Applied Physics Lecture 11

Chapter 7

Magnetism and Electromagnetism

7.6 Magnetic terms and Units

Following terms are commonly used while discussing the subject of magnetism and electromagnetism.

1. Magnetic Flux (Φ)

The entire group of magnetic lines of force coming out of the N-pole of a magnet is called magnetic flux (Fig. 7.4).

Unit. Unit of magnetic flux is weber (Wb).

2. Flux Density (B)

It is given by the flux incident normally on a unit area. As shown in Fig. 7.5, if a magnetic flux of Φ webers falls perpendicularly on an area of A m^2, then flux density is given by

$$B = \frac{\Phi}{A}$$

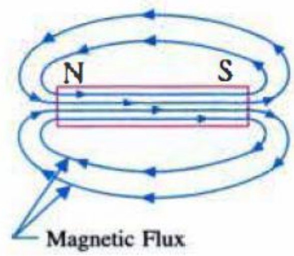


Fig. 7.4

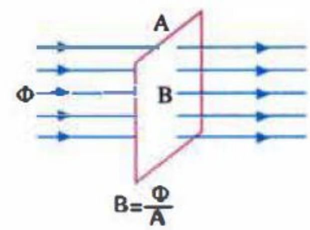


Fig. 7.5

Unit. Obviously, the unit for flux density is weber/metre^2 (Wb/m^2) which is also called Tesla (T).

3. Magnetic Field Strength (H)

It is also called intensity of magnetic field or (more commonly) magnetising force. As we know, each magnet has its own magnetic field consisting of lines of force which start from its *N*-pole, pass through the surrounding medium, re-enter the *S*-pole and complete their path from *S* to *N*-pole through the body of the magnet. When a magnetic material is placed in the magnetic field, it becomes magnetised whereas non-magnetic materials remain unaffected.

The strength of a magnetic field at any point is measured by the force experienced by a *N*-pole of 1 Wb placed there. A uniform magnetic field is one whose strength remains the same everywhere (Fig. 7.7). It is represented by equally-spaced straight lines of flux.

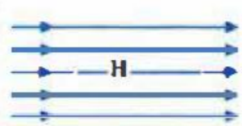


Fig. 7.6

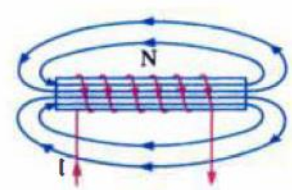


Fig. 7.7

Unit. The unit of H is newton/weber (N/Wb). It is the same thing as an ampere/meter (A/T) which is sometimes written as ampere-turn/meter (AT/m).

How

$$\frac{\boldsymbol{N}}{\boldsymbol{Wb}} = \frac{\boldsymbol{A}}{\boldsymbol{m}}\ \textbf{?}$$

Recall F = ILB

B = F/IL = N/Am

and

$$\Phi = B.A$$

$$Wb = \frac{N}{Am}.m^2 = \frac{Nm}{A}$$

Now

$$\frac{N}{Wb} = \frac{N}{\frac{Nm}{A}} = \frac{A}{m}$$

4. Magnetising Force of a Solenoid

As shown in Fig. 7.7, if L is the length of the iron core, the value of magnetising force produced by the electromagnetic is

$$H = \frac{NI}{l}\ \text{A/m or AT/m} \quad \text{OR N/Wb}$$

5. Permeability

It is the ability of a magnetic material to conduct magnetic flux through it. If it allows the flux to pass through more easily or readily, it is said to have greater permeability. The permeability of a substance is measured both in absolute terms and in relative terms with respect to vacuum (or approximately, air).

(a) Absolute Permeability (μ)

Suppose there is a uniform magnetic field of strength H established in air as shown in Fig. 7.8. Further, suppose that a bar of a magnetic material, say, iron is placed in it as shown in Fig. 7.9. The iron bar gets magnetised by *induction*. Suppose, it develops a *polarity* of m weber. Then, induced flux developed by it is also m weber. The lines of induction flux emanate from its N-pole, go around and re-enter its S-pole and then continue from S- to N-pole within the magnet as shown in Fig. 7.9.

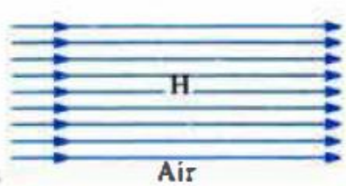


Fig. 7.8

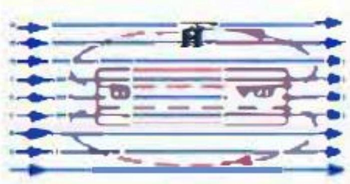


Fig. 7.9

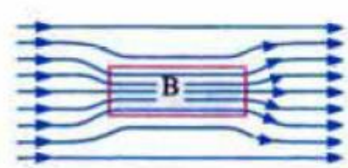


Fig. 7.10

These lines are seen to be in opposition to the lines of force of the main field H ***outside*** the magnet but in the same direction ***within*** it. The resultant field is shown in Fig. 7.10. If Φ is the ***total*** flux* passing through the bar and A is its pole area, then flux density within the bar is

$$B = \frac{\Phi}{A} \text{ tesla or Wb/m}^2$$

The absolute permeability of the bar is given by

$$\mu = \frac{B}{H} = \frac{\text{flux density}}{\text{magnetising force}}$$

Its unit is henry/metre (H/m).

Also, $\quad B = \mu H$ tesla

(b) Relative Permeability (μ_r)

The absolute permeability of vacuum is denoted by μ_0 and has been allotted the value of $4\pi \times 10^{-7}$ H/m. Permeabilities of all other magnetic materials are expressed in terms of the absolute permeability of vacuum which has been selected (by mutual agreement) as the reference medium.

Suppose a certain medium has an absolute permeability of μ. Then, its relative permeability (μ_r) *i.e.*, permeability as compared to vacuum is given by

$$\mu_r = \frac{\mu}{\mu_0} = \frac{\text{absolute permeability of medium}}{\text{absolute permeability of vacuum}}$$

Being a mere ratio of two similar quantities, it has no unit.

Also $\quad \mu = \mu_0 \mu_r$

As an example, suppose mild steel has a relative permeability $\mu_r = 400$. Then, its absolute permeability is given by

$$\mu = \mu_0 \mu_r = 4\pi \times 10^{-7} \times 400 \text{ H/m}$$
$$= 16\pi \times 10^{-5} \text{ H/m}$$

It is universal practice to give relative permeabilities of various media since μ can always be found by multiplying μ_r with μ_0 which is a universal constant.

6. Retentivity

It is the ability of a material to hold its magnetism after the magnetising force has been removed. Materials having high retentivity make good permanent magnets.

7. Hysteresis

Suppose the exciting coil of an electromagnet is energised by a source of alternating current (Fig. 7.11). As the current reverses its direction of flow through the coil, the flux also reverses its direction. Hence, the core also undergoes reversal of magnetisation. But it is found that magnetisation of the core does not reverse as quickly as the reversal of flux *i.e.*, the two are not in step with each other. This phenomenon is called hysteresis and is due to the retentivity of the magnetic material of the core.

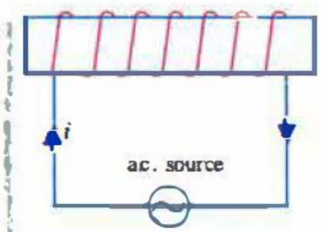


Fig. 7.11

Hysteresis leads to net loss of energy which is called hysteresis loss. This loss depends directly on

(*i*) maximum flux density B_{max} established in the core

(*ii*) frequency of reversal of magnetisation.

Reluctance ($\mathcal{R}$) The opposition to the establishment of a magnetic field in a material is called **reluctance ($\mathcal{R}$)**. The value of reluctance is directly proportional to the length (l) of the magnetic path, and inversely proportional to the permeability (μ) and to the cross-sectional area (A) of the material, as expressed by the following equation:

$$\mathcal{R} = \frac{l}{\mu A}$$

Reluctance in magnetic circuits is analogous to resistance in electric circuits. The unit of reluctance can be derived using l in meters, A (area) in square meters, and μ in Wb/At · m as follows:

$$\mathcal{R} = \frac{l}{\mu \mathrm{A}} = \frac{\cancel{\mathrm{m}}}{(\mathrm{Wb/At} \cdot \cancel{\mathrm{m}})(\cancel{\mathrm{m}}^2)} = \frac{\mathrm{At}}{\mathrm{Wb}}$$

At/Wb is ampere-turns/weber.

8. Permeance

It is the reciprocal of reluctance and resembles electrical conductance. Its unit is henry.

9. Reluctivity

It is specific reluctance and corresponds to electrical resistivity which is 'specific resistance'.

7.7. Ohm's Law for Magnetic Circuit

In Fig. 7.12 (*a*) is shown a magnetic circuit having iron path only, whereas in Fig. 7.12 (*b*) there is a small air gap in the circuit. Like electric circuit, a magnetic circuit also has three quantities interconnected by a law similar to Ohm's law.

The three quantities are :

1. Magnetomotive force (MMF)

It resembles voltage or *electromotive force* (*EMF*) in an electric circuit and is responsible for producing magnetic flux in a magnetic circuit. Its value is given by the product of current through the coil and its number of turns *i.e.*, *NI*. Its unit is ampere-turn*.

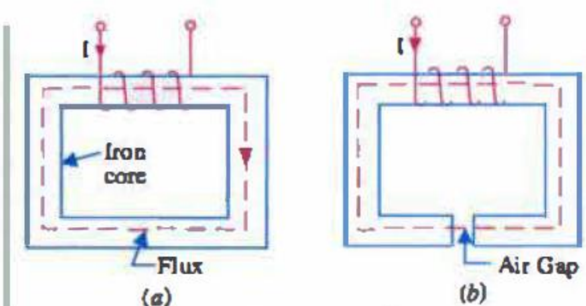


Fig. 7.12

2. Magnetic flux (Φ)

It resembles *current* in an electric circuit. It consists of magnetic lines of force and its unit is weber.

3. Reluctance (S)

It resembles *resistance* in an electric circuit. It represents the opposition wbicb a core offers to the production of flux througb it. Its value is

$$S = \frac{l}{\mu A} = \frac{l}{\mu_0 \mu_r A}$$

Its unit is 'reciprocal' henry *i.e.,* per benry.

Example 1

Mild steel has a relative permeability of 800. Calculate the reluctance of a mild steel core that has a length of 10 cm, and has a cross section of 1.0 cm × 1.2 cm.

First, determine the permeability of mild steel.

$$\mu = \mu_0\mu_r = (4\pi \times 10^{-7}\,\text{Wb/At}\cdot\text{m})(800) = 1.00 \times 10^{-3}\,\text{Wb/At}\cdot\text{m}$$

Next, convert the length to meters and the area to square meters.

$$l = 10\,\text{cm} = 0.10\,\text{m}$$

$$A = 0.010\,\text{m} \times 0.012\,\text{m} = 1.2 \times 10^{-4}\,\text{m}^2$$

Substituting values into Equation 3,

$$\mathcal{R} = \frac{l}{\mu A} = \frac{0.10\,\text{m}}{(1.00 \times 10^{-3}\,\text{Wb/At}\cdot\text{m})(1.2 \times 10^{-4}\,\text{m}^2)} = \mathbf{8.33 \times 10^5\,At/Wb}$$

Example 2

There is 0.1 ampere of current through a coil with 400 turns.

(a) What is the mmf?

(b) What is the reluctance of the circuit if the flux is 250 μWb?

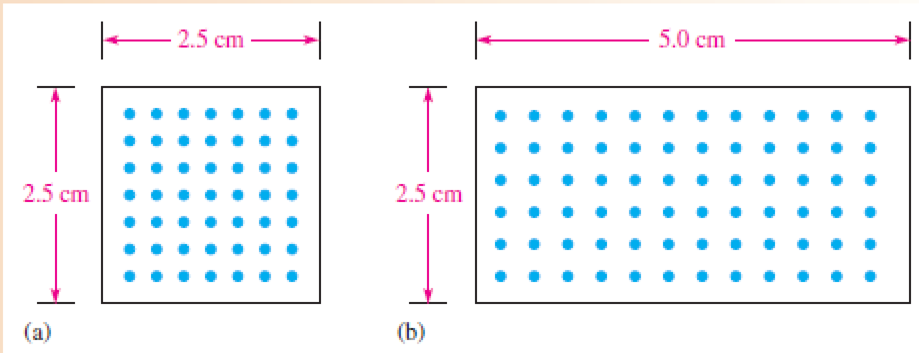
(a) $N = 400$ and $I = 0.1$ A

$$F_m = NI = (400\,\text{t})(0.1\,\text{A}) = \mathbf{40\,At}$$

(b) $$\mathcal{R} = \frac{F_m}{\phi} = \frac{40\,\text{At}}{250\,\mu\text{Wb}} = \mathbf{1.60 \times 10^5\,At/Wb}$$

Example 3

Compare the flux and the flux density in the two magnetic cores shown in Figure. The diagram represents the cross section of a magnetized material. Assume that each dot represents 100 lines or 1 μWb.



The flux is simply the number of lines. In Figure (a) there are 49 dots. Each represents 1 μWb, so the flux is 49 μWb. In Figure (b) there are 72 dots, so the flux is 72 μWb.

To calculate the flux density, first calculate the area in m^2. For Figure (a) the area is

$$A = l \times w = 0.025\ \text{m} \times 0.025\ \text{m} = 6.25 \times 10^{-4}\ \text{m}^2$$

For Figure (b) the area is

$$A = l \times w = 0.025\ \text{m} \times 0.050\ \text{m} = 1.25 \times 10^{-3}\ \text{m}^2$$

Use Equation 1 to calculate the flux density. For Figure (a) the flux density is

$$B = \frac{\phi}{A} = \frac{49\ \mu\text{Wb}}{6.25 \times 10^{-4}\ \text{m}^2} = 78.4 \times 10^{-3}\ \text{Wb/m}^2 = 78.4 \times 10^{-3}\ \text{T}$$

For Figure (b) the flux density is

$$B = \frac{\phi}{A} = \frac{72\ \mu\text{Wb}}{1.25 \times 10^{-3}\ \text{m}^2} = 57.6 \times 10^{-3}\ \text{Wb/m}^2 = 57.6 \times 10^{-3}\ \text{T}$$