DIRECT CURRENT MACHINES

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Contents

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Summary

This chapter gives a background to the principles behind the operation of dc motors and stepper motors. Permanent magnet, shunt, separately excited, series and compound wound dc motor connections are described. A description of the equations behind the basic behavior of these machines is given and the torque vs speed and speed vs armature (voltage and current) characteristics are illustrated, which gives a background to the control of these motors.

1. Introduction

Electrical machinery has been in existence for many years. The applications of electrical machines have expanded rapidly since their first use many years ago. At the present time, applications continue to increase at a rapid rate.

The use of electrical motors has increased for home appliances and industrial and commercial applications for driving machines and sophisticated equipment. Many machines and automated industrial equipment require precise control. Direct current motors are ideal for applications where speed and torque control are required. Direct current motor design and complexity has changed from early times where dc machines were used primarily for traction applications. Direct current motors are used for various applications ranging from steel rolling mills to tiny robotic systems. Motor control methods have now become more critical to the efficient and effective operation of machines and equipment. Such innovations as servo control systems and industrial robots have led to new developments in motor design.

Our complex system of transportation has also had an impact on the use of electrical machines. Automobiles and other means of ground transportation use electrical motors for starting and generators for their battery-charging systems. Recently there have been considerable developments in electric vehicles and also in hybrid electric vehicles which use a combination of a dc motor and an internal combustion engine for efficient operation.

In this chapter machines driven by dc electrical supplies are considered. Since the operation of this type of machine is based upon the flow of current in conductors and their interaction with magnetic fields, common principles that underlie the behavior of dc machines will be examined first.

2. Magnetism and Electromagnetic Principles

Magnetism and electromagnetic principles are the basis of operation of rotating electrical machines and power systems. For this reason, a review of basic magnetic and electromagnetic principles will be given.

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2.1. Permanent Magnets

Permanent magnets are generally made of iron, cobalt, nickel or other ‘hard’ magnetic materials, usually in an alloy combination. The ends of a magnet are called north and south poles. The north pole of a magnet will *attract* the south pole of another permanent magnet. A north pole *repels* another north pole and a south pole *repels* another south pole. The two laws of magnetism are:

1) Unlike poles attract (see Figure 1);
2) Like poles repel (see Figure 2).

The magnetic field patterns when two permanent magnets are placed end to end are shown in Figures 1 and 2. When the magnets are farther apart, a smaller force of attraction or repulsion exists. A *magnetic field*, made up of *lines of force* or *magnetic flux*, is set up around any magnetic material. These magnetic flux lines are invisible but have a definite direction from the magnet’s north to south pole along the outside of the magnet. When magnetic flux lines are close together, the magnetic field is stronger than when further apart. These basic principles of magnetism are extremely important for the operation of electrical machines.

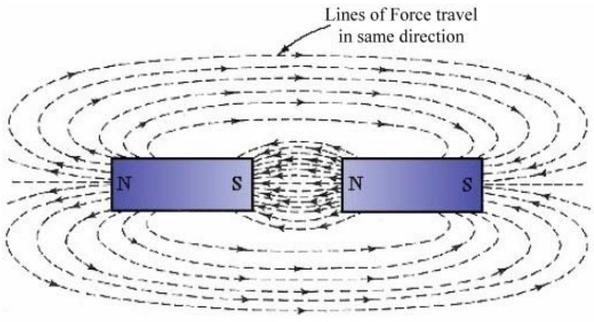

Figure 1: Unlike poles attract

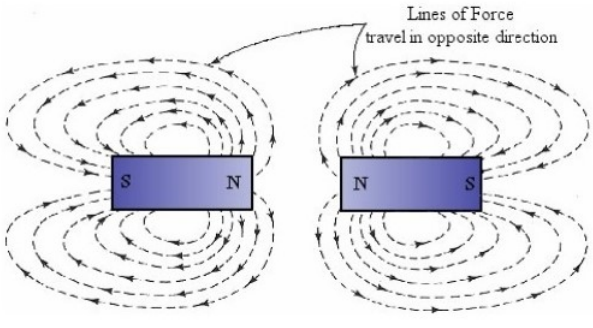

Figure 2: Like poles repel

2.2. Magnetic Field around Conductors

Current-carrying conductors, such as those in electrical machines, produce a magnetic field. It is possible to show the presence of a magnetic field around a current-carrying conductor. A compass may be used to show that magnetic flux lines around a conductor are circular in shape.

A method of remembering the direction of magnetic flux around a conductor is the right-hand "cork-screw" rule. If a conductor is held in the right hand as shown in Figure 3, with the thumb pointing in the direction of current flow from positive to negative, the fingers then encircle the conductor, pointing in the direction of the magnetic flux lines.

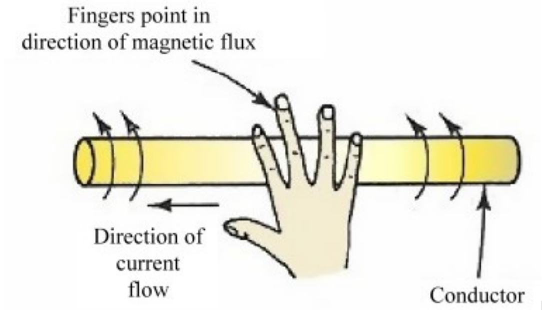

Figure 3: Right-hand rule

The circular magnetic field is stronger near the conductor and becomes weaker at a greater distance. A cross-sectional end view of a conductor with current flowing toward the observer is shown in Figure 4. Current flow towards the observer is shown by a circle with a dot in the centre. Notice that the direction of the magnetic flux lines is counter-clockwise, as verified by using the right-hand rule.

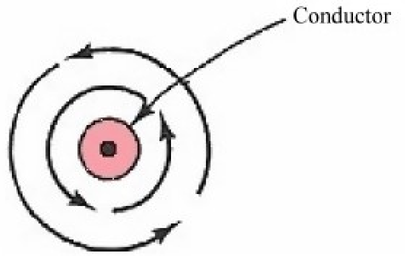

Figure 4: Current out of the page

When the direction of current flow through a conductor is reversed, the direction of the magnetic lines of force is also reversed. The cross-sectional end view of a conductor in Figure 5 shows current flow in a direction away from the observer. Notice that the direction of the magnetic lines of force is now clockwise.

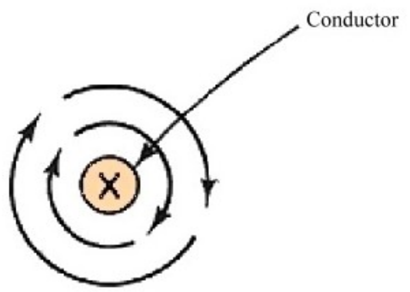

Figure 5: Current into the page

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When two conductors are placed parallel to each other, and the direction of current through both of them is the same, the magnetic field lines amalgamate to become one and the two conductors attracted together. See Figure 6.

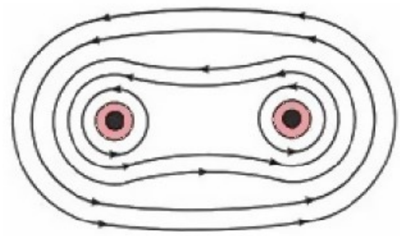

Figure 6: Two parallel conductors

The presence of magnetic lines of force around a current-carrying conductor can be observed by using a compass. When a compass is moved around the outside of a conductor, its needle will align itself tangentially to the lines of force as shown in Figure 7.

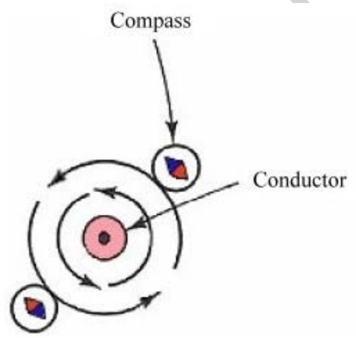

Figure 7: Field's effect on a compass

When current flow is in the opposite direction, the compass polarity reverses but remains tangential to the conductor.

2.3. Magnetic Field around a Coil

The magnetic field around one loop of wire is shown in Figure 8.

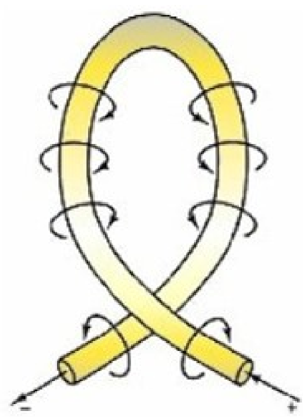

Figure 8: Loop of wire

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Magnetic flux lines extend around the conductor as shown when current passes through the loop. Inside the loop, the magnetic flux is in one direction. When many loops are joined together to form a coil as shown in the Figure 9, the magnetic flux lines surround the coil as shown in Figure 10. The field produced by a coil is much stronger than the field of one loop of wire. The field produced by a coil is similar in shape to the field around a bar magnet. A coil carrying current, often with an iron or steel core inside it is called an electromagnet. The purpose of a core is to provide a low reluctance path for magnetic flux, thus increasing the flux that will be present in the coil for a given number of turns and current through the coil.

Figure 9: Coil formed by loops

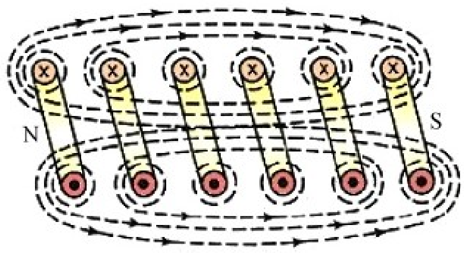

Figure 10: Cross-sectional view of the above coil

2.4. Electromagnets

Electromagnets are produced when current flows through a coil of wire as shown below. Almost all electrical machines have electromagnetic coils. The north pole of a coil of wire is the end where the lines of force exit, while the south polarity is the end where the lines of force enter the coil. To find the north pole of a coil, use the right-hand rule for polarity, as shown in Figure 11. Grasp the coil with the right hand. Point the fingers in the direction of current flow through the coil, and the thumb will point to the north polarity of the coil. When the polarity of the voltage source is reversed, the magnetic poles of the coil reverse.

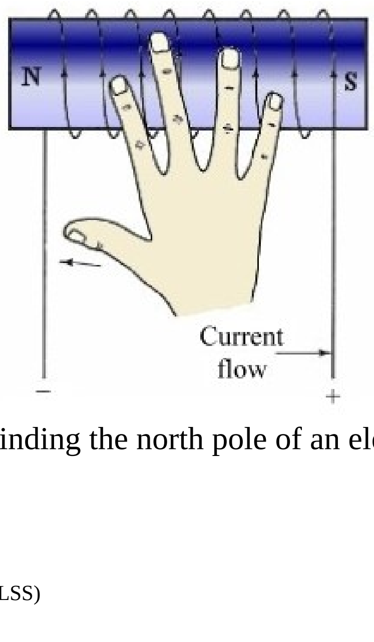

Figure 11: Finding the north pole of an electromagnet

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The poles of an electromagnet can be checked by placing a compass near a pole of the electromagnet. The north-seeking pole of the compass will point toward the north pole of the coil.

2.5. Magnetic Strength of Electromagnets

The magnetic strength of an electromagnet depends on three factors: (1) the amount of current passing through the coil, (2) the number of turns of wire, and (3) the type of core material. The number of magnetic lines of force is increased by increasing the current, by increasing the number of turns of wire, by decreasing any air gap in the path of the magnetic flux, or by using a more desirable type of core material.

2.6. Electromagnetic Induction

The principle of electromagnetic induction is one of the most important discoveries in the development of modern electrical technology. Electromagnetic induction is the induction of electric voltage in an electrical circuit caused by a change in the magnetic field coupled to the circuit. When electrical conductors, such as alternator windings, are moved within a magnetic field, an electrical voltage is developed in the conductors. The electrical voltage produced in this way is called an *induced voltage*. A simplified illustration showing how induced voltage is developed is shown in Figure 12. Michael Faraday developed this principle in the early nineteenth century.

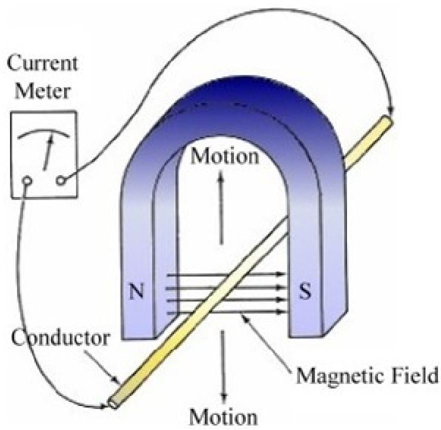

Figure 12: Faraday's Law

If a conductor is placed within the magnetic field of a horseshoe magnet so that the left side of the magnet has a north pole (N) and the right side has a south pole (S), magnetic lines of force travel from the north pole of the magnet to the south pole. The ends of the conductor in Figure12 are connected to a volt meter to measure the induced voltage. The meter can move either to the left or to the right to indicate the direction and magnitude of induced voltage. When the conductor is moved, the amount of magnetic flux contained within the electrical circuit (which includes the wire and the connections to the meter and the meter itself) changes. This change induces voltage through the conductor. Electromagnetic induction takes place whenever there is a change in the amount of flux coupled by a circuit. In this case the motion of the conductor in the **up** direction causes more magnetic flux to be contained within the circuit and the meter needle moves in one direction. Motion of the conductor in the **down** direction causes **less** magnetic flux to be coupled by the circuit and the meter needle moves in the opposite direction. The principle demonstrated here is the basis for large-scale electrical power generation.

In order for an induced current to be developed, the conductor must be in a complete path or closed circuit, the induced voltage will then cause a current to flow in the circuit.

3. Current Carrying Wires and Coils

The basic requirement of any electrical machine, whether ac or dc, is a method of producing torque. This section explores how two magnetic fields in a machine interact to produce a force which produces a torque in a rotating machine.

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Biographical Sketch

E.D. Spooner graduated from the University New South Wales, Australia, and obtained his ME in 1965. He is currently a project leader for Australia's Renewable Energy Systems testing Laboratory and Lecturer in Electrical Engineering. His research has covered power electronics and drives and is currently focused in renewable energy systems.