the conductor. In Fig. 2.1 the current will flow from top to bottom in the conductor. This is known as *Fleming's right-hand rule,* and is illustrated in Fig. 2.4.

Using the right-hand rule, it can be seen that changing *either* the direction of motion of the conductor *or* the direction of the lines of flux will cause the direction of the current to change. If both directions are reversed, the direction of current will remain the same.

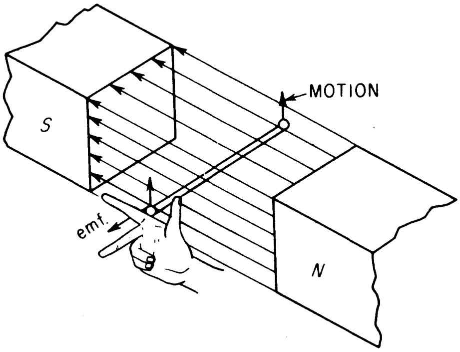


FIG. 2.4. The right-hand rule.

LENZ'S LAW 2.4

When a conductor is moved through a magnetic field a voltage is induced in the conductor. If the circuit is closed, the induced voltage will cause a current flow. The magnetic field produced by the current will always oppose the motion of the conductor. This is known as *Lenz's law.* The principle is illustrated in Fig. 2.5.

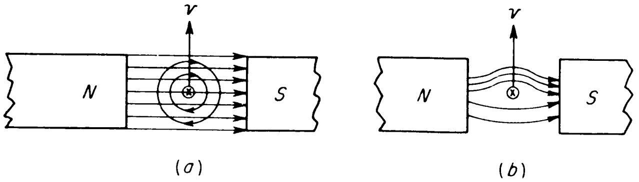


FIG. 2.5. (a) Magnetic field produced by poles and by current in a conductor; (b) resultant magnetic field.

It can be seen from the resultant field that the flux density is greater above the conductor than below. This greater flux density opposes the motion of the conductor. This agrees with the law of conservation of energy in that the mechanical energy expended to overcome the opposing force is converted to electrical energy. Lenz's law also agrees with Newton's third law of motion: to every action there is an equal and opposite reaction.

in a 10-in. conductor traveling at right angles to the magnetic field with a velocity of 10 ft per sec?

2.10 Convert the answer to the preceding problem into webers per square meter.

2.11 The angle between the direction of motion of a conductor and the lines of flux is 30°. The length of the conductor in the magnetic field is 1.5 ft, and its velocity is 10,800 ft per min. Find the voltage induced in the conductor if the flux density is 10,000 lines per sq in.

2.12 The following is known: (*a*) length of a conductor in a magnetic field, 50 cm; (*b*) velocity of the conductor in the magnetic field, 10,000 ft per min; (*c*) flux density, 0.2325 Wb/m^2; (*d*) angle of travel between flux and conductor, 30 degrees. Determine the induced voltage in the conductor.

2.13 (*a*) If the conductor in Prob. 2.12 were moving at right angles to the direction of flux, what length of conductor would be necessary to produce the same induced voltage? (*b*) The direction of motion of the conductor has been changed so that the induced voltage is zero. Find the angle between the path of the conductor and the lines of flux.

2.14 The flux per pole of a two-pole generator is 4000 lines. Find the average voltage induced in a coil of 30 turns rotating at (*a*) 1800 r/min; (*b*) 3600 r/min.

2.15 A two-pole generator produces 2.5×10^{-5} Wb. Determine the average induced voltage in a coil of 50 turns rotating at 7536 rad/min.

2.16 If the generator in the previous problem were a four-pole generator, find the induced voltage when the coil is rotating at (*a*) 1800 r/min; (*b*) 3600 r/min.

2.17 How many turns are required to obtain a voltage of 0.06 V in a coil rotating at 2000 r/min if the flux per pole of a six-pole generator is 3×10^3 maxwells?

2.18 The following information is known about a generator: number of poles, 4; flux per pole, 20,000 lines; turns per coil, 50; speed of rotation, 1800 r/min. How many coils must be connected in series to obtain a voltage of 120?

2.19 Determine the number of coils required in a generator with four poles having a flux per pole of $15{,}000 \times 10^{-8}$ Wb and rotating at a speed of 30 r/s. There are 60 turns in each coil and the total required voltage is 115 V.

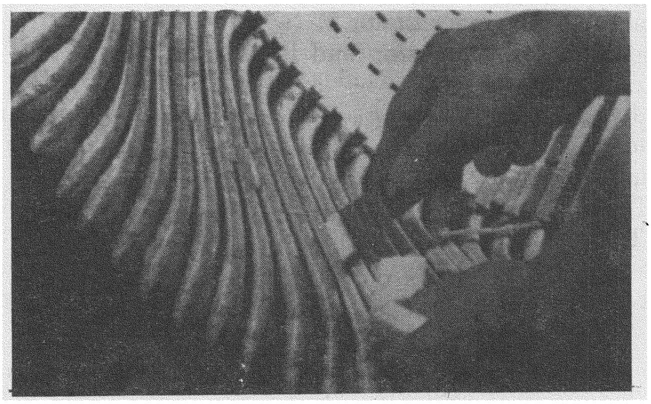
2.20 The voltage obtained from several coils connected in series is 75 V. What voltage will be obtained if the speed is reduced from 1800 to 1200 r/min?

2.21 What voltage will be obtained from the coils in Prob. 2.20 if the flux is reduced by 20 per cent and the speed remains constant?

CHAPTER 4
Armature Windings

GENERAL 4.1

The subject of windings always seems to be difficult for the student to grasp. This is due to the introduction of complex diagrams and new terminology, and therefore the ultimate purpose of the winding is lost in the discussion of the topic. We shall therefore attempt to simplify the diagrams, introduce and define new terms, and present the theory and purpose of each winding.



Detail of coil-lock bracing, showing application of felt pads between coil sides. (Courtesy of General Electric Co.)

TERMINOLOGY 4.2

It is necessary to understand the following terms before discussing windings:

coil. One or more turns of wire grouped together and mounted on the drum-wound armature in order to cut lines of flux (Fig. 4.1).

coil side. Any side of the coil that cuts lines of flux.

inductor. One of the wires making up the coil side. A voltage is induced in the inductor.

the lap winding, the wave winding is *progressive* if the coils fill the slots in a *clockwise* direction, or *retrogressive* if the slots are filled in a *counterclockwise* direction, when viewed from the commutator end.

4.9 OTHER WAVE WINDINGS

In addition to the simplex winding, a wave winding may also be wound on an armature as a duplex or triplex winding in much the same manner as the lap winding. For a duplex winding the coils are placed in every second slot, and for a triplex winding the coils are placed in every third slot, until all the slots are filled.

A wave winding may also be a double or triple reentrant winding, depending upon the number of times the completed winding closes upon itself.

4.10 CHARACTERISTICS OF THE WAVE WINDING

All wave windings exhibit a marked characteristic. A careful examination of Fig. 4.8 shows that some of the coils that are not cutting lines of flux connect

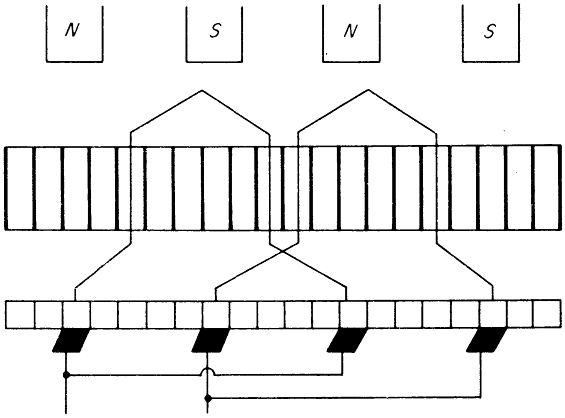


FIG. 4.8. Wave winding. Coils in neutral plane electrically connect brushes of like potential.

all the positive brushes together. Other coils not cutting lines of flux connect together all the negative brushes. Since these coils act as electrical connections between brushes, it is necessary to have only *two brushes, regardless of the number of poles in the dynamo.* More than two brushes may be found on some dynamos, but this is done to avoid the use of large brushes.

A further study shows that there are only *two parallel paths in a simplex wave winding regardless of the number of poles.* A duplex wave winding has four parallel paths, and a triplex wave winding has six parallel paths, regardless of the number of poles.