D.C. Machines

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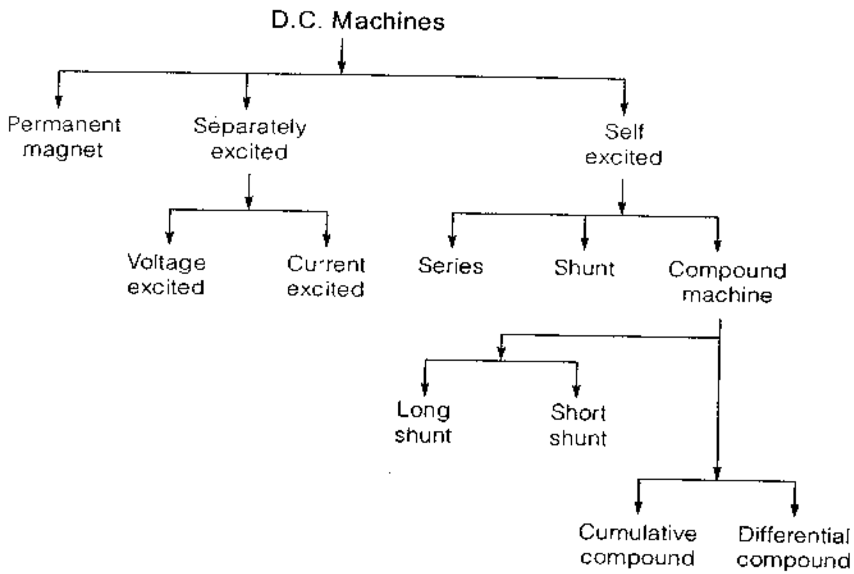
D.C. machine is a flexible and highly versatile energy conversion machine. It can easily supply the demand of loads requiring high starting torque, high accelerating and high decelerating torques. D.C. machine is also suitable for drives requiring wide range of speed control.

Classification of D.C. Machines



- **Separately excited**: Field winding is energized by an external D.C. source.
- **Self excited:** Field winding is excited by its own armature.

Remember:

- Series field winding is thick, has small number of turns and carry large current.
- Shunt field winding is thin, has large number of turns and carry less current.

❑ E.m.f generated in the armature

$$E_a = \frac{\phi Z N}{60} \times \left(\frac{P}{A}\right) = k\phi\omega_m$$

where, ϕ = Flux per pole, wb
P = Number of poles
Z = No. of conductor
A = No. of parallel paths = P for lap winding
= 2 for wave winding
N = Speed in rpm

$$\omega_m = \frac{2\pi N}{60} = \text{Mech. angular velocity (mech. rad per sec.)}$$

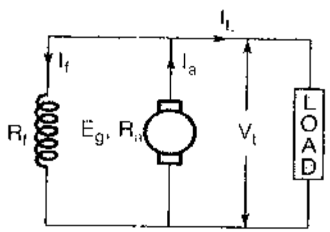
$$k = \frac{PZ}{2\pi A} = \text{Constant of the machine}$$

❑ Torque equation

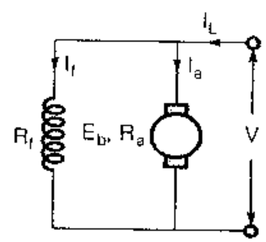
$$\boxed{T = k\phi I_a = \frac{1}{\omega_m} E_a I_a}$$

where, T = Torque developed, in N-m
I_a = Armature current

Circuit Model



(Generator)



(Motor)

$\boxed{V_t = E_g - I_a R_a}$ ...For generator

$\boxed{V = E_b + I_a R_a}$ ...For motor

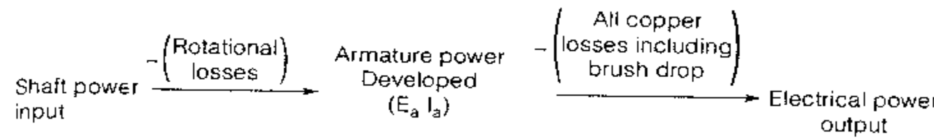
where, V_t = Terminal voltage
V = supply voltage to motor
E_g = Generated Emf
E_b = Back Emf
R_a = Armature resistance
R_f = Field resistance
I_a = Armature current
I_f = Field current
I_L = Load current
E_g = $E_b = E_a$ = Voltage developed in armature

Note:

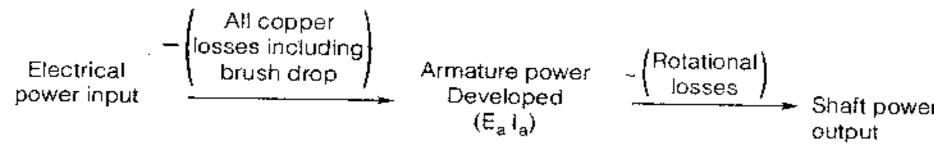
Generated emf in generator is called back emf in motor.

Power Balance in D.C. Machine

(a) Generator Action



(b) Motor Action



❑ Armature power developed

$$\boxed{P_a = E_a I_a}$$

Efficiency

$$\boxed{\eta = 1 - \frac{\text{Losses}}{\text{Input power}} = \frac{\text{Output power}}{\text{Input power}} = \frac{\text{Output power}}{\text{Output power + Losses}}}$$

1. DC generator

$$\boxed{\eta_g = \frac{\text{Output power}}{\text{Output power + losses}}}$$

$$\boxed{\eta_g = \frac{V_t I_L}{V_t I_L + (I^2 R + V_{BD} I + P_K)}}$$

where, $V_t I_L$ = Output power
I^2R = Total ohmic losses
P_K = Constant losses
$V_{BD}I$ = Brush contact losses
V_t = Output voltage
I_L = Load current

2. DC motor

$$\eta_m = \frac{\text{Input power} - \text{Losses}}{\text{input power}}$$

$$\eta_m = \frac{VI - (I^2R + V_{BD}I + P_K)}{VI}$$

where, VI = Input electrical power

Note: ....

- For generator and motor maximum efficiency occurs when

  constant loss = variable loss

i.e. $P_k = I^2R$ (ohmic loss)

- Maximum power output by DC motor when

$$E_a = \frac{V}{2} \quad \text{and} \quad I_a = \frac{V}{2R_a}$$

- When motor operates at maximum power output, it gives only 50% efficiency.

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Characteristics of D.C. Generator

1. No load (or) magnetisation characteristic (or) open circuit characteristics (O.C.C.)

Magnetisation characteristic gives the variation of generated voltage (or no load voltage with field current at a constant speed.

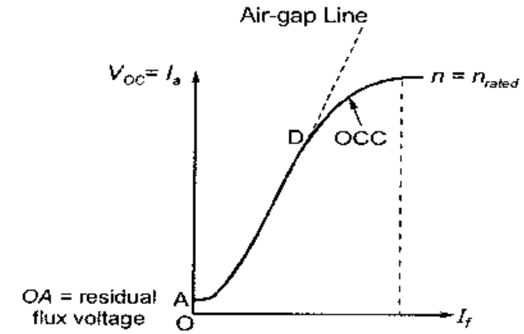
2. Internal characteristics

It is plot between the generated voltage and load current.

3. Load or external characteristics

Between terminal voltage Vs load current (I_L) at a constant speed.

(a) Open circuit characteristics (OCC) (no load) for all types of generator



Open circuit characteristic of all types of generator

Note: ....

OCC does not start from origin due to the presence of residual magnetism.

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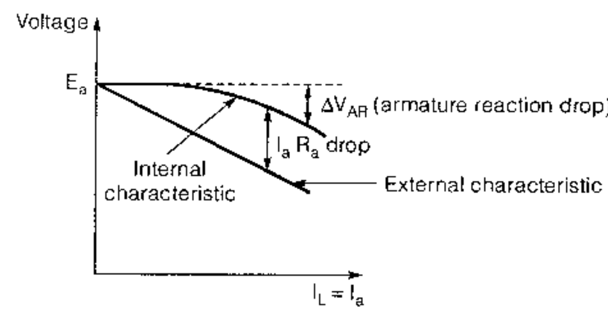
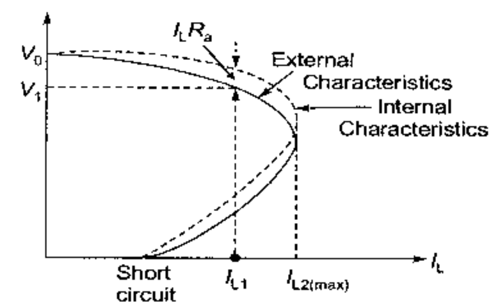
(b) Characteristics for separately excited generator



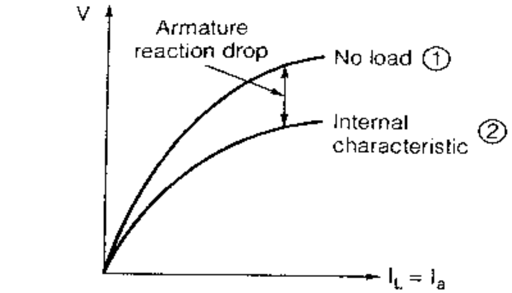
Characteristics of separately excited DC generator

(c) Characteristics for shunt generator

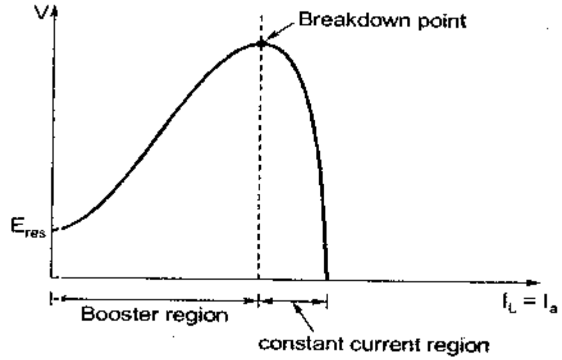


External Characteristics of DC shunt Generator

(d) Characteristics for series generator



Characteristics of DC series generator

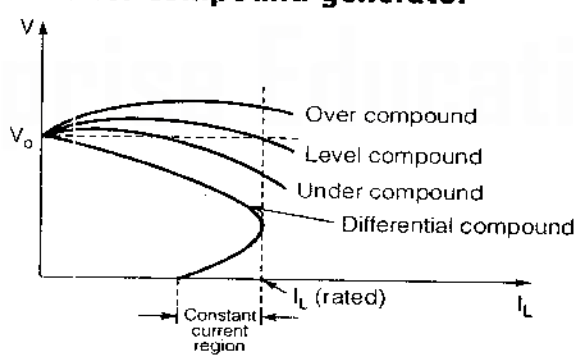


External characteristics of series generator

Note:

- Constant current region is suitable for welding.
- Series generator is used in booster region for line drop compensation.

(e) Characteristics for compound generator

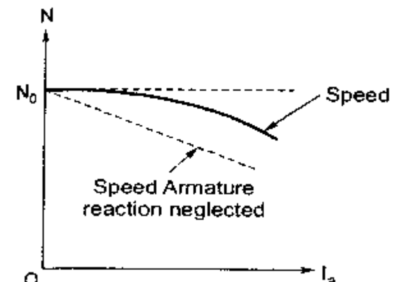


External characteristics of a compound generator

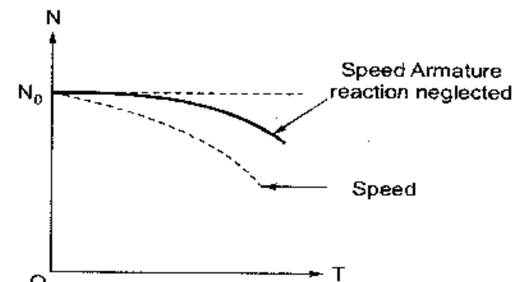
Characteristics of D.C. Motor

1. Speed Vs armature current (N Vs I_a).
2. Torque Vs armature current (T Vs I_a).
3. Speed Vs torque (N Vs T).

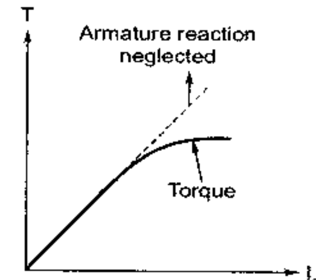
(a) Characteristics for DC shunt motor



N versus I_a

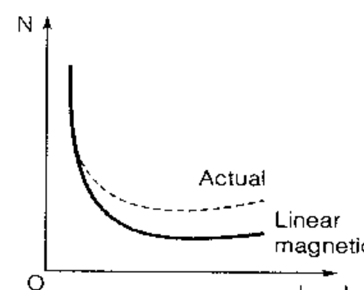


N versus T

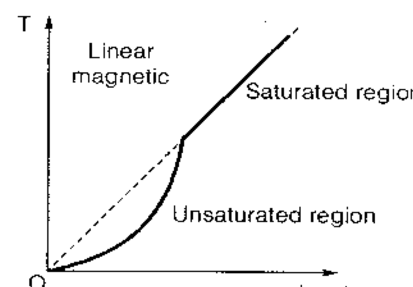


T versus I_a

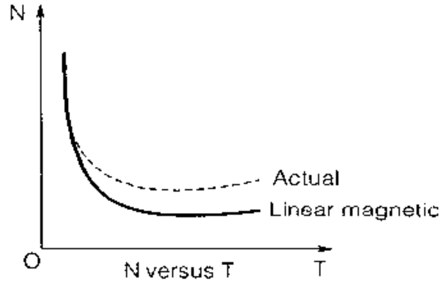
(b) Characteristics for DC series motor



N versus I_a



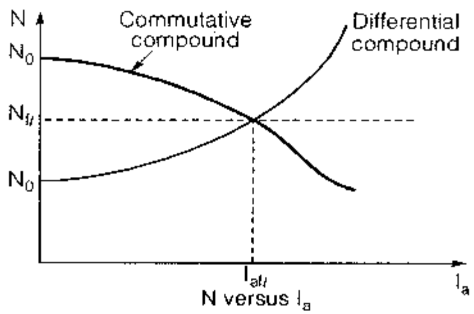
T versus I_a

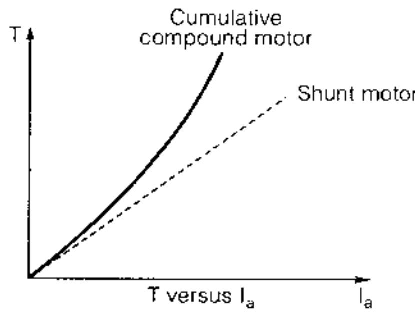


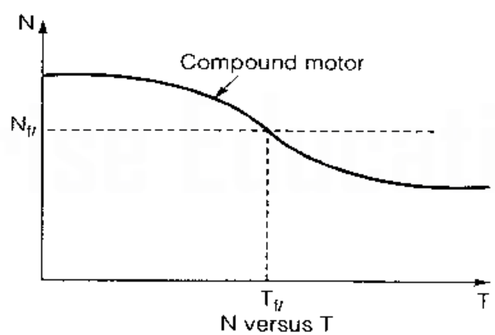
Note:

In a traction system, we use series motor where high starting torque is requried.

(c) Characteristics of DC compound motor







Note:

- Magnetic flux has a tendency to follow a minimum reluctance path.
- Exciting or field windings produces the working flux or main flux.
- In Armature winding, the working emf is induced by working flux.
- For the development of electromagnetic torque in all rotating machine, the number of rotor poles should be equal to the number of stator poles.

Voltage Build up fails in generator if

- Residual flux absent.
- Field connection is wrong, reverse I_f destroys ϕ_{Res}.
- Direction of rotation is wrong.
- Field resistance is more than critical field resistance.
- Speed less than critical speed.

Remember:

- In D.C. machine, the field winding is on the stator and the armature winding is on rotor.
- Commutator serve as:

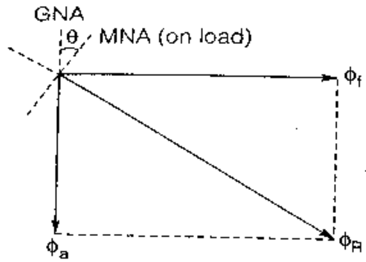
  For D.C. generator: Mechanical rectifier.

  For D.C. motor: Mechanical inverter.
- D.C. series motor never runs at no load.

Armature Reaction

- The effect of armature flux on the main field flux distribution in the air gap is called armature reaction.
- The armature mmf produces two undesirable effects on the main flux.
  1. Net reduction in the main field.
  2. Distortion of the main field flux wave along the air gap periphery.
- The effect of armature flux on the main field is cross-magnetizing as well as demagnet zing.
- Flux created by the armature mmf is called cross-flux

$$\overline{\phi}_R = \overline{\phi}_a + \overline{\phi}_f$$



where, ϕ_f = Flux produced by field mmf
ϕ_a = Flux produced by armature mmf
ϕ_F = Resultant flux

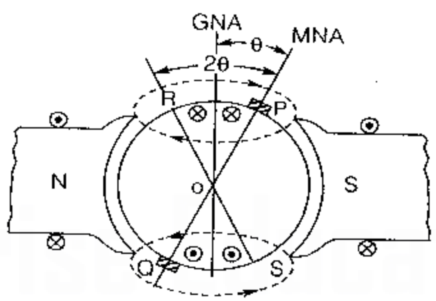
Remember:

- Magnetic neutral axis (MNA) is always perpendicular to the axis of resultant field flux.
- Geometric neutral axis (GNA) is along the quadrature axis of the d.c machine.

Effect of brush shift

MNA shift in the direction of rotation for a generator and against the direction of rotation for a motor to ensure good commutation.

Demagnetizing ampere turns

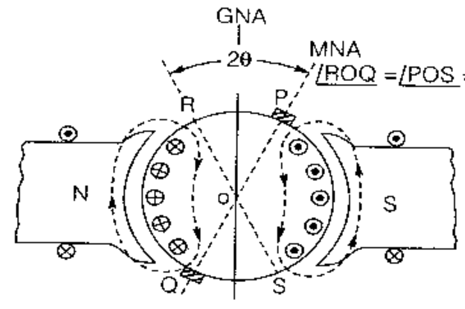


(a)

- Demagnetizing armature mmf per pole.

$$F_{ar(demag)} \text{ per pole} = \frac{(Z/2)}{P} \times \left(\frac{2\theta_{elc}}{180^\circ}\right) \times \frac{I_a}{A}$$

Cross-magnetizing ampere turns



(b)

- Cross magnetizing armature mmf per pole.

$$F_{ar(cross)} \text{ per pole} = \frac{(Z/2)}{P} \times \left(1 - \frac{2\theta_{elc}}{180^\circ}\right) \times \frac{I_a}{A}$$

- Compensating winding mmf per pole (AT_c).

$$AT_c = \frac{(Z/2)}{P} \cdot \frac{\text{Pole arc}}{\text{Pole pitch}} \times \frac{I_a}{A}$$

Note:

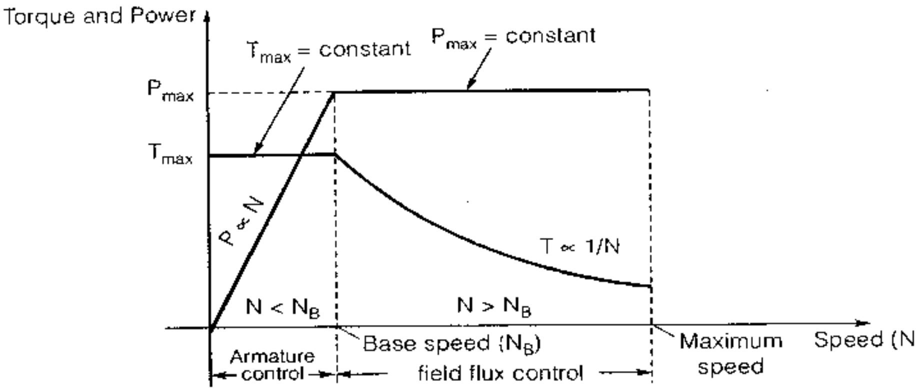
- Compensating winding mmf neutralizes the armature mmf only under the main pole face.
- Interpoles are use to neutrallised the armature reaction flux in the interpolar axis. It also produce some rotational voltage in the coil undergoing commutation and neutralize the reactance voltage and improve the commutation.
- Polarity of interpoles is same as the succeeding main pole in generator action and of the preceding main pole in motor action.
- The interpole winding and compensating winding carry armature current.
- Interpoles are long but narrow in shape to avoid saturation.

Speed Control of D.C. Machine

$$N = \frac{V - I_a R_a}{k\phi}$$

Speed can be controlled by

- **Armature voltage control:**
  - (i) Constant torque drive.
  - (ii) Speed control is possible only below base speed i.e. $N < N_B$.
- **Armature resistance control:**
  - (i) Constant torque drive.
  - (ii) Speed control is possible only below base speed i.e. $N < N_B$.
  - (iii) Wide range of speed control is not possible.
- **Field flux control:**
  - (i) It is constant power drive.
  - (ii) Speed control is possible above base speed i.e. $N > N_B$.



Torque and power characteristics is combined armature voltage and field control

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