Nadar Saraswathi College of Engineering & Technology

NSCET E-LEARNING PRESENTATION

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ELECTRICAL AND ELCTRONICS ENGINEERING

II nd YEAR / III rd SEMESTER

EE8391 – Electromagnetic Theory

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UNIT 04 – Electrodynamic fields

Planning is doing today to make us better tomorrow because the future belongs to those who make the hard decisions today.

-Business Week

UNIT-4

- Magnetic circuits
- Faraday’s law
- Displacement current
- Maxwell’s equation(differential and integral form)
- Relation between field theory and circuit theory
- Application

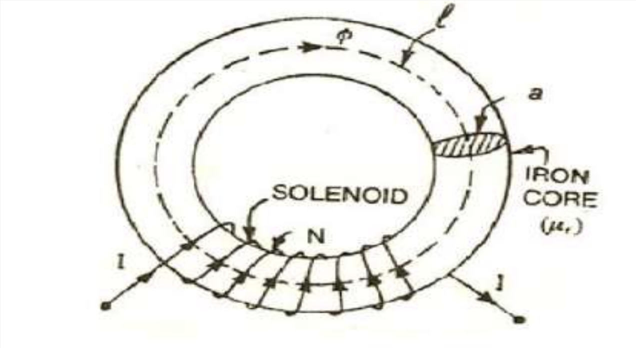
Magnetic circuits

- The closed path followed by magnetic lines of forces is called the **magnetic circuit**. In the **magnetic circuit**, magnetic flux or magnetic lines of force starts from a point and ends at the same point after completing its path.

- Flux is generated by magnets, it can be a permanent magnet or electromagnets.

- A **magnetic circuit** is made up of magnetic materials having high permeability such as iron, soft steel, etc. **Magnetic circuits** are used in various devices like electric motor, transformers, relays, generators galvanometer, etc.

- Consider a solenoid having N turns wound on an iron core. The magnetic flux of ø Weber sets up in the core when the current of I ampere is passed through a solenoid.



l = mean length of the magnetic circuit
A = cross-sectional area of the core
μr = relative permeability of the core

Now the flux density in the core material

$$B = \frac{\varphi}{a} \quad (Weber/m^2)$$

Magnetising force in the core

$$H = B/\mu_0\mu_r$$

$$H = {}^{\varphi}/_{a}\mu_0\mu_r \text{ AT/m (Ampere turns/meter)}$$

According to work law, the work done in moving a unit pole once round the magnetic circuit is equal to the ampere-turns enclosed by the magnetic circuit.

$$Hl = NI$$

$$H = \frac{\varphi}{a\mu_0\mu_r} x\ l$$

$$H = NI$$

$$\varphi = \frac{NI}{{}^{l}/_{a\mu_0\mu_r}}$$

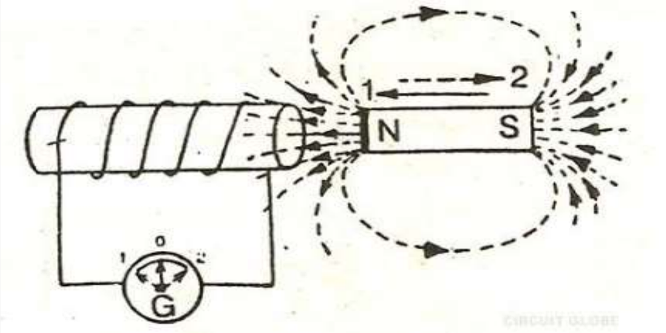
Faraday’s Law Of Electromagnetic Induction

- Faraday’s Law of **Electromagnetic Induction** states that “ the magnitude of voltage is directly proportional to the rate of change of flux.”

- In a closed circuit when the current flows and the emf is induced, therefore the phenomenon by which an emf is induced in a circuit when magnetic flux linking with it changes is called **Electro Magnetic Induction.**

- For example, Consider a coil having a large number of turns to which the galvanometer is connected

Case 1: – When the coil is stationary, and the magnet is moving



When a permanent bar magnet is taken nearer to the coil (position 2) or away from the coil (position 1) as shown in the above figure, the deflection takes place in the galvanometer. The deflections are the opposite in both cases.

Displacement Current

Displacement current is a quantity appearing in Maxwell's equations. Displacement current definition is defined in terms of the rate of change of the electric displacement field (D).

Current in a capacitor.

When a capacitor starts charging there is no conduction of charge between the plates. However, because of change in charge accumulation with time above the plates, the electric field changes causing the displacement current as below-

ID=JDS=S∂D∂t

Where,

S is the area of the capacitor plate.

I_D is the displacement current.

J_D is the displacement current density.

D is related to electric field E as D=εE

ε is the permittivity of the medium in between the plates.

Displacement Current Equation

Displacement current has the same unit and effect on the magnetic field as is for conduction current depicted by Maxwell’s equation-

$\nabla \times H = J + J_D$ Where,

H is related to magnetic field B as $B = \mu H$

μ is the permeability of the medium in between the plates.

J is the conducting current density.

J_D is the displacement current density.

We know that

$\nabla . (\nabla \times H) = 0$ and $\nabla . J = -\frac{\partial \rho}{\partial t} = -\nabla . \frac{\partial D}{\partial t}$ using Gauss’s law that is $\nabla . D = \rho$

Here, ρ is the electric charge density.

Thus, $J_D = \frac{\partial D}{\partial t}$

Maxwell’s equation

Maxwell’s equations integral form explain how the electric charges and electric currents produce magnetic and electric fields. The equations describe how the electric field can create a magnetic field and vice versa.

$\nabla \cdot \mathbf{D} = \rho$	(1)	Gauss’ Law
$\nabla \cdot \mathbf{B} = 0$	(2)	Gauss’ Law for magnetism
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	(3)	Faraday’s Law
$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$	(4)	Ampère-Maxwell Law

Maxwell First Equation

Maxwell first equation is based on the Gauss law of electrostatic which states that “when a closed surface integral of electric flux density is always equal to charge enclosed over that surface”

Mathematically Gauss law can be expressed as,
Over a closed surface the product of electric flux density vector and surface integral is equal to the charge enclosed.

$$\oiint \vec{D} \cdot \bar{ds} = Q_{enclosed} \quad \text{——}(1)$$

Any closed system will have multiple surfaces but a single volume. Thus, the above surface integral can be converted into a volume integral by taking the divergence of the same vector. Thus, mathematically it is-

$$\oiint \bar{D}.\bar{ds} = \iiint \nabla.\vec{D}\, d\vec{v} \quad \text{—-(2)}$$

Thus, combining (1) and (2) we get-

$$\iiint \nabla.\vec{D}\, d\vec{v} = Q_{enclosed} \quad \text{——(3)}$$

Maxwell Second Equation

Maxwell second equation is based on Gauss law on magnetostatics.

Gauss law on magnetostatics states that “closed surface integral of magnetic flux density is always equal to total scalar magnetic flux enclosed within that surface of any shape or size lying in any medium.”

Mathematically it is expressed as –

$$\oiint \vec{B} \cdot ds = \phi_{enclosed} \quad \text{——(1)}$$

Hence we can conclude that magnetic flux cannot be enclosed within a closed surface of any shape.

$$\oint\!\!\oint \vec{B}\,.ds=0 \text{ ———(2)}$$

Applying Gauss divergence theorem to equation (2) we can convert it(surface integral) into volume integral by taking the divergence of the same vector.

$$\Rightarrow \oint\!\!\oint \vec{B}\,.ds=\iiint \nabla.\vec{B}\,dv \text{ ———(3)}$$

Substituting equation (3) in (2) we get-

$$\iiint \nabla.\vec{B}\,dv=0 \text{ ——-(4)}$$

Maxwell Third Equation

Statement: Time-varying magnetic field will always produce an electric field.

Maxwell's 3rd equation is derived from Faraday's laws of Electromagnetic Induction.

It states that "Whenever there are n-turns of conducting coil in a closed path which is placed in a time-varying magnetic field, an alternating electromotive force gets induced in each and every coil." This is given by Lenz's law.

Which states that "An induced electromotive force always opposes the time-varying magnetic flux."

The surface integral can be canceled on both sides. Thus, we arrive at Maxwell's third equation

$\nabla \times \vec{E} = -\delta \vec{B}\ \delta t$

Hence, we can conclude that the time-varying magnetic field will always produce an electric field.

Extended Maxwell's third equation or Maxwell's third equation for the static magnetic field

Which states that Static electric field vector is an irrotational vector.

Static field implies the time-varying magnetic field is zero,

$\Rightarrow -\delta \vec{B}\ \delta t = 0 \Rightarrow \nabla \times \vec{E} = 0$ Hence it is an irrotational vector.

Maxwell's Fourth Equation

It is based on Ampere's circuit law. To understand Maxwell's fourth equation it is crucial to understand Ampere's circuit law,

Consider a wire of current-carrying conductor with the current I, since there is an electric field there has to be a magnetic field vector around it.

Ampere's circuit law states that "The closed line integral of magnetic field vector is always equal to the total amount of scalar electric field enclosed within the path of any shape" which means the current flowing along the wire(which is a scalar quantity) is equal to the magnetic field vector (which is a vector quantity)

Mathematically it can be written as –

$$\oint \vec{H}.\vec{dl} = I_{enclosed} \text{——}(1)$$

Any closed path of any shape or size will occupy one surface area. Thus, L.H.S of equation (1) can be converted into surface integral using Stoke's theorem, Which states that "Closed line integral of any vector field is always equal to the surface integral of the curl of the same vector field"

$$\oint \vec{H}.\vec{dl} = \iint (\nabla \times \vec{H}).\vec{ds} \text{ —-}(2)$$

Substituting equation(2) in (1) we get-

$$\iint (\nabla \times \vec{H}).\vec{dl} = I_{enclosed} \text{ ——}(3)$$

Here, $\iint (\nabla \times \vec{H}).\vec{dl}$ is a vector quantity and Ienclosed is a scalar quantity.

Field theory:

Field theory is important for the following reasons:

1. Field theory helps to understand the behaviour of particles when they are placed at different points in the field.

2. When any particular forces are applied on the particles, field theory helps to understand the magnitudes of these forces at different positions and when the same magnitude acts on the particles at different locations but at the same time.

3. Field theories such as electric and magnetic field theories can be used for studying the electric and magnetic field of a unit positive charge.

4. Electromagnetic waves can be studied with the help of field theory.

Thank you