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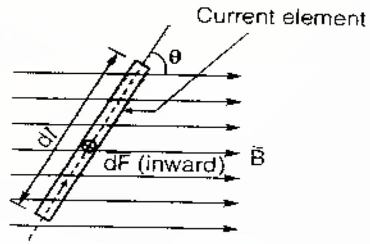
Magnetic Properties of Materials

Magnetic Field

- Force on a current Element

$$\overline{dF} = I\left(d\bar{l} \times \bar{B}\right)$$



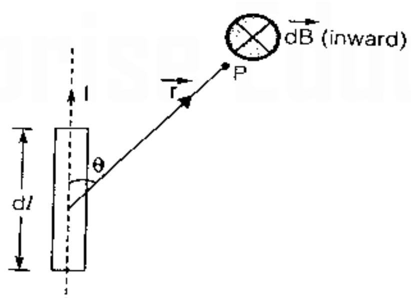
where, B = Flux density, Wb/m²
dF = Force on conductor, Newtons
dl = Differential length of current carrying conductor, metres
I = Current in conductor

For linear conductor of length l in a uniform field B

$$\bar{F} = I(\bar{l} \times \bar{B})$$

- Biot savart law

$$\overline{dB} = \frac{\mu}{4\pi}\frac{I\left(dl \times \bar{r}\right)}{|r|^3}$$



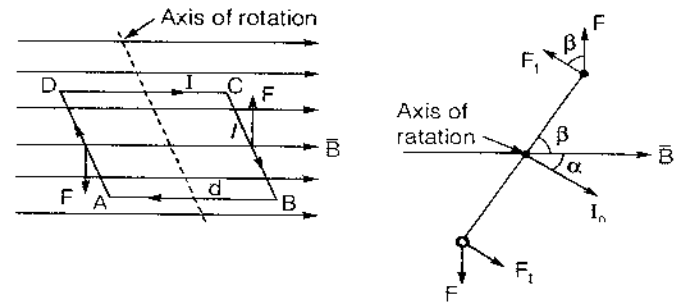
where, $\overline{dB}$ = Magnetic flux density produced by a current carrying element
$\bar{r}$ = Radius vector

- **Flux density produced by a infinitely long current carrying wire at a distance R**

$$B_P = \frac{\mu I}{2\pi R}$$

- Torque on a current carrying loop

$$T = BINA \sin\alpha$$



where, A = Area of the loop = ld
α = Angle between normal to the plane of the loop and direction B
N = Number of loops

Torque

$$\bar{T} = \bar{p}_m \times \bar{B}$$

Magnetic Parameters

1. Permeability

In magnetic field the relationship between two principal quantities i.e. magnetic field intensity (H) and magnetic flux density (B) is given by

$$B \propto H$$

$$B = \mu H$$

Where, μ = Permeability of the material or medium measured in henry/meter

$$\mu = \mu_0 \mu_r$$

Where, μ_0 = Permeability of free space

= $4\pi \times 10^{-7}$ H/M

μ_r = relative permeability

2. Magnetic Dipole Moment

The magnetic field reduces by a small current loop is called magnetic dipole. The magnetic dipole moment is defined as the product of the area of the loop to the magnitude of the circulating current

$$p_m = i \cdot A \cdot \hat{n}$$; Ampere-m^2

Note:

- It is a vector quantity.
- For a permanent bar magnet the dipole moment is defined as the product of pole strength and distance between them.

3. Magnetization

Magnetization is defined as the total magnetic dipole moment per unit volume,

$$M = \frac{p_m}{\text{volume}}$$; Ampere/m

$$M = Np_m$$

Where, N = Number of magnetic dipoles per unit volume.

p_m = Elementary dipole moment

4. Magnetic Flux Density

$$B = \mu H$$

where H = Magnetic field intensity

Note:

The above equation is valid for the materials in which factor 'M' is constant or in homogeneous magnetic field.

- Magnetic flux density when a magnetic field is applied

$$B = \mu_0 H + \mu_0 M = \mu_0 \mu_r H$$

- Magnetization

$$M = (\mu_r - 1)H = \chi_m H$$

- Magnetic susceptibility

$$\chi_m = \mu_r - 1$$

Remember:

- For diamagnetic materials χ_m is negative
- For paramagnetic materials χ_m is small and positive
- For ferromagnetic materials χ_m is large and positive

Types of Magnetic Materials (Depending upon susceptibility)

1. Diamagnetic materials

Do not have permanent dipole moment

$$\bar{p}_m = \bar{p}_{m,orb} + \bar{p}_{m,spin} = 0$$

Such material get magnetize in the opposite direction of applied magnetic field.

Remember:

- For perfect diamagnetic material, $\chi_m = -1$
- In general, χ_m comes out to the order of -10^{-5} to -10^{-6}.

Magnetic susceptibility

$$\chi_m = -\frac{Ne^2}{4m} r^2 \mu_0$$

2. Paramagnetic material

These materials have positive but very small of susceptibility. Spontaneous magnetization for paramagnetic material is zero

Magnetic susceptibility

$$\chi_m = \frac{N\beta^2 \mu_0}{kT}$$

Curie law

Magnetic susceptibility

$$\chi_m = \frac{C}{T}$$

where C = Curie constant

T = Temperature

Example: $MnSO_4$, $FeSO_4$, $FeCl_3$.

3. Ferromagnetic Material

- These are the material which get spontaneously magnetize even in the absence of external field.
- These materials are characterized the parallel alignment of the dipoles in a single direction.
- These material have very large and positive value of susceptibility.
- The magnetic field inside the ferromagnetic material, when the effect of internal field is considered

$$H_i = H + \gamma M$$

where, γ = Internal or molecular field constant

γM = Measure of tendency of environment to align a particular dipole parallel to the magnetisation already existing

Curie weiss law

Magnetic susceptibility

$$\chi_m = \frac{C}{T - \theta}; T > 0$$

where θ is Paramagnetic curie temperature. Above this temperature the ferromagnetic material behaves as a paramagnetic material.

Example: Fe, CO, Ni etc.

4. Antiferromagnetic Material

These materials have positive but small value of susceptibility the magnetic moment of adjacent atoms are align in the opposition direction so that the net magnetic moment of the specimen become zero even in the presence of field.

Curie weiss law

Magnetic susceptibility

$$\chi_m = \frac{C}{T + \theta_n}$$

where, θ_n = Need temperature

Example: MnO, MnO_2, NiO, Cr_2O_3.

5. Ferrimagnetic Material

- In this material the adjacent atoms are align in the opposite direction but the moments are not equal and therefore there is a net magnetic moment along a particular direction.
- Ferrimagnetic materials are also known as ferrites. For example, hard ferrites, soft ferrites rectangular loop ferrites and microwave ferrites.

Magnetostriction

Magnetostriction is an effect that describes a change in dimension when a ferromagnetic material is exposed to magnetic field. It is of three types.

1. Longitudinal magnetostriction

Which is change length in the direction of magnetization.

2. Transverse magnetostriction

Change in dimension, perpendicular to magnetization direction.

3. Volume magnetostriction

Change in volume result from the above two effects.

Villari effect

This effect is inverse of magnetostriction when material is subjected to mechanical stress, the magnetic properties of material changes.

Types of Magnetic Materials

1. Soft Magnetic Materials

Soft magnetic are easy to magnetize and easy to demagnetize. The direction of magnetization can be altered easily by applying an external field in the reverse direction.

Note:

- Soft magnetic have high permeability and low coercive force.
- Soft magnetic material having small hystereses losses, lower retentivity.
- Soft magnetic material are used as the core of the transformer, electric machines and magnetic memory.

2. Hard Magnetic Materials

These magnetic materials are hard to magnetize and hard to demagnetize. These materials retain high value of residual flux density and coercive force. These materials are also called as permanent magnetic materials.

Note:

- hard magnetic materials having large hystereses loss, higher residual magnetism.
- hard magnetic materials having high curie temperature
- hard magnetic materials are used in measuring instrument transducers and picture tube.

Remember:

- Permanent magnet-High retentivity and high coercivity.
- Electromagnets-High retentivity and low coercivity.
- Transformers-Least possible area of Hysteresis.