current:

$$i = \begin{cases} 0 & 0 < \omega t < \alpha \\ \dfrac{V_m}{Z} [\sin (\omega t - \phi) + Be^{-(R/L)t}] - \dfrac{e'}{R} & \alpha < \omega t < \beta \\ 0 & \beta < \omega t < 2\pi \end{cases} \tag{8.9}$$

where

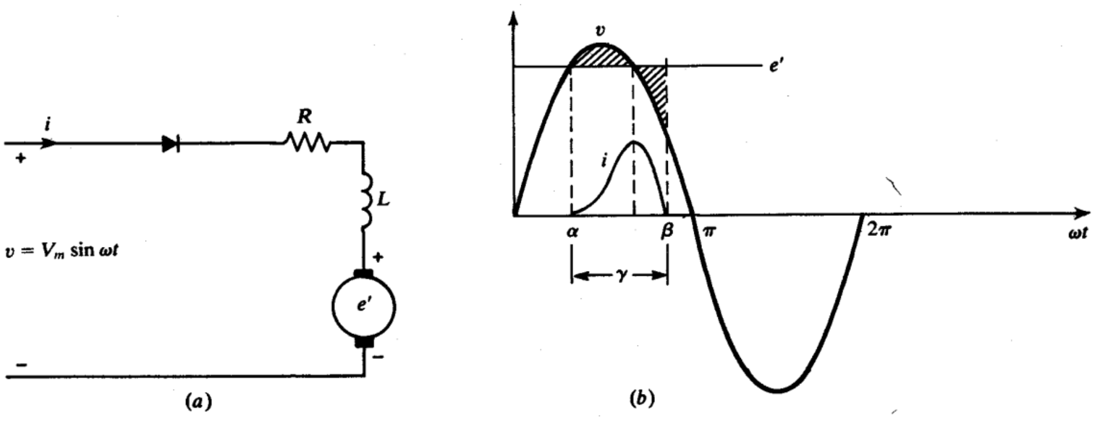


Fig. 8-11

$$Z = \sqrt{R^2 + (\omega L)^2} \qquad \tan \phi = \frac{\omega L}{R}$$

and where

$$B \equiv \left[\frac{e'}{V_m \cos \phi} - \sin (\alpha - \phi) \right] e^{\alpha R/\omega L} \tag{8.10}$$

is such as to make i continuous at $\omega t = \alpha$. It is seen from (*8.9*) that the diode starts conducting at $\omega t = \alpha$; the *firing angle*, α, is determined by the condition $v = e' + 0$, i.e.,

$$\sin \alpha = \frac{e'}{V_m} \tag{8.11}$$

As is shown in Fig. 8-11(b), conduction does not necessarily stop when v becomes less than e'; rather, it ends at $\omega t = \beta$, when the energy stored in the inductor during the current buildup has been completely recovered. The *extinction angle*, β, may be determined from the continuity of (*8.9*) at $\omega t = \beta$; we find

$$\sin(\beta - \phi) + Be^{-\beta \cot\phi} = \frac{\sin \alpha}{\cos \phi} \tag{8.12}$$

as the transcendental equation for β, in which B is known from (*8.10*). The average value of the current over one period of the applied voltage is found to be

$$I_{\text{avg}} = \frac{1}{R} V_{R\text{avg}} = \frac{V_m}{2\pi R}(\cos \alpha - \cos \beta - \gamma \sin \alpha) \tag{8.13}$$

where $\gamma \equiv \beta - \alpha$ is the *conduction angle*. Figure 8-10(b) shows the waveforms.

SCR-Controlled DC Motor

In the example above, the dc-motor load was not controlled by the half-wave rectifier; the back emf remained constant, implying that the motor speed was unaffected by the cyclic firing and extinction of the diode. To achieve a control, we use a thyristor instead of the diode, as shown in Fig. 8-12(a). The corresponding waveforms are illustrated in Fig. 8-12(b). The motor torque (or speed) may be varied by varying α. Explicitly, for the armature we integrate

$$v_m = Ri + L\frac{di}{dt} + e \tag{8.14}$$

over the conduction period $\alpha/\omega < t < \beta/\omega$, during which v_m coincides with the line voltage v. The result is:

$$V'_m = \frac{V_m(\cos \alpha - \cos \beta)}{\gamma} = RI' + E' \tag{8.15}$$

where a prime indicates an average over the conduction period. Over a full period of the line voltage, the average armature current is given by

$$I_{\text{avg}} = \frac{\gamma}{2\pi} I' \tag{8.16}$$

and the average torque is given by

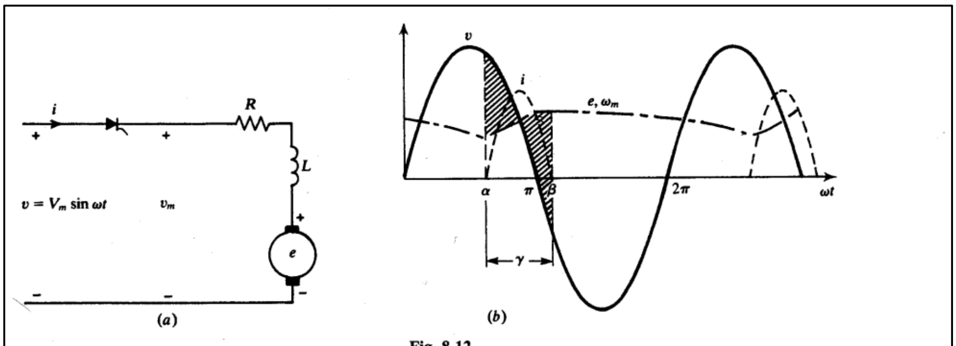


Fig. 8-12

$$T_{avg} = kI_{avg} = \frac{k\gamma}{2\pi} I' \tag{8.17}$$

Equations (*8.15*), (*8.16*), and (*8.17*) govern the steady-state performance of a thyristor-controlled dc motor.

Chopper-Controlled DC Motor

A motor-chopper simplified circuit, and the corresponding voltage and current waveforms are given in Fig. 8-13. Observe that when the thyristor turns off, the applied voltage, v_m drops from V_t to zero. However, armature current i continues to flow through the path completed by the freewheeling diode until all the energy stored in L has been dissipated in R. Then v_m becomes equal to the motor back emf and stays at that value until the thyristor is turned on, whereupon it regains the value V_t.

If the speed pulsations are small, then the motor back emf may be approximated by its average value, $k\Omega_m$, yielding

$$L\frac{di}{dt} + Ri + k\Omega_m = v_m = \begin{cases} V_t & 0 < t < \alpha\lambda \\ 0 & \alpha\lambda < t < \gamma\lambda \\ k\Omega_m & \gamma\lambda < t < \lambda \end{cases} \tag{8.18}$$

as the electrical equation of the system. Here, λ is the period of the thyristor signal, α is the fraction of the period over which the thyristor is conductive (the *duty cycle*), and γ is the fraction of the period over which armature current flows.