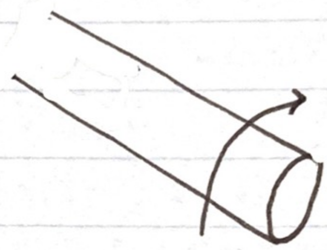
Introduction to Machinery Principles

- **Generator**: Mechanical energy → Electic energy
- **Motor**: Electric energy → Mechanical energy
- **Transformer**: Converts AC Electric energy at one voltage level to another

Definitions :-

1. Angular Position (θ) : [rad]
   - → + : counterclockwise
   - → − : Clockwise



2. Angular Velocity (ω): [rad/s]

$$\omega = \frac{d\theta}{dt}$$

$$f_m = \frac{\omega_m}{2\pi} \quad rev/s$$

$$n_m = 60 f_m \quad rev/m$$

3. Angular acceleration (α): [rad/s²]

$$\alpha = \frac{d\omega^2}{d^2t}$$

4. Torque : τ : Nm

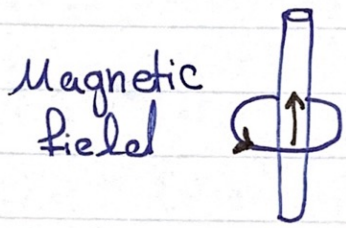
In Rotational movement : $\tau = J\alpha$ ← moment of inertia

5. Work (W) : [J]
In Rotational movement: $W = \tau\theta$

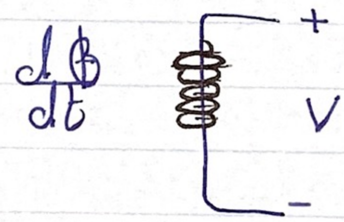
6. Power (P): [J/s]
" " " : $P = \tau\omega$

Basic principals of Magnetic field

1. A current carrying a wire produces magnetic field in the area around it.

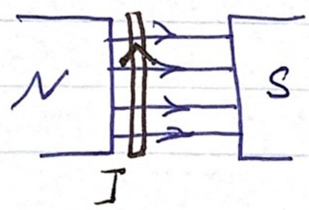


2. A time changing magnetic fikel induces a Voltage in a coil of wire if it passes through that Coil



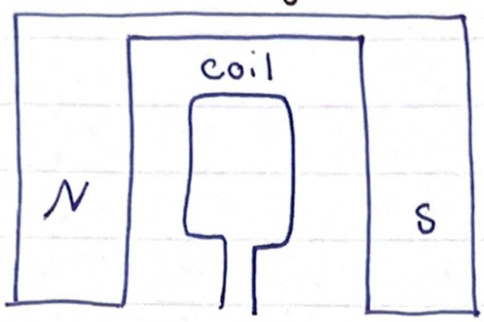
3. In a current-carrying wire in the presence of magnetic field has a force induced to it.

$F = i.(l \times B)$
↓
This force will move the conductor (Mechanical energy)



4. A moving wire in the presence of a magnetic field has a voltage enduced to it

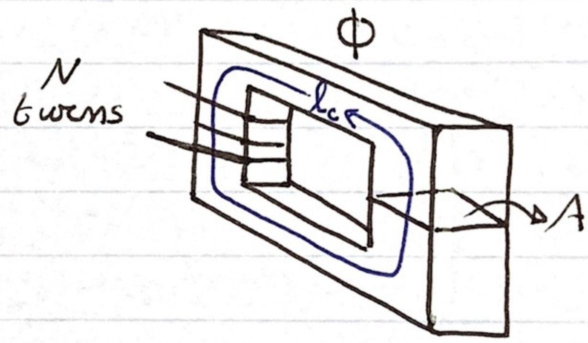
$e_{ind} = l.(V \times B)$
so (electrical energy)



Production of a Magnetic field

$$H = \frac{Ni}{l_c}$$

- magnetic field intensity [A.N/m]



$$B = \mu H$$

μ → permeability [Henrys / m]

- magnetic flux density [Webers / m² (T)]

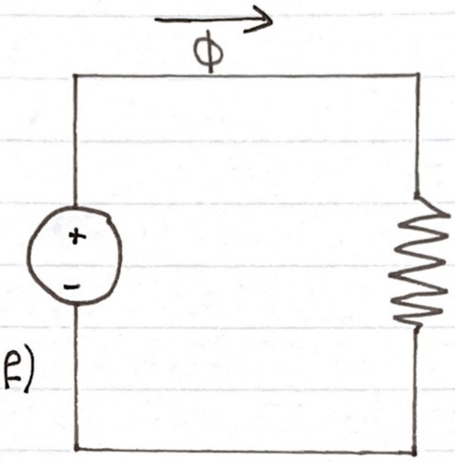
for steel = 2000 → 6000 → $\mu_r = \frac{\mu}{\mu_0}$

μ_0 → perm. of free space = Perm. of air = $4\pi \times 10^{-7}$

flux ← $\phi = \frac{\mu N i A}{l_c}$ [weber]

Magnetic Circuit

$\mathcal{F} = Ni$ magnetomotive force (mmf)

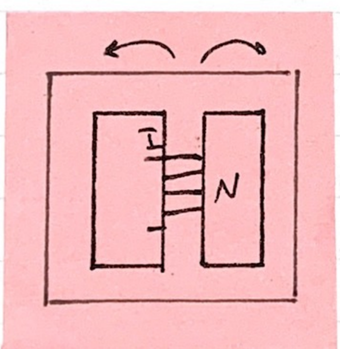


$\mathcal{R}$: Reluctance [A.N/weber]

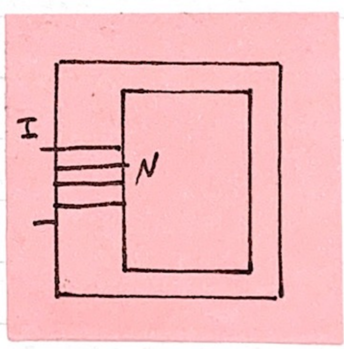
$\phi = \frac{\mathcal{F}}{\mathcal{R}}$

$\mathcal{R} = \frac{l_c}{\mu A}$

Parallel
$1/\mathcal{R}_{eq} = 1/\mathcal{R}_1 + 1/\mathcal{R}_2 \cdots$



Series
$\mathcal{R}_{eq} = \mathcal{R}_1 + \mathcal{R}_2$

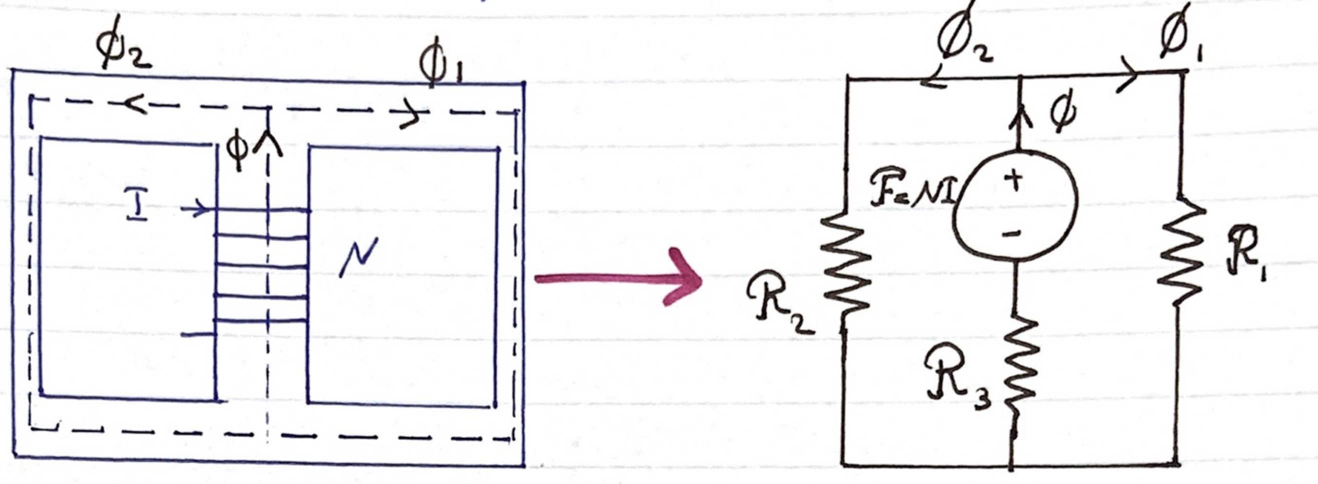


→ permeance

$\mathcal{P} = \frac{1}{\mathcal{R}}$ → $\phi = \mathcal{F}\mathcal{P}$ $\mathcal{P} = \frac{\mu A}{l_c}$

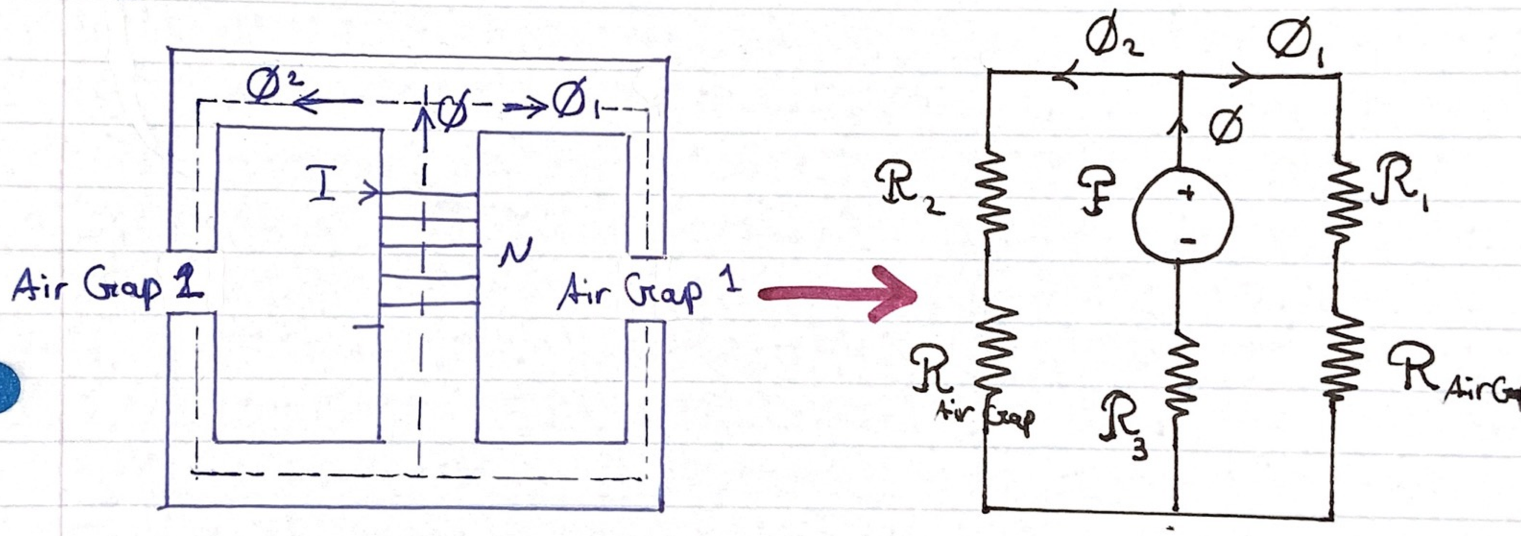
Examples of Magnetic Circuits

1



- We deal with Ø like current (You can use Current Divider Rule

2



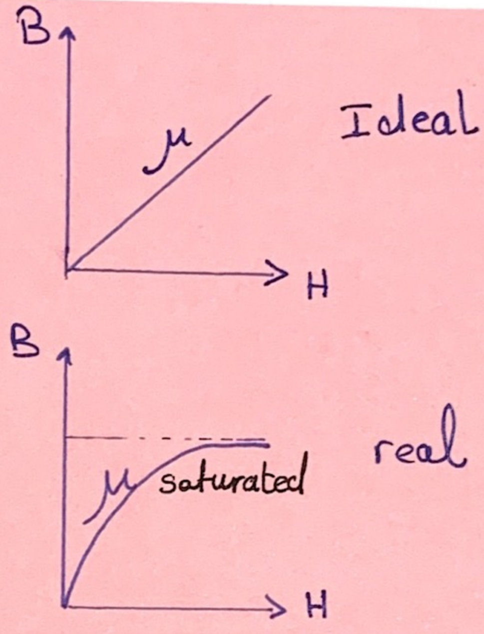
- Air Gap Represents a Resistance

- Inaccuracy in the magnetic circuit approach

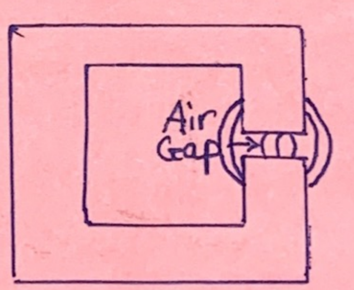
1. leakage flux: flux that escapes from the core into surroundings

2. Cross sectional area changes at corners

3. Material's permeability is not constant (Non linearity)



4. Fringing effects: losses of flux Due to air gap

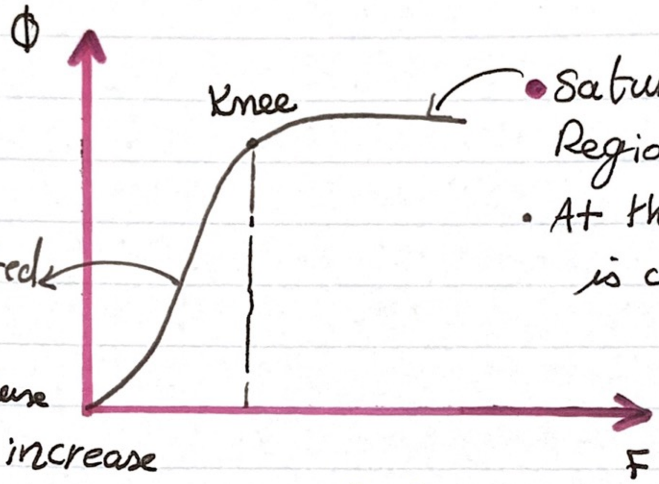


This is used in DC Motors

Magnetic behavior of ferromagnetic Materials

In electrical machines, a linear relationship between B and I is desired → by limiting the current

- Magnetization curve : ϕ vs $\mathcal{F}$



- Saturated Region
- At this region $F\uparrow \rightarrow \phi$ is constant

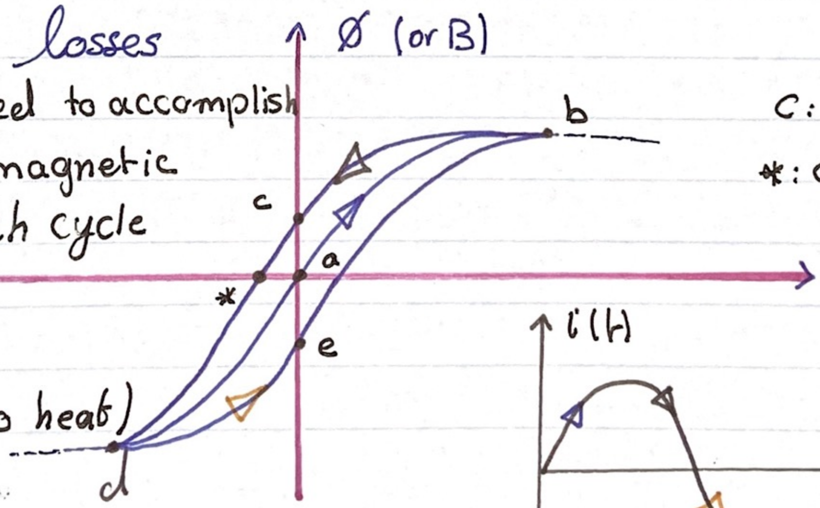
- unsaturated region
Small increase in F, high increase in ϕ (so the core must be operated in this region) near to the knee

Why is this curve important?
To determine the rated value of the Motor, Generator & transformer

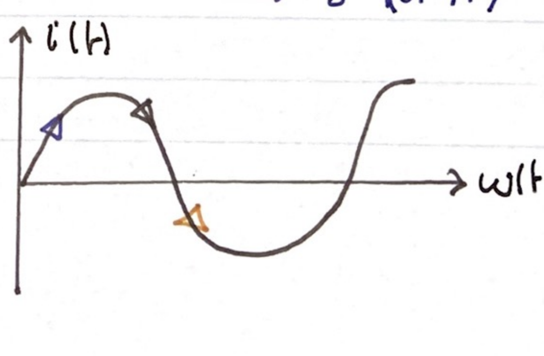
$$\tau = K\phi i \qquad E_A = K\phi\omega$$

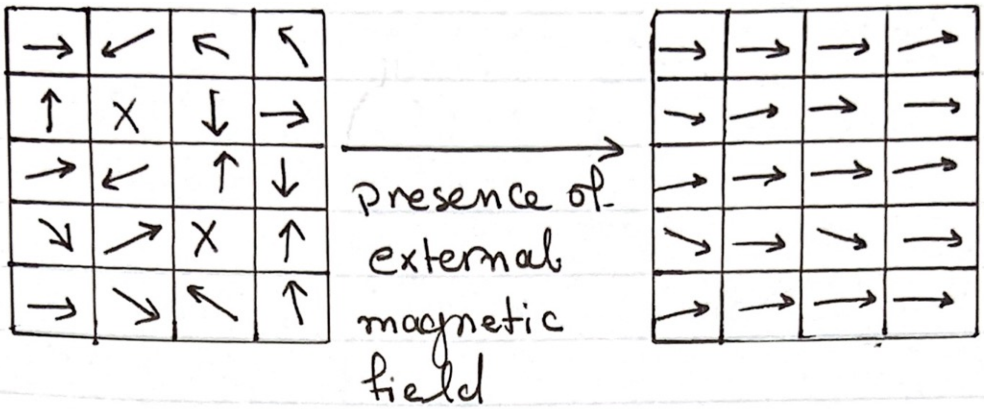
Hysteresis losses

Energy required to accomplish reorientation of magnetic domains per each cycle of applied AC curre (It is converted to heat)



c: Residual flux
*: coercive mmf $\mathcal{F}_c$

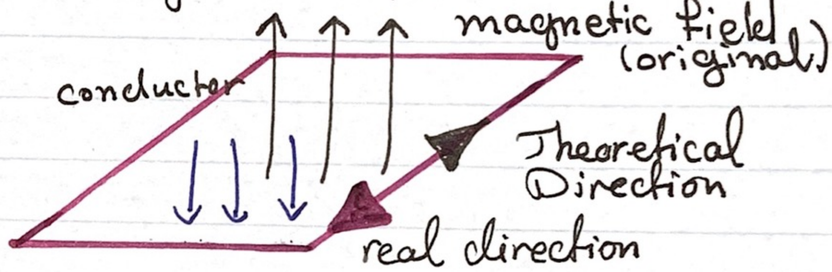




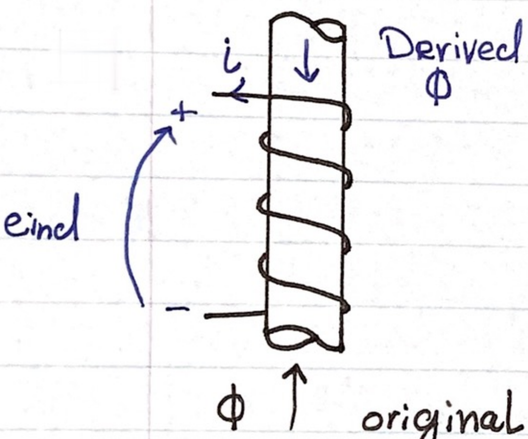
- **Faraday's law:** Induced voltage from a time changing Magnetic field (basis of transformer)

$$e_{ind} = -N\frac{d\phi}{dt}$$ not calculated

negative sign : due to lenz' law
Value of induced voltage is opposite to reach constant value



Explanation



Flux linkage

$$e_{ind} = \frac{d\lambda}{dt}$$

$$\lambda = \sum_{i=1}^{N} \phi_i$$

- **Eddy Current**

→ Current that flows in the core due to the voltage induced by the time changing flux

→ It causes energy losses

Motor

- Back to principal 3. (basis of motor action)

$$F = i\,(l \times B)$$

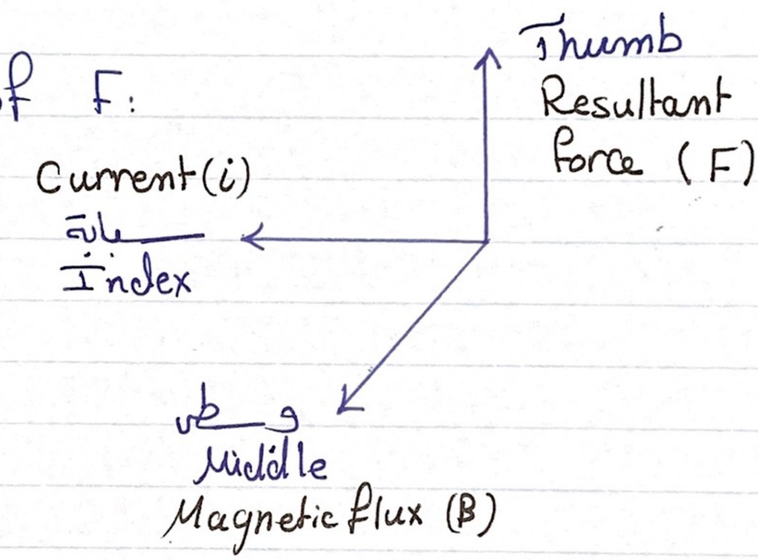
l ← length of wire

i ← current flow in the conductor

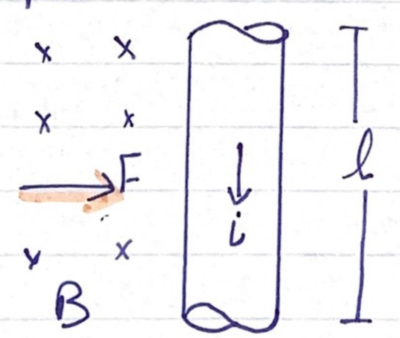
$$\boxed{F = i\,l\,B\sin\theta}$$

θ ← Angle between the conductor and the direction of the magnetic field

Direction of F:



▸ For example:



Generator

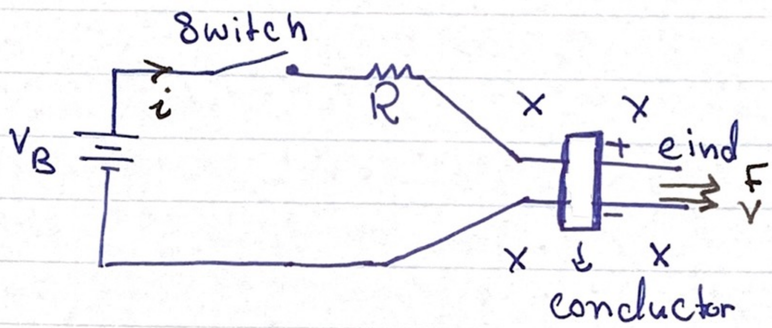
Back to principal 4 (basis of the Generator)

$$e_{ind} = (v \times B)\,l = v B l \cos\theta$$

θ: smallest angle between the conduct and Direction of $(v \times B)$

Polarity voltage polarity is in the direction $v \times B$

The linear DC Machine



When the switch is closed, current flows in the Circuit

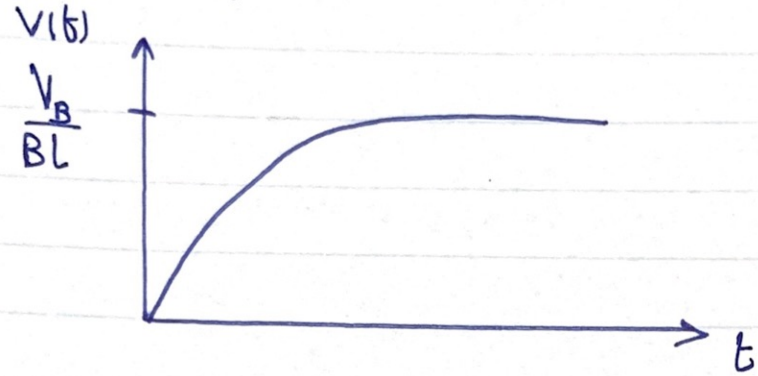
$$i = \frac{V_B - e_{ind}}{R} \qquad (1)$$

- At the beginning, $e_{ind} = 0$ since $V = 0$
- When the force is induced into the conductor due to current flow, $V \uparrow$, $e_{ind} \uparrow$: The Bar accelerates to the right

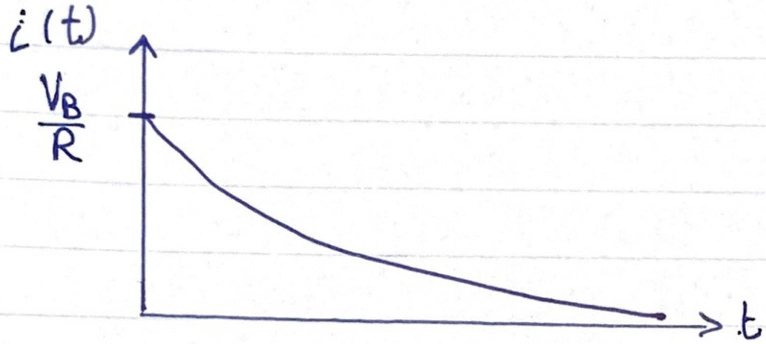
$F = i\,(l \times B)$ — To the right — and — $e_{ind} = (v \times B)\,l$ — positive upwards

- As seen in equation 1: $e_{ind} \uparrow$, $i \downarrow$ until $e_{ind} = V_B$ and constant velocity $V_{\text{steady state}} = \frac{V_B}{Bl}$

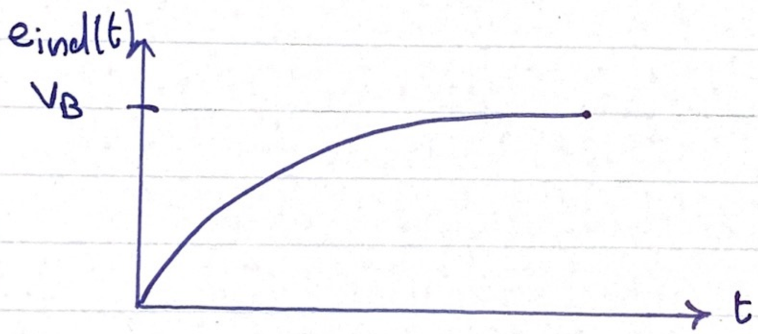
- To explain the Machine's Work:



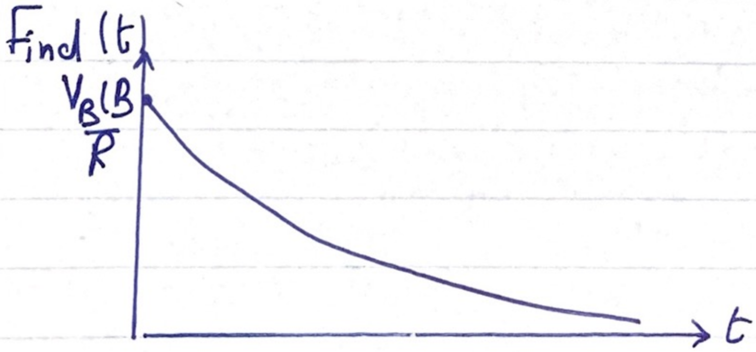
Velocity of the conductor starts at Zero, then ↑ until it reach stead staty ($v = \frac{V_B}{BL}$)



current in the circuit starts at $\frac{V_B}{R}$ ($e_{ind} = 0$), then v ↑, eind ↑, I ↓



eind starts at 0 when $v = 0$ then increases until it equals V_B (steady state)

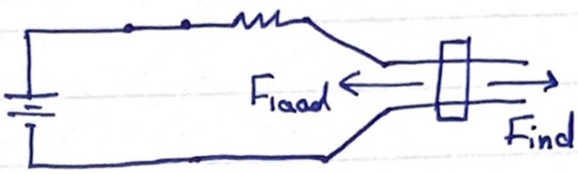


Find starts at $\frac{V_B lB}{R}$ $= i(lB)$, then current i ↓ since eind ↑

- Assumptions:

[1] IF an external force is applied : F_{Load} opposite to motion

$$F_{net} = F_{load} - F_{ind}$$



The bar will slow down so V↓

decreases

$$e_{ind} = VBL = V_B - iR$$

So current increases $i\uparrow$ and so $F_{ind}\uparrow$

Increases

$$F_{ind} = ilB$$

$F_{ind}\uparrow$ until: $F_{ind} = F_{load}$ → Bar at steady state But At lower Speed

Electrical Power → Mechanical Power (Motor)

[2] IF an external force is applied : F_{app} same to direction of motion

$$F_{net} = F_{load} + F_{ind}$$

The bar will accelerate, V↑

Increase

$$e_{ind} = VBl = V_B + iR$$

Until $e_{ind} > V_B$: At this point i reverses It's Direction and F_{ind} is to the opposite Direction of F_{app}

And So $F_{app} = F_{ind}$ and V of conductor is higher

Mechanical Power → Electrical power (Generator)

Mechanical Power:

$P = F_{ind} V$

Electrical Power:

$P = e_{ind}\, i$

} $= \tau_{ind}\, \omega$

Electrical Machines

Generator

- $e_{ind} > V_B$
- Applied force in the
- Direction of Motion

P Mechanical → P Electrical

$e_{ind} = V_B + iR$

$V_{ss} = \frac{e_{ind}}{BL}$

- To Solve the Problem of high Starting curren:

Extra Resistance (R_{start}) is inserted on series with R.

Motor

- $e_{ind} < V_B$
- Applied force in the opposite Direction of Motion
- P Electrical → P Mechanical

$e_{ind} = V_B - iR$

$V_{ss} = \frac{e_{ind}}{BL}$

Note:

- To control the speed of a linear dc machine:-

1- Reducing B → ↑ V_{ss}

2- Reducing V_B → ↓ V_{ss}