9. ELECTROMAGNETIC INDUCTION

Synopsis :

ELECTROMAGNETIC INDUCTION :

1. Magnetic flux and magnetic induction : The number of lines of force passing through any area in a magnetic field is known as magnetic flux.
2. When magnetic field makes an angle θ with the normal to the plane then
   The magnetic flux linked with the plane is
   $\phi = (B\cos\theta)A$
   $\phi = \vec{B}.\vec{A}$
3. The flux emanating out of a surface depends upon
   a) the area of surface (A)
   b) the magnetic induction (B)
   c) the angle enclosed between the direction of magnetic field and the normal to the surface (at θ)
4. **Electromagnetic induction :**
   i) The phenomenon of production of electromotive force on account of change in magnetic flux linked with a circuit, is defined as electromagnetic induction.
   ii) The phenomenon of production of induced current in a closed circuit on account of change in magnetic flux linked with the circuit is defined as electromagnetic induction.
   iii)In the phenomenon of electromagnetic induction, the mechanical and magnetic energy is converted into electrical energy.

   Faraday's laws of electromagnetic induction :

   First law :
5. When the flux linked with a closed circuit changed then an e.m.f. is induced in the circuit. The induced e.m.f. exist so long as the change in magnetic flux lasts.
6. If the circuit is closed then an induced electric current also flows in the circuit on account of induced e.m.f. which depends on the rate of change of magnetic flux i.e., $\frac{d\phi}{dt}$

   Second law :
7. The magnitude of induced e.m.f. depends upon the rate of change of magnetic flux linked with the circuit, i.e., $e \alpha \frac{d\phi}{dt}$. If during small interval of time Δt, the change in magnetic flux is $\Delta\phi$ these $e \alpha \frac{d\phi}{dt}$ or $e \alpha \frac{\phi_2 - \phi_1}{t_2 - t_1}$.
8. This law explains the magnitude of induced e.m.f.
9. If the number of turns in the coil is N, then $e \alpha \frac{d}{dt}(N\phi)$, or $e \alpha N\frac{d\phi}{dt}$ where $N\phi$ is effective flux linked with the coil.
10. If the area of coil of N turns is A and angle between $\vec{B}$ and $\vec{A}$ is θ, then

    $e = \frac{d}{dt}(NBA\cos\theta)$

    $= \frac{d}{dt}(NBA\cos\omega t)$

    $e = -NAB\omega\sin\omega t$
11. Induced e.m.f. depends on the following factors :
    a) on magnetic permeability μ,

b) on the number of turns N,

c) on rate of change of flux $\frac{d\phi}{dt}$,

d) on area A,

e) on relative motion between the coil and the magnet.

Lenz's law :

12. The direction of induced e.m.f. or induced current in any circuit or coil is such that it opposes the very cause which is responsible for its own production.
13. $e = -N\frac{d\phi}{dt}$
14. Induced e.m.f. is generated on account of change in magnetic and mechanical energy.
15. This law explains the direction of induced e.m.f. or induced current.
16. This law is based on the law of conservation of energy.
17. If the rod moves with velocity v along a direction making an angle θ emf induced at its ends is e =Bvlsinθ.
18. The induced e.m.f. generated on account of rotation of a conducting rod in a perpendicular magnetic filed

    $e = -\frac{B\omega L^2}{2}$
19. Induced e.m.f. generated in a disc rotating with a constant angular velocity in a perpendicular magnetic field

    $e = -B\pi r^2 f = -\frac{Br^2\omega}{2}$
20. Induced e.m.f. generated due to linear motion of a rectangular coil in a uniform magnetic field.
    $\Delta\phi = 0 \ \therefore e = 0$
21. Induced e.m.f. generated on account of linear motion of a coil in a uniform finite magnetic field.
22. Induced e.m.f. generated on account of linear motion of a conducting rod in a perpendicular uniform magnetic field $e = \vec{\ell} \bullet (\vec{V} \times \vec{B})$; $e = \vec{B}(\vec{\ell} \times \vec{v})$.

Self induction :

23. Self inductance is the property of a conductor or coil which enables to induce an emf due to change of current in the same coil.
24. When an inductive circuit is closed then the main current in it rises from zero to maximum value.
25. Due to this the value of magnetic flux produced in the coil also increases from zero to maximum.
26. Due to this varying flux in the coil, an induced current is generated in the coil which flows in a direction opposite to that of main current and thus opposes the rise of main current.
27. The phenomenon of production of induced current in a circuit due to change in main current in the same circuit is defined as self induction.
28. The magnetic flux produced in a coil is directly proportional to the current flowing in it, i.e., $\phi \propto I$ or $\phi = LI$

    The constant of proportionality L is defined as the **coefficient of self induction.**
29. If I=1 amp, then L=ϕ, i.e., the self inductance of coil is equal to the magnetic flux produced in it as a result of unit current flow in it.
30. The induced e.m.f. generated in the coil is given by $e = -\frac{d\phi}{dt} = -L\frac{dI}{dt}$

31. If $\frac{dI}{dt}=1$ amp/sec, then L=e i.e., the self inductance of a coil is equal to the induced e.m.f. generated in it as a result of unit change of current in it.
32. The inductance of a coil (L) depends on
    a) the area of cross section of the coil (A)
    b) the number of turns in the coil (N)
    c) the permeability of the core material inside the coil
33. Self inductance of a plane coil is given by the formula $L=\frac{\mu_0 N^2 A}{2r}$ (or) $L=\frac{\mu_0 \pi N^2 r}{2}$.
34. The inductance of long solenoid or a toroid is give by $L=\frac{\mu_0 N^2 A}{\ell}$. Where N is total number of turns, *l* is length and A is area of cross- section.
35. Energy stored in inductor is $E=\frac{1}{2}LI^2$
36. If two inductors connected in series effective inductance is $L_1 + L_2$.
37. If two inductors connected in parallel effective inductance is $\frac{L_1 L_2}{L_1+L_2}$.

Mutual induction :

38. The phenomenon of production of induced e.m.f. in an inductive circuit, as a result of change of current in another closely lying inductive circuit, is defined as mutual induction.
39. That phenomenon of electromagnetic induction, in which if the current in one of the two closely lying coils is changed then e.m.f. is induced in another coil, is defined as mutual induction.

Coefficient of mutual induction (M) :

40. The coefficient of mutual induction between two coils is equal to that magnetic flux linked with the secondary coil which is produced as a result of unit current flow in the primary coil.

    $M_{21}=\frac{\phi_2}{I_1}$ when I_1=1 amp, then $M_{21}=\phi_2$
41. The coefficient of mutual induction is numerically equal to that induced e.m.f. in the secondary coil, which is produced as a result of unit rate of change of current in the primary coil,

    $M_{21}=\frac{e_2}{\left(\frac{dI_1}{dt}\right)}$ when $-\frac{dI_1}{dt}$=1 amp/s, then $M_{21}=e_2$
42. Similarly

    $M_{12}=\frac{\phi_1}{I_2} \Rightarrow M_{12}=\frac{e_1}{\left(\frac{dI_2}{dt}\right)}$
43. According to reciprocity theorem $M_{21}=M_{12}=M$. Hence $M=\frac{\phi}{I}$ and $M=\frac{e}{\left(\frac{-dI}{dt}\right)}$ i.e., on changing the names of the coils, M remains unchanged.
44. Dependence of M : M depends on
    1) Number of turns in the coils
    2) The distance between the coils
    3) The geometrical shape of coils
    4)The material of the core and
    5) The angle between the axes of the coils .If angle between two coils is 0°, then M is maximum and if it is 90°, then M is minimum

45. Mutual inductance of 2 plane coils given by the formula $M = \frac{\mu_0 N_p N_s A}{2r_p}$
46. Mutual inductance of two solenoids or coils is M = $\frac{\mu_0 N_1 N_2 A}{\ell}$. N_1, N_2 are number of turns in primary coil, secondary coil, ℓ is length and A is area of cross section of the coils.
47. If L_1 and L_2 are self inductances of two coils, the mutual inductance between the coils M = $\sqrt{L_1 L_2}$.

TRANSFORMER :

48. The device based on the principle of mutual induction used to change the value of alternating voltage (or e.m.f.) is defined as transformer.
49. There are two coils in a transformer which are wound on the same iron core. A) primary coil, B) secondary coil.
    Primary coil: The coil, to which the source of alternating voltage is connected, is defined as the primary coil.
    Secondary coil: The coil in which induced alternating voltage is generated is known as the secondary coil. $\frac{v_p}{v_s} = \frac{n_p}{n_s}$
50. These coils are wound on the opposite sides of the same laminated soft iron core.
51. These coils are mutually connected to each other magnetically.
52. In an ideal transformer these coils are tightly coupled (i.e., K=1) i.e., the magnetic flux generated in the primary is fully linked to the secondary.
53. There are two types of transformer
    a) step-up transformer b) step-down transformer

Other Salient features :

54. In a transformer V_S and V_P are in opposite phase i.e., a phase difference of π exists between them.
55. In this the frequency of induced e.m.f. (output voltage) is same as that of applied e.m.f. (input voltage) i.e., $n_P=n_S$.
56. For this the law of conservation of energy is held valid.
57. It converts magnetic energy into electrical energy.
58. Direct voltage or current cannot be varied with the help of this instrument.
59. Alternating current or voltage is obtained with the help of it.
60. Long distance transmission of electrical energy is effected with the help of it.
61. It does not amplify power.

Energy losses in transformer and their minimisation:

62. Copper loss : Due to current flow in primary and secondary coils of a transformer Joule heat is generated in both the coils on account of their finite resistance. i.e., electrical energy is dissipated in the form of heat energy. This loss of energy is known as copper loss. To minimise this energy loss the primary and secondary coils are made of thick copper wire.
63. Magnetic flux leakage : Some magnetic flux leaks in air between primary and secondary. Hence the flux produced in the primary does not wholly get linked with the secondary. This type of energy loss is known as magnetic flux leakage. This type of energy loss is minimised by winding the two coils one over the other.
64. **Eddy current losses:** When a transformer core is placed in a variable magnetic field then induced currents (Eddy currents) are produced in it. The heat energy produced due to these induced currents is known as Eddy current losses. This type of energy loss can be minimised by taking a laminated soft iron core.

65. **Hysteresis loss:** On account of alternating currents in the transformer coils, its core is magnetized and demagnetized again and again. Consequently due to repeated rotations of domains the core gets heated i.e., the magnetic energy gets converted into heat energy. This type of energy loss can be minimised by using core of high resistance ferrites at high frequencies and soft iron or silicon core at low frequencies.
66. **Uses :** Transformer is used in a) power stations, b) television, c) telephones, d) telegraph, e) radio