8.1 Effect of a Magnet on a Current-carrying Conductor

8.1.1 Straight Wire

- Magnetic fields are circular
- Field is strongest close to the wire
- Increasing the current increases the strength of the field
- To determine the direction of the circular magnetic fields, use the right hand rule

Remember: X marks the spot!

Labeling of direction of current

- The magnetic field is similar to two straight lines carrying current in opposite directions
- The magnetic field between the wires are straight lines whereas the ones near the wire are circular

- When the number of turns on a coil is increased, it becomes a solenoid
- The magnetic fields are similar to a bar magnet, i.e. magnetic poles on either end
8.1.2 Electromagnet

- An electromagnet is a magnet made by winding a coil of insulated wires around a soft iron core, so that a magnetic field is produced when a current passes through the coil.
- To increase the strength of the electromagnet:
  - Increase the current
  - Increase the number of turns on the coil
  - Insert a soft iron core in the middle of the solenoid

8.1.3 Applications of Electromagnets

- Electromagnetic lifter
- Circuit breaker
- Electric bell
Chapter 8: Electromagnetism

8.2 Interaction Between Current-carrying Conductor and the Magnetic Field

8.2.1 Interaction of magnetic fields of a current-carrying conductor and permanent magnets

<table>
<thead>
<tr>
<th>Permanent magnet</th>
<th>Current-carrying conductor</th>
<th>Catapult field</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Permanent magnet" /></td>
<td><img src="image" alt="Current-carrying conductor" /></td>
<td><img src="image" alt="Catapult field" /></td>
</tr>
</tbody>
</table>

8.2.2 Determining the direction of the induced force

Fleming’s left-hand rule

Remember: Feed My Cat

Fleming’s Left Hand Rule Right Hand Slap Rule

The force is increased if:
- Current is increased
- A stronger magnet is used
- The length of wire in the field is increased
8.2.3 D.C. Motor

D.C. Motor

EXTRA INFORMATION
Alternating Current Motor
Unlike DC motors which use permanent magnets, alternating current motors use electromagnets. The polarity of the electromagnet changes at the same frequency as the alternating current, so there is no change in the direction of rotation of the motor.

8.2.4 Applications

Moving coil meter
Used to measure direct current only

Moving coil loudspeaker
8.3 Electromagnetic Induction

8.3.1 Inducing e.m.f. and current

E.m.f and current can be induced by:

- Moving a magnet bar in and out of a solenoid
- Moving a conductor across a magnetic field

E.m.f. and current can only be induced when there is relative motion between a conductor and magnetic fields that are perpendicular to each other.

8.3.2 Determining the direction of the induced current

8.3.2.1 Single wires

Remember: Feed My Cat

Fleming’s Right Hand Rule

Right Hand Slap Rule
8.3.2.2  Lenz's Law

Lenz's Law states that the direction of the induced current is such that the change producing it will be opposed.

The solenoid will always resist any movement of the magnet relative to the solenoid.
- When the bar magnet is inserted into the solenoid, the solenoid will try to repel the bar magnet. Therefore, the polarity of that end of the solenoid will be the same as the bar magnet's.
- When the bar magnet is removed from the solenoid, the solenoid will try to attract the bar magnet. Therefore, the polarity of that end of the solenoid will be the opposite of the bar magnet's.

<table>
<thead>
<tr>
<th>Based on direction of current flow observed at the either end of the solenoid</th>
<th>Using the right-hand grip rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Diagram of solenoid with direction of current flow]</td>
<td>[Diagram of right-hand grip rule]</td>
</tr>
</tbody>
</table>

8.3.3  Determining the magnitude of the induced current (Faraday's Law)

Faraday's Law states that the magnitude of the induced e.m.f. is directly proportional to the rate of change magnetic flux through a coil or alternatively the rate of the magnetic flux being cut.

If there is no relative motion between a magnet and a solenoid, there is no electromagnetic induction.

To increase the e.m.f. and current:
- Increase the relative motion
- Increase the number of turns on the coils
- Increase the magnetic strength
- Increase the cross-section area of the wire
- Insert a soft iron core in between the coils of the wire
8.3.4 Direct Current & Alternating Current

To increase induced current in the generators:
- Increase the magnetic field strength
- Increase the number of windings on the armature
- Insert a soft iron core in the armature
- Increase the speed of rotation of the armature
- Increase the area of the armature

8.3.4.1 Root mean square voltage and current

- When two identical light bulbs are connected to a direct current and an alternating current of the same e.m.f., it is found that the light bulb connected to the d.c. shines with brighter intensity.
- This is due to the changing values of alternating current.
- The overall effective voltage of the alternating current can be calculated, and is known as root mean square voltage.

\[
V_{rms} = \frac{V_{peak}}{\sqrt{2}}
\]

where \( V_{rms} = \) root mean square voltage [V] \( V_{peak} = \) peak voltage [V]

- The overall effective current of the alternating current can also be calculated, and is known as root mean square current.

\[
I_{rms} = \frac{I_{peak}}{\sqrt{2}}
\]

where \( I_{rms} = \) root mean square current [A] \( I_{peak} = \) peak current [A]
### 8.3.5 Operating Principles of Current-measuring Devices

<table>
<thead>
<tr>
<th><strong>Moving coil meter</strong></th>
<th><strong>Hot wire meter</strong></th>
<th><strong>Moving iron meter</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Moving coil meter diagram" /></td>
<td><img src="image2" alt="Hot wire meter diagram" /></td>
<td><img src="image3" alt="Moving iron meter diagram" /></td>
</tr>
</tbody>
</table>

- **Built on the principle of electromagnetism**
- When current flows through the coil, the mutual interaction between the magnet and the coil forms a rotating force that turns the coil and hence deflects the indicator.
- Sensitivity can be increased by:
  - Using a stronger magnet
  - Increasing the windings on the coil
  - Increasing the area of the coil
  - Using a recovery spring with smaller spring constant
  - Using a lighter indicator

- **Built on the principle of heating effect of electric current**
- When current flows through the wire $AB$, the wire heats up and expands.
- This causes the thread to be taut and the pulley turns causing the indicator to deflect.
- The rate of heating is not directly proportional to the magnitude of the current, therefore a non-linear scale is used.

- **Built in the principles of electromagnetism**
- When current flows through the solenoid, the solenoid is magnetized, causing iron rods $P$ and $Q$ to be magnetized with the same polarity.
- Therefore both rods repel each other and $Q$ rotates, causing the indicator needle to deflect.
- For measuring **direct current** and **alternating current**
- Only can measure large magnitudes of current because small currents are unable to induce a magnetic field strong enough to magnetize the two iron rods.

- **Only for measuring direct current**
- **For measuring direct current and alternating current**
- **For measuring direct current and alternating current**
8.4 Transformer

8.4.1 Basics of a transformer

- Transformers are used to change the potential difference of an alternating current (AC) source.

\[
\frac{V_p}{V_s} = \frac{N_p}{N_s}
\]

where

- \( V_p \) = primary voltage / input voltage [V]
- \( V_s \) = secondary voltage / output voltage [V]
- \( N_p \) = number of turns on primary coil
- \( N_s \) = number of turns on secondary coil

8.4.2 Operating principle of a transformer

- Input circuit must be connected to a.c.
- D.c. is uniform in magnitude and has a fixed direction. Therefore the induced e.m.f. is not produced in the secondary coil which depends on change in the magnetic flux.
- A.c. always has changing direction and magnitude. Therefore the direction and magnitude of the induced magnetic field in the primary coil also changes, inducing e.m.f. in the secondary coil.

8.4.3 Types of transformers

<table>
<thead>
<tr>
<th>Step-up transformer</th>
<th>Step-down transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase the potential difference</td>
<td>Reduce potential difference</td>
</tr>
<tr>
<td>Number of turns in the secondary coil is greater than in the primary coil</td>
<td>Number of turn in the secondary coil is less than in the primary coil</td>
</tr>
<tr>
<td>Current in primary coil is greater than in secondary coil</td>
<td>Current in primary coil is less than in secondary coil</td>
</tr>
</tbody>
</table>
8.4.4 Efficiency

Efficiency = \frac{\text{Output power}}{\text{Input power}} \times 100\%

Because \( P = IV \),

\[
\text{Efficiency} = \frac{V_sI_s}{V_pI_p} \times 100\%
\]

where

\( V_p \) = primary voltage / input voltage [V]
\( V_s \) = secondary voltage / output voltage [V]
\( I_p \) = current in primary coil [A]
\( I_s \) = current in secondary coil [A]

If the transformer is said to be ideal, the efficiency = 100%.
Therefore,

\[
\frac{V_p}{I_p} = \frac{V_s}{I_s}
\]

8.4.5 Factors that affect the efficiency of a transformer

<table>
<thead>
<tr>
<th>Factors</th>
<th>Methods to increase efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating effect of current in coil</td>
<td>• Use thicker copper wires of low resistance</td>
</tr>
<tr>
<td>Power lost as heat ( P = \bar{I}R )</td>
<td>• Use coolant to decrease the temperature of the transformer</td>
</tr>
<tr>
<td>Heating effect of induced eddy currents*</td>
<td>• Use a laminated iron core where each layer is insulated with enamel paint to prevent flow of eddy currents</td>
</tr>
<tr>
<td>Eddy currents are generated within the iron core</td>
<td></td>
</tr>
<tr>
<td>*Eddy currents: circulating electrical currents that are induced in electrically conductive elements when exposed to changing magnetic fields, creating an opposing force to the magnetic flux.</td>
<td></td>
</tr>
<tr>
<td>Magnetization of the iron core</td>
<td>• Use a soft iron core that is easily magnetized and demagnetized</td>
</tr>
<tr>
<td>Energy used in the magnetization and demagnetization of the iron core everytime the current changes its direction is known as hysteresis. This energy is lost as heat which subsequently heats up the iron core.</td>
<td></td>
</tr>
<tr>
<td>Flux leakage</td>
<td>• Secondary coils are intertwined tightly with the primary coils</td>
</tr>
<tr>
<td>Some of the induced magnetic flux from the primary coil is not transferred to the secondary coil</td>
<td>• Iron core should resemble a closed loop</td>
</tr>
</tbody>
</table>

![output coil wound over input coil](image)
8.5 Transmission of Electricity

8.5.1 Transmission of electricity

- To reduce power lost through transmission, electricity is sent at very high voltage through thick cables of low resistance
- When voltage increases, current decreases
- Based on \( P = I^2R \), when current decreases, power loss decreases

\[
P = IV
\]

\[
P = I^2R
\]

8.5.2 National electricity grid system

![Diagram of national electricity grid system]

**END OF CHAPTER**

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