Unit 4

Electromagnetism

Introduction to Electromagnetism

Electromagnetism is a fundamental force in nature that combines the principles of electricity and magnetism. It deals with the electromagnetic force, which is the force exerted between charged particles. This force is carried by electromagnetic fields composed of electric and magnetic fields. When charged particles, like electrons, move, they generate a magnetic field. If these particles oscillate, they produce electromagnetic radiation, such as radio waves.

The relationship between electricity and magnetism was first discovered in 1819 by Hans Christian Oersted, who noticed that an electric current could deflect a compass needle, revealing a link between the two forces. Later, scientists like Michael Faraday and Joseph Henry found that a changing magnetic field could generate an electric current, leading to the understanding that electricity and magnetism are interconnected.

Magnets and Magnetic Fields

A magnet creates a magnetic field, an invisible force that affects certain materials like iron, nickel, and cobalt. Every magnet has two poles: a north pole (N) and a south pole (S). Like poles repel each other, while opposite poles attract.

There are two main types of magnets:

1. **Permanent Magnets**: These generate a magnetic field due to their internal structure and maintain their magnetism over time.
2. **Electromagnets**: These are created by wrapping a coil of wire around a core (usually iron) and passing an electric current through the wire. The magnetic field is present only when the current flows.

The Earth itself behaves like a giant magnet, with a magnetic field that causes compass needles to align in a north-south direction.

Differences Between Electric and Magnetic Fields

- **Electric Field**: Surrounds electric charges and is measured in Newtons per Coulomb (N/C).
- **Magnetic Field**: Surrounds magnets and is measured in Teslas (T).
- Electric field lines originate from positive charges and end on negative charges, while magnetic field lines form continuous loops without a beginning or end.

Magnetic Field Lines

Magnetic field lines are imaginary lines used to represent the strength and direction of a magnetic field. The density of these lines indicates the field's strength:

- They have direction and magnitude.
- The field is stronger where lines are closer together.
- Magnetic field lines never cross each other and form closed loops.

Current and Magnetism

When an electric current flows through a conductor, it generates a magnetic field around it. The direction of this magnetic field can be determined using Fleming's Right Hand Rule: If you grip the wire with your right hand, with your thumb pointing in the direction of the current, your fingers will curl in the direction of the magnetic field.

Electromagnetic Induction

Electromagnetic induction is the process of generating an electric current from a changing magnetic field. This principle, discovered by Michael Faraday in 1831, is the foundation of modern electrical technology, including generators and transformers.

- **Magnetic Flux**: Magnetic flux refers to the total magnetic field passing through a given area. It's calculated using the formula:

  $$\Phi_B = B \cdot A \cdot \cos(\theta)$$

  where B is the magnetic field strength, A is the area, and θ is the angle between the field and the area.

This fundamental understanding of electromagnetism is crucial in explaining the operation of many modern devices, including motors, generators, and transformers. Through this, we see the profound connection between electricity and magnetism and their applications in everyday life.

4.5 Faraday's Law of Electromagnetic Induction

Faraday's Law of Electromagnetic Induction explains how changing magnetic fields can induce an electromotive force (emf) in a coil of wire. This principle is based on the experiments of Michael Faraday and Joseph Henry, who discovered that when the magnetic flux through a coil changes over time, an emf is induced in the coil.

Key Concepts:

- **Electromagnetic Induction**: The process of generating an emf by changing the magnetic flux through a coil.
- **Magnetic Flux (Φ)**: A measure of the number of magnetic field lines passing through a given area.

Faraday's Law of Electromagnetic Induction: The law states that the magnitude of the induced emf (ε) is directly proportional to the rate of change of the magnetic flux (Φ) through the coil. Mathematically, it is expressed as:

$$\epsilon = -\Delta\Phi_B/\Delta t$$

Where:

- ϵ is the induced emf,
- $\Delta\Phi_B$ is the change in magnetic flux,
- Δt is the change in time.

For a coil with N turns, the total induced emf is given by:

$$\epsilon = -N(\Delta\Phi_B/\Delta t)$$

The negative sign indicates that the direction of the induced emf opposes the change in magnetic flux, as described by **Lenz's Law**.

Lenz's Law: Lenz's Law states that the direction of the induced current in a coil is such that it opposes the change in magnetic flux that caused it. This is a consequence of the conservation of energy and can be understood through Newton's Third Law of Motion.

Example: Consider a square loop of side 10 cm with a resistance of 0.5 ohms, placed in a magnetic field of 0.10 T. If the magnetic field decreases to zero in

0.70 seconds, we can calculate the induced emf and current. The induced emf is found to be 1.01 mV, and the current is 2.01 mA.

4.6 Transformers

A transformer is an electrical device that transfers electrical energy between two circuits through electromagnetic induction. It is commonly used to increase (step up) or decrease (step down) voltage levels without altering the frequency.

Principle of Operation: A transformer consists of two coils, the primary and the secondary, wound on a common core. When an alternating current (AC) flows through the primary coil, it creates a changing magnetic flux, which induces a current in the secondary coil.

Voltage Relationship: The voltage across the primary and secondary coils is related by the number of turns in each coil. The relationship is given by:

$$V_p/V_s=N_p/N_s$$

Where:

- Vp] and Vs are the voltages across the primary and secondary coils, respectively,
- Np and Ns are the number of turns in the primary and secondary coils, respectively.

Efficiency: Transformers are highly efficient, often reaching efficiencies of up to 98%. The efficiency (η\etaη) is calculated as:

$$\eta=(\text{Output Power}/\text{Input Power})\times 100\%$$

Applications: Transformers are used in various applications, such as power distribution, mobile phone chargers, and household appliances. For example, a step-down transformer in a phone charger reduces the high voltage from the wall outlet to a lower, safer voltage suitable for charging the device.

4.7 Applications and Safety of Electromagnetism

Applications of Electromagnetism: Electromagnetism has countless applications in modern society, ranging from large-scale industrial machinery to small electronic components. Devices like electric motors, generators, and transformers all operate based on electromagnetic principles.

Electromagnets at Home or School: Electromagnets are widely used in everyday devices such as electric bells, headphones, loudspeakers, and MRI machines. For example, in an electric bell, when the switch is pressed, an electromagnet attracts a hammer that strikes the bell, producing sound.

Safety Considerations: While electromagnets are generally safe, precautions should be taken in certain contexts. For instance, powerful electromagnets can damage computer hard drives or distort images on CRT television screens.

Summary

- **Magnetic Field**: The area around a magnetic material where magnetic forces are exerted.
- **Magnetic Poles**: Regions of a magnet where the magnetic force is strongest.
- **Electromagnetic Induction**: The process of generating emf by changing magnetic flux.
- **Transformers**: Devices that transfer electrical energy between circuits, stepping up or down the voltage.
- **Applications**: Electromagnetism is used in a wide range of devices, from household appliances to industrial machinery.
- **Safety**: Electromagnets are safe but require precautions in certain applications to avoid damage to sensitive devices.