Magnetic Material Chapter - 5.

Materials which can be magnetised are called magnetic materials. When magnetised, such materials create a magnetic field around them.

When current flows through a coil it creates an m.m.f. Thus the circulating electrons in a material also develop m.m.f. In most materials the direction of motion of the electrons in the various orbit is such that they develop m.m.f in opposite direction thus cancelling each other.

In magnetic materials there are a number of unneutralised orbits which produce a resultant m.m.f creating magnetic poles called magnetic dipoles.

In an unmagnetized material the dipoles are scattered at random.

In a magnetised material the dipoles line up parallel with exciting m.m.f.

The property of a material by virtue of which it allow itself to be magnetised is called permeability.

In magnetic material, the value of permeability is constant and is the same as for free space.

The permeability of free space is denoted by μ_0 and equals to $4\pi \times 10^{-7}$.

The permeability of air is almost same as for free space i.e. $4\pi \times 10^{-7}$.

For magnetic material the permeability μ is given by $\mu = \mu_0 \times \mu_r$ where μ_r is called the relative permeability.

$$B = \mu_0 \times H$$

Relative permeability depends upon the nature of the material and on temperature.

When relative permeability is positive the magnetic dipoles arranged themselves in the same direction as the applied field intensity.

When relative permeability is negative the magnetic dipoles allign themselve in the opposite direction to the applied field.

The materials are classified into

- Magnetic material → These material respond to an external magnetic field.
- Non magnetic materials → These material do not respond to an external magnetic field.

Magnetic materials are classified in

→ Diamagnetism
→ Paramagnetism
→ Ferromagnetism

This classification is made on the manner they respond to external magnetic field.

Diamagnetic and paramagnetic ~~and~~ fall into the category of non magnetic material.

Ferromagnetic material are classified as magnetic.

Diamagnetism

Permanent magnetic dipole are absent in them because there is cancellation of magnetic fields due to electrons rotating in opposite directions in the various orbit of the atom is total.

Materials which lack ~~permanent~~ permanent magnetic dipoles are called Dia magnetic material.

If an external magnetic field is applied to a diamagnetic material it introduces a magnetisation M in opposite direction to the applied field intensity H.

The relative permeability μ_r, of a dia magnetic material is negative due to this reason diamagnetic material are not used in electrical engineering application.

eg → Silver, copper, bismuth, hydrogen.

Paramagnetism

Many materials have small but positive relative permeability. Such materials are called Paramagnetic. The atomic dipoles are oriented in a random fashion. (↑ ↘ ← ↙ ↑)

The resultant magnetic field is thus negligible.

On application of an external magnetic field the permanent magnetic dipoles orient themselves parallel to the applied magnetic

field and give rise to a positive magnetisation M.
The orientation of dipoles parallel to the applied magnetic field is not complete therefore the magnetisation M is small. The relative permeability of paramagnetic materials are approximately unity. Thus paramagnetic material have negligible application in the field of electrical engineering.

eg → Aluminium, platinum, oxygen.

Ferromagnetism

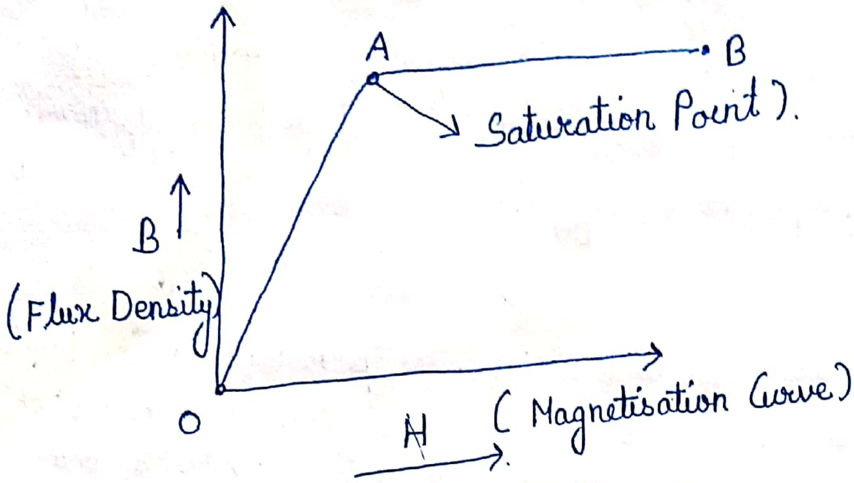
Ferromagnetic materials are crystalline solids. The permanent atomic dipoles are alligned parallel to each other within groups called domains. Each domain is therefore at all times completely magnetised. When a weak external magnetic field is applied, it is not enough to cause any change in the orientation of the domains. The flux density with such low applied field is entirely due to the externally applied magnetic field.

When the externally applied magnetic field is increased, a stage is reached where domain is still weak, it will start orienting themselves such that their resultant magnetic field coincides with the externally applied magnetic field and the material will develop strong magnetic field of its own.

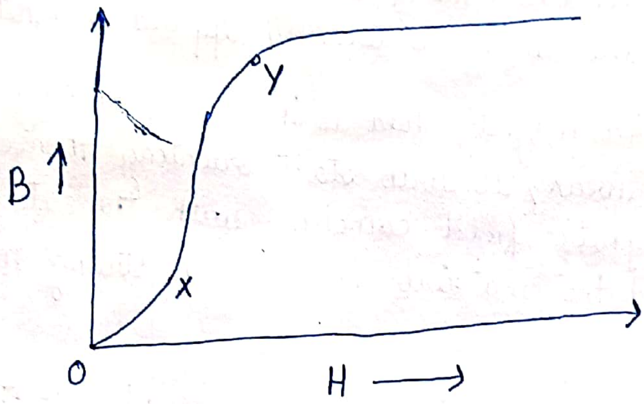
There are some domains whose original magnetic orientation greatly diverges from that of the applied field and require a stronger external field to be able to orient their magnetisation in the same direction as the applied field. i.e the domains whose original direction of magnetization is less divergent from that of the applied field, the rate of strengthening of the internal magnetic field decreases with increase in the applied magnetic field and gives rise to magnetic saturation.

eg → iron, cobalt, nickel.

Magnetisation Curve.



or.



With very weak external field H, the flux density B, rise in direct proportion (i.e. as a straight line from the origin). This means that during this region upto the point x, the domains of the ferromagnetic material do not orient themselves. parallel to the applied field and therefore the material is not. magnetized. The flux density is entirely due to the external field thus the permeability of the material upto the point x is constant is called initial permeability. If the external field H is increased beyond the point x, there is sharp increase in the flux density because the external field is strong enough to orient parallel to its own axis. Upto point y the relative permeability of the material is not constant but keeps increasing. When the magnetization curve reaches the point y, the material is start saturating. After this ~~point~~ curve becomes almost zero.

Hysteresis

→ When ferromagnetic material the flux density B increases when external magnetic field applied to it is increased. When saturation arrives the increase in B almost ceases even though H may be increased.

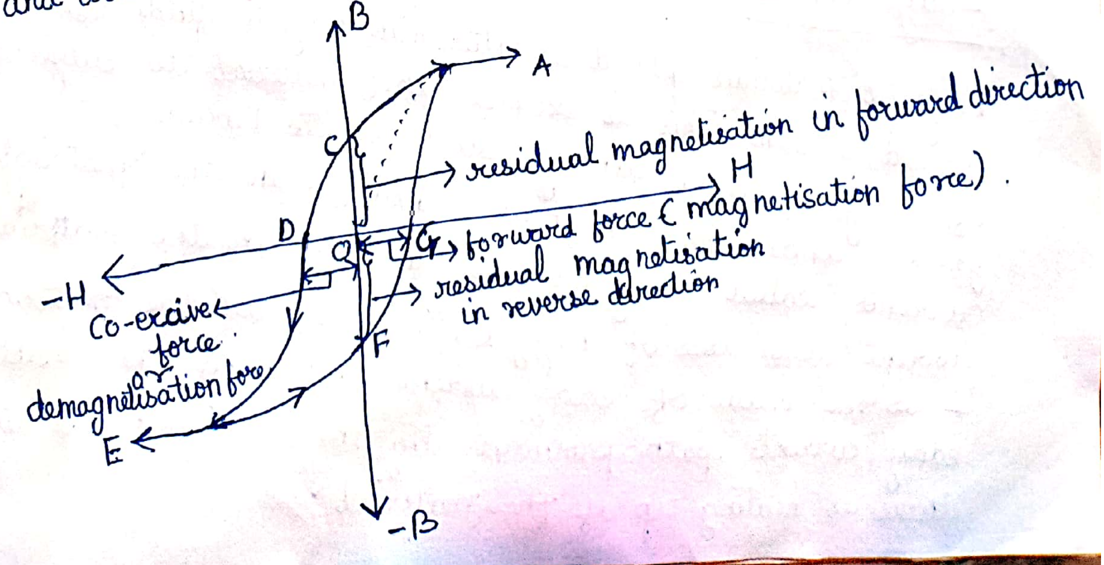
→ If the ~~mo~~ external magnetic field is reduced it is found that the curve OA is not retraced. At $H = 0$, the material is still magnetised and the flux density B has the value OC which is called residual magnetism.

→ In order to demagnetise the material completely the external magnetic field H, is reversed when H reaches the value OD in the reverse direction and $B = 0$ in this time. Hence this applied magnetising force H in the reverse direction which causes B to be zero is co-ercive force. This force is also known as demagnetisation force.

→ Further increase of H in the reverse direction will now increase B in the reverse direction and again at point E saturation occur.

→ Again the external field is ~~there~~ ~~dec~~ increased in forward direction and when $H = 0$, then $B = OF$ which is called the residual magnetisation.

→ To neutralise the residual magnetisation H is increased to the value OG in the positive i.e the original direction. Further increase of H in the positive direction will again magnetize the material in this direction and saturation will occur at A.



→ Flux density B always lags behind H.

→ This property of B lagging behind H is a characteristic of the magnetic behaviour of the ferro magnetic materials. When H is taken from positive maximum through zero to negative maximum and then through zero again back to positive maximum, the graph relating B and H traces a loop ACDEFGA. This is called Hysteresis loop.

→ When a ferromagnetic material is subjected to repeated cycles of magnetisation a loss occur. This losses due to hysteresis is known as hysteresis loss. This loss is directly proportional to the supply frequency.

→ Hysteresis loss depends upon flux density and frequency of variation of flux and can be expressed as

$$\text{Hysteresis loss} = K B_m^{1.6} f V_c \text{ watts}$$

where K is a constant whose value depend upon the core material

B_m is the maximum flux density of the magnetic field in which the core is placed.

f is the frequency of variation of flux.

V_c is the volume of the core material in m^3.

→ Magnetic core used in transformer & rotating electrical machines are made from materials whose hysteresis loops are narrow in order to keep down hysteresis loss.

Eddy Currents

Magnetic materials placed in alternating magnetic fields also have eddy currents induced in them. This is because the material is subjected to rate of change of flux linkage according to Faraday's law of electromagnetic induction e.m.f are induced in the material causing currents, called eddy currents, to flow in the material. These current cause loss of energy (I^2R) loss in the material, where I is the value of eddy current and R is the resistance of the eddy current path provided by the material. Due to this loss there is heating up of the material.

→ Eddy current loss is proportional to the square of the frequency and the square of the thickness of the material and is inversely proportional to the resistivity of the material.

→ To prevent eddy current loss magnetic cores to be used in alternating magnetic fields are built up on thin sheets of steel lamination separated from each other by thin film of insulation.

→ The insulating film may be a coat of insulating varnish, a sheet of papper or a film of oxide.

→ An efficient of insulation for silicon steel is a film of phosphate chemically deposited on the surface. This film hold the high temperature annealing required by lamination punched out of sheets. This increases the resistance to the path of eddy current thus reducing their magnitude and eddy current loss.

→ The losses due to hysteresis and eddy current are also affected by the magnitude of the flux density. Hysteresis loss varies directly in proportional to B at low flux densities say upto $0.1\ Wb/m^2$ to $1.0\ Wb/m^2$ it is proportional to $B^{1.6}$.

→ Eddy current losses are proportional to the square of the flux density.

Eddy Current loss = $K B_m^2 f^2 t^2 V_c$ Watt.

where K is a constant which depends upon the core material and t is the thickness of the core lamination.

<u>Curie Point</u> → The critical temperature above which the ferromagnetic materials losses their magnetic properties is called curie point.

At curie point or curie temperature the domain structure tend to disrupt and the domains lose their alignment, become arranged in random fashion thus the material loses its ferromagnetic property.

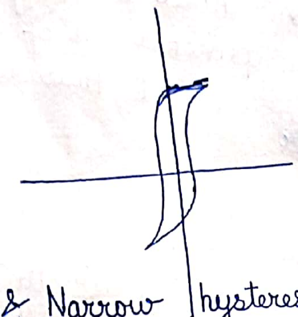
<u>Magnetostriction</u> → When ferromagnetic material are magnetised a small change of dimension of the material takes place. There is a small extension with reduction of cross section of the crystal of which the material is made. When subjected to rapid alternating magnetic fields there is a rapid and continuous extension and contraction of the material. This is called magnetostriction.

All ferromagnetic materials are divided into two groups.

Soft Magnetic Material

→ Materials which have a steeply rising magnetization curve, relatively small and narrow hysteresis loop and small energy losses during cyclic magnetisation are called soft magnetic material.

→



Small & Narrow hysteresis loop

→ Used in building cores for use in alternating magnetic fields.

→ eg → soft pure iron, silicon iron alloy, nickel iron alloy and soft ferrites.

→ Used in construction of cores for electric machines, transformers, electromagnets, reactors, relays etc

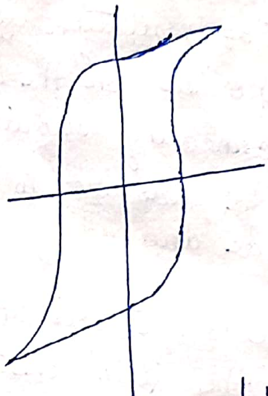
→ They have small enclosed area of hysteresis loop.

→ High permeability.

→ High saturation value of flux density.

Hard Magnetic material

Magnetic materials which have a gradually rising magnetisation curve large hysteresis loop and large energy losses during cyclic magnetization are called hard magnetic material.



Large & Broad hysteresis loop.

→ Used for making permanent magnets.

→ eg → Carbon steel, tungsten steel cobalt steel, alnico, hard ferrites

→ They have high saturation values, high coercive force and high residual magnetisation.