Lecture-31

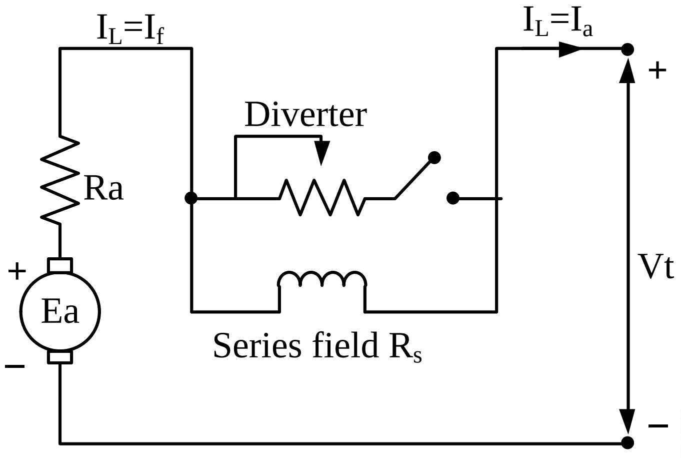
On

INTRODUCTION TO ELECTRICAL ENGINEERING (ESO203)

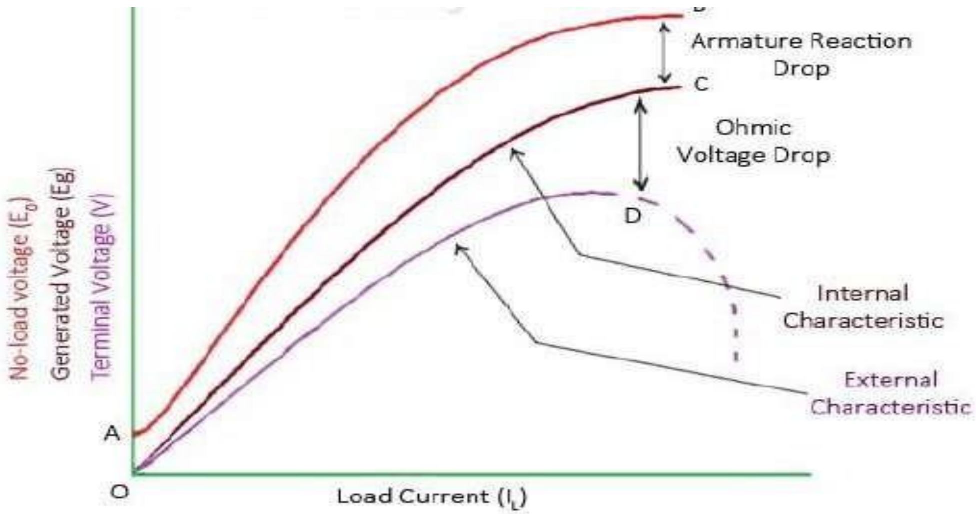
- DC generator.
- DC motor.
- Speed control of DC motor.
- Application of DC machines.

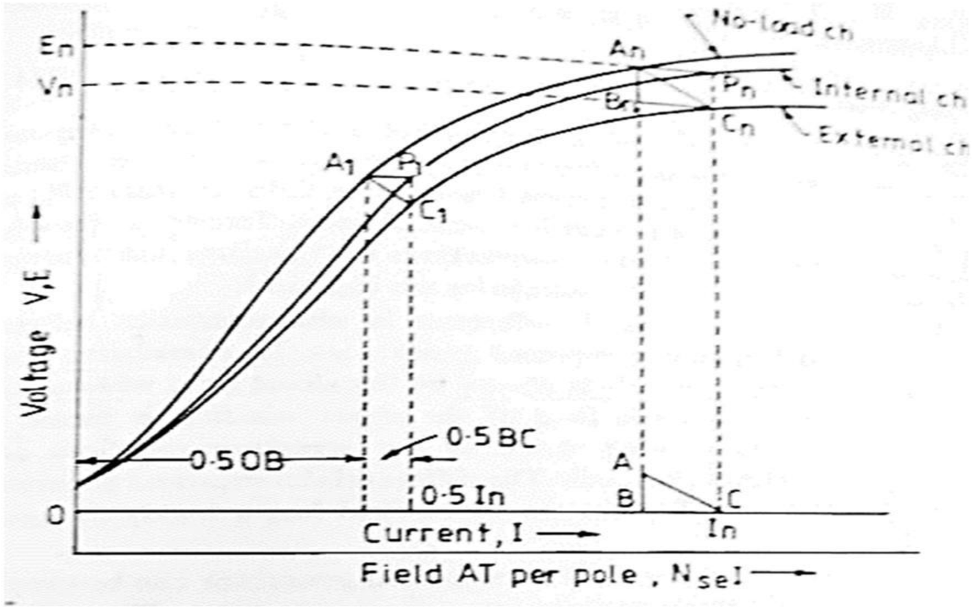
Series Generator

Terminal voltage increases with the load current. As the load current increases, field current also increases. Beyond a certain limit, terminal voltage starts decreasing with increase in load. This is due to excessive demagnetizing effects of the armature reaction.



$V_t=E_a-I_a(R_s+R_a)$

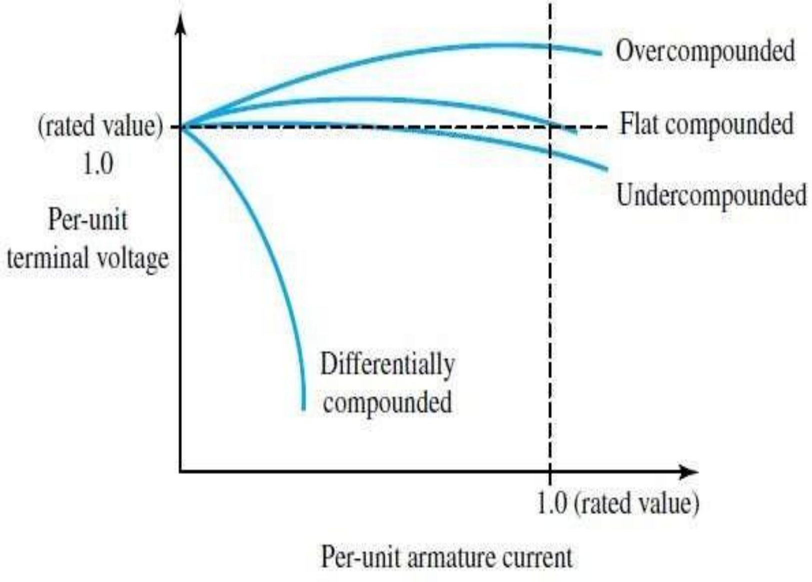




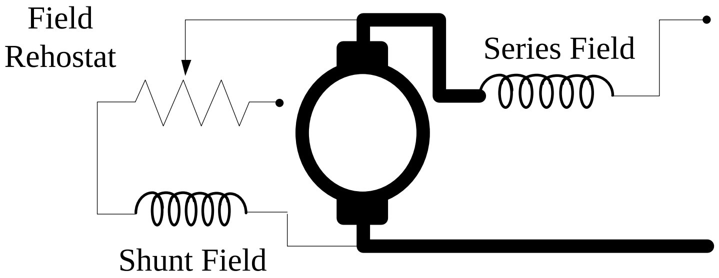
External Characteristics of DC Compound Generators

Overcompounding can be used to counteract the effect of a decrease in the prime-mover speed with increasing load, or to compensate for the line drop when the load is at a considerable distance from the generator.

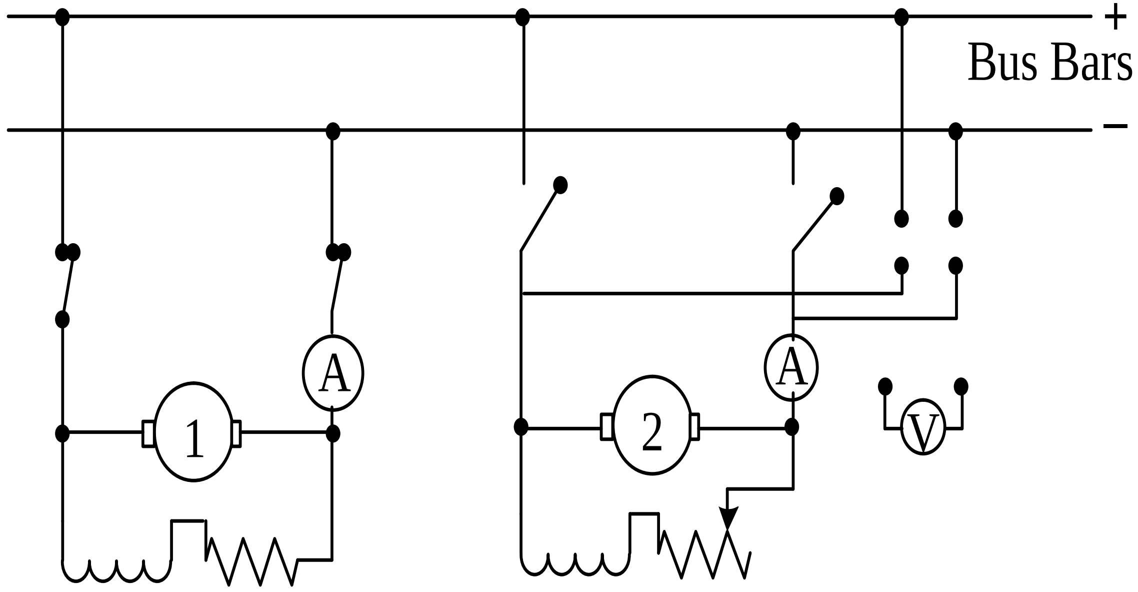
Differentially compounded generators, in which the series-winding mmf opposes that of the shunt-field winding, are used in applications in which wide variations in load voltage can be tolerated, and when the generator might be exposed to load conditions approaching short circuit.

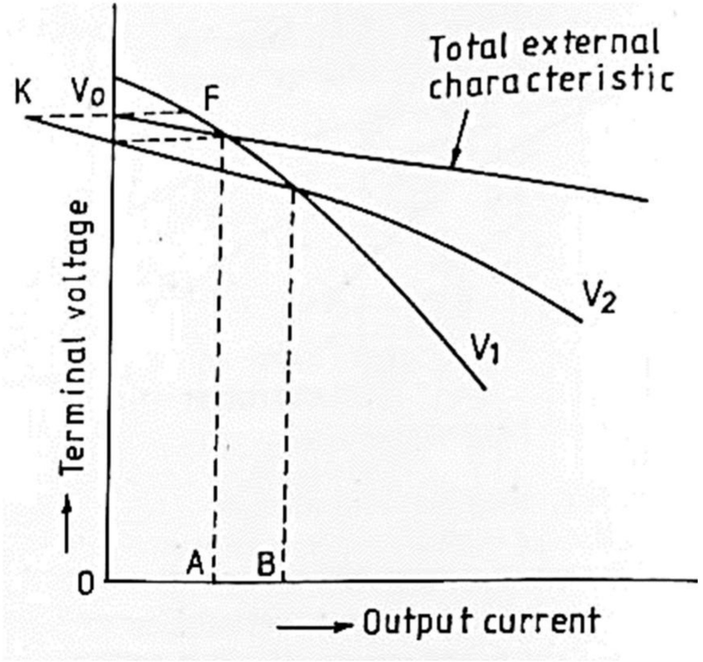


SERIES- AND SHUNT- FIELD WINDING MMFS ARE AIDING

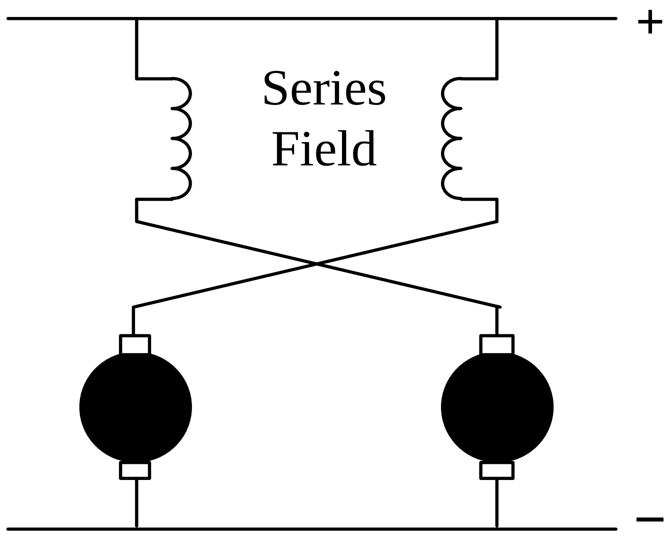


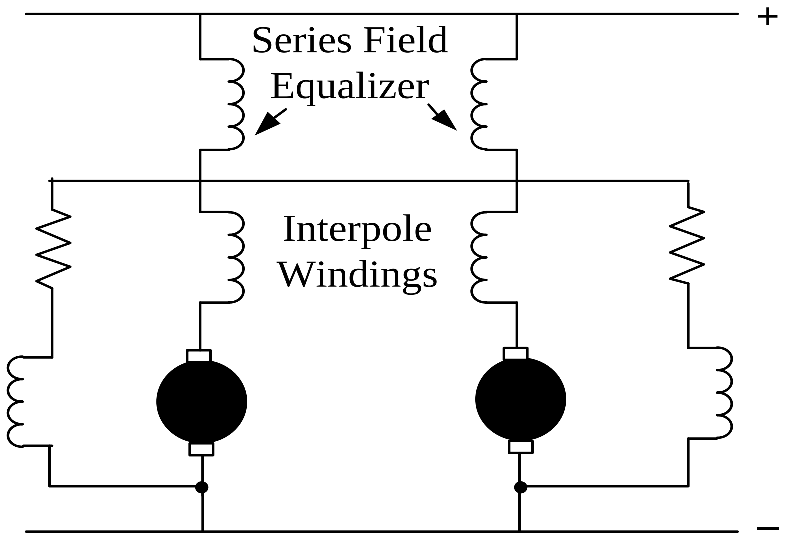
Parallel Operation of DC Shunt Generators



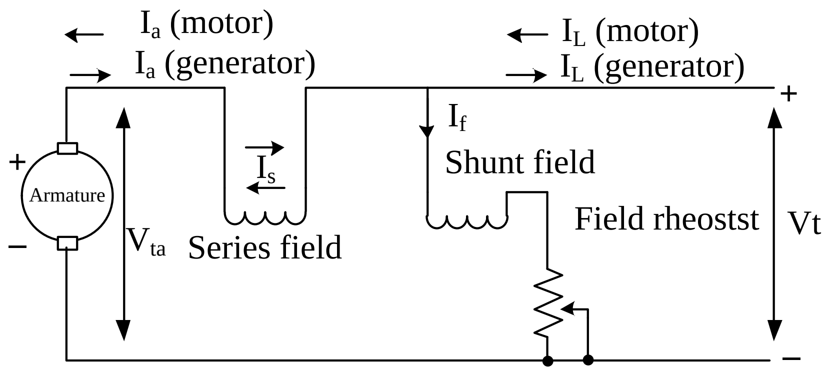


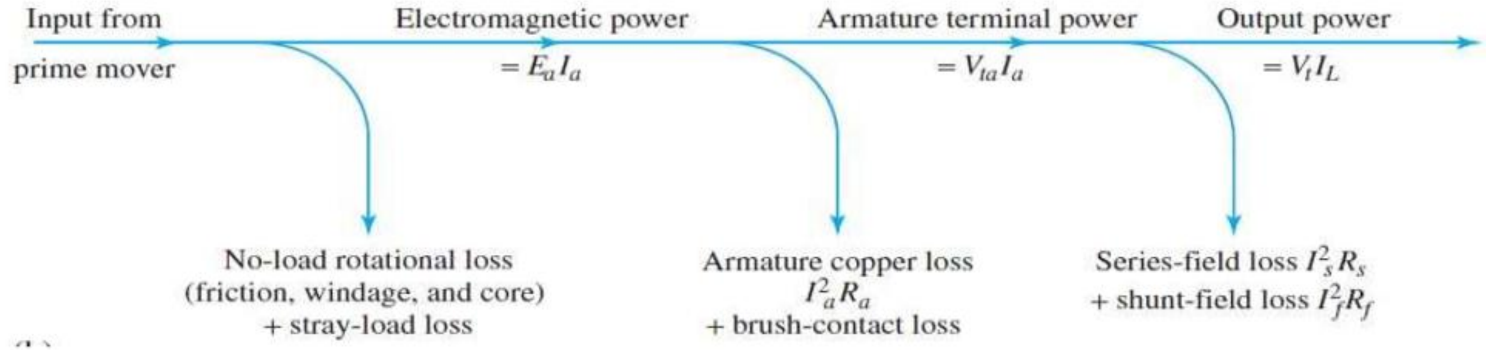
Parallel Operation of DC Series and Compound Generators



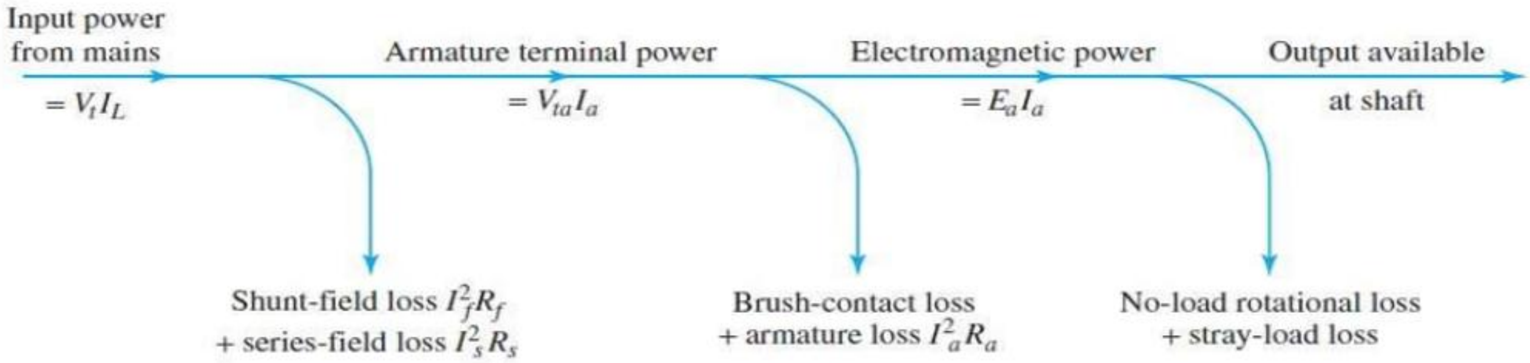


Power division in a DC generator and DC motor





Power division in a dc generator



Power division in a dc motor

Efficiency

$$\text{Efficiency} = \frac{output}{input} = \frac{input - losses}{input} = 1 - \frac{losses}{input}$$

rotational (3 to 15%)
armature-circuit copper (3 to 6%)
shunt-field copper losses (1 to 5%)

The resistance voltage drop, also known as arc drop, between brushes and commutator is generally assumed constant at 2V, and the brush- contact loss is therefore calculated as $2I_a$.

Speed of a Motor

$$E = k N_r \phi$$

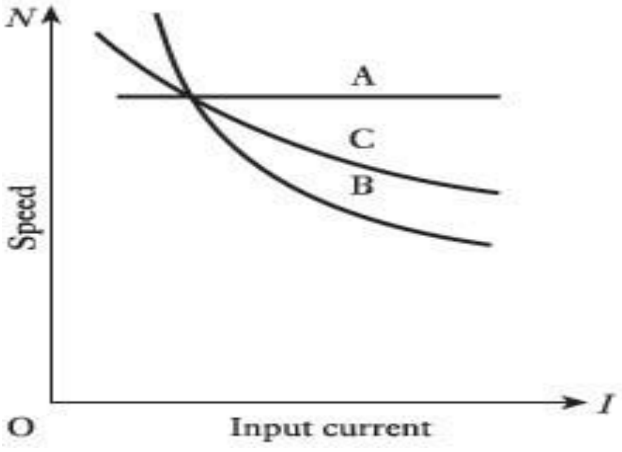
$$V = k N_r \phi + I_a R_a$$

$$N_r = \frac{V - IaRa}{k\phi}$$

The value of $I_a R_a$ *is usually less than 5 per cent of the terminal voltage V*

$$N_r \; \alpha \; \frac{V}{\phi}$$

Speed Characteristics



$$N_r = \frac{V - IaRa}{K\phi}$$

Generally, the speed decreases only by 5 to 15% of full load speed. The shunt motor is essentially a constant-speed machine with a low speed regulation.

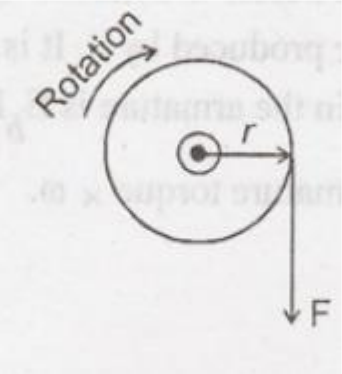
At very low values of field flux, speed will be high. When a shunt motor is to be designed to operate with a low value of shunt-field flux, it is usually fitted with a small cumulative series winding, known as a *stabilizing winding*.

In series motors, the flux increases at first in proportion to the current and then less rapidly owing to magnetic saturation Also R_a includes the resistance of the field winding. Hence the speed is roughly inversely proportional to the current. If the load falls to a very small value, the speed may become dangerously high. Should never be started without some mechanical load. It has a small shunt-field winding to limit the no-load speed.

Torque of a DC machine

Let the force 'F' cause the wheel to rotate at 'N' rpm. The angular velocity of the wheel is:

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



- Torque, T = F x r N-m
- Work done per revolution = F x distance moved = F x $2\pi r$ joules.
- Power developed, P = Work done / Time = (F x $2\pi r$) / Time for one revolution = (F x $2\pi r$) / (60/N)
- rps = rpm/60 ; rps = N/60 ; time for one revolution = 60/N
- P = (F x r) $2\pi N/60$
- P = T ω Watts.

- The torque developed by a DC Motor is obtained by looking at the electrical power supplied to it and mechanical power produced by it. It is also called armature torque. The gross mechanical power developed in the armature is $E_b I_a$.

Then, power in armature = Armature torque x ω.

Torque of a DC machine (cont…)

power in armature = Armature torque x ω.

$$E_b I_a = T_a \times \frac{2\pi N}{60}$$

$$E_b = \frac{\phi PNZ}{60A}$$

$$\frac{\phi PNZ}{60A} \times I_a = T_a \times \frac{2\pi N}{60}$$

$$T_a = \frac{\phi I_a PZ}{2\pi A}$$

$$E_b = \frac{\phi PNZ}{60A} \times \frac{2\pi}{2\pi} = \frac{\phi PZ}{2\pi A}\omega \qquad \left[\therefore \omega = \frac{2\pi N}{60}\right]$$

$$E_b = \frac{\phi PZ}{2\pi A}\omega = k\phi\omega \qquad \left[\therefore k = \frac{PZ}{2\pi A}\right]$$

$$T_a = \frac{\phi I_a PZ}{2\pi A} = k\phi I_a \qquad \left[\therefore k = \frac{PZ}{2\pi A}\right]$$

Quiz-3

Date:	**11^{th} April 2025**
Time:	6:00 pm
Venue:	L18
Syllabus:	Till 10^{th} April 2025

Torque Characteristics

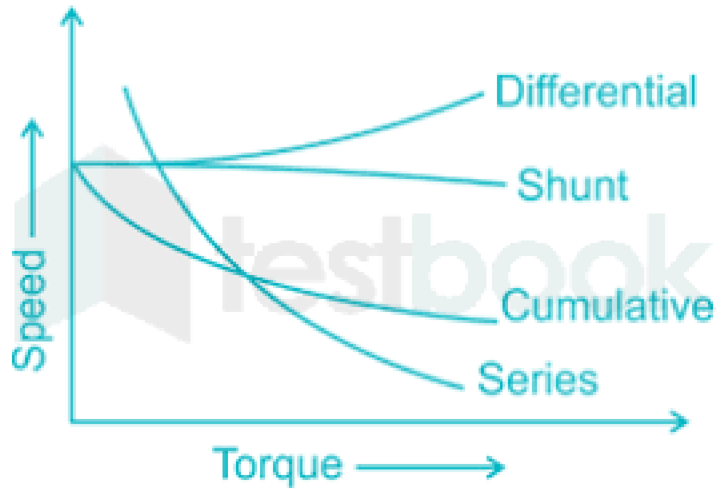
$$T \propto \phi I_a$$

The flux in a shunt motor is practically independent of the armature current.

$$T \propto I_a$$

In a series motor the flux is approximately proportional to the current upto full load.

$$T \propto I_a^2$$



For a given current below the full-load value, the shunt motor exerts the largest torque, but for a given current above that value the series motor exerts the largest torque. The maximum permissible current at starting is usually about 1.5 times the full-load current. Where a large starting torque is required, the series motor is the most suitable machine.

Since heavy starting load needs heavy starting current, shunt motor should never be started

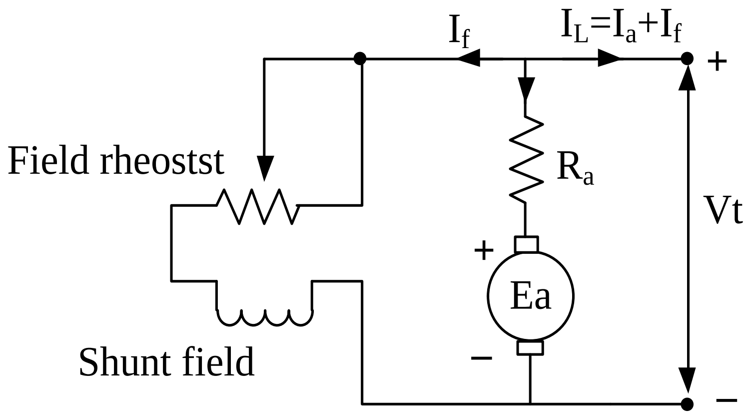
DC Motor Characteristics

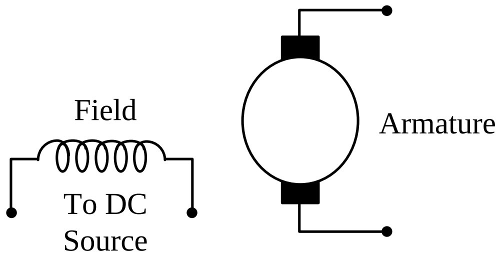
- Shunt/separately excited DC motor speed–torque characteristics

$$V_t = E + I_a R_a \quad \text{—— ①}$$

$$E = K\phi\,\omega_m \quad \text{—— ②}$$

$$T = K\phi\, I_a \quad \text{—— ③}$$





From eqn ①

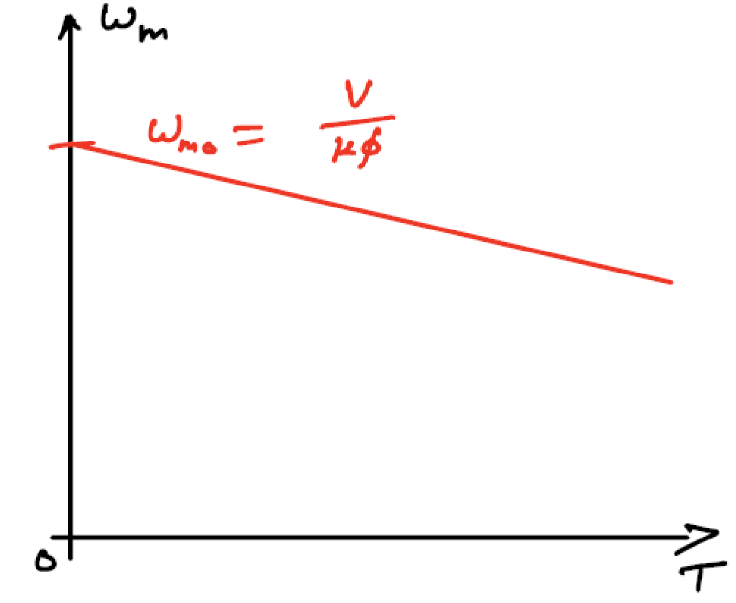
$$E = V_t - I_a R_a$$

$$K\phi\,\omega_m = V_t - I_a R_a$$

$$\omega_m = \frac{V_t}{K\phi} - \frac{I_a R_a}{K\phi}$$

$$= \frac{V_t}{K\phi} - \frac{T R_a}{(K\phi)^2}$$

$$\boxed{\omega_m = \frac{V_t}{K\phi} - \frac{R_a}{(K\phi)^2}\cdot T}$$



Speed Control of DC Motors

1. shunt-field rheostat control
2. armature circuit-resistance control
3. armature terminal-voltage control

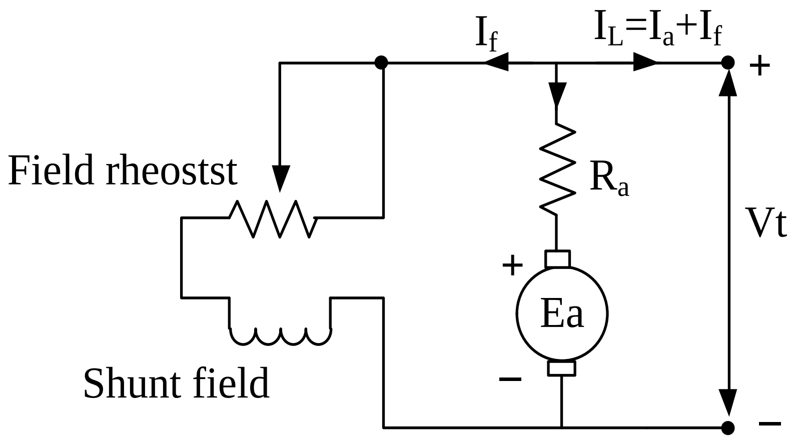
The base speed of the machine is defined as the speed with rated armature voltage and normal armature resistance and full field flux

Speed control above the base value can be obtained by varying the field flux.
Flux reduces $\Longrightarrow$ speed increases $\Rightarrow$ EMF constant $\Rightarrow$ T reduces (flux reduces) constant-horsepower drive. $\omega_m T_e$

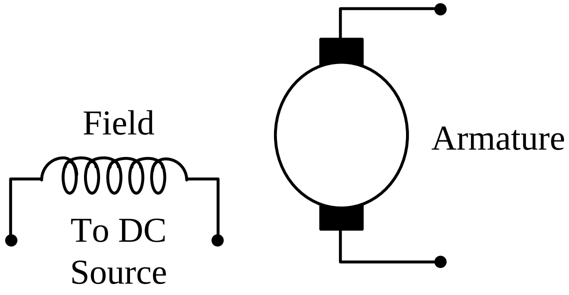
For speed control below the base speed, the effective armature resistance can be increased. The series resistance, carrying full armature current, will cause significant power loss and reduction in efficiency. The speed of the machine is governed by the value of the voltage drop in the series resistor and is therefore a function of the load on the machine. constant-torque drive: both flux and, to a first approximation, allowable armature current remain constant as speed varies.

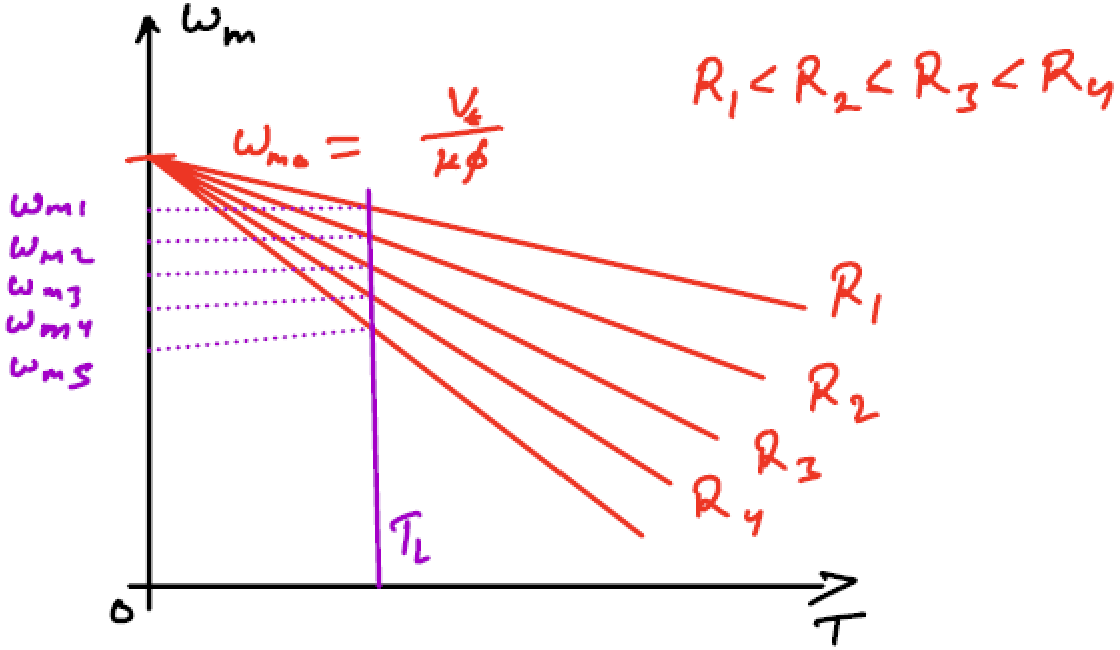
Speed Control of DC Motor

- Shunt/separately excited DC motor: Armature resistance control



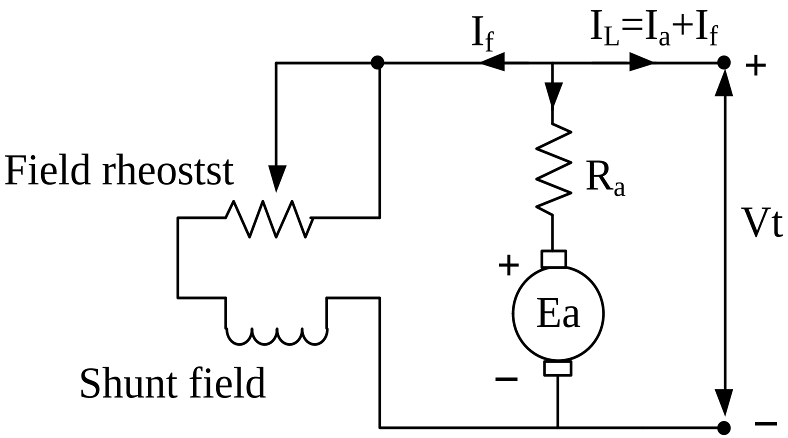
$$\omega_m = \frac{V_t}{K\phi} - \frac{R_a}{(K\phi)^2} \cdot T$$





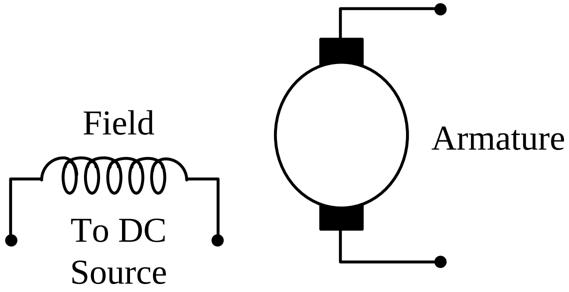
Speed Control of DC Motor

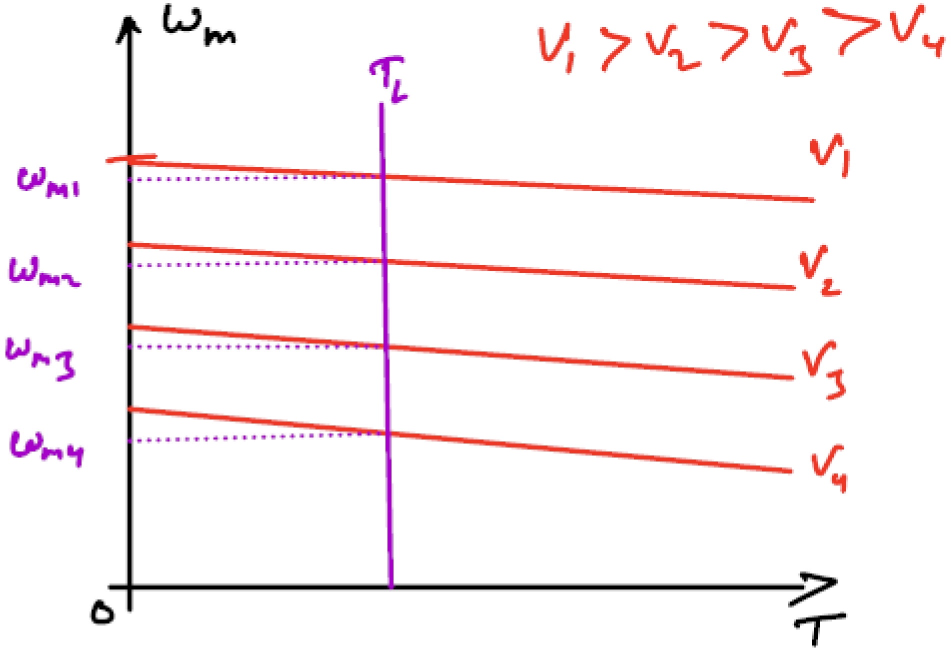
- Shunt/separately excited DC motor: Armature voltage control



$$\boxed{\omega_m = \frac{V_t}{K\phi} - \frac{R_a}{(K\phi)^2}\cdot T}$$

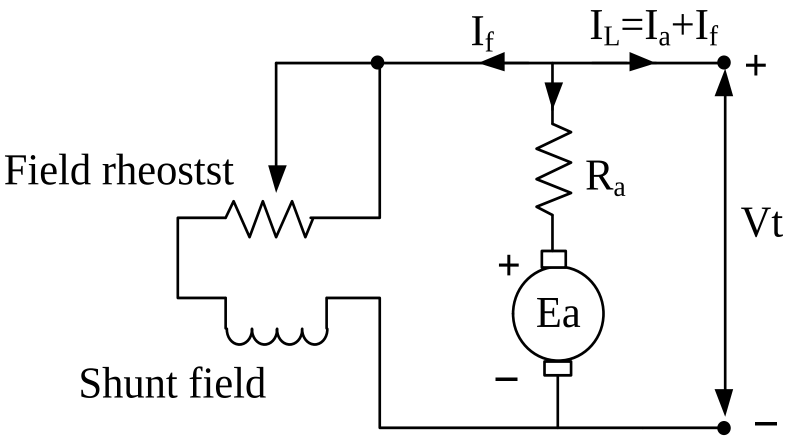
$\omega_{m1} > \omega_{m2} > \omega_{m3} > \omega_{m4}$



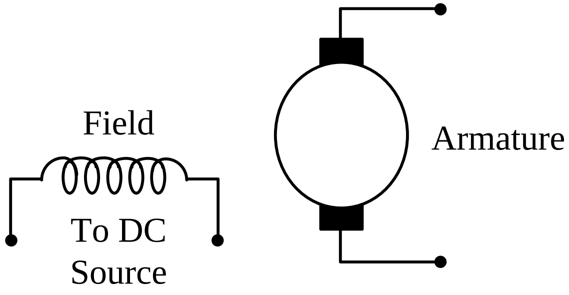


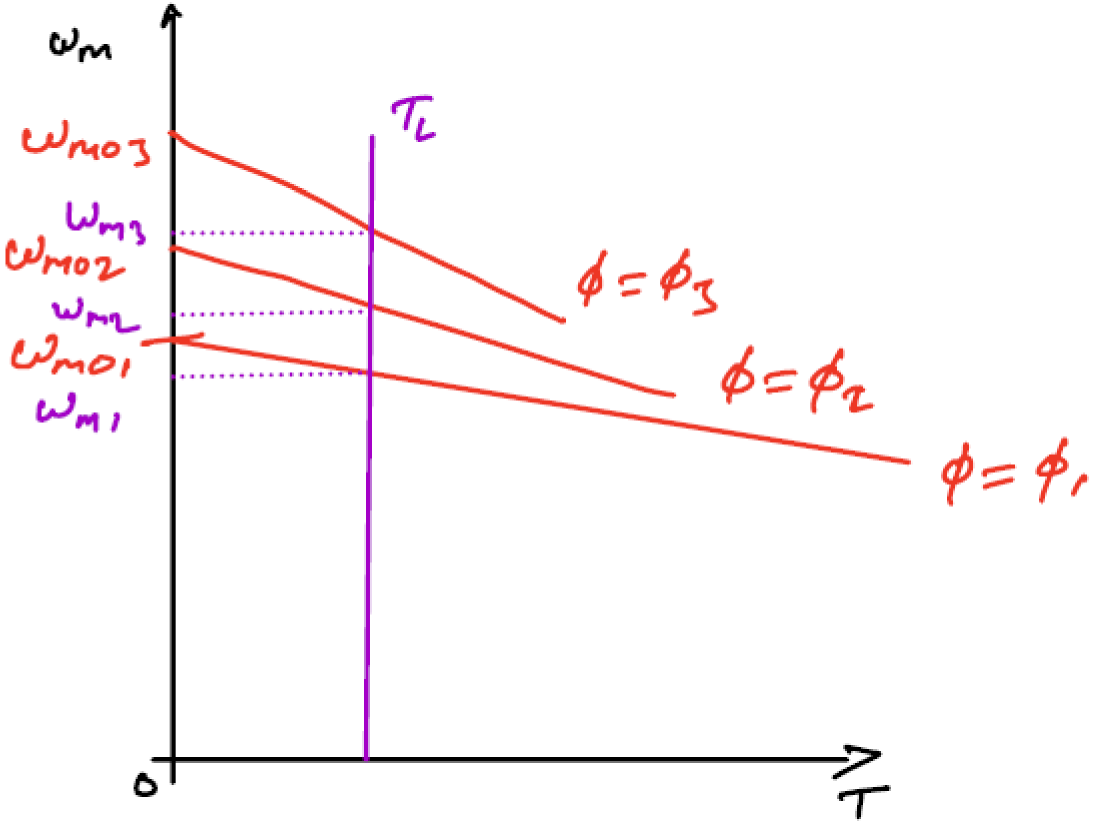
Speed Control of DC Motor

❑ Shunt/separately excited DC motor: field control



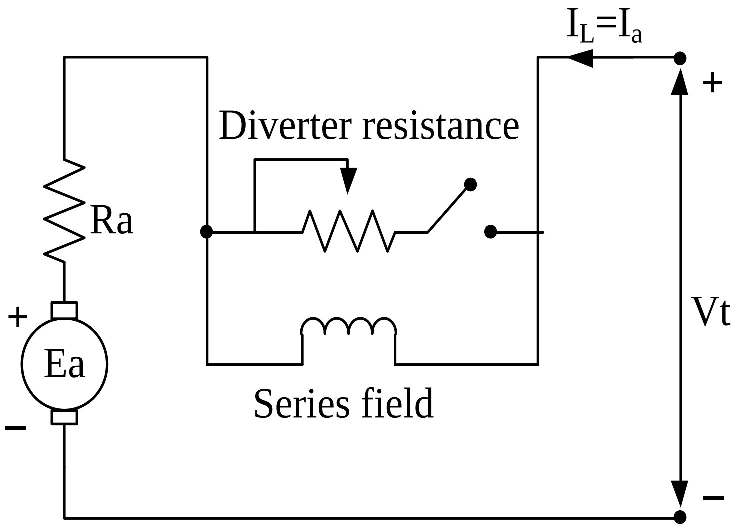
$$\boxed{\omega_m = \frac{V_t}{K\phi} - \frac{R_a}{(K\phi)^2}\cdot T}$$





DC Motor Characteristics (Contd…)

- DC series motor: speed–torque characteristics



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

$$E = k\phi\omega_m \quad \text{— (2)}$$

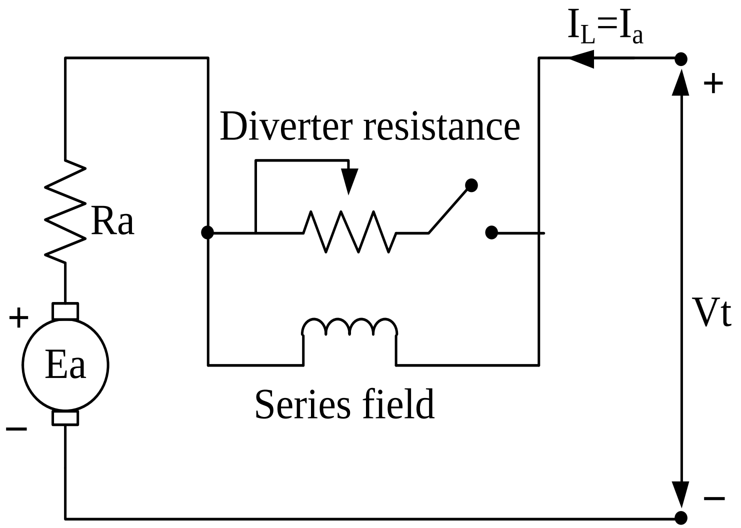
$$T = k\phi I_a \quad \text{— (3)}$$

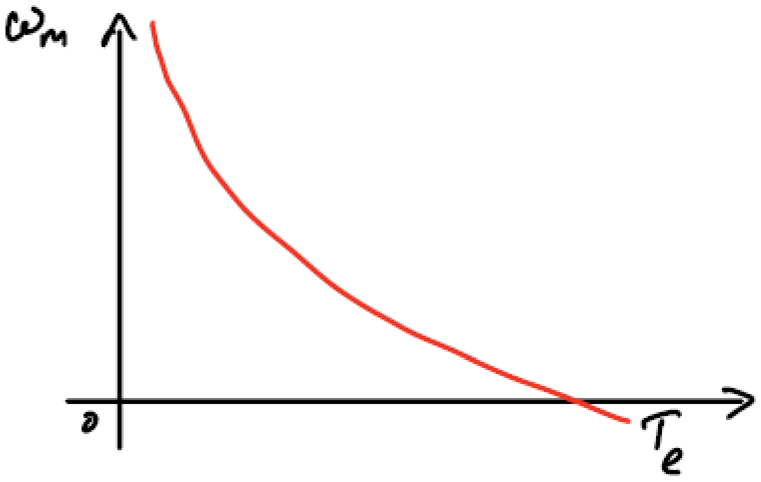
$$\phi = k_f \cdot I_f \quad (\text{magnetic linearity})$$

$$T = k\phi I_a = k k_f I_f I_a = k k_f I_a^2 \quad \text{— (4)}$$

DC Motor Characteristics (Contd…)

- DC series motor: speed–torque characteristics





From eqn ①

$$E = V_t - I_a R_a$$

$$K\phi\,\omega_m = V_t - I_a R_a$$

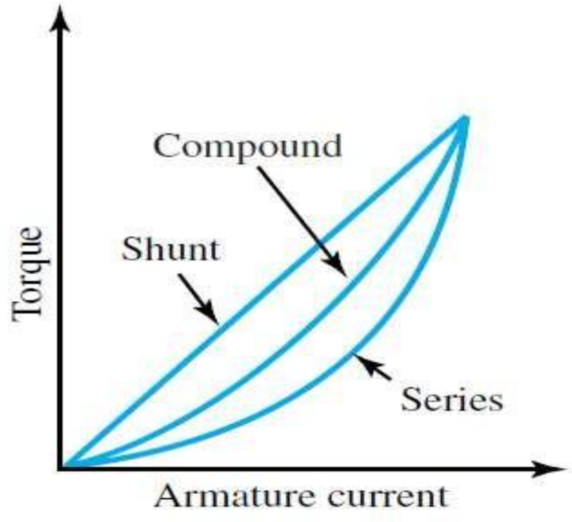
$$K K_f I_a \omega_m = V_t - I_a R_a$$

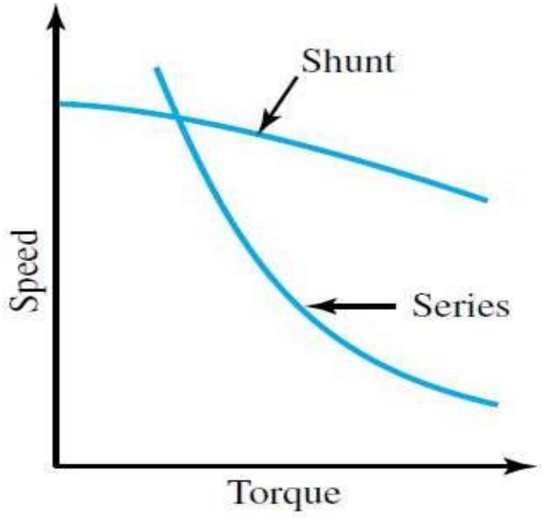
$$\omega_m = \frac{V_t}{K K_f I_a} - \frac{R_a}{K K_f}$$

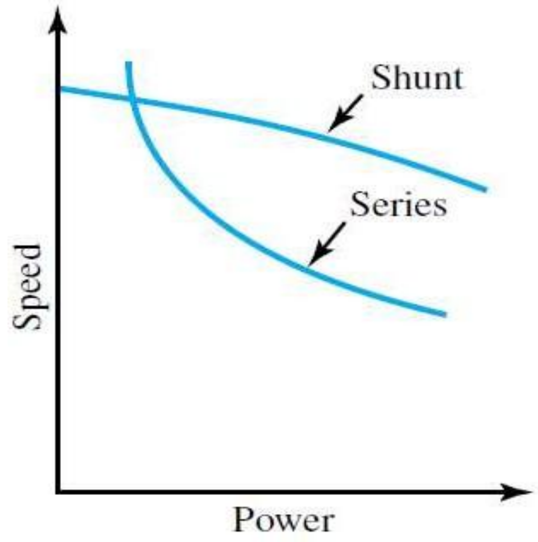
$$\boxed{\omega_m = \frac{V_t}{\sqrt{K K_f}\cdot\sqrt{T}} - \frac{R_a}{K K_f}}$$

$$\left[\because I_a = \sqrt{\frac{T}{K K_f}}\right]$$

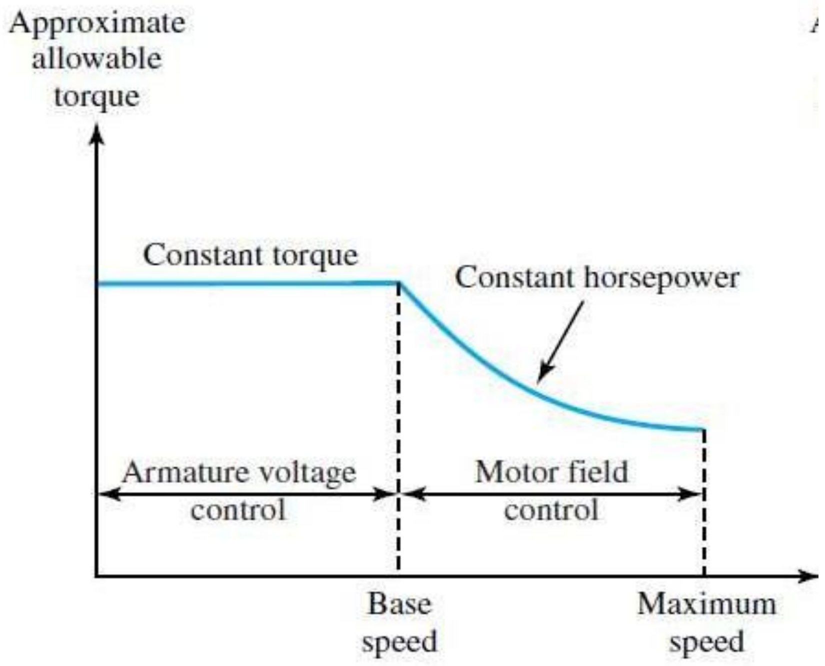
DC Motor Characteristics (contd…)

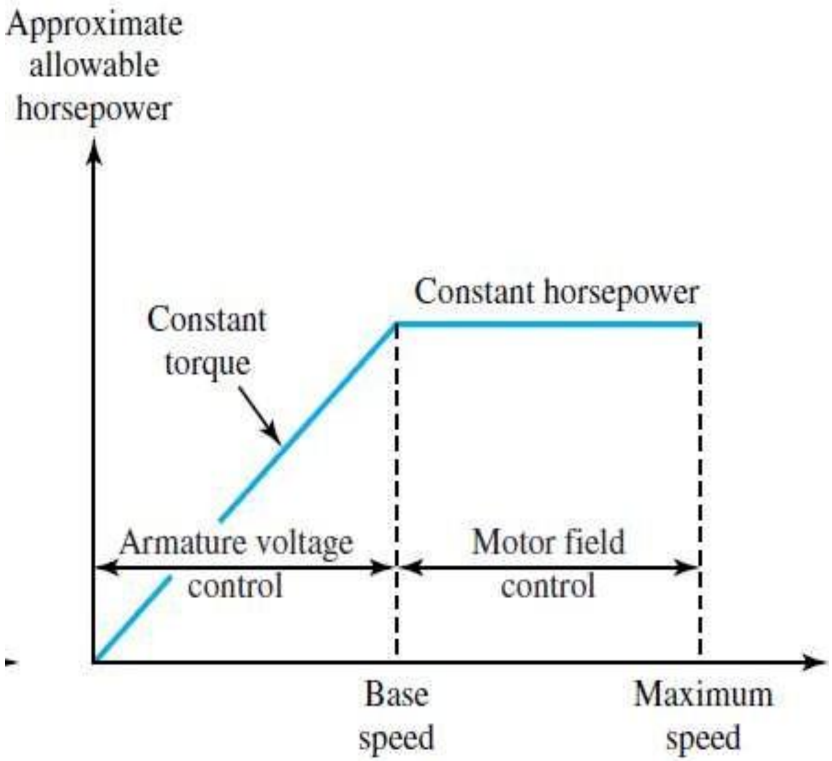






SPEED CONTROL OF DC MOTORS (contd..)





DC Motor Starting

When voltage is applied to the armature of a DC motor with the rotor stationary, no emf is generated. The armature current is limited only by the internal armature resistance of the machine.

$$E = V - I_a R_a$$

$$I_a = V/R_a$$

So, to limit the starting current to the value that the motor can commutate successfully, all except very small DC motors are started with variable external resistance in series with their armatures. This starting resistance is cut out manually or automatically as the motor comes up to speed.

Application of DC Machines

- DC motors find wide applications in which control of speed, voltage, or current is essential.
- Shunt motors with constant speed are used for centrifugal pumps, fans, blowers, and conveyors.
- Shunt motors with adjustable speed are employed in rolling mills and paper mills.
- Compound motors used for plunger pumps, crushers, punch presses, and hoists.
- Series motors are utilized for electric locomotives, cranes, and car dumpers.
- The DC shunt generators are often used as exciters to provide DC supply.
- The series generator is employed as a voltage booster and also as a constant- current source in welding machines.
- The cumulative-compound generator used where a constant DC voltage is essential.
- The differential-compound generator is used in applications such as arc welding, where a large voltage drop is desirable when the current increases.


THANKS
FOR YOUR
ATTENTION