



Magnetism

Lecture 7

Diamagnetism

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Magnetic Materials in Electric Vehicles

Magnetic materials are essential in electric vehicles, as they significantly contribute to improving the vehicle's performance and efficiency. These materials are widely used in many of the main components and systems within electric vehicles.

Definition of Magnetic Materials

Magnetic materials are those that exhibit ferromagnetism or ferrimagnetism and possess practical application value. The main difference between magnetic materials and other materials is that they respond sensitively to an external magnetic field.



Classification of Magnetic Materials

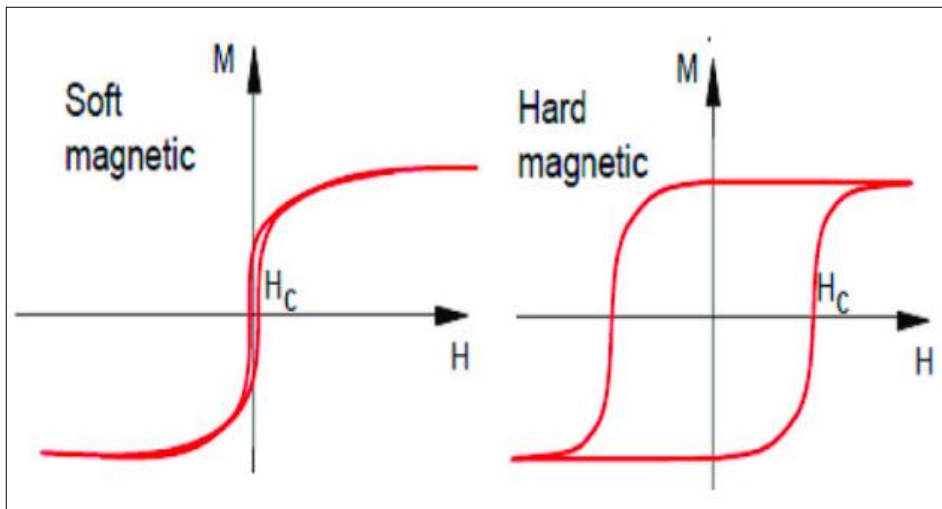
Magnetic materials can be classified into hard magnetic materials and soft magnetic materials based on their function.

Soft Magnetic Materials

Soft magnetic materials are materials that can be easily magnetized and demagnetized when exposed to a relatively weak external magnetic field. They are characterized by low energy loss during the magnetization and demagnetization process, making them ideal for applications that require continuous and rapid switching between magnetized and demagnetized states.

The most important features are:

- They do not retain their magnetization after the external field is removed (low residual magnetization).
- They do not require a strong field to change the direction of their magnetization (low coercivity).



Detailed Properties of Soft Magnetic Materials

High Magnetic Permeability

- It indicates how easily magnetic flux lines can pass through the material.
- The higher the permeability, the stronger the internal magnetic field becomes, even if the external field is weak.

1. Low Coercivity

- Coercivity is the field required to remagnetize the material or remove its magnetization.
- In soft magnetic materials, it is very low, which means they respond quickly to the external field.

2. Low Remanence

- After removing the magnetic field, only a very small internal field remains, or none at all.
- This property is important for minimizing losses in electrical applications.

3. **Low Hysteresis Losses**

- The hysteresis loop (B–H curve) is narrow, resulting in low energy loss per magnetization cycle.
- This makes soft magnetic materials suitable for devices that operate on alternating current (AC).

4. **Relatively High Electrical Resistivity**

- Especially in ferrites, this helps reduce eddy currents.
- It enables efficient operation at high frequencies.

The Most Common Types of Soft Magnetic Materials

1. **Silicon Steel**

- Contains 1–4% silicon.
- Silicon reduces hysteresis losses and improves electrical resistivity.
- Used in transformers, generators, and electric motors.

2. **Iron–Nickel Alloys (Permalloy – Fe–Ni Alloys)**

- Typically contain 80% nickel and 20% iron.
- Characterized by extremely high magnetic permeability and very low coercivity.
- **Used in:**
 - o Sensitive magnetic circuits
 - o Measuring instruments
 - o Small transformers

3. **Soft Ferrites**

- Ceramic materials composed of iron oxide combined with metals such as MnZn or NiZn.
- They have very high electrical resistivity, making them suitable for high-frequency applications (MHz).
- Used in:
 - o High-frequency transformers
 - o Chokes
 - o Cores for radio and communication circuits

4. **Amorphous Metals**

- Metallic materials with a non-crystalline (amorphous) structure.
- Feature extremely low magnetic losses.
- Ideal for modern high-efficiency transformers.

Hard Magnetic Materials

Definition: Hard magnetic materials are those that, once magnetized by an external magnetic field, retain a strong magnetic field even after the external field is removed.

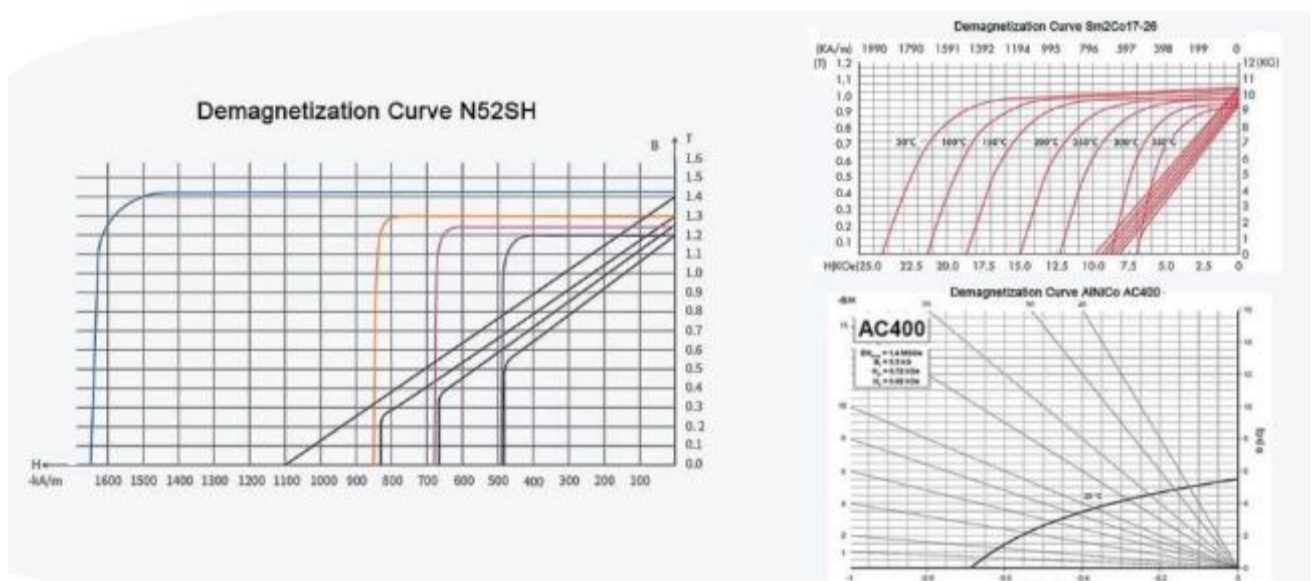
Properties: They have high coercivity, high remanence, and wide hysteresis loops.

Types: Neodymium–iron–boron (NdFeB) magnets, samarium–cobalt alloys, and hard magnetic ferrites.

Performance Evaluation of Magnetic Materials in Electric Vehicles

The performance of magnetic materials is measured using the following indicators:

Stability: The product of the maximum magnetic energy is the key parameter. Higher values indicate stronger magnetic fields and a better ability of the material to maintain its magnetic properties.



Demagnetization Resistance: The key parameter is intrinsic coercivity. Higher values indicate better resistance to demagnetization and higher efficiency.

Temperature Resistance: The key parameters are intrinsic coercivity, maximum operating temperature, and Curie temperature. Higher values indicate better temperature resistance and greater stability of the magnetic properties of the material.

Hard Magnetic Materials in Electric Vehicles

Neodymium Magnets

Neodymium-Iron-Boron (NdFeB) magnets, primarily composed of $\text{Nd}_2\text{Fe}_{14}\text{B}$, are renowned for their high remanent magnetization and high coercive force. These materials significantly enhance motor efficiency and reduce energy loss. Each electric vehicle typically requires around 2.5 kg of NdFeB magnets, which are mainly used in drive motors, ABS, EPS, and other components.

❖ Uses of Hard Magnetic Materials in Medical Devices

1. MRI (Magnetic Resonance Imaging)

The largest medical application of permanent magnets.

It relies on strong magnets (mainly NdFeB or superconducting coils) to generate a high magnetic field, allowing accurate imaging and analysis of body tissues.

2. Magnetic Physiotherapy Equipment

Permanent magnets are placed in straps or therapeutic devices to stimulate blood circulation and relieve pain (*though its effectiveness is still scientifically debated*).

3. Drug Pumps and Pacemakers

Small magnets are used to control or detect the opening and closing of precise mechanical components.

4. Bone Fixation Devices and Prosthetics

High-strength magnets are used for external fixation and magnetic joining of components.

5. Bio-Sensors

NdFeB or SmCo materials are used in magnetic sensors to measure heartbeat signals or muscle activity.

1- Permanent Magnets in MRI Systems

Hard magnetic materials are used to generate a stable and strong magnetic field inside MRI scanners.

These magnets form the core of the device, as they align hydrogen protons in the body to produce high-resolution images of tissues and organs.

2-Magnetic Sensors and Positioning Devices

They are used to manufacture high-precision sensors that detect instrument movement or measure the position of mechanical components in medical equipment.

This enhances motion control and reduces errors during delicate surgical procedures.

3- Drug Delivery & Targeted Therapy

Due to their strong and stable magnetic properties, hard magnets help direct drug-loaded nanoparticles inside the body using an external magnetic field.

This enables cancer treatment with high accuracy while minimizing damage to healthy cells.

4- Magnetic Pumps and Flow Control Systems

Some medical devices use magnetic pumps based on permanent magnets to move fluids, such as in dialysis systems.

These pumps reduce friction, extend device lifetime, and operate with lower noise.

5- Cochlear Implants and Hearing Devices

Hard magnets are used in cochlear implants to secure internal and external device components.

They also assist in transmitting electrical signals into the ear via magnetic coupling.

6- Orthopedic Surgical Tools

They are used in magnetized surgical screwdrivers and tools, helping surgeons pick up and place small metal parts easily.

Some magnetic systems are also used for bone fixation and surgical implants.

7- Cardiac Pacemakers and Neurostimulators

Permanent magnets enable wireless control and adjustment of cardiac pacemakers and neural stimulators.

Magnetic fields can safely activate, deactivate, or modify device settings when needed.

8- Magnetic Separation in Diagnostics

Hard magnets are used to separate cells, proteins, and viruses using magnetic particles attracted by a permanent magnetic field.

This technique is essential for biomedical analysis and laboratory diagnostics.