DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB101J-Electromagnetic Theory, Quantum Mechanics, Waves and Optics

Module II- Lecture-3

Hard and soft magnetic materials: Discussion considering magnetization and application, Energy product-Explanation

Classification of Magnetic Materials

- **It has been seen earlier that the permanent magnetic moment is mainly due to the spin magnetic moment of the electrons**. Generally, every two electrons in an energy state of an atom will form a pair with opposite spins.

- **If all the electrons are paired, their spin magnetic moments will be cancelled and so their net magnetic moment is zero**.

- Whereas if there are unpaired electrons in an atom, the spin magnetic moment of these unpaired electrons interact with the spin magnetic moment of the unpaired electrons of the adjacent atom, in a parallel manner resulting in enormous permanent magnetic moment.

So, magnetic materials are broadly classified into two categories, as follows.

- Those not having any permanent magnetic moment – diamagnetic materials, and

- Those having permanent magnetic moment, para, ferro, antiferro and ferrimagnetic materials.

Hard and Soft Magnetic Materials

The magnetic materials are classified into two types, namely, hard and soft magnetic materials, depending upon the direction of magnetization by an applied magnetic field.

Soft magnetic materials

The materials, which are easily magnetized and demagnetized, are said to be soft magnetic materials. In soft materials, the domain walls move easily and reversibly so that magnetization changes by large amounts for small changes in the magnetic field.

The soft magnetic material is prepared by heating the pure materials to a temperature at which sufficient movement of the atoms is possible for them to settle into an ordered lattice, followed by slow cooling.

Properties

The soft magnetic materials have the following properties

- The nature of the hysteresis loop of a soft magnetic materials is very steep
- The hysteresis area is very small and hence the hysteresis loss is also small.
- The materials have a large value of susceptibility and permeability.
- The resistivities of these materials are very high and hence they have low eddy current loss.
- These materials are free from irregularities like strain or impurities.
- The magnetostatic energy of a soft magnetic material is very small.

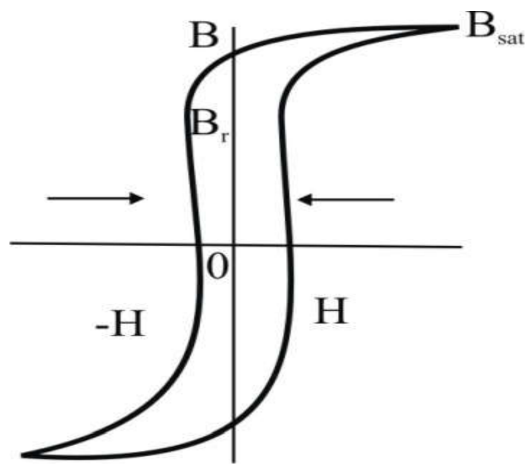


Fig. Hysteresis loop of a soft magnetic material

Examples

(i) Iron and silicon alloys(silicon steel)

(ii) Nickel-Iron alloy, and

(iii) Iron-cobalt alloy

Applications

(i) Iron-silicon alloy are used in electrical equipment and magnetic cores of transformers operating at power line frequencies. Silicon steel is also extensively used in large alternators and high frequency rotating machines.

(i) Nickel alloys are used in high frequency devices such as high –speed relays, wide band transformers and inductors. They are also used to manufacture small motors and synchros. They are also used for precision current and voltage transformers, and inductive potentiometers.

Hard Magnetic Materials

- The materials, which are very difficult to magnetize, are said to be hard magnetic materials. In hard magnetic materials, the rotation of domain wall is very difficult.

- The hard magnetic materials are prepared by heating magnetic materials to the required temperature and then suddenly cooling them by dipping in a cold liquid. In a hard magnetic material, the impurities are purposely introduced, to make them hard.

Properties

The properties of hard magnetic materials are listed as follows:

- The nature of the hysteresis curve is very broad and has a large area.
- Since the area of the hysteresis curve is large, the hysteresis loss is also large.
- These materials have low value of susceptibility and permeability.
- The coercivity and retentivity are large.
- The eddy current loss is very large.
- These materials have large amount of impurities and lattice defects the magneto static energy is very large.

Examples

Carbon steels, tungsten steel, chromium steel, alnico, etc.,

Applications

- The carbon steel is used as magnets for toys, compass needle, latching relays and certain types of meters.

- The tungsten steel finds use in d.c meter magnets and in other devices where comparatively large size is permissible.

- Chromium steel is the best permanent magnet.

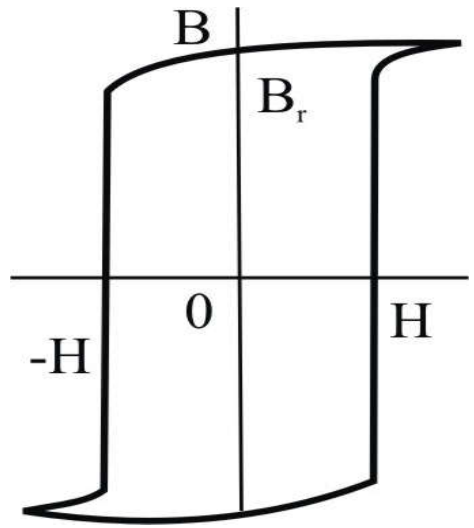


Fig. Hysteresis loop of a hard magnetic material

Comparison between soft and hard magnetic materials

Soft Magnetic Materials	Hard Magnetic Materials
Definition: Materials, which are easy to magnetize and demagnetize are called soft magnetic materials.	Definition: Materials, which are difficult to magnetize and demagnetize are called soft magnetic materials.
The nature of the hysteresis loop is very steep	The nature of the hysteresis loop is very broad
These materials have small hysteresis loss due to small hysteresis loop area.	These materials have large hysteresis loss due to large hysteresis loop area.
These materials have a large value of susceptibility and permeability.	These materials have low value of susceptibility and permeability.

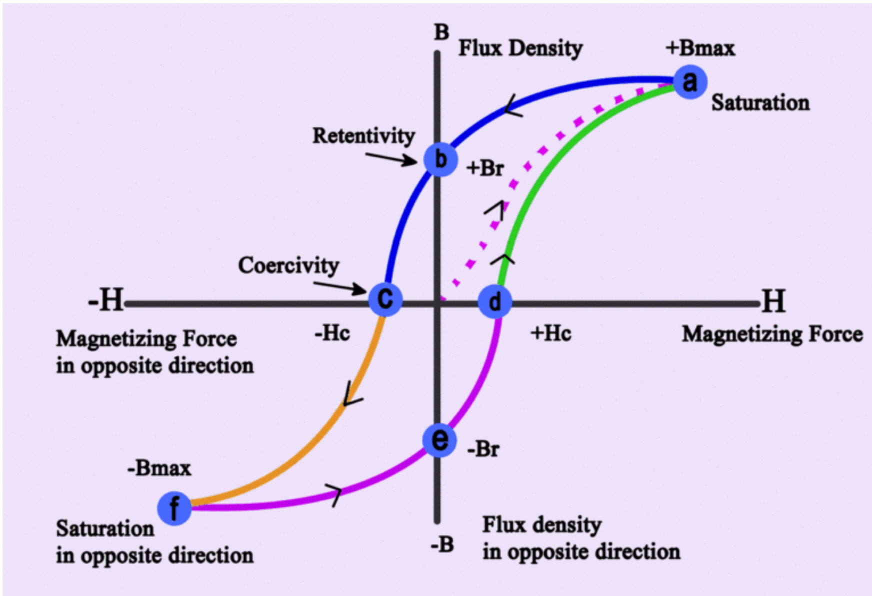
Comparison between soft and hard magnetic materials

Soft Magnetic Materials	Hard Magnetic Materials
The coercivity and retentivity are small.	The coercivity and retentivity are large.
The eddy current loss is small due to their high resistivity.	The eddy current loss is more due to their small resistivity.
These materials are free from irregularities like strain or impurities.	These materials have large amount of impurities and lattice defects.
Its magneto static energy is very small.	Its magneto static energy is very large.
Examples: Iron and silicon alloys(silicon steel), Nickel-Iron alloy and Iron-cobalt alloy,etc.	Examples: Carbon steels, tungsten steel, chromium steel, alnico, etc.

Hysteresis Loop

Hysteresis Definition

Hysteresis is the lagging of the magnetization of a ferromagnetic material behind the magnetizing force H.



➢In above figure, the specimen is assumed to be unmagnified, and the current is starting from zero in the center of the graph. As H increases positively, B follows the red dotted curve from origin to saturation point a, indicated by $\mathbf{B_{max}}$.

Hysteresis Loop

➢As H decreases to zero, the flux follows the curve ab and drops to $\mathbf{B_r}$ which indicates the retentivity or residual induction. This point represents the amount of flux remaining in the core after the magnetizing force is removed.

➢When H starts in the negative direction, the core will lose its magnetism, as shown by following the curve from point b to c. The amount of magnetizing force required to completely demagnetize the core is called the coercive force and is designated as $\mathbf{-H_c}$ in the figure.

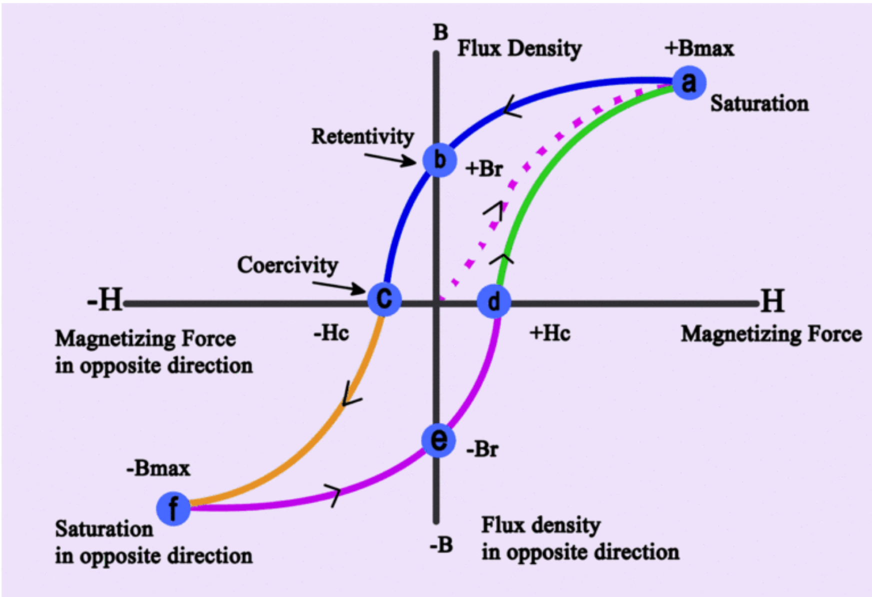
➢The force required to remove the retentivity of the material is known as Coercive force (C).

➢In the opposite direction, the cycle is continued where the saturation point is f, retentivity point is e and coercive force is e.

➢Due to the forward and opposite direction process, the cycle is complete and this cycle is called the hysteresis loop.

Hysteresis Loop

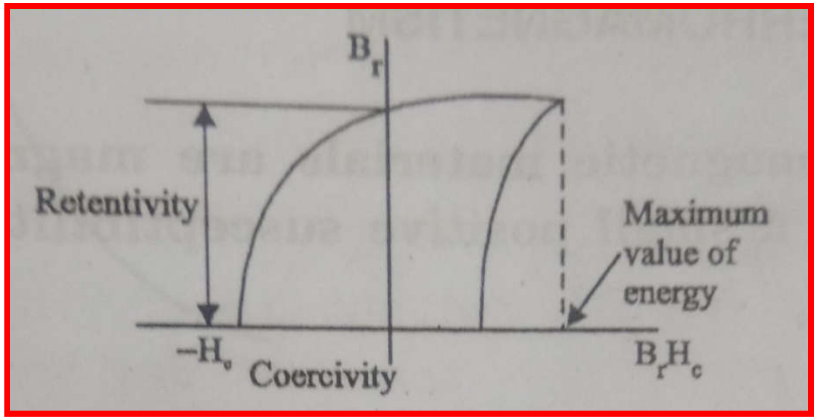
➢A coercive force of **+H$_c$** is required to reduce the core magnetization to zero. As the magnetic force continues to increase in the positive direction, the portion of the loop from point f to a is completed. The periodic reversal of the magnetizing force causes the core flux to repeatedly trace out the hysteresis loop.



Energy Product-Explanation

➢The product of retentivity (B_r) and coercivity (H_c) is known as energy product. It represents the maximum amount of energy stored in the specimen.

➢Therefore, for permanent magnets the value of energy product should be very high as shown in Fig.



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