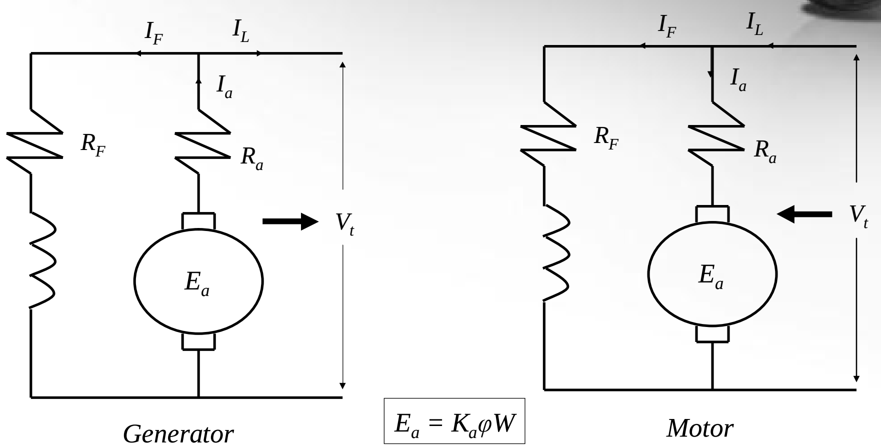
Electrical Power and Machines
Lecture 5

<Dr Ahmed El-Shenawy>
<Dr Hadi El Helw>

DC Motor

theory of operation

- In a dc motor, the stator poles are supplied by dc excitation current, which produces a dc magnetic field.
- The rotor is supplied by dc current through the brushes, commutator and coils.
- The interaction of the magnetic field and rotor current generates a force that drives the motor



$E_a = K_a \varphi W$

Driving e.m.f — Back e.m.f

$V_t = E_a - I_a R_a$

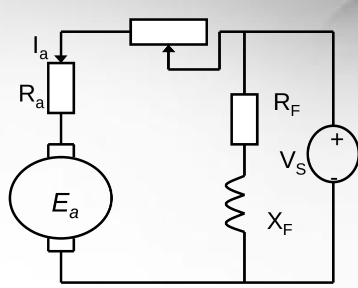
$V_t = E_a + I_a R_a$

Starting of DC motor

$V_S = E_a + I_a R$

At Starting E_a is zero (back $e.m.f = 0$), so $I_a = V_S/R$ and since R is very small then I_a is very big. Consequently a DC motor should never be started at rated voltage and an external resistance must be added and acts as temporarily starting resistance that is removed as soon as the armature has attained its normal speed, then

$I_a = V_S/(R_a+R_S)$



$R_S >>>> R_a$

Speed Regulation (SR): is a measure of the change in speed from no load to full load

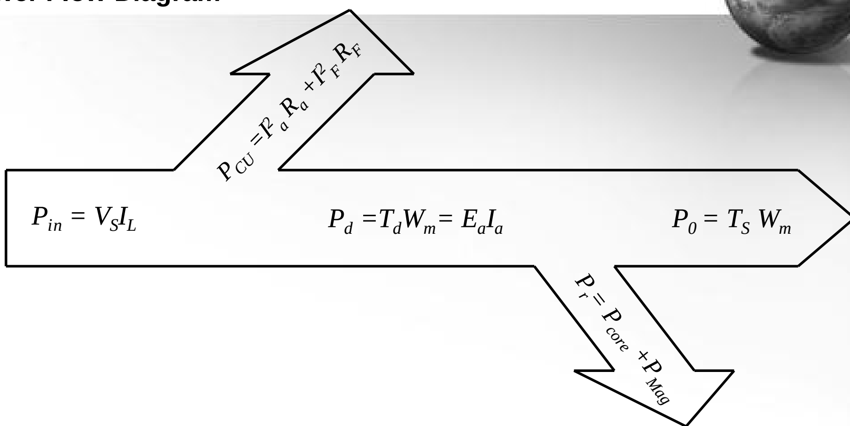
As I_a increases, E_a decreases thus N decreases

$SR\ \% = 100(N_{NL} - N_{FL})/N_{NL} = 100(W_{NL} - W_{FL})/W_{NL}$

Series Motor: SR is high (variable speed motor)

Shunt Motor: SR is very low (constant speed motor)

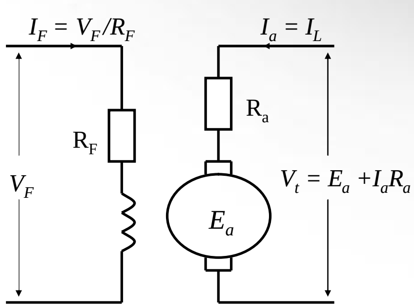
Power Flow Diagram



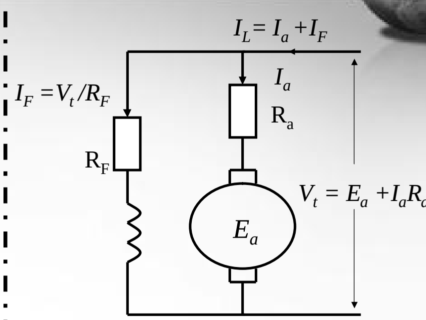
Efficiency "η"

$\eta\ \% = (P_0 / P_{in}) \times 100$

Separately Excited and DC shunt Motors

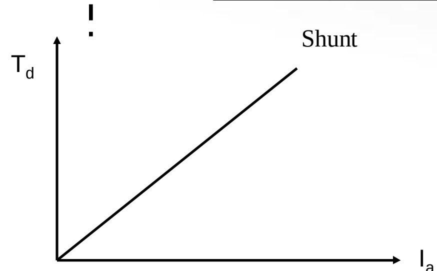


Separately Excited



Shunt

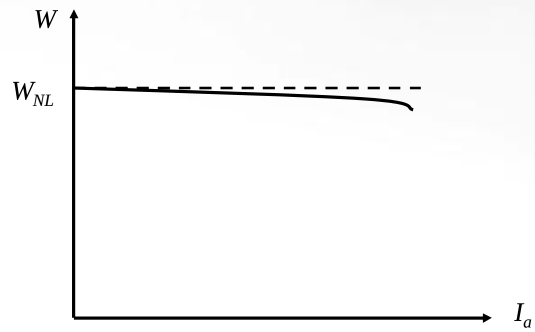
$T_d = K\, I_a = K_a\, \varphi_p\, I_a$



For a Shunt Motor

$E_a = V_t - I_a R_a = K_a \varphi_P W$ Then $W = \frac{V_t - I_a R_a}{K_a \varphi_P} = W_{NL} - \frac{I_a R_a}{K_a \varphi_P}$

If R_a is very small then $W = W_{NL}$, consequently a shunt motor is a constant speed motor



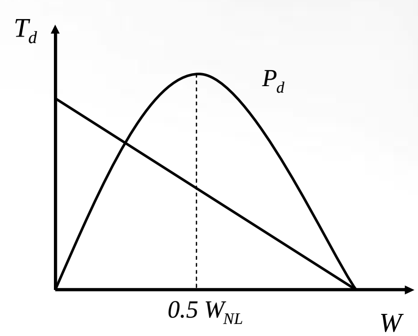
Torque-Speed Characteristics

$$T_d = K_a \varphi_P I_a \ldots\ldots\ldots\ldots I_a = \frac{T_d}{K_a \varphi_P} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$W = \frac{V_t}{K_a \varphi_P} - \frac{I_a R_a}{K_a \varphi_P} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

By substituting by (1) in (2) then

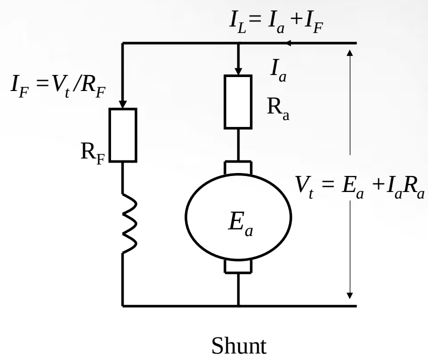
$$T_d = \frac{K_a \varphi_P V_t}{R_a} - \frac{K_a^2 \varphi_P^2}{R_a} W$$



Example

A 125 V shunt motor has an armature resistance of 0.2 Ω and a shunt field resistance of 45 Ω. If the load current is 50 A, find both E_a and P_d

Solution



$I_F = V_t/R_F = 125/45 = 2.78\ A$

$I_a = I_L - I_F = 50 - 2.78 = 47.22\ A$

$E_a = V_t - I_a R_a = 125 - 47.22 \times 0.2 = 115.55\ V$

$P_d = E_a I_a = 115.55 \times 47.22 = 5456.43\ watts$

Series Motor

$I_a = I_F = I_L$

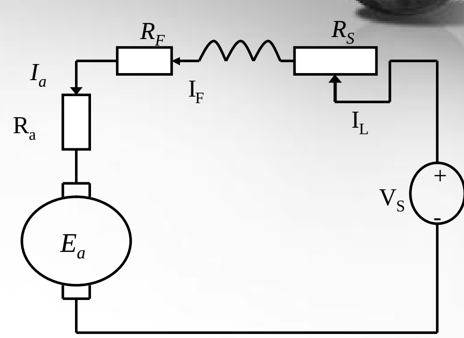
$V_t = E_a + I_a (R_a + R_F)$

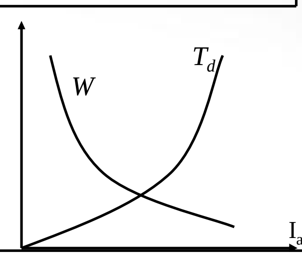
$\varphi_P = K_F I_F = K_F I_a$

$E_a = K_a \varphi_P W = K_a K_F I_a W$

$T_d = K_a \varphi_P I_a = K_a K_F I^2_a$ ……….(1)

$$W = \frac{E_a}{K_a K_F I_a} = \frac{V_t - I_a R}{K_a K_F I_a} \text{..........(2)}$$





- Speed of a series motor is inversely proportional to I_a
- A Series motor has a wide range of speed variation

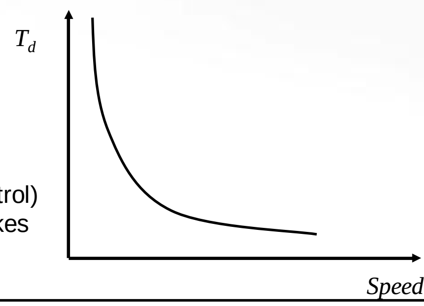
$$I_a = \frac{V_t}{K_a K_F W + R} \qquad T_d = K_a K_F I_a^2 = \frac{K_a K_F V_t^2}{(K_a K_F W + R)^2}$$

As $T_d \; \alpha \; 1/W^2$ the series motor has a very high starting torque and that makes it suitable for electrical vehicles, electric traction applications and drilling

Speed control

$$W = \frac{V_t - I_a R}{K_a K_F I_a}$$

- As R increases W decreases
- As φ_P increases W decreases (field control)
- Using a variable DC voltage source makes W increases as V_t increases



Example

A series motor has a combined series and armature resistance of 0.85 Ω, runs at 1000 rpm and draws 20A from a 250 V source, calculate:

1.The rotational speed if a 3.75 Ω resistor is connected in series with the motor

2.The developed power and developed torque at both speeds

Solution

1. $E_{a1} = V_t - I_a (R + R_S) = 250\text{-}20\times0.85 = 233$ V,

   $E_{a2} = 250\text{-}20\times(0.85+3.75) = 158$ V,

   as $E_a = K_a \varphi_P W$,

   then $(E_{a1}/E_{a2}) = (N_1/N_2)$

   then $N_2 = 158\times1000/233 = 678.1$ rpm

   or $W_2 = 678.11\times2\times3.14/60 = 71$ rad /sec

2. $P_{d1} = E_{a1} I_a = 233 \times 20 = 4660\ w$, $P_{d2} = E_{a2} I_a = 158 \times 20 = 3160\ w$

$T_{d1} = P_{d1} / W_1 = 4660/104.72 = 44.5\ N.m$

$T_{d2} = P_{d2} / W_2 = 3160/71 = 44.5\ N.m$