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Area Of Study 1, Electric Power, Study Notes 3

Electromagnetic Induction

Remember: **moving a wire in a magnetic field, or moving a magnetic field near a wire, causes current in the wire.** Relative motion between any conductor and a magnetic field causes electrons to move. This is electromagnetic induction; current is induced electromagnetically.

Right Hand "Back-Slap" (RHB) Rule

This gives the **direction of the current** in a wire when in relative motion to a magnetic field (assuming an angle of 90° between the current in the wire and the magnetic field affecting it).

- Use your **right** hand.
- Stick your fingers out.
- Align your **fingers with the magnetic field** affecting the wire (not the magnetic field **of** the wire).
- Point the **back** of your hand in the direction of the wire's motion (this is perpendicular to the wire itself, as the current and magnetic field [and hence the motion] are 90° to each other).
- Stick your thumb out.

Your **thumb points in the direction of the current induced in the wire**.

Note that the back of your hand, indicating the direction of the wire's motion, is on the opposite side to the palm of your hand, showing that the force experienced by the wire due to the magnetic field (**not** due to the cause of its motion) is in the opposite direction of its motion.

Lenz's Law

This relates the directions of magnetic fields involved with electromagnetic induction.

- If there's relative motion between one and the other, a magnetic field causes current in a wire.
- If there's current in a wire, this causes the wire to have a magnetic field of it's own.

Lenz's Law states that **the directions of these magnetic fields oppose each other**.

Lenz's Law shows a relationship between the Right Hand Push and Back-Slap rules: The **force experienced by a current carrying wire in a magnetic field opposes the direction of the motion causing the current**. This also shows a deficiency of electric motors: the rotation of the coil in the magnetic field causes current in the opposite direction to the one making it rotate, reducing the force on the coil and generating what's referred to as "back-voltage".

Lenz's Law is used to operate tram brakes. By bringing a fixed magnetic field into the proximity of a rotating aluminium disc, **Eddy currents** are generated in the disc. An Eddy current is an electrical current that has nowhere to be conducted to, so it moves around enclosed inside an object. The magnetic field due to the Eddy currents opposes the other one, causing the rotation to stop.

Lenz's Law is also used in the operation of speedometers. A car's gearbox rotates a magnet very close to an aluminium disc, causing Eddy currents in the disc. The magnetic field due to these currents oppose the other one, causing rotation.

Generators And Alternators

Generators operate on exactly the same principle as electric motors, but rather than current through a coil in a magnetic field causing rotation, something else (almost anything; an unrelated source of kinetic energy) rotates the coil in a magnetic field causing current: electricity is generated.

- Electric motors: current causes rotation.
- Generators: rotation causes current.

A DC generator has practically the same parts as an electric motor. Electric motors will usually act as generators when the armature is manually rotated. DC is output because of the commutator.

An AC generator uses slip-rings instead of a commutator. AC is output because of the current reversing in the coil every half rotation.

Alternators comprise a magnetic field rotating in a coil of wire, rather than a coil of wire rotating in the magnetic field, so the difference between a generator and an alternator is that the moving parts are reversed. Alternators generate electricity because there is still relative motion between a wire and a magnetic field. Alternators can be more efficient than generators for AC, because slip-rings and brushes are not needed if a permanent magnet is used.

Faraday's law

This is usually used in reference to a coil rotating in a magnetic field, and relates the voltage induced in the coil with flux rate of change. Flux changes for a rotating coil in a magnetic field because the area of the coil exposed to the magnetic field varies as it rotates.

Faraday's law states that **the faster flux changes, the more voltage is induced**. For a generator, this means that faster a coil rotates in a magnetic field, the more the voltage that will be induced in the coil.

Neumann's Equation

$$\varepsilon = \frac{-\Delta\phi_B}{\Delta t}$$

Where: ε = electromotive force (EMF, potential difference or induced voltage), in V
$\Delta\phi_B$ = change in magnetic flux, in Weber, Wb
Δt = change in time, in s

Neumann's equation allows the quantification of the voltage induced in a loop or coil of wire moved relative to a magnetic field. It is essentially a mathematical expression of Faraday's Law. The negative sign is due to Lenz's Law, and indicates the direction of the induced voltage in consideration of the wire's magnetic field opposing the direction of the other. Since this equation is normally used for finding a magnitude of voltage, this negative sign can often be ignored.

Where multiple loops are used to create a coil, multiply by the number of loops:

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

Where: N = number of loops of wire in coil

Voltage Generated By Electromagnetic Induction

$$\varepsilon = -Blv$$

Where: ε = electromotive force (EMF, potential difference or induced voltage), in V
B = magnetic flux density (magnetic field strength), in T
l = length of the wire in the magnetic field, in m
v = velocity of relative motion between wire and magnetic field, in ms^{-1}

Again, the above formula is a further expression of Faraday's Law, but in consideration of the length of the wire moving relative to a magnetic field. The negative sign is for the same reason as in Neumann's equation.

$$\varepsilon_{max} = NBA2\pi f$$

Where:
- ε_{max} = electromotive force (EMF, potential difference or induced voltage), in V
- N = number of loops of wire in coil
- B = magnetic flux density (magnetic field strength), in T
- A = area of wire loop (across which B is considered), in m^2
- f = frequency of rotation of wire loops, in Hz

The above formula allows the calculation of the **maximum** voltage generated by a any number of loops of wire rotating in a magnetic field. It does **not** give the voltage generated at any given time throughout the rotation of the loop.

Transformers

These are devices that transform one voltage to another, but are **not** voltage dividers (studied previously). Voltage can be transformed to be higher as well as lower. Transformers **only work with AC**. They're constructed from **two solenoids**. The solenoids can be side by side, one above the other, or one inside of the other. The solenoids **share no electrical connection**.

The constantly alternating magnetic field from the AC in the first ("primary") solenoid induces AC in the other. The voltage of the AC in the second (secondary) solenoid depends on the relative number of loops in each solenoid. Whether Voltage is transformed to be higher or lower, with an ideal transformer, the **electrical power going into the first solenoid is equal to the power coming out of the second solenoid**, so if voltage is increased, current decreases as a consequence, and vice versa.

Transformer solenoids are usually built around soft iron cores to enhance their magnetic fields. Eddy currents occur in these iron cores, against very high resistance, causing the generation of heat, resulting in energy loss. Eddy currents are minimised by constructing the soft iron cores from thin sheets insulated from each other and laminated together. For an ideal transformer (in which no energy loss occurs):

$$\frac{N_S}{N_P} = \frac{V_S}{V_P}$$

$$\frac{N_S}{N_P} = \frac{I_P}{I_S}$$

$$P_P = P_S \rightarrow V_P I_P = V_S I_S$$

Where:
- N_P = number of loops in primary solenoid
- N_S = number of loops in secondary solenoid
- V_P = voltage across primary solenoid, in V
- V_S = voltage across secondary solenoid, in V
- I_P = current through primary solenoid, in A
- I_S = current through secondary solenoid, in A
- P_P = power in primary solenoid, in W
- P_S = power in secondary solenoid, in W