<u>Unit-3 Transformer</u>

<u>Magnetic Material</u>

Although all materials have magnetic properties of some kind beiug either diamagnetic, paramagnetic or ferromagnetic, the term "magnetic material" is customarily applied only to substances which exhibit ferromagnetism.

1. Paramagnetic Materials. The materials, which are not strongly attracted by a magnet, such as aluminium, tin, platinum, magnesium, manganese etc., are known as paramagnetic materials. Their relative permeability is small but positive. For example, the relative permeabilties for aluminium, air and platinum are 1.00000065, 1.0000031 and 1.00036 respectively. Such materials are slightly magnetized when placed in a strong magnetic field and act in the direction of the magnetic field.

In paramagnetic materials the individual atomic dipoles are oriented in a random fashion, as shown in Fig. 10.1. The resultant magnetic field is, therefore, negligible. When an external magnetic field is applied, the permanent magnetic dipoles orient themselves parallel to the applied magnetic field and give rise to a positive magnetization. Since the orientation of the dipoles parallel to the applied magnetic field is not complete, the magnetization is small. These materials have little application in the field of electrical engineering.

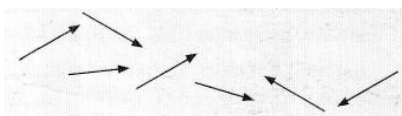

Fig. 10.1

2. Diamagnetic Materials. The materials which are repelled by a magnet such as zinc, mercury, lead, sulphur, copper, silver, bismuth, wood etc., are know n as diamagnetic materials. Their permeability is slightly less than unity. For example, the relative permeabilities of bismuth, copper and wood are 0.99983, 0.999995 and 0.9999995 respectively. They are slightly magnetized when placed in a strong magnetic field and act in the direction opposite to that of applied magnetic field.

In diamagnetic materials, the two relatively weak magnetic fields (one caused due to orbital revolution and other due to axial rotation) are in opposite directions and cancel each other. Permanent magnetic dipoles are absent in them. Diamagnetic materials are unimportant from the point of view of application in the field of electrical engineering.

3. Ferromagnetic Materials. Ferromagnetism may be thought of as a special case of paramagnetism in which the individual spin magnetic moments are interacting or coupled. As with paramagnets, ferromagnets have strong and positive magnetic susceptibility. Ferromagnetism is possible only when atoms are arranged in a lattice and the atomic magnetic moments interact to align parallel with each other. This effect is explained in classical theory by the presence of a molecular field within the ferromagnetic material, which was first postulated by Weiss in 1907. This field is sufficient to magnetize the material to saturation.

Unlike paramagnets, when the applied field is removed, they retain a component of magnetization in the direction of the applied field – they are "permanently" magnetized (they have hysteresis) and their susceptibility is not dependent upon temperature in a way that follows the Curie Law.

In general, iron, nickel, cobalt and some of the rare earths (gadolinium, dysprosium) exhibit a unique magnetic behavior, which is called ferromagnetism because iron (ferrum in Latin) is the most common and most dramatic example. Samarium and neodymium in alloys with cobalt have been used to fabricate very strong rare-earth magnets.

Ferromagnetic materials are of two types: (a) soft magnetic material and (b) hard magnetic material.

Soft Magnetic Material: Soft magnetic materials are those which have thin and narrow *B-H* curves, i.e. the area within the hysteresis loop is small. Hence, soft magnetic materials are used in devices that are subjected to alternating magnetic fields and in which energy losses must be low. A soft magnetic material should also have a high initial permeability and low coercivity. Soft magnetic materials are iron and its alloy with nickel, cobalt, tungsten and aluminium. A material possessing these properties may reach its saturation magnetization with a relatively low applied field (i.e., is easily magnetized and demagnetized) and still has low hysteresis energy losses. In these materials, the direction of magnetization can be altered easily by an applied magnetic field. Such materials have permeability and low cohesive force. Both high and low values of remanent flux density may be required for specific applications.

The important applications of soft magnetic materials are in transformer and machine cores, and as memory cores in computers. The transformer materials account for the bulk of the material produced. The properties sought in a transformer material are,

(1) high permeability, ensured by keeping the content of ferromagnetic element as large as possible,

(2) low hysteresis and eddy current losses,

(3) low cost, a real production problem.

Hard Magnetic material: Hard magnetic materials are those which retain a considerable amount of their magnetic energy after the magnetizing force has been removed i.e. the materials, which are difficult to demagnetize. These materials are also called permanent magnetic materials. Typical hard magnetic materials include cobalt, steel and various ferromagnetic alloys of nickel, aluminium and cobalt. The important applications of permanent magnets are in meters, transducers, electron tubes, motors, focusing magnets in television tubes etc. Materials for use as permanent magnets should have the following characteristics:

(i) high permeability ensured by a large content of magnetic atoms or ions,

(ii) high coercive force, generally, above 104 A/m,

(iii) appreciable remanent flux density,

(iv) high Curie temperature, to minimize easy demagnetization,

(v) low cost.

Comparison of difference types of magnetic material

Properties	Paramagnetic Materials	Diamagnetic Material	Ferromagnetic Materials
State	They can be solid, liquid or gas.	They can be solid, liquid or gas.	They are solid.
Effect of Magnet	Weakly attracted by a magnet.	Weakly repelled by a magnet.	Strongly attracted by a magnet.
Behavior under non-uniform field	Tend to move from low to high field region.	Tend to move from high to low region.	Tend to move from low to high field region.
Behavior under external field	They do not preserve the magnetic properties once the external field is removed.	They do not preserve the magnetic properties once the external field is removed.	They preserve the magnetic properties after the external field is removed.
Effect of Temperature	With the rise of temperature, it becomes a diamagnetic.	No effect.	Above curie point, it becomes a paramagnetic.
Permeability	Little greater than unity	Little less than unity	Very high
Susceptibility	Little greater than unity and positive	Little less than unity and negative	Very high and positive
Examples	Lithium, Tantalum, Magnesium	Copper, Silver, Gold	Iron, Nickel, Cobalt

Important terms

Magnetic field: *The space (or field) in which a magnetic pole experiences a force is called a* **magnetic field.** *The magnetic field around a magnet is represented by imaginary lines called magnetic lines of force.*

Magnetic Flux: *The total number of magnetic lines of force produced by a magnetic source is called* magnetic flux. It is denoted by Greek letter φ (phi). The unit of magnetic flux is weber (Wb).

$$1\text{Wb} = 10^8 \text{ lines of force}$$

Magnetic Flux Density: *The* **magnetic flux density** *is defined as the magnetic flux passing normally per unit area i.e*.

Magnetic flux density, $B = \varphi/A$ Wb/m^2

where φ = flux in Wb

A = area in m^2 normal to flux

The SI unit of magnetic flux density is Wb/m^2 or tesla. Flux density is a measure of field concentration *i.e*. amount of flux in each square meter of the field.

Magnetic Intensity or Magnetizing Force (H): Magnetic intensity (or field strength) at a point in a magnetic field is the force acting on a unit *N*-pole (*i.e.*, *N*-pole of 1 Wb) placed at that point. Clearly, the unit of *H* will be N/Wb.

Magnetic Potential: The **magnetic potential** at any point in the magnetic field is measured by the work done in moving a unit N-pole (i.e. 1 Wb strength) from infinity to that point against the magnetic force.

Absolute and Relative Permeability: Permeability of a material means its conductivity for magnetic flux. The greater the permeability of a material, the greater is its conductivity for magnetic flux and *vice-versa.* Air or vacuum is the poorest conductor of magnetic flux. The absolute (or actual) permeability μ_0 (Greek letter "*mu*") of air or vacuum is $4\mu\times10^{-7}$ H/m. The absolute (or actual) permeability μ of magnetic materials is much greater than μ_0. The ratio μ/μ_0 is called the relative permeability of the material and is denoted by μ_r *i.e*.

$$\mu_r = \mu/\mu_0$$

where μ = absolute (or actual) permeability of the material

μ_0 = absolute permeability of air or vacuum

μ_r = relative permeability of the material

Relation between B and H:

The flux density B produced in a material is directly proportional to the applied magnetizing force H. In other words, the greater the magnetising force, the greater is the flux density and *vice versa. i.e*.

$$B \propto H$$

$$\text{or } B/H = \text{Constant} = \mu$$

The ratio B/H in a material is always constant and is equal to the absolute permeability μ (= $\mu_0 . \mu_r$) of the material. This relation gives yet another definition of absolute permeability of a material.

Obviously, $B = \mu_0 \mu_r H$ ...*in a medium*

$= \mu_0 H$ ...*in air*

Suppose a magnetizing force H produces a flux density B_0 in air. Clearly, $B_0 = \mu_0 H$. If air is replaced by some other material (relative permeability μ_r) and the same magnetizing force H is applied, then flux density in the material will be $B_{mat} = \mu_0 \mu_r H$

$B_{mat}/B_0 = \mu_0 \mu_r H/\mu_0 H = \mu_r$

Hence **relative permeability** *of a material is equal to the ratio of flux density produced in that material to the flux density produced in air by the same magnetizing force.*

B-H curve and magnetic hysteresis of magnetic material:

B-H Curve

- The curve plotted between flux density B and magnetizing force H of a material is called magnetizing or B-H curve.
- The shape of curve is non-linear. This indicates that relative permeability ($\mu r = B / \mu 0 H$) of a material is not constant but it varies.
- B-H curves are very useful to analyze the magnetic circuit. If value of flux density and dimension of magnetic circuit is known than from B-H curve total ampere turn can be easily known.

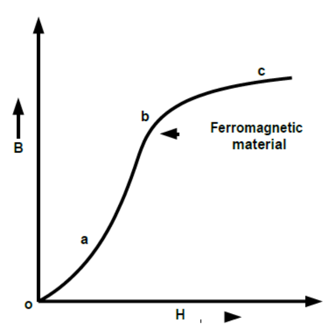

Fig:1 B-H Curve

Magnetic hysteresis

- The phenomenon of lagging behind of induction flux density (B) behind the magnetizing force (H) in magnetic material is called magnetic hysteresis.
- Hysteresis loop is a four quadrant B – H graph from where the hysteresis loss, coercive force and retentively of magnetic material are obtained.
- To understand hysteresis loop, we suppose to take a magnetic material to use as a core around which insulated wire is wound.
- The coils is connected to the supply (DC) through variable resistor to vary the current I. We know that current I is directly proportional to the value of magnetizing force (H).
- When supply current I = 0, so no existence of flux density (B) and magnetizing force (H). The corresponding point is o in the graph above.

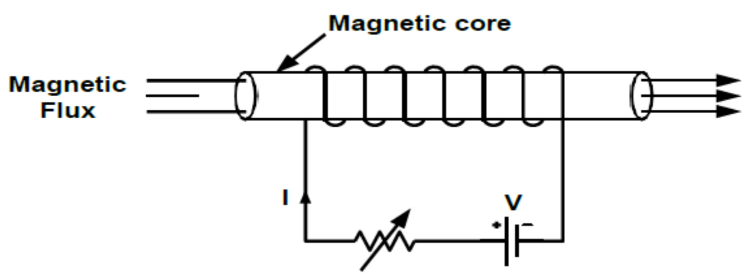

Fig.2 Circuit diagram form Magnetic hysteresis

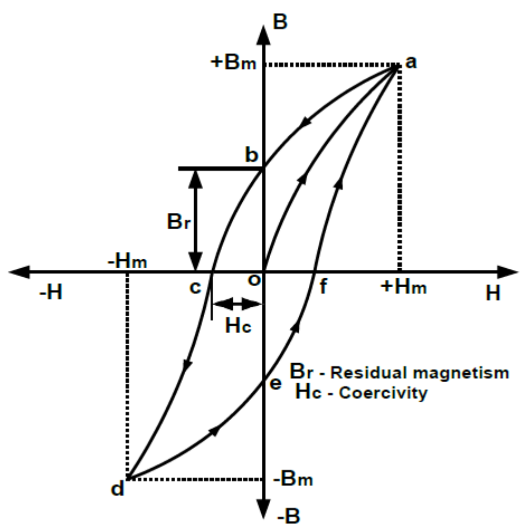

Fig.3.magnetic hysteresis loop

- When current is increased from zero value to a certain value, magnetizing force and flux density both are set up and increased following the path o to a.
- For a certain value of current, flux density becomes maximum (Bm). The point indicates the magnetic saturation or maximum flux density of this core material. All element of core material get aligned perfectly.

- When the value of current is decreased from its value of magnetic flux saturation, H is decreased along with decrement of B not following the previous path rather following the curve a to b.
- The point b indicates H = 0 for I = 0 with a certain value of B. This lagging of B behind H is called hysteresis.
- The point b explains that after removing of magnetizing force (H), magnetism property with little value remains in this magnetic material and it is known as residual magnetism (Br) or residual flux density.
- If the direction of the current I is reversed, the direction of H also gets reversed. The increment of H in reverses direction following path b – c decreases the value of residual magnetism that gets zero at point c with certain negative value of H. This negative value of H is called coercive force (Hc)
- Now B gets reverses following path c to d. At point'd', again magnetic saturation takes place but in opposite direction with respect to previous case. At point'd', B and H get maximum values in reverse direction.
- If decrease the value of H in this direction, again B decreases following the path d. At point e, H gets zero valued but B is with finite value.
- The point e stands for residual magnetism (-Br) of the magnetic core material in opposite direction with respect to previous case.
- If the direction of H again reversed by reversing the current I, then residual magnetism or residual flux density (-Br) again decreases and gets zero at point 'f' following the path e to f.
- Again further increment of H, the value of B increases from zero to its maximum value or saturation level at point a following path f to a.
- Hard and soft material hysteresis loop are given below.

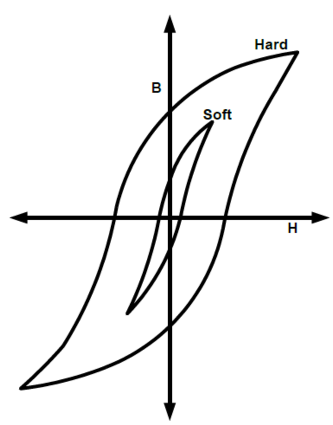

Fig.4. Types of hysteresis loop