UNIT – 3

MAGNETIC PROPERTIES OF MATERIALS

3.1 Hysteresis

When a magnetic material is taken through a cycle of magnetization, the variation of magnetic induction (B) with respect to magnetic field intensity (H) can be represented by a closed curve. In other words, the lagging of magnetization behind the magnetizing field is known as hysteresis curve.

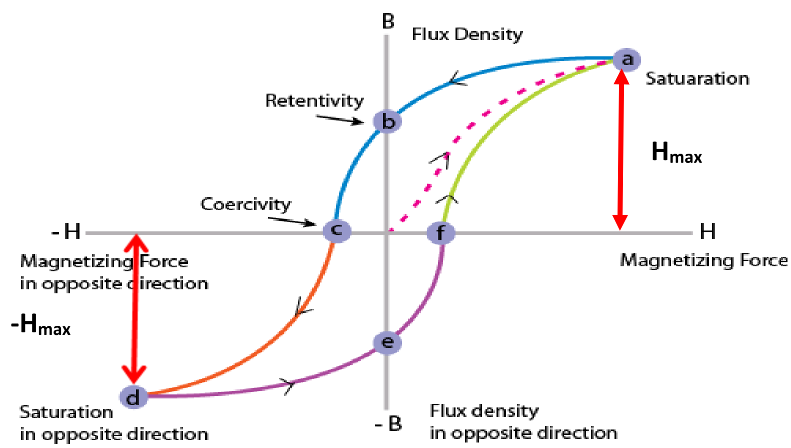

Fig:3.1

- In the curve OA magnetization is due to the small movement of domain wall.
- When the magnetic field is removed it returns to original position. It is reversible domain.
- In the curve AB the magnetization is due to the large movement of domain wall.
- When the magnetic field is removed it does not return to original position. It is irreversible domain.
- In the curve BC the magnetization is due to the rotation of domain.
- When the magnetic field is removed it does not retrace the path but it moves along CD.

- At D it has residual magnetization even when the magnetic field is zero called retentivity.
- A large amount of reverse field is applied to reduce the magnetization to zero, this reverse field is called coercive field.

Energy Product

A product of retentivity and coercivity is called energy product, which gives the maximum amount of energy stored in the specimen.

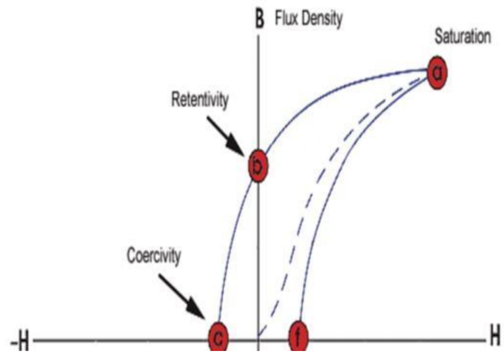

Fig:3.1.2

Hysteresis loss

When the specimen is taken through a complete cycle of magnetization, there is a loss of energy in the form of heat. This loss of energy is known as hysteresis loss.

Basic definitions

Magnetic field

Space around the magnet is called magnetic field.

Magnetic dipole

Magnetic dipole is a system consisting of two equal and opposite magnetic pole separated by a small distance (l).

Magnetic dipole moment

The diploe moment of a magnet is defined as the product of its pole strength (m) and the distance between two poles (l). Unit -Weber/m.

Magnetic moment = m x l

Magnetic flux (Φ)

The number of magnetic lines of force passing through a surface is known as magnetic flux. It is represented by the symbol Φ. Unit -*Webber*

Magnetic flux density (or) magnetic Induction (B)

Magnetic flux density is defined as the number of magnetic lines of force passing through a unit area of cross-section.

$$B = \Phi/A \quad (Weber/m^2)$$

Intensity of magnetization (I)

It is the measure of magnetization of a magnetized specimen. It can also be defined as the magnetic moment per unit volume.

$$I = M/V \quad (A/m)$$

Magnetic field intensity (H)

It is defined as the force experienced by a unit north pole placed in a magnetic field.

$$H = F/m \quad (A/m)$$

Magnetic permeability (μ)

It is defined as the ratio of the magnetic flux density to the applied magnetic field intensity

$$\mu = B/H \quad (Henry/m)$$

Relative permeability (μ_r)

It is the ratio between the absolute permeability of a medium to the permeability of a free space.

$$\mu_r = \mu / \mu_o \quad (No\ unit)$$

Magnetic susceptibility (χ)

It is the ratio of intensity of magnetization induced in it to the magnetizing field

$$\chi = I/H$$

Relation between χ and μ

We know that the magnetic induction is,

$$B = \mu H$$

This equation can be written in another way as

$$B = \mu_o (I+H)$$

$$= \mu_o H ((I/H) + 1)$$

$$B = \mu_o H (\chi + 1)$$

$$B/H = \mu_o (\chi + 1)$$

$$\mu = \mu_o(\chi + 1)$$

$$\mu_o \mu_r = \mu_o(\chi + 1)$$

$$\mu_r = 1 + \chi$$

Origin of magnetic moment

The magnetic moment of a material originates from the orbital and spin motion of electrons in an atom. The permanent magnetic moment arises due to the

- Orbital angular momentum of the electron
- Spin angular momentum of the electron
- Nuclear magnetic moment

Orbital angular momentum of the electron

The orbital motion of electron revolving about a nucleus is equivalent to a tiny current loop. This produces a magnetic moment perpendicular to the plane of the orbit.

Let us consider an electron moving with constant speed *"v"* in a circular radius *"r"*. Let *"T"* be time taken for one revolution and *"e"* be the charge of the electron.

Magnetic moment associated with the orbit is,

$$\mu_L = current \times Area\ of\ the\ orbital\ (loop)\ \dots\dots(1)$$

The current I across at any point in the orbit is,

$$I\ \frac{Charge\ of\ the\ electron}{Time}$$

$$I = \frac{-e}{T} \qquad \dots\dots\dots\dots..(2)$$

$$Area\ of\ the\ orbital\ (loop) is = \pi r^2 \qquad \dots\dots\dots.(3)$$

Substitute equation (2) and (3) in equation (1), we get

$$\mu_L = -\frac{e\pi r^2}{T} \qquad \dots\dots\dots\dots.(4)$$

Since, T is time taken by electron for one complete revolution. The distance (Circumference of the orbit) travelled by an electron in a given time (T) is called velocity.

$$Velocity\ (v) = \frac{2\pi r}{T}\ or\ T = \frac{2\pi r}{v}$$

Substitute T in equation (4), we get,

$$\mu_L = -\frac{e\pi r^2}{2\pi r/v}$$

$$\mu_L = -\frac{evr}{2} \qquad \dots\dots\dots\dots(5)$$

Dividing and multiplying the RHS of equation (5) by *m* (mass of the electron), we get

$$\mu_L = -\frac{mevr}{2m}$$

$$\mu_L = -\frac{eL}{2m} \qquad \dots\dots\dots\dots.(6)$$

Where, $L = mvr$ is the orbital angular momentum of the electron. The equation (6) is the final expression for the magnetic moment associated with the orbital motion of the electron.

Bohr Magnetron

The magnetic moment associated with the orbital magnetic moment of the electron is

$$\mu_L = -\frac{eL}{2m} \qquad \dots\dots\dots\dots.(1)$$

According to the quantum theory, orbital angular momentum is,

$$L = n\hbar$$

$$L = \frac{nh}{2\pi} \qquad \dots\dots\dots\dots..(2)$$

Where, *n* is the orbital angular momentum quantum number and substitute equation (2) in equation (1) we the Bohr magnetron,

$$\mu_B = -\frac{enh}{2\pi m} \qquad \dots\dots\dots\dots\dots(3)$$

This is the final expression for Bohr magnetron and the value is calculated by the substitution of all the constants in equation (3). The calculated Bohr magnetron value is $\mu_B = 9.724 \times 10^{-24}$.

Spin angular momentum of the electron

Similar to orbital motion, magnetic moment due to spin motion of the electron is given by,

$$\mu_e = -\frac{eS}{m}$$

Where, *S* is the spin angular momentum and it is given by,

$$S = -\frac{sh}{2\pi}$$

Where, *s* is the spin quantum number and it takes +1/2 or -1/2.