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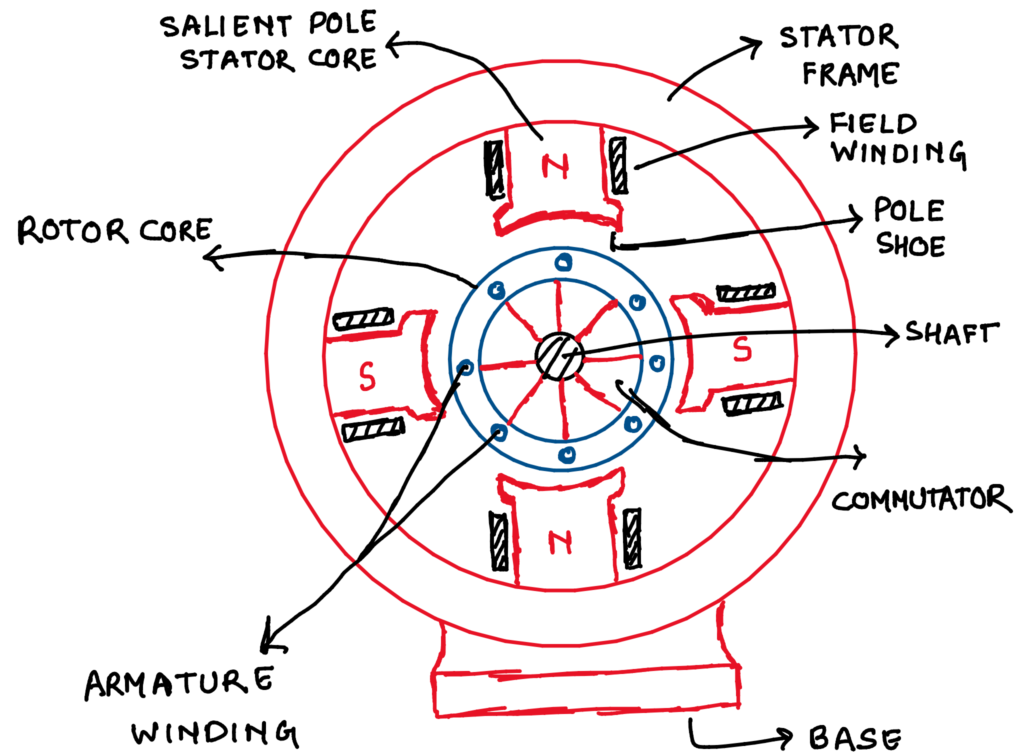
## CONSTRUCTION OF DC MACHINES :

- It has mainly two parts
  - The stationary part is called STATOR.
  - The rotating part is called ROTOR.
  - Apart from these two there is end covers, base, bearing, shaft etc.




4-POLE DC MACHINE

## STATOR:

- It consists frame of unlaminated ferromagnetic material.
- It has salient pole.
- The pole shoe area of salient pole is larger to increase flux per pole.
- There is concentrated field winding on salient pole.
- Field winding is always DC (direct current) excited.

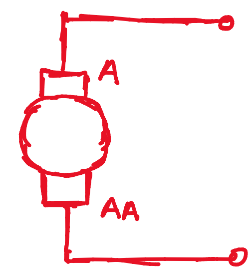
## ROTOR:

- Rotor core is made of stacked laminated steel.

ROTOR:

- → Rotor core is made of stacked laminated steel.
- → There is distributed winding in the rotor core.
- → It also has a commutator which is basically a mechanical rectifier which convert AC to DC with help of carbon brushes & vice versa.
- → The generated emf in armature winding is AC in nature which is converted to DC across brushes with the help of commutator.

* schematic diagram of armature is




## TYPES OF DC MACHINES:

→ Based on Electro mechanical conversion

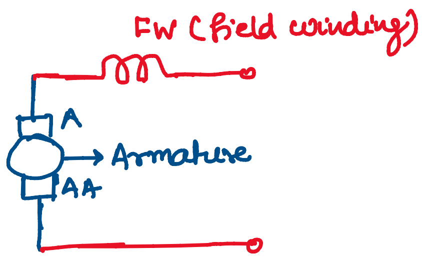
- DC Generator
- DC Motor

Mechanical energy input → DC Generator → Electrical energy output

Electrical energy input → DC Motor → Mechanical energy output

→ Based on Field winding construction

- SELF-EXCITED
  - DC Series Machine
    - Field winding is connected in series with armature.

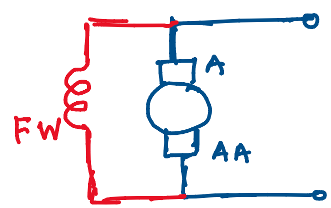



* In DC Series Machine flux per pole

$$\boxed{\phi \propto I_a}$$

$I_a$ = armature current

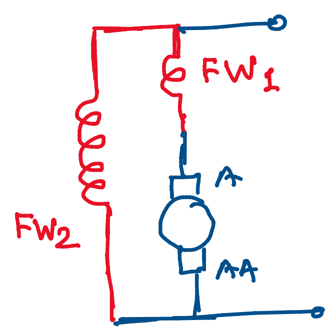
  - DC Shunt Machine
    - Field winding is connected parallel (shunt) with armature.



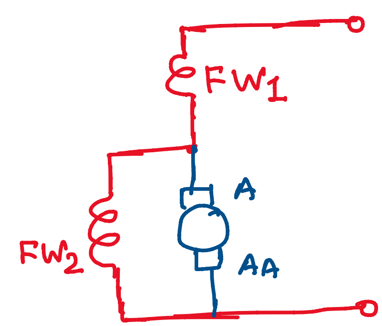

* In DC shunt machine flux per pole

$$\boxed{\phi = \text{Constant}}$$

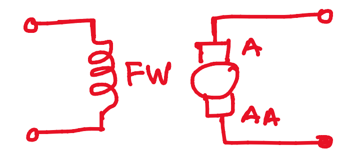
  - Compound DC Machine
    - Long shunt




    - Short shunt

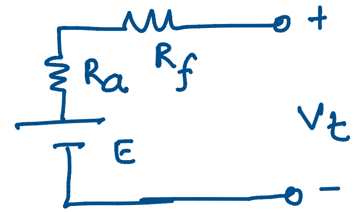



- SEPARATELY EXCITED
  - Field winding is excited separately




→ For mathematical analysis i.e. DC analysis the circuit of DC Machines is

* DC Series Machine



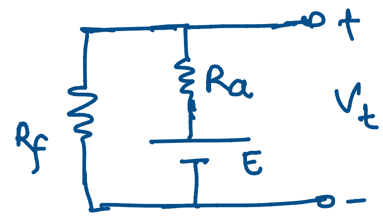

$R_f$ = field winding resistance

$R_a$ = armature winding resistance

$E$ = emf

$V_t$ = terminal voltage

* DC Shunt Machine



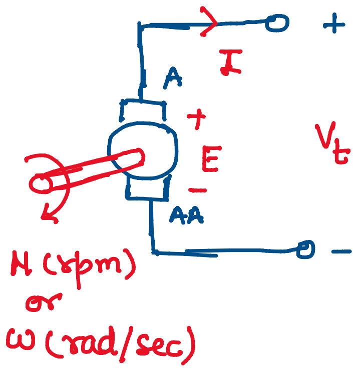

→ Based on Armature winding

- Lap wound
  - In lap wound, the number of parallel path (A) = No. of Poles (P) i.e. $\boxed{A = P}$
- Wave wound
  - Irrespective of no. of poles, number of parallel path $\boxed{A = 2}$

* DC Generator :

Working Principle :

Mechanical energy as a input is provided to Rotor by using primer mover → Since the field winding is DC excited there is relative motion in between flux and Rotor → flux cuts the Rotor Radially → Due to the relative motion an emf is induced or generated in armature winding of Rotor → i.e. it converted into electrical energy as a output.




## Generated EMF in Generator :

Let's assume

$P$ = No. of poles

$\phi$ = flux per pole

$N$ = rotor speed in rpm (rev./min)

$Z$ = total No. of conductors

$A$ = No. of parallel path

According to faraday's law of electromagnetic induction emf in a single conductor is

$$e = \frac{d\phi}{dt} = \frac{\text{Total flux}}{\text{Total time per revolution}} \quad \text{--- (1)}$$

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$\because$ Total flux = flux per pole × No. of Poles

$$= \phi \times P \quad \text{--- (2)}$$

$\because$ rotor speed = N rpm (rev/min)

$$= N \frac{\text{rev}}{60 \text{ sec}} = \frac{N}{60} \text{ rev/sec}$$

$\because$ time for $\frac{N}{60}$ revolution = 1 sec

$\therefore$ time for 1 (ONE) revolution $= \frac{1}{N/60} = \frac{60}{N}$ sec --- (3)

$\therefore$ emf in single conductor $e = \frac{P\phi}{60/N} = \frac{NP\phi}{60} = \frac{P}{60} \times N\phi$ --- (4)

$\because$ no. of conductors is Z & no. of parallel path is A

then No. of series connected conductor $= \frac{Z}{A}$

$\therefore$ Total Generated emf in armature winding

$$E = \frac{Z}{A} \times e = \frac{Z}{A} \times \frac{P}{60} \times N\phi$$

$$\boxed{E = \frac{ZP}{60A} \times N\phi} \Rightarrow E \propto N\phi$$

* If speed in rpm is N then speed in rad/sec is $\because$ 1 rev = $2\pi$ rad
1 min = 60 sec

$$\omega = N \times \frac{2\pi \text{ rad}}{60 \text{ sec}} = \frac{2\pi}{60} \times N \text{ rad/sec}$$

i.e. $\boxed{\omega = \frac{2\pi}{60} \times N}$

$$\because \quad E = \frac{ZP}{60A} \times N\phi = \frac{ZP}{\cancel{60}A} \times \frac{\cancel{60}}{2\pi} \omega \phi \qquad \because N = \frac{60}{2\pi}\omega$$

$$E = \frac{ZP}{2\pi A} \phi\omega = K\phi\omega \qquad \text{where } K = \frac{ZP}{2\pi A}$$

$$\therefore \quad \boxed{E = K\phi\omega}$$

* Circuits for DC Generator for analysis :

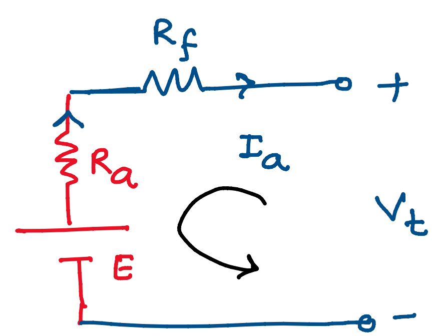
→ DC Series Generator

As shown in the circuit

$R_f$ = field winding Resistance

$R_a$ = Armature winding Resistance

E = Generated emf



$R_a$ = Armature winding Resistance

$E$ = Generated emf

$V_t$ = terminal voltage

$I_a$ = armature current

Apply KVL in the circuit

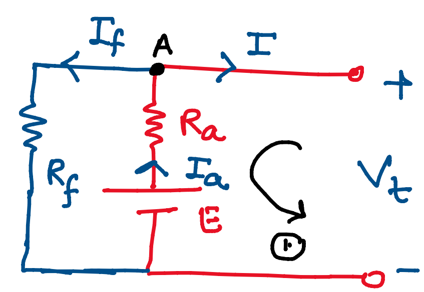
$$V_t + I_a R_f + I_a R_a - E = 0$$

$$\boxed{E = V_t + I_a (R_a + R_f)}$$

* NOTE: If the brush drop $V_{BD}$ given in the numerical then

$$\boxed{E = V_t + I_a (R_a + R_f) + V_{BD}}$$

## → DC Shunt Generator:




As shown in the circuit

$R_f$ = field winding Resistance

$R_a$ = Armature winding Resistance

$E$ = Generated emf

$V_t$ = terminal voltage

$I$ = line current

$I_a$ = armature current

$I_f$ = field current

Applying KVL in loop 1

* NOTE: If the brush drop $V_{BD}$ given in the numerical then

$$\boxed{E = V_t + I_a R_a + V_{BD}}$$

$$V_t + I_a R_a - E = 0 \Rightarrow \boxed{E = V_t + I_a R_a} \quad \text{——} \ (1)$$

$\because$ voltage across field winding is $V_t$

$$\therefore \ V_t = I_f R_f \Rightarrow \boxed{I_f = \frac{V_t}{R_f}} \quad \text{——} \ (2)$$

Applying KCL at Node A

$$\boxed{I_a = I + I_f} \quad \text{——} \ (3)$$

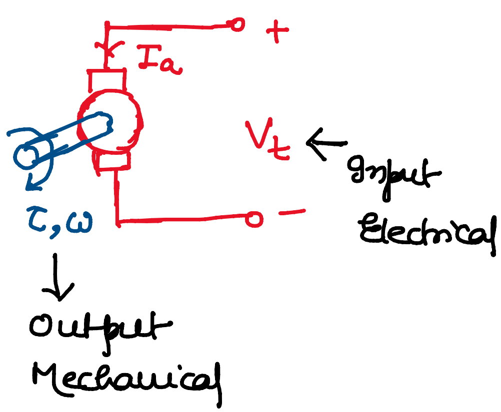
## DC Motor :

### * Working Principle :

A DC supply is given to the Motor → Since field winding is DC excited → A flux is produced → This flux cuts the armature winding of Rotor radially.

↓

Due to this an emf is induced in armature winding



winding

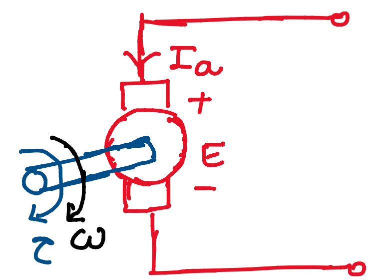
↓

Now a current flow through Armature winding ← The armature current is now interacts with flux cutting action ⟵ Due to this a torque is developed in Rotor ⟵ Now Rotor starts Rotating

## Torque Developed in Motor :

Let's assume there is no mechanical losses

$\because$ Electrical input to the rotor which converts into mechanical output power is




$$P_{e_{i/p}} = E I_a \quad \text{———} \quad (1)$$

where $E$ = Back emf & $I_a$ = armature current

Now the developed mechanical output power is

$$P_{m_{o/p}} = \tau \omega \quad \text{———} \quad (2)$$

where $\tau$ = developed torque & $\omega$ = speed of rotor in rad/sec

$\because$ there is no losses (mechanical)

$$\therefore \quad P_{e_{i/p}} = P_{m_{o/p}} \Rightarrow E I_a = \tau \omega$$

$$\Rightarrow \quad \tau \omega = E I_a \quad \text{———} \quad (3)$$

$$\Rightarrow \quad \tau\omega = E I_a \quad \text{——} \quad (3)$$

$\because$ Back emf $E = K\phi\omega$ where $K = \frac{ZP}{2\pi A}$

Now put the value of $E$ in equation (3)

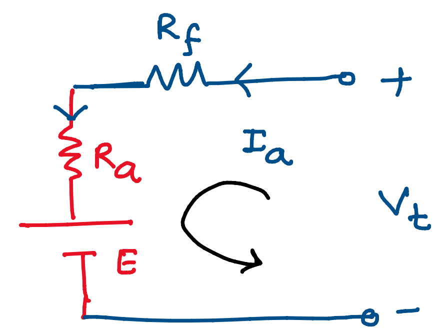
$$\tau\cancel{\omega} = K\phi\cancel{\omega} I_a$$

$$\Rightarrow \boxed{\tau = K\phi I_a} \quad \text{where} \quad K = \frac{ZP}{2\pi A}$$

$Z$ = No. of Conductors
$P$ = No. of Poles
$A$ = No. of parallel path

## * Circuits for DC Motor for analysis :

### → DC Series Motor




As shown in the circuit

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$E$ = Generated emf
$V_t$ = terminal voltage
$I_a$ = armature current

Apply KVL in the circuit

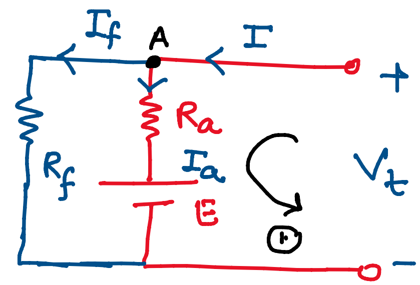
$$V_t - I_a R_f - I_a R_a - E = 0$$

* NOTE: If the brush drop $V_{BD}$ given in the numerical then

$$\boxed{E = V_t - I_a(R_a + R_f) - V_{BD}}$$

$$\boxed{E = V_t - I_a(R_a + R_f)}$$

→ DC Shunt Motor :




As shown in the circuit

$R_f$ = field winding Resistance

$R_a$ = Armature winding Resistance

$E$ = Generated emf

$V_t$ = terminal voltage

$I$ = line current

$I_a$ = armature current

$I_f$ = field current

Applying KVL in loop 1

$$V_t - I_aR_a - E = 0 \Rightarrow \boxed{E = V_t - I_aR_a} \quad \text{—— (1)}$$

∵ voltage across field winding is $V_t$

$$\therefore V_t = I_fR_f \Rightarrow \boxed{I_f = \frac{V_t}{R_f}} \quad \text{—— (2)}$$

* NOTE: If the brush drop $V_{BD}$ given in the numerical then

$$\boxed{E = V_t - I_aR_a - V_{BD}}$$

Applying KCL at Node A $\boxed{I = I_a + I_f}$ —— 3