Electromagnetism and Magnetic Circuits

6

6.1 INTRODUCTION

An understanding of electromagnetism is an essential aspect of electrical engineering because it is the key to the operation of large number of electrical devices and systems, found in industry as well as in homes. All electric motors and generators depend upon the electromagnetic field as the coupling device permitting interchange of energy between and electrical system and a mechanical system and vice-versa. Similarly, static transformers provide the means of transferring energy from one electrical system to another through the medium of a magnetic field.

It is the purpose of this chapter to provide the background related to magnetic fields and its salient characteristics and more readily appreciate the role played by magnetic fields in electrical equipments. The subject matter is discussed under two main headings *viz.* electromagnetism and magnetic circuits.

Part I : *ELECTROMAGNETISM*

6.2 BRIEF HISTORY AND IMPORTANT TERMS

- Oersted discovered in 1819 that whenever an electric current flows through a conductor, a magnetic field is created in the space around the conductor. This was explained by the statement that the flow of current through a conductor causes movement of the flow of the electron. The motion of the electrons produces magnetic field. The research was carried out to find out the converse *i.e.*, if conductor is brought in a magnetic field, does an e.m.f. induce or movement of electrons take place. Thus the work advanced in the direction of conversion of magnetism into electricity.
- In 1831, Michael Faraday discovered that if a closed conductor is moved in a magnetic field in a certain manner there will be an induced current in the moving conductor. This phenomenon is known as *electromagnetic induction*. Further, Faraday enunciated the basic laws of electromagnetic induction upon which is based the working of most of the commercial apparatus like motors, generators and transformers etc. This was produced experimentally and then analytically that when a magnetic field linking with a closed conductor moves relative to the conductor, it produces a flow of electrons (*i.e.*, current).

We will now define some of the terms as under:

Magnet

- A magnet is defined as that solid body which possess the property of attracting magnetic substances such as iron pieces and pieces of other metals like nickel, manganese, cobalt etc. to a greater or smaller extent. This property is also found in magnetic (a mineral stone), which exhibits the following properties:
- It attract small pieces of iron filings or small pieces of steel and other magnetic substance.
- It takes a position point North and South, when suspended freely in a horizontal position.

Magnetic Pole

The force of attraction of the magnet for iron filings is maximum at both ends but is almost nil at the centre. The ends of the magnet, where attraction is maximum, are referred as *poles*. The end which points towards the geographical North Pole is called the *North Pole*, and the other is called the *South Pole*. It should be clearly understood that the pole of a magnet is a region and not a point, although for purposes of calculations, it is assumed to be so.

If a magnetic needle is brought nearer to a magnet, its *S* pole is attracted by the *N*-pole of the magnet. However, the *N*-pole of the needle is repelled by the *N*-pole of the magnet. This shows that *like poles repel whereas unlike poles attract each other*. This fact helps us in the practical field to determine the poles of the electric motors and generators.

Magnetic Field

It is the entire space around the magnet where magnetic force (or effect) is experienced.

The magnetic field can be mapped with the help of a small compass needle into a series of imaginary lines, called *lines of magnetic flux* or *magnetic lines of forces*. At any point the needle settles so that its length is tangential to the lines of magnetic flux through that point. At that point the north-seeking end of the needle points in the direction of the field. The lines of force due to a bar magnet are shown in Fig. 6.1.

In any horizontal plane, the shape and distribution of the lines of forces can be demonstrated with the help of iron filings. The filings settle in continuous chains demonstrating, the idea of the lines of flux.

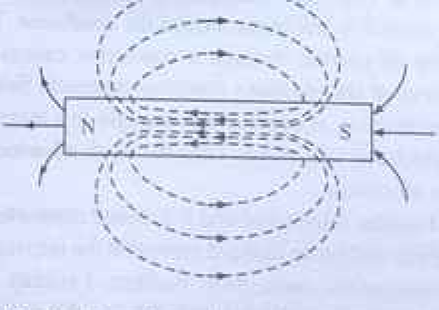

Fig. 6.1 *Lines of force due to a bar magnet*

Line of Induction

The lines of force are external to the magnet and they pass from north-pole through the field to the south-pole. But the lines within the magnetic material are called *lines of induction*. This is shown in Fig. 6.1.

Magnetic Flux

The lines obtained while drawing a map of the magnetic field with a compass needle are called lines of magnetic flux. They have no physical existence and so are referred as imaginary lines. They simply represent the distribution of a magnetic field.

The M.K.S. unit of magnetic flux is the weber (1 weber = 10^8 Maxwell). An e.m.f. of one volt is generated when a conductor cuts flux at the rate of one weber per second.

$$1 \text{ weber} = 1 \text{ volt} \times 1 \text{ second}$$

Field Strength (or Field Intensity H)

It is measured by the magnetic flux passing per unit area, taken round the point, where the strength is to be determined, and held perpendicular to it. Also it can be measured by the force experienced by a N-pole of one weber placed at that point. Hence the unit of H is Nw/Wb.

Flux Density (or Magnetic Induction B)

It is given by the flux passing per unit area within the substance through a plane at right angles to the flux. It is denoted by B and is measured in webers/m².

If a bar of magnetic material, say iron, is placed in a uniform magnetic field, it is magnetized by induction as shown in Fig. 6.1. If it develops a polarity of m webers, then its own flux is m webers. As explained above the lines within the iron bar are known as *line for induction and* those outside it are known as *lines of force*. The lines of induction per unit area is known as *induction density* (B)

$$B = \frac{\Phi}{A} \text{ Wb/m}^2 \text{ (or Tesla T)} \qquad \text{...(6.1)}$$

where Φ = Total flux through the bar in webers and A = Face or pole area of the bar in meter square.

Permeability

It is the ratio of flux density (B) produced in the material to that produced in air under similar conditions

$$\mu = \frac{B}{H} \qquad \text{...(6.2)}$$

where B = Flux density in Wb/m²

H = Magnetising force in amp-turns/m.

$\mu = \mu_0\mu_r$ = Absolute permeability of the material, with

$\mu_0 = 4\pi \times 10^{7}$ Henry/metre = free space permeability

μ_r = Relative permeability *i.e.*, the permeability of the material with respect to that for free space

$$= \left[\frac{B(\text{material})}{B(\text{vacuum})}\right]_{H\text{-constant}} \qquad \text{...(6.3)}$$

This expression shows that the relative permeability can be defined by the ratio of flux density produced in the material to the flux density produced in vacuum by the same magnetising force (H).

Intensity of Magnetisation (I)

It is the pole strength developed per unit area of the bar, or magnetic moment developed per unit volume of the bar.

Similarities :

Sr. No.	Electric Circuit	Magnetic Circuit
1.	**Current** - Flow of Electrons through conductor is current, it is measured in Amp.	**Flux** - Lines of force through a medium from N pole to S pole form flux. It is measured in Weber.
2.	**EMF** - It is driving force for current, measured in volts.	**MMF** - It is driving force for flux, measured in amp - turn.
3.	**Resistance** - It is opposition of conductor to current measured in ohms.	**Reluctance** - It is opposition offered by magnetic path to flux measured in AT/Wb.
4.	Resistance is directly proportional to Length of conductor.	Reluctance is directly proportional to length of magnetic path.
5.	Resistance is inversely proportional to cross sectional area of conductor.	Reluctance is inversely proportional to cross sectional area of magnetic path.
6.	Resistance depends upon nature of conductor material (/)	Reluctance varies inversely according to permeability of medium $\frac{1}{\mu}$
7.	For electric circuit $I = \frac{\text{EMF}}{\text{Resistance}}$	For magnetic circuit $\phi = \frac{\text{MMF}}{\text{Reluctance}}$
8.	$\text{Conductance} = \frac{1}{\text{Resistance}}$	$\text{Permeance} = \frac{1}{\text{Reluctance}}$
9.	For electrical circuits we define the conductance.	For magnetic circuits we define permeability.
10.	Current density $\delta = I/a$ A/m^2	Flux density $B = \phi/a$ tesla
11.	Electric circuit is a closed path for current.	Magnetic circuit is a closed path for magnetic flux.
12.	The KVL and KCL are applicable to the electrical circuits.	The Kirchhoff's flux and m.m.f. laws are applicable to the magnetic circuit.

Dissimilarities :

Sr. No	Electric Circuit	Magnetic Circuit
1.	Current is actual flow of electrons.	Flux is direction of force - Nothing flows between N pole and S pole.
2.	Energy is required to produce current and to maintain it.	Energy is required to produce flux but not for its maintenance.
3.	Current does not pass through air.	Flux can pass through air also.
4.	Resistance is almost constant. It can vary slightly due to change in temperature.	Reluctance depends on permeability. Hence it can vary to a great extent due to the variations in the flux density. But reluctance does not change much with temperature.
5.	We can use insulation to define the path of current.	There is no insulator for magnetic flux. Hence its path cannot be defined.