Electromagnetic Induction

Module 6: Electromagnetism

Table of contents

Overview

Electromagnetic induction is the process of generating an electromotive force (EMF) by changing the magnetic flux through a circuit. This fundamental phenomenon underlies generators, transformers, and many electrical devices.

Key Syllabus Points:

- Describe how magnetic flux can change
- Analyse Faraday's Law and Lenz's Law qualitatively and quantitatively

- Evaluate transformer operation and efficiency

Key Concepts

Magnetic Flux

Definition

Magnetic flux (Φ) is a measure of the total magnetic field passing through a surface.

$$\Phi = B_{\parallel}A = BA\cos\theta$$

Where: - B = magnetic field strength (T) - A = area of surface (m^2) - θ = angle between field and surface normal

Unit: Weber (Wb), where 1 Wb = 1 T $\cdot$ m^2

Faraday's Law

Faraday's Law of Electromagnetic Induction

The induced EMF equals the negative rate of change of magnetic flux through the circuit.

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

Where: - ε = induced EMF (V) - N = number of turns in coil - $\Delta\Phi$ = change in magnetic flux (Wb) - Δt = time interval (s)

Ways to change flux: 1. Change the magnetic field strength (B) 2. Change the area (A) 3. Change the angle (θ) 4. Move the conductor through the field

Lenz's Law

> **!** Lenz's Law
>
> The direction of the induced current is such that it opposes the change in flux that produces it.

This is a consequence of **conservation of energy** - the induced current creates a magnetic field that opposes the change, requiring work to be done.

Application: - Flux increasing → induced current creates opposing field - Flux decreasing → induced current creates reinforcing field

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Transformers

Ideal Transformer Equations

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_p I_p = V_s I_s$$

(power conservation)

Type	Turns Ratio	Voltage	Current
Step-up	$N_s > N_p$	Increases	Decreases
Step-down	$N_s < N_p$	Decreases	Increases

Real Transformer Losses

1. **Resistive losses**: $P = I^2R$ heating in windings
2. **Eddy current losses**: Circulating currents in iron core
3. **Hysteresis losses**: Energy lost reversing magnetic domains
4. **Flux leakage**: Incomplete flux linkage between coils

Efficiency improvements: - Use laminated iron core (reduces eddy currents) - Use soft iron core (reduces hysteresis) - Use thick copper windings (reduces resistance)

Worked Examples

Example 1: Faraday's Law Calculation

A coil with 200 turns and area 0.05 m² is perpendicular to a magnetic field that changes from 0.4 T to 0.1 T in 0.2 s. Calculate the induced EMF.

Solution:

Initial flux: $\Phi_1 = BA = 0.4 \times 0.05 = 0.02$ Wb Final flux: $\Phi_2 = BA = 0.1 \times 0.05 = 0.005$ Wb Change: $\Delta\Phi = 0.005 - 0.02 = -0.015$ Wb

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} = -200 \times \frac{-0.015}{0.2} = 15 \text{ V}$$

Example 2: Transformer Calculation

A step-down transformer has 1000 primary turns and 50 secondary turns. If the primary voltage is 240 V and the secondary current is 8 A, calculate: (a) Secondary voltage (b) Primary current (assuming 100% efficiency)

Solution:

(a) Using turns ratio:

$$V_s = V_p \times \frac{N_s}{N_p} = 240 \times \frac{50}{1000} = 12 \text{ V}$$

(b) Using power conservation:

$$I_p = \frac{V_s I_s}{V_p} = \frac{12 \times 8}{240} = 0.4 \text{ A}$$

Common Misconceptions

⚠ Avoid These Mistakes

1. **Confusing flux and field** - Flux depends on area AND field, not just field strength
2. **Forgetting the negative sign** - The negative in Faraday's Law represents Lenz's Law
3. **Assuming DC transformers work** - Transformers require changing flux, so only work with AC
4. **Ignoring angle** - Remember $\Phi = BA\cos\theta$, flux depends on orientation

5. **Power gain misconception** - Transformers conserve power (ideally), they don't create energy

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HSC Exam Analysis

Question Types

1. **Calculation questions (4-6 marks)**: Calculate EMF, flux change, transformer values
2. **Explanation questions (4-5 marks)**: Explain Lenz's Law, transformer losses
3. **Application questions (5-7 marks)**: Power transmission, generator operation

Recent HSC Questions

- 2024 Q25: Transformer efficiency and power transmission
- 2023 Q27: Faraday's Law application to moving conductor
- 2022 Q26: Lenz's Law and conservation of energy

Practice Problems

1. A 500-turn coil rotates in a 0.2 T field. If the flux through it changes from maximum to zero in 0.05 s, calculate the average induced EMF.

2. A transformer steps up 240 V to 12,000 V for transmission. If the transmission line current is 5 A, calculate the current in the primary coil (assuming 95% efficiency).

3. Explain why the core of a transformer is made from laminated sheets rather than solid iron.

4. A magnet is dropped through a copper tube. Using Lenz's Law, explain why it falls slower than in free fall.

Related Topics

- The Motor Effect
- DC Motors and Generators
- Magnetism (Year 11)