ELEMENTS OF ELECTRICAL ENGINEERING
Course Code : UE25EE141A/B

PES UNIVERSITY

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ELEMENTS OF ELECTRICAL ENGINEERING

ANALYSIS OF MAGNETIC CIRCUITS ; ELECTROMAGNETIC INDUCTION

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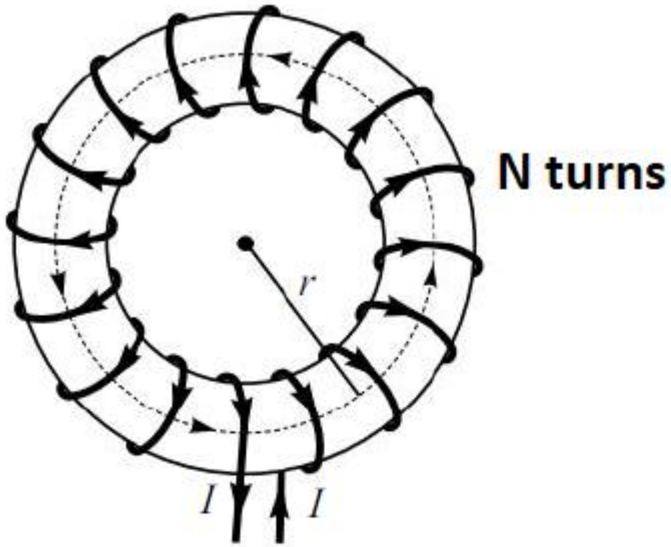
Magnetic circuit

A magnetic circuit is a closed path that is followed by magnetic field i.e., magnetic lines of force. Materials having high permeability such as soft steel, iron, etc. are used as core in the magnetic circuits.

Analogy between Electric and Magnetic Circuits

S. No.	Electric Circuits		Magnetic Circuits	
	Quantity	Units	Quantity	Units
1.	EMF, E	volts (V)	MMF, $\mathcal{F}$	ampere turn (At)
2.	current, I	ampere (A)	Flux, Φ	weber (Wb)
3.	Resistance, R $R = \frac{1}{\sigma} \cdot \frac{l}{A}$	ohm (Ω)	Reluctance, $\mathcal{R}$ $\mathcal{R} = \frac{1}{\mu_r \mu_0} \cdot \frac{l}{A}$	ampere turn/weber (At/Wb)
4.	Conductivity, σ	siemen/metre (S/m)	Permeability, μ	tesla metre per ampere (Tm/A)
5.	Conductance, G	siemen (S)	Permeance, $\mathcal{G}$	weber/ampere (Wb/A)
6.	Current density, J	ampere/metre^2 (A/m^2)	Flux density, B	weber/metre^2 or tesla (Wb/m^2 or T)
7.	Electric field intensity, $\mathcal{E}$	volt/metre (V/m)	Magnetic field intensity, H	ampere turn per metre (At/m)
8.	**Ohm's law** : $I = \frac{E}{R}$		$\Phi = \frac{\mathcal{F}}{\mathcal{R}}$	



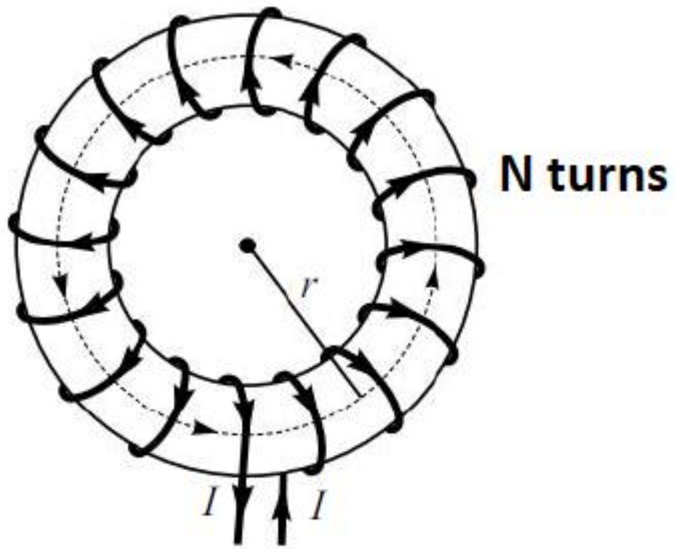
Numerical Example 1

A coil of 200 turns is wound uniformly over a wooden ring having a mean circumference of 60cm and a uniform cross-sectional area of 500mm^2. If the current through the coil is 4A, calculate a) The magnetic field strength, b) The flux density, c) The total flux.

Solution

(*a*) The magnetic field strength is

$$H = \frac{NI}{l} = \frac{200 \times 4}{0.6} = \mathbf{1333.33\ AT/m}$$



(*b*) The flux density, $B = \mu H = \mu_r \mu_0 H = 1 \times 4\pi \times 10^{-7} \times 1333 = \mathbf{1675\ \mu T}$

(*c*) The total flux, $\Phi = BA = (1675 \times 10^{-6}) \times (500 \times 10^{-6}) = \mathbf{0.8375\ \mu Wb}$

Numerical Example 2

A mild-steel ring having a cross-sectional area of 500mm^2 and a mean circumference of 400mm has a coil of 200 turns wound uniformly around it. Calculate a) Reluctance of the ring and b) the current required to produce a flux of 800 μWb in the ring. Assume the relative permeability of mild-steel to be 380.

Solution

(a) The reluctance, $\mathcal{R} = \dfrac{1}{\mu_r \mu_0} \dfrac{l}{A} = \dfrac{0.4}{380 \times 4\pi \times 10^{-7} \times 500 \times 10^{-6}} = \mathbf{1.675 \times 10^6}$ **AT/wb**

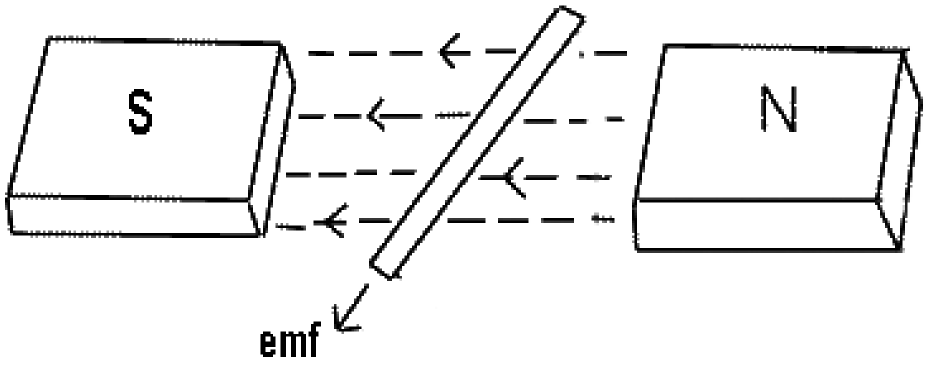
(b) The mmf, $\mathcal{F} = \Phi \mathcal{R} = (800 \times 10^{-6}) \times (1.675 \times 10^6) =$ **1340 AT**

$\therefore$ magnetising current, $I = \dfrac{\mathcal{F}}{N} = \dfrac{1340}{200} = \mathbf{6.7}$ **A**

Faraday's Laws Of Electromagnetic Induction

- It explains the relationship between electric circuit and magnetic field. This law is the basic working principle of the most of the electric motors, generators, transformers, inductors etc.

- Michael Faraday has said that there are two laws of electromagnetic induction.

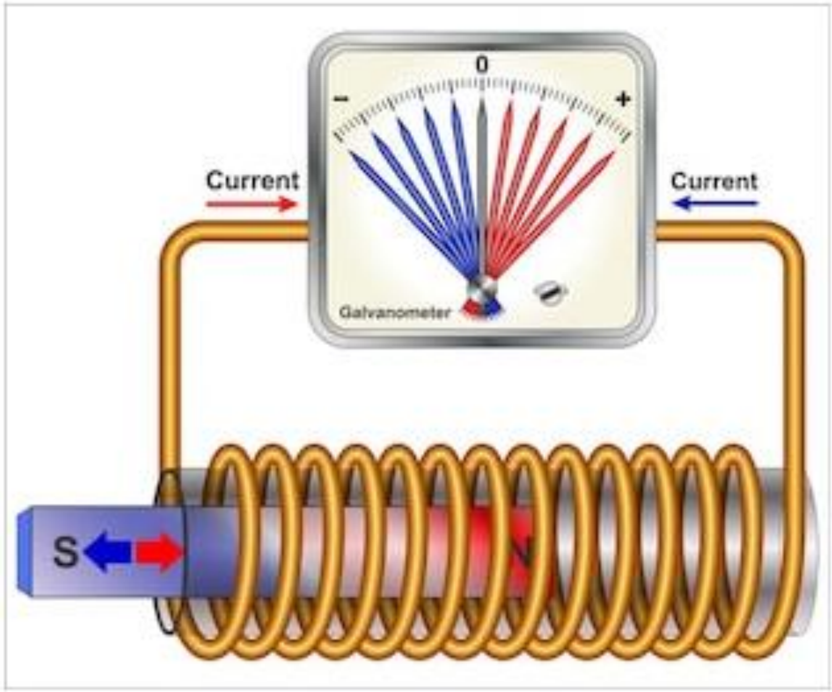


Faraday's First Law

Whenever a conductor is placed in a varying magnetic field an EMF gets induced across the conductor (called as induced emf), and if the conductor is a closed circuit then induced current flows through it.

Magnetic field can be varied by various methods -

1. By moving magnet
2. By moving the coil
3. By rotating the coil relative to magnetic field



Faraday's Second Law

Faraday's second law of electromagnetic induction states that, the magnitude of induced emf is equal to the rate of change of flux linkages with the coil. The flux linkages is the product of number of turns and the flux associated with the coil.

$$\boldsymbol{e} \propto \frac{\boldsymbol{d}\psi}{\boldsymbol{dt}}$$

$$\boldsymbol{e} = \boldsymbol{N}\frac{\boldsymbol{d\phi}}{\boldsymbol{dt}}$$

where N is number of turn in the coil.

Lenz's Law

Lenz's law of electromagnetic induction states that, when an emf is induced according to Faraday's law, the polarity (direction) of that induced emf is such that it opposes the cause of its production.

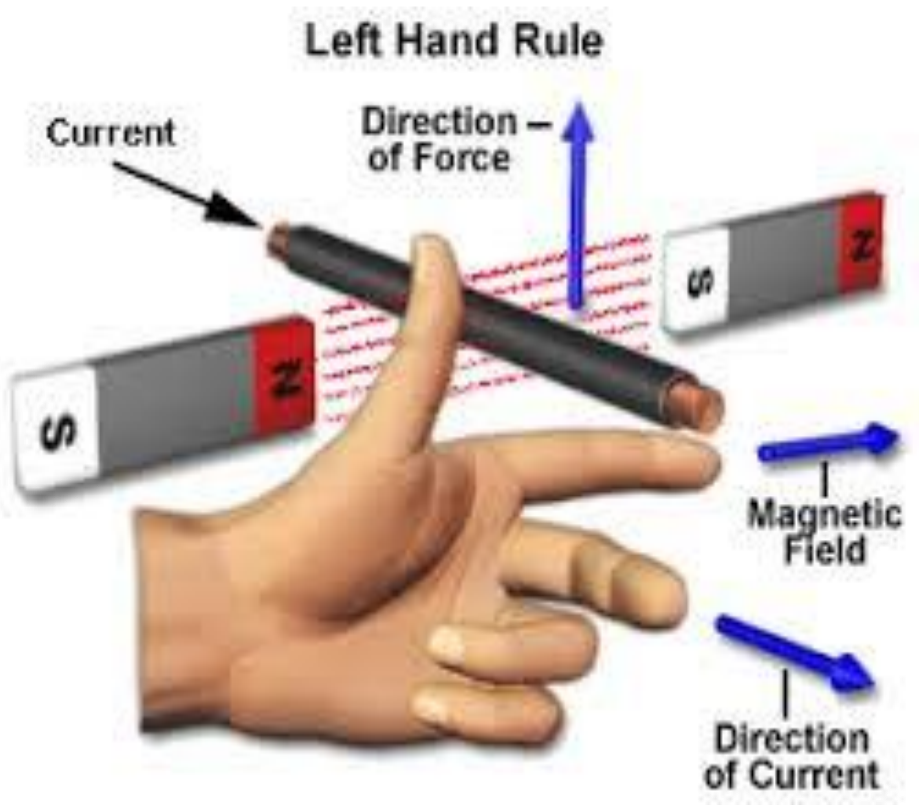
Thus, considering Lenz's law

$$e = -N\frac{d\phi}{dt}$$

The negative sign shows that, the direction of the induced emf and the direction of change in magnetic fields have opposite signs.

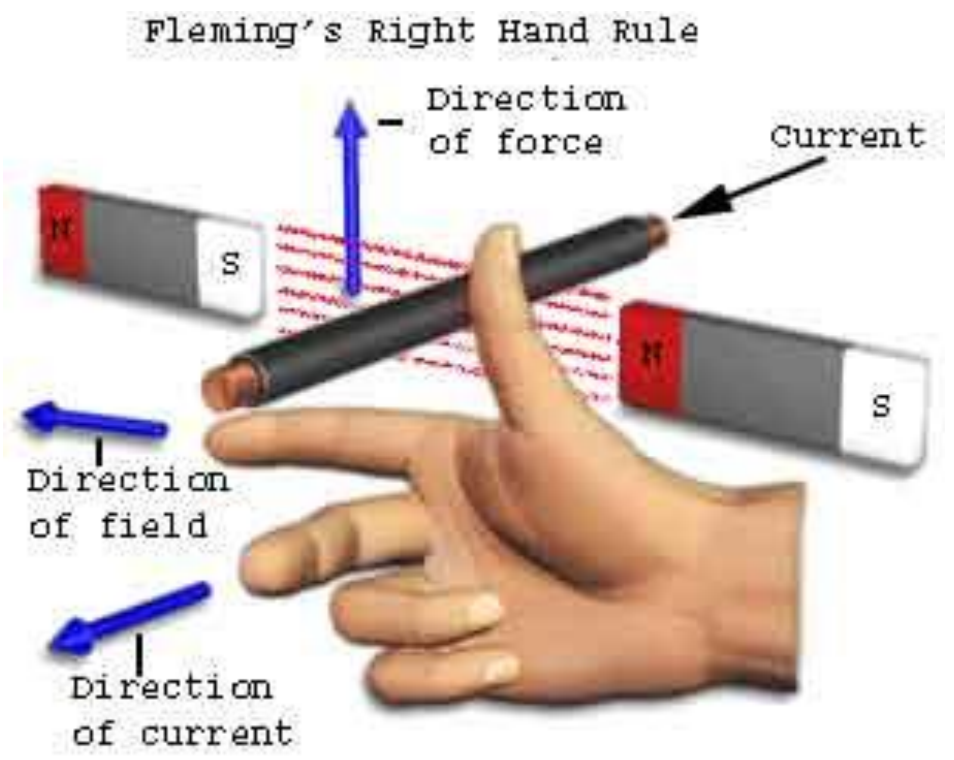
Fleming's Left Hand Rule

Whenever a current carrying conductor is placed in a magnetic field, the conductor experiences a force which is perpendicular to both the magnetic field and the direction of current. According to **Fleming's left hand rule**, if the thumb, fore-finger and middle finger of the left hand are stretched to be perpendicular to each other as shown in the illustration, and if the fore finger represents the direction of magnetic field, the middle finger represents the direction of current, then the thumb represents the direction of force. Fleming's left hand rule is applicable for motors.



Fleming’s Right Hand Rule

Fleming's right hand rule is applicable for electrical generators. Whenever a conductor is forcefully moved in an electromagnetic field, an emf gets induced across the conductor. If the conductor is provided a closed path, then the induced emf causes a current to flow. According to the Fleming's right hand rule, the thumb, fore finger and middle finger of the right hand are stretched to be perpendicular to each other as shown in the illustration, and if the thumb represents the direction of the movement of conductor, fore-finger represents direction of the magnetic field, then the middle finger represents direction of the induced current.



Induced EMF- Its Definition & Types

When a magnetic flux linking a conductor or coil changes, an electromotive force (EMF) is induced in the conductor or coil, is known as induced EMF. Depending upon the way of bringing the change in magnetic flux, the induced EMF is of two types −

- Statically Induced EMF
- Dynamically Induced EMF

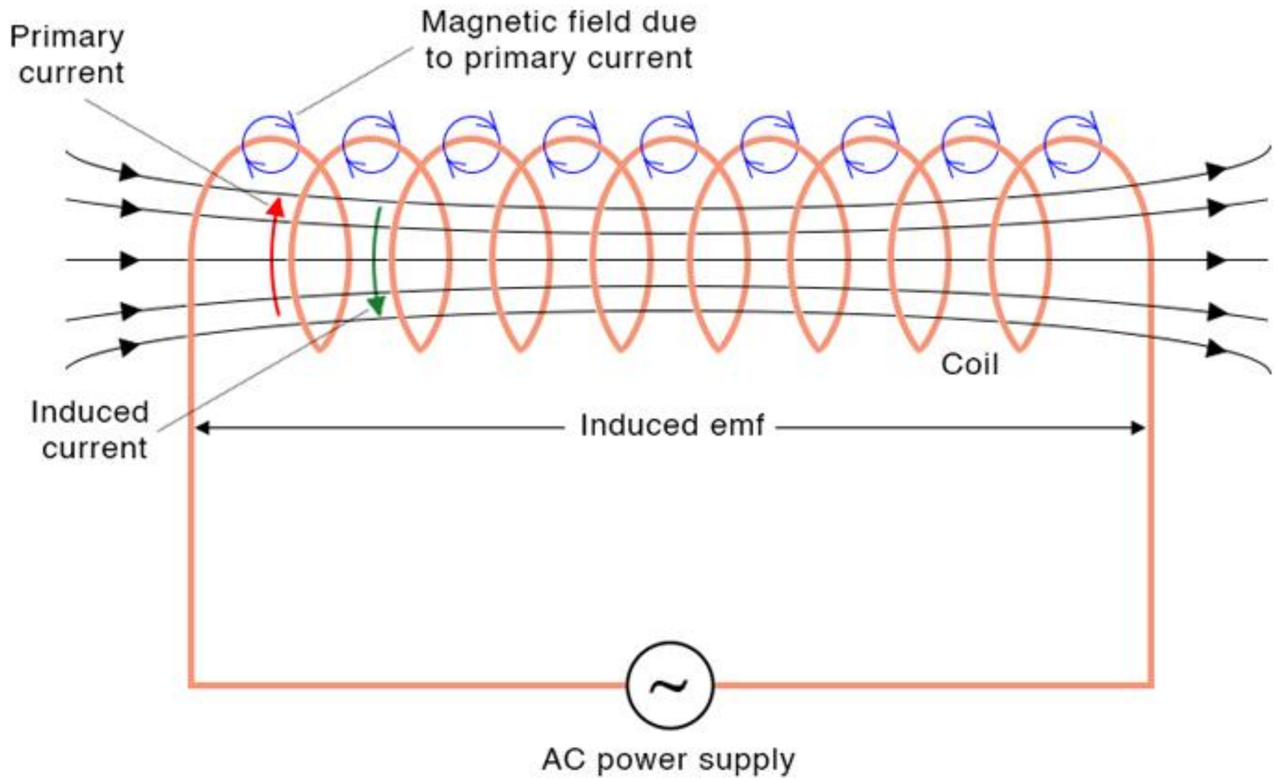
Statically Induced EMF

When the conductor is stationary and the magnetic field is changing, the induced EMF in such a way is known as statically induced EMF (as in a transformer). It is so called because the EMF is induced in a conductor which is stationary. The statically induced EMF can also be classified into two categories –

- Self-Induced EMF
- Mutually Induced EMF

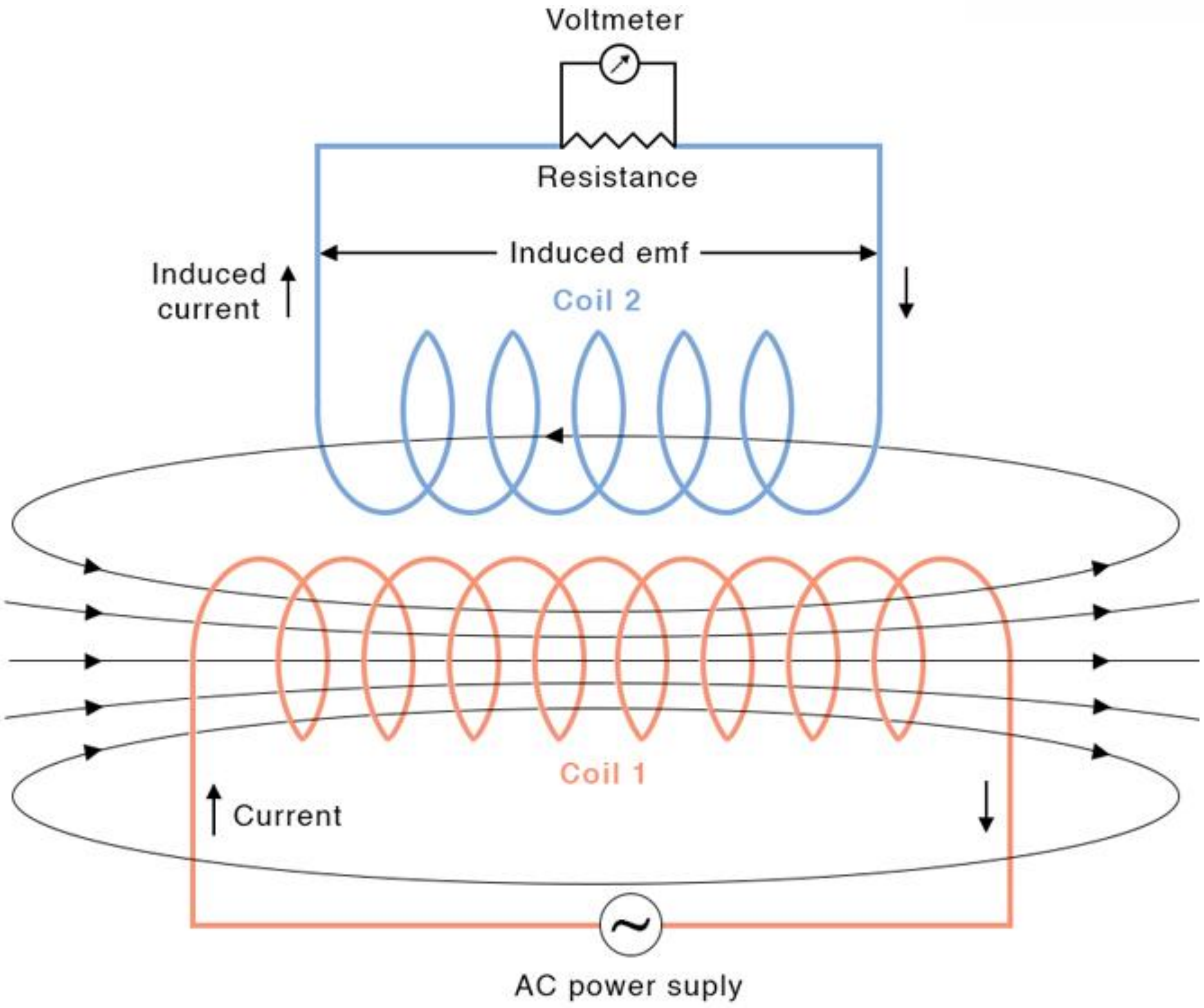
Self-Induced EMF

When an EMF is induced in the coil due to the change of its own magnetic flux linked with it is known as self-induced EMF.



Mutually Induced EMF

When an EMF is induced in a coil due to changing magnetic flux of neighbouring coil is known as mutually induced EMF.



Dynamically Induced EMF

In dynamically induced emf, if the field is stationary the conductor is moving, and if the field is moving conductor is stationary. In the DC generator usually, the coil rotates and the field remains in the stationary state, but in the AC alternator usually, the field rotates and the coils are stationary. Thus by following either of the above processes, the conductor cuts across the magnetic field causing induced EMF in the coil.

Numerical Example 3

Calculate the magnetomotive force (MMF) required to produce a flux of 0.015 Wb across an air gap of 2.5 mm long, having an effective area of 200cm^2.

Solution

The magnetic flux density, $B = \dfrac{\Phi}{A} = \dfrac{0.015}{200 \times 10^{-4}} = 0.75\ \text{T}$

Therefore, magnetic field strength for the gap, $H = \dfrac{B}{\mu_0} = \dfrac{0.75}{4\pi \times 10^{-7}} = 597000$ **AT/m**

$\therefore$ mmf required, $\mathcal{F} = Hl = 597000 \times 2.5 \times 10^{-3} = \mathbf{1492}$ **AT**

Text Book & References

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Text Book:

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2. "Basic Electrical Engineering", D. C. Kulshreshta, 2nd Edition, McGraw-Hill. 2019
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1. "Engineering Circuit Analysis" William Hayt, Jack Kemmerly, Jamie Phillips and Steven Durbin, 10th Edition McGraw Hill, 2023

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THANK YOU

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