Lecture No. 50
DC Motor (Types & Characteristics)

Lecture delivered by:

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Objectives

At the end of this lecture, student will be able to:

- Classify DC Motors based upon methods of excitation
- Derive an expression for torque developed in a DC Motor
- Discuss Speed-Torque characteristics of DC Motors
- Explain methods of Speed Control

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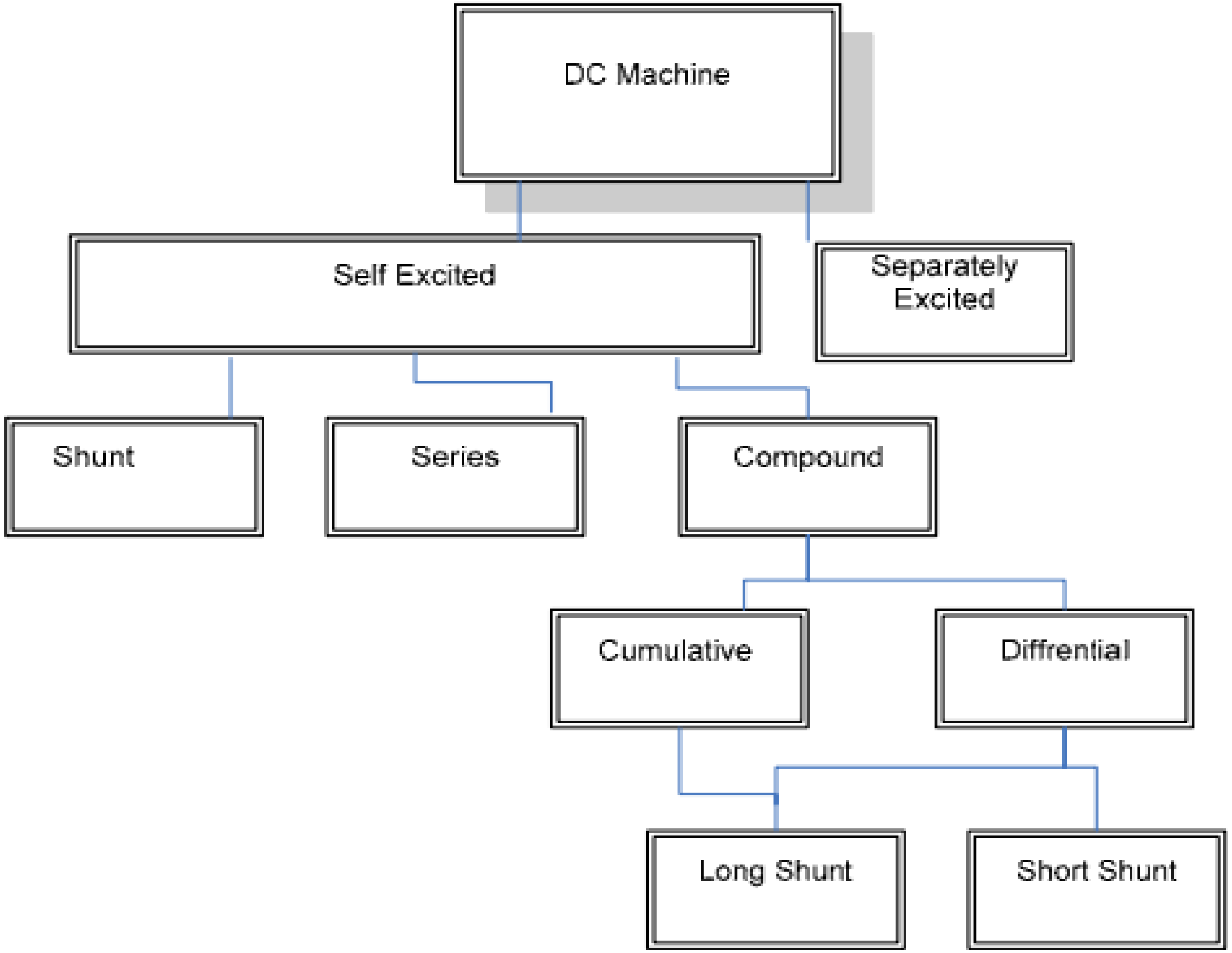
Methods of Excitation of DC



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Methods of Excitation of DC Machines

- In DC machine current carrying conductors rotate inside static magnetic field.
- DC machine can be termed as an electro mechanical energy converter which only works in the presence of a field excitation.
- Two types of excitation present for dc machine
  1. Separate excitation
  2. Self excitation

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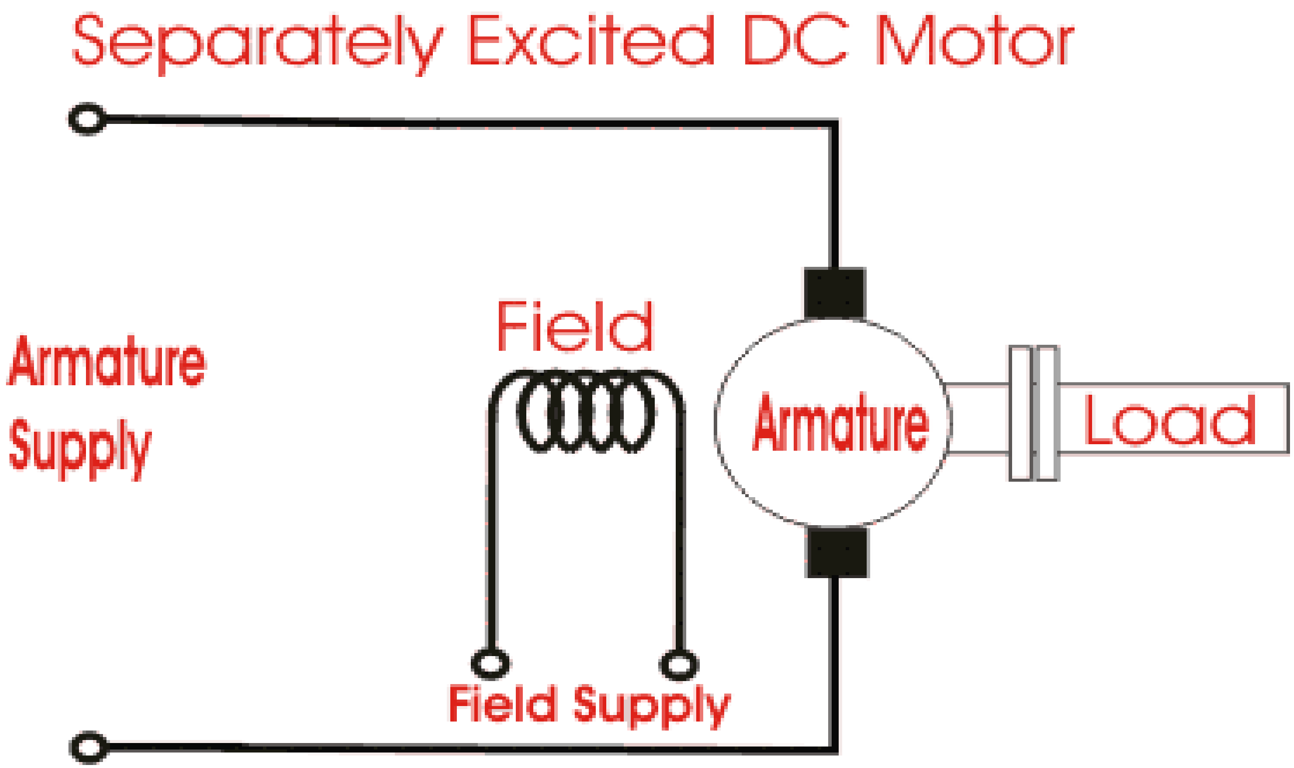
Separate Excitation

- Field excitation is only possible by dc supply



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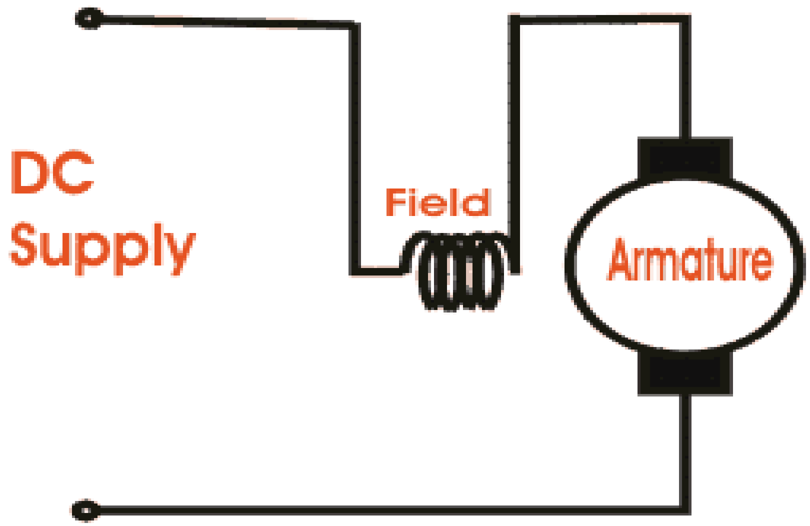
Self Excitation

A self excited dc machine can be divided into:

1. **Series excitation** – in this case the field is in series with the rotor and the armature current itself acts as the field current



Series Excited DC Motor

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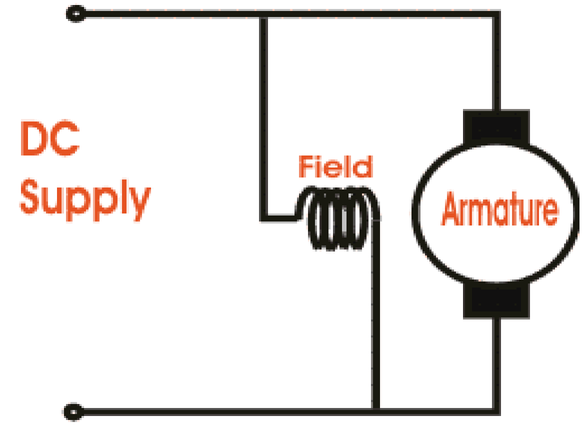
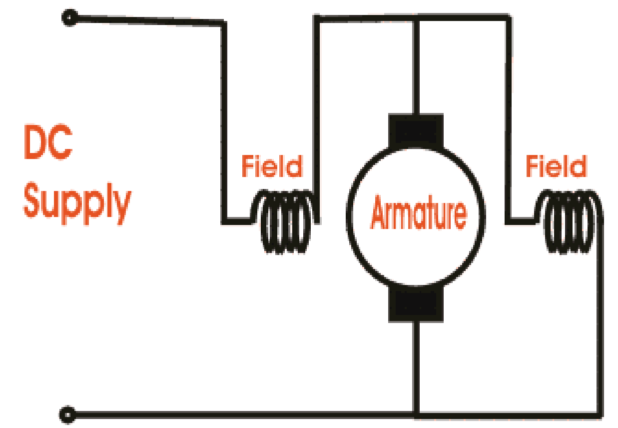
Self Excitation

2. **Shunt excitation-** when the field is in the parallel with the armature, then that excitation is called shunt excitation.



Shunt Excited DC Motor

3. **Compound excitation-** both series and shunt excitation winding is present in the circuit then this is called compound excitation.



Cumulatively Compound Excited DC Motor

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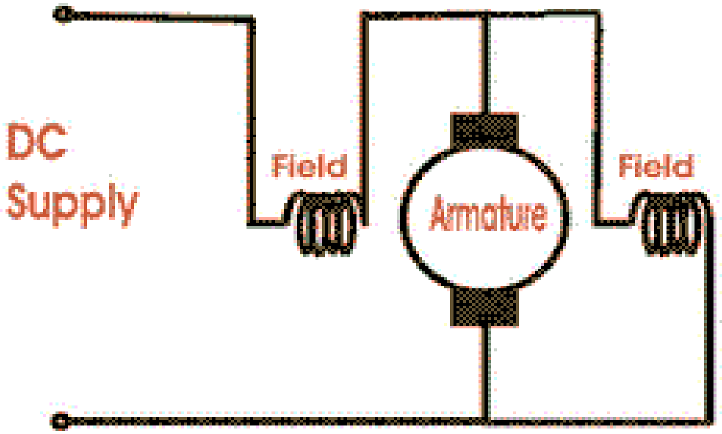
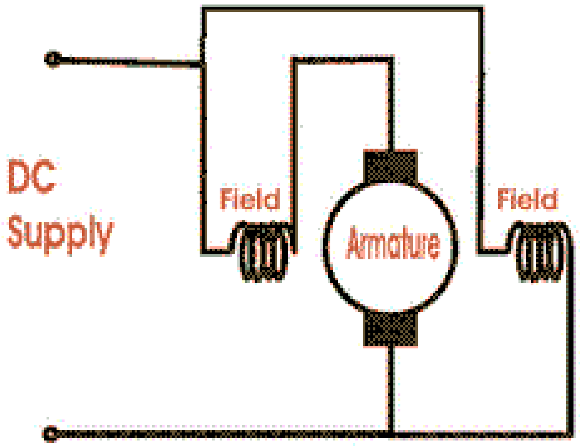
Self Excitation

Short Shunt DC Motor



Long Shunt DC Motor



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Torque of a D.C. Machine

- For a D.C. Motor, the supply voltage V is given by

$$V = E + I_a R_a$$

- Multiplying each term by current Ia gives:

$$VI_a = EI_a + I^2{}_a R_a$$

- The term VI_a is the total electrical power supplied to the armature, the term $I^2{}_a R_a$ is the loss due to armature resistance, and the term EI_a is the mechanical power developed by the armature
- If T is the torque, in newton metres, then the mechanical power developed is given by $T\omega$ watts

$$Hence\ T\omega = 2\pi nT = EI_a\ \ from\ which,$$

$$torque\ T = \frac{EI_a}{2\pi n}\ newton\ metres$$

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Torque of a D.C. Machine

- The e.m.f. E generated is given by:

$$E = \frac{2p\Phi nZ}{c}$$

$$Hence\ 2\pi nT = EI_a = \left(\frac{2p\Phi nZ}{c}\right)I_a$$

$$and\ torque\ \boxed{T = \frac{\left(\frac{2p\Phi nZ}{c}\right)I_a}{2\pi n}}$$

$$i.e.,\quad T = \frac{p\Phi ZI_a}{\pi c}\ newton\ metres$$

$$For\ a\ given\ machine,\ Z,\ c\ and\ p\ are\ fixed\ values$$

$$Hence\ torque\ \boxed{T\alpha\Phi I_a}$$

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Problem

- **Problem 14**. An 8-pole D.C. motor has a wave-wound armature with 900 conductors. The useful flux per pole is 25 mWb. Determine the torque exerted when a current of 30 A flows in each armature conductor.

Sol^n

$$p = 4, c = 2 \;\; for\ a\ wave\ winding, \phi = 25x10^{-3} Wb, Z = 900$$

$$I_a = 30A$$

$$torque\ T = \frac{p\Phi Z I_a}{\pi c}$$

$$= \frac{(4)(25x10^{-3})(900)(30)}{\pi(2)} = 429.7 Nm$$

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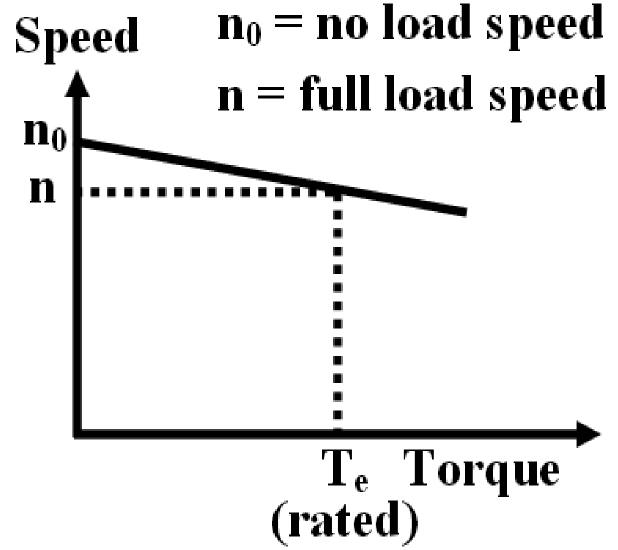
Speed Torque Characteristics (Shunt)

$$n = \frac{V - I_a R_a}{k\varphi}$$



- The graph above shows a torque/speed curve of a D.C. shunt motor.
- For shunt motors Φ will be constant, and Torque is proportional to ΦIa, hence the curve will be straight line with –ve slope

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Speed Torque Characteristics (Series)

$$T \propto \varphi I_a \qquad n = \frac{V - I_a R_a}{k\varphi}$$

In linear region,

$$T \propto I_a^2 \qquad n = \frac{V}{k' I_a} - \frac{R_a}{k'}$$

In saturation region,

$$T \propto \varphi_{sat} I_a \qquad n = \frac{V - I_a R_a}{k' \varphi_{sat}}$$

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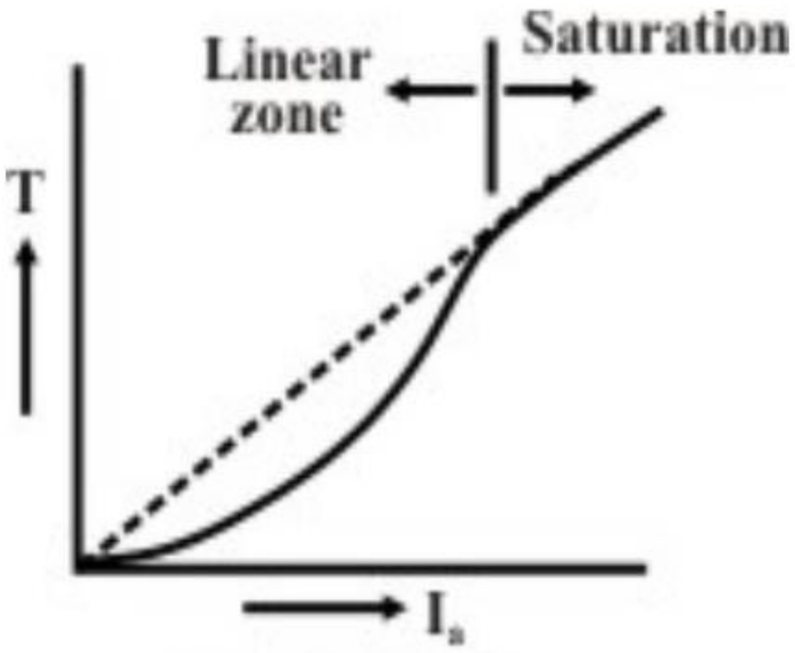
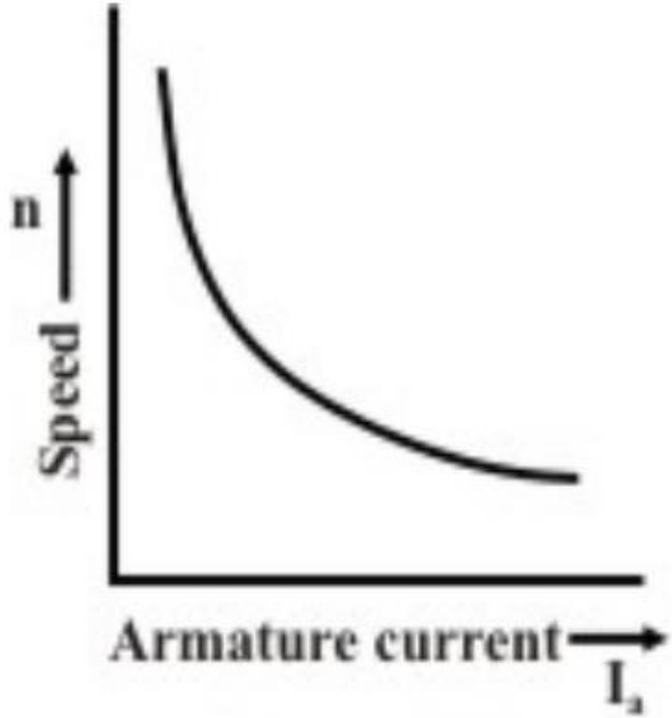
Speed Torque Characteristics (Series)



Torque Vs. Current



Speed Vs. Current

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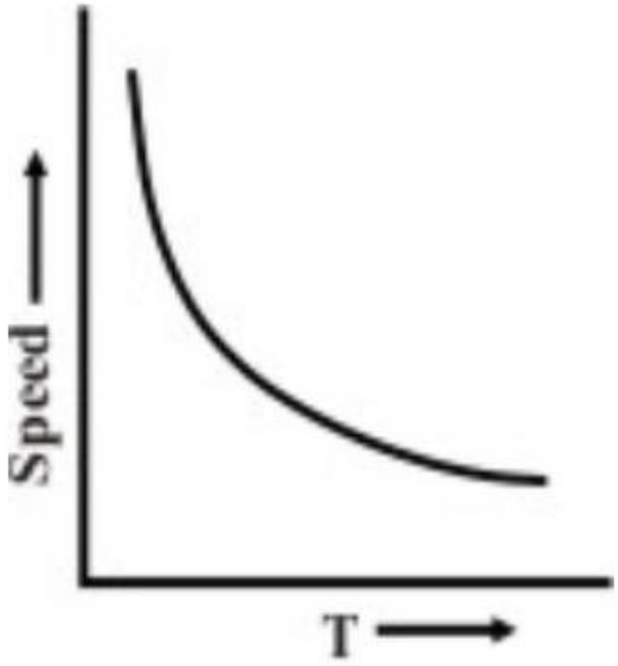
Speed Torque Characteristics



Speed Vs. Torque

- Series motor should never be started with no load
- It is not suitable for constant speed applications

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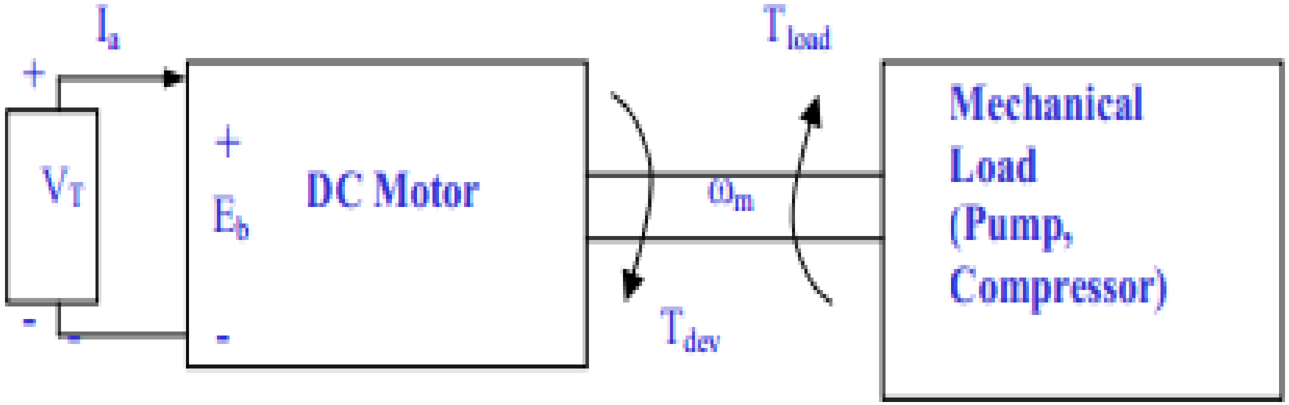
Speed Torque Characteristics

- Motor characteristics are frequently given as two points on this graph:
  - The stall torque, represents the point on the graph at which the torque is a maximum, but the shaft is not rotating
  - The no load speed, is the maximum output speed of the motor (when no torque is applied to the output shaft)



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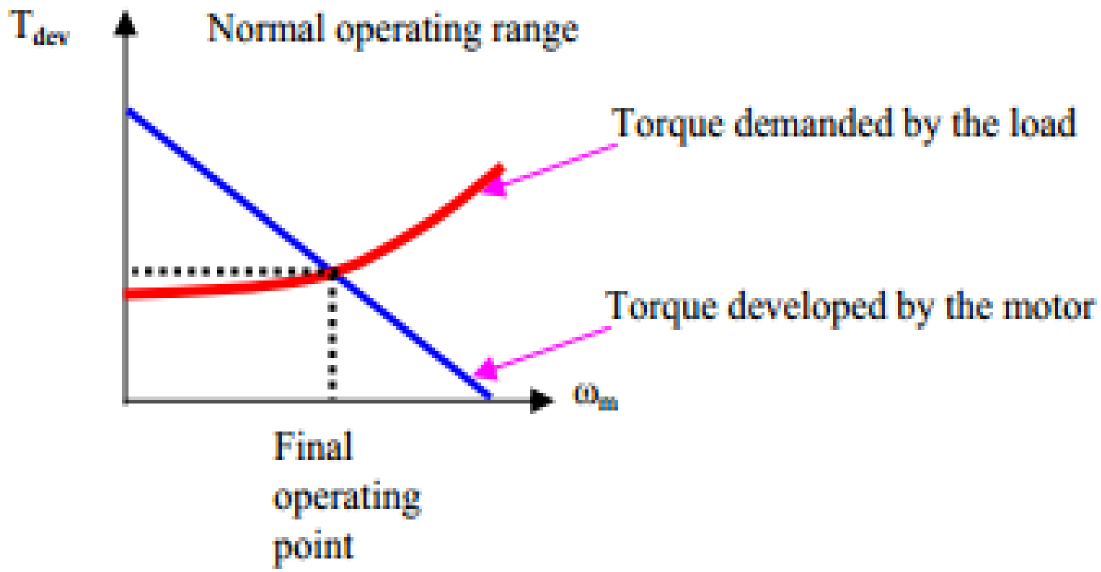
Speed Torque Characteristics

- As the motor starts to rotate and picks up speed, the developed torque decreases. The motor finally comes to a stable operating point when the two torques balance each other



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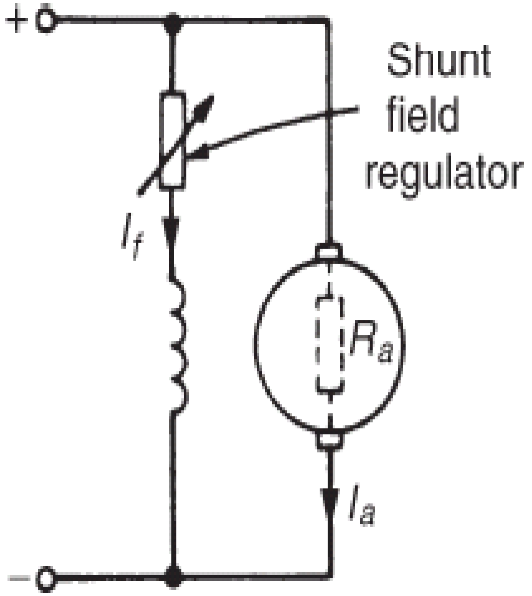
Speed Control of DC Motors

- **Shunt-wound Motors: -** The speed of a shunt-wound D.C. motor, *n*, is proportional to $(V-I_aR_a)/\phi$
- The former is achieved by using a variable resistor in series with the field winding, such a resistor is called the **shunt field regulator**



$$n \ \alpha \ \frac{V - I_a(R_a + R)}{\Phi}$$

Shunt Wound Motors

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Problem

- **Problem 16**. A 500 V shunt motor runs at its normal speed of 10 rev/s when the armature current is 120 A. The armature resistance is 0.2
  - (a) Determine the speed when the current is 60 A and a resistance of 0.5 is connected in series with the armature, the shunt field remaining constant
  - (b) Determine the speed when the current is 60 A and the shunt field is reduced to 80% of its normal value by increasing resistance in the field circuit

Sol^n

$$(a)\ back\ e.m.f\ \ at\ 120A,\ \ E_1 = V - I_a R_a$$

$$= 500 - (120)(0.2)$$

$$= 500 - 24 = 476\ volts$$

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$$When\ I_a = 60A,\ E_2 = 500 - (60)(0.2 + 0.5)$$
$$= 458\ volts$$

$$Now\ \frac{E_1}{E_2} = \frac{\Phi_1 n_1}{\Phi_2 n_2}$$

$$i.e.,\ \frac{476}{458} = \frac{\Phi_1 (10)}{\Phi_2 n_2}\ \sin ce\ \Phi_2 = \Phi_1$$

$$from\ which,\ speed\ n_2 = \frac{(10)(458)}{(476)} = 9.62 rev/s$$

$$(b)\ Back\ e.m.f\ when\ I_a = 60A,\ E_2 = 500 - (60)(0.2)$$
$$= 488\ volts$$

$$Now\ \frac{E_1}{E_2} = \frac{\Phi_1 n_1}{\Phi_2 n_2}$$

$$i.e.,\ \frac{476}{458} = \frac{\Phi_1 (10)}{(0.8\Phi_1) n_3}\ \sin ce\ \Phi_2 = 0.8\Phi_1$$

$$from\ which,\ speed\ n_3 = \frac{(10)(458)}{(0.8)(476)} = 12.82 rev/s$$

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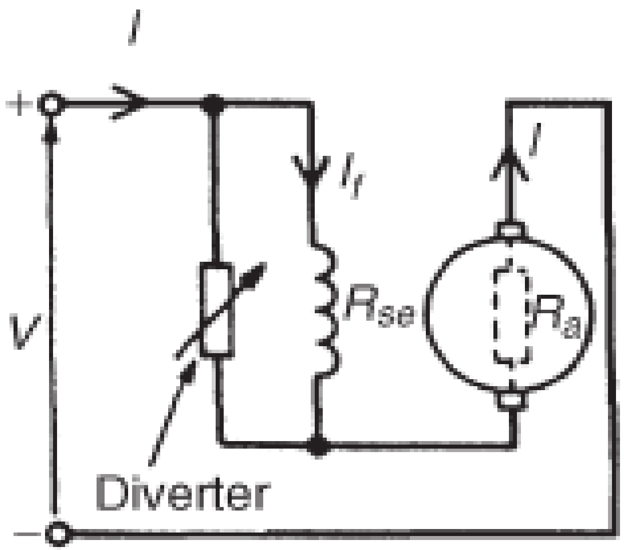
Speed Control of DC Motors

- **Series-wound motors: -**The speed control of series-wound motors is achieved using either (a) field resistance, or (b) armature resistance techniques

a) Field resistance series wound motor: The speed of a D.C. series-wound motor is given by:

$$n = k\left(\frac{V - IR}{\Phi}\right)$$



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- **Problem 17**. On full-load a 300 V series motor takes 90 A and runs at 15 rev/s. The armature resistance is 0.1Ω and the series winding resistance is 50 mΩ. Determine the speed when developing full load torque but with a 0.2Ω diverter in parallel with the field winding. (Assume that the flux is proportional to the field current.)

Sol^n

$$At\ 300\ V,\ e.m.f.\ E_1 = V - IR$$

$$= V - I(R_a + R_{se})$$

$$= 300 - (90)(0.1 + 0.05) = 286.5 volts$$

$$with\ the\ 0.2\Omega\ diverter\ in\ parallel\ with\ R_{se}$$

$$theequivalent\ resistance,\ R = \frac{(0.2)(0.05)}{(0.2)+(0.05)} = 0.04\Omega$$

$$By\ current\ division,\ current\ I_1 = \left(\frac{0.2}{0.2+0.05}\right) I = 0.8I$$

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$$\text{Torque, } T \;\alpha\; I_a\Phi \textit{ and for full load torque, } I_{a1}\Phi_1 = I_{a2}\Phi_2$$

$$\textit{Since flux is proportional to field current } \Phi_1 \alpha I_{a1} \textit{ and } \Phi_2 \alpha 0.8 I_{a2}$$

$$\textit{then } (90)(90) = (I_{a2})(0.8 I_{a2})$$

$$\textit{from which, } I^2_{a2} = \frac{(90)^2}{0.8} \textit{ and } I_{a2} = \frac{90}{\sqrt{0.8}} = 100.62A$$

$$\textit{Hence e.m.f } E_2 = V - I_{a2}(R_a + R)$$

$$= 300 - (100.62)(0.1 + 0.04) = 285.9 volts$$

$$\textit{Now e.m.f., } E \;\alpha\; \Phi n \textit{ from which, } \frac{E_1}{E_2} = \frac{\Phi_1 n_1}{\Phi_2 n_2} = \frac{I_{a1} n_1}{0.8 I_{a2} n_2}$$

$$\textit{Hence } \frac{(286.5)}{285.9} = \frac{(90)(15)}{(0.8)(100.62) n_2}$$

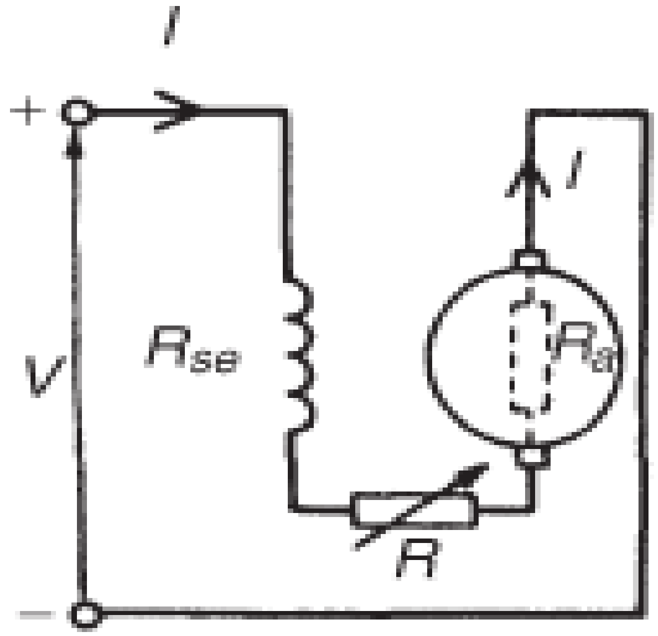
$$\textit{and new speed, } n_2 = 16.74\; rev/\mathrm{s}$$

Thus the speed of the motor has increased from 15 rev/s (i.e., 900 rev/min) to 16.74 rev/s (i.e., 1004 rev/min) by inserting a 0.2 diverter resistance in parallel with the series winding.

Speed Control of DC Motors

(b) Armature resistance technique

- Speeds below normal are obtained by connecting a variable resistor in series with the field winding
- reduces the speed
- large power loss



$$n = k\left(\frac{V - IR}{\Phi}\right)$$

Armature Resistance Technique

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- **Problem 18**. A series motor runs at 800 rev/min when the voltage is 400 V and the current is 25 A. The armature resistance is 0.4Ω and the series field resistance is 0.2Ω . Determine the resistance to be connected in series to reduce the speed to 600 rev/min with the same current.
- *Sol*^{n} $e.m.f.\ E_1 = V - I(R_a + R_{se})$

$$= 400 - (25)(0.4 + 0.2) = 385 volts$$

At 600 rev/min, since the current is unchanged, the flux is unchanged.

$$Thus\ E\ \alpha\ \Phi n\ from\ which, \frac{E_1}{E_2} = \frac{\Phi_1 n_1}{\Phi_2 n_2} ==> \frac{385}{E_2} = \frac{800}{600} = 288.75 volts$$

$$and \qquad E_2 = V - I(R_a + R_{se} + R)$$

$$Hence\ \ 288.75 = 400 - 25(0.4 + 0.2 + R)$$

$$R = 3.85\Omega$$

Thus the addition of a series resistance of 3.85Ω has reduced the speed from 800 rev/min to 600 rev/min

Summary

- Torque developed by a DC motor is proportional to flux and armature current
- Shunt motors run at almost constant speed
- Series motors are used for high torque applications
- Series motors should never be operated without load

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