

Welcome to

Electric Machines & Drives

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**Session 3:
DC Motors**

Fall 2011

Session 3

➤ Chapter 5 – DC Motors

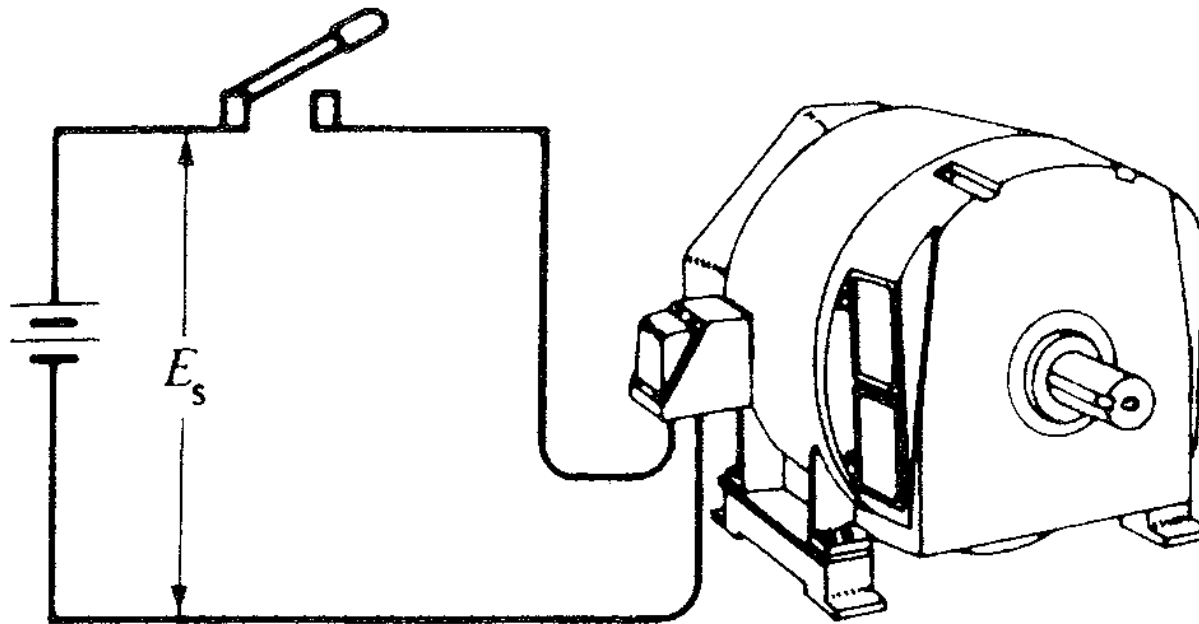
Chapter 5 – DC Motors



Electric Machines and Drives
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Chapter 5 – DC Motors

Constructed same as DC generator
Torque & Speed control with high efficiency
Starting methods



Chapter 5

$$E_o = Z n \Phi / 60$$

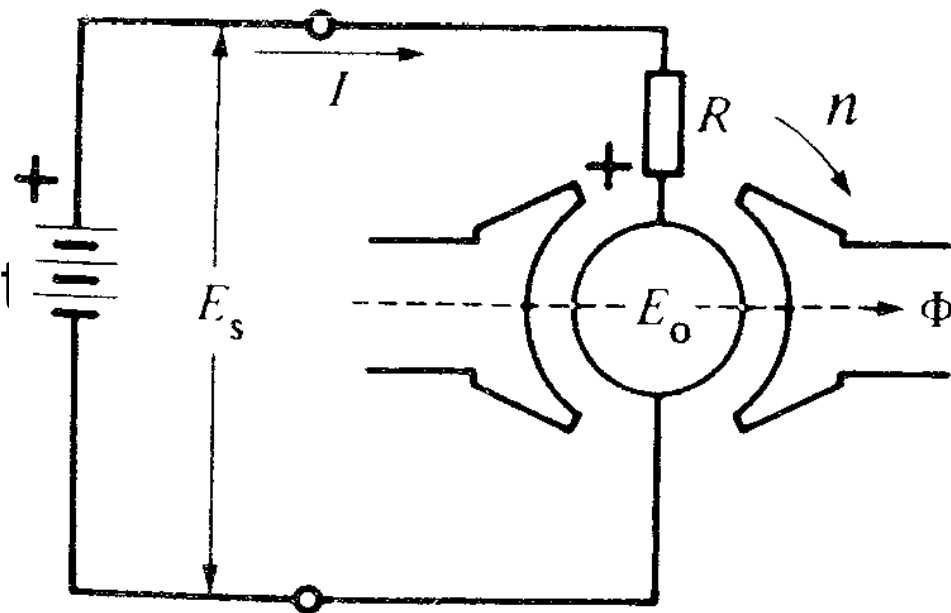
E_o proportional to speed

At rest $E_o = 0$

At steady state

$$E_o = E_s - I * R$$

E_o = counter-electric force (CEMF)



Chapter 5

Starting Current many times running current

Speed ceases to increase when

$T_{load} = T_{motor}$

$$I = (E_s - E_o) / R$$

$$I = E_s / R \text{ (during start)}$$

Example 5-1

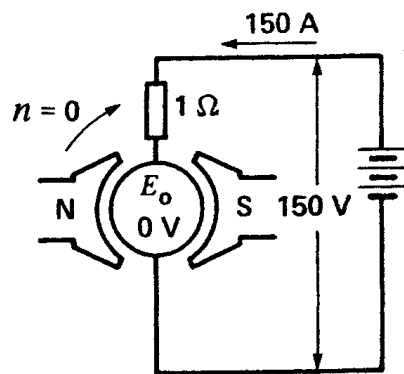
The armature of a permanent magnet DC generator has a resistance of 1Ω and generates a voltage of 50V when the speed is 500 rpm. If the armature is connected to a source of 150V, calculate the following;

- a. The starting current
- b. The counter emf when the motor runs at 1000 rpm and at 1460 rpm
- c. The armature current at 1000 rpm and at 1460 rpm

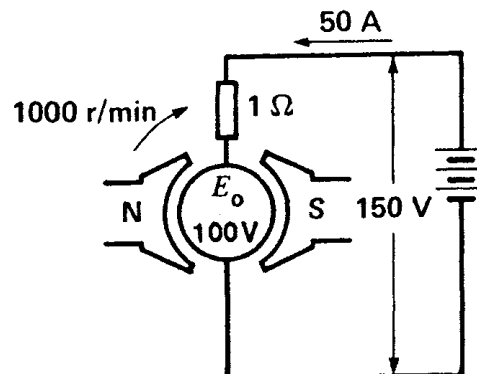
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Example 5-1

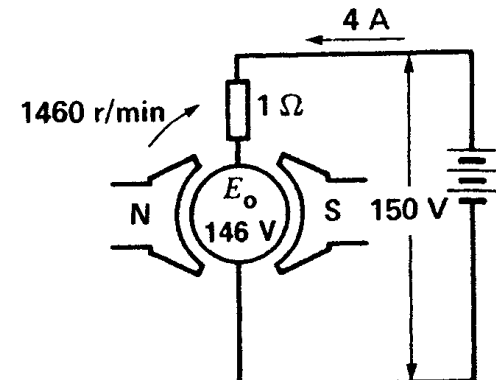
Solution



(a)



(b)



(c)

Chapter 5

Mechanical Power & Torque

$$P = n T / 9.55 = E_o I$$

$$E_o = Z n \Phi / 60$$

P = mechanical power developed by motor (W)

E_o = induced voltage in armature (cemf) (V)

I = total current supplied to the armature (A)

Example 5-2

The following details are given on a 225kW (300HP), 250V, 1200rpm dc motor. Calculate

- A. The rated armature current
- B. The number of conductors per slot
- C. The flux per pole

armature coils	243
turn per coil	1
type of winding	lap
armature slots	81
commutator segments	243
field poles	6
diameter of armature	559 mm
axial length of armature	235 mm

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Speed of Rotation – Proportional to E_s and inversely proportional to flux (field current)

Bonus Question, what happens to DC motor on Loss of Field Current?

$$N = 60 E_s / (Z \Phi) \text{ [approximately]}$$

N = speed of rotation (rpm)

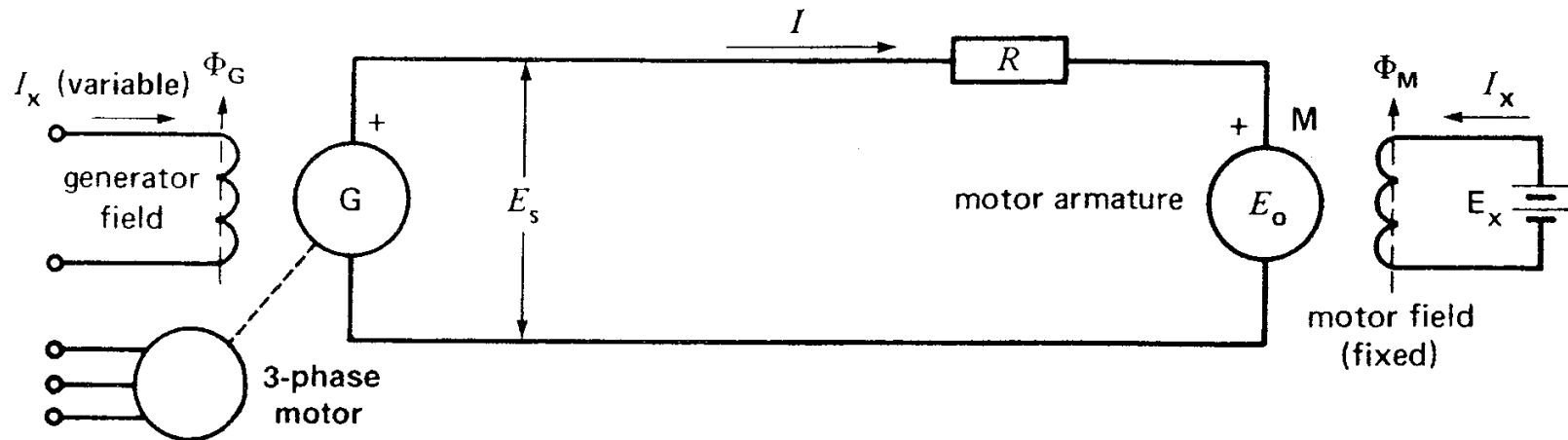
E_s = armature voltage (V)

Z = total number of armature conductors

Chapter 5

Speed control from MG set – controlling ES

- controlling I_x
- Can flow power in both directions due to MG set
- High efficiency



Example 5-3

A 2000kW, 500V, variable speed motor is driven by a 2500KW generator, using a Ward Leonard control system. The total resistance of the motor and generator armature circuit is $10 \text{ m}\Omega$. The motor turns at a nominal speed of 300 rpm, when E_o is 500V. Calculate

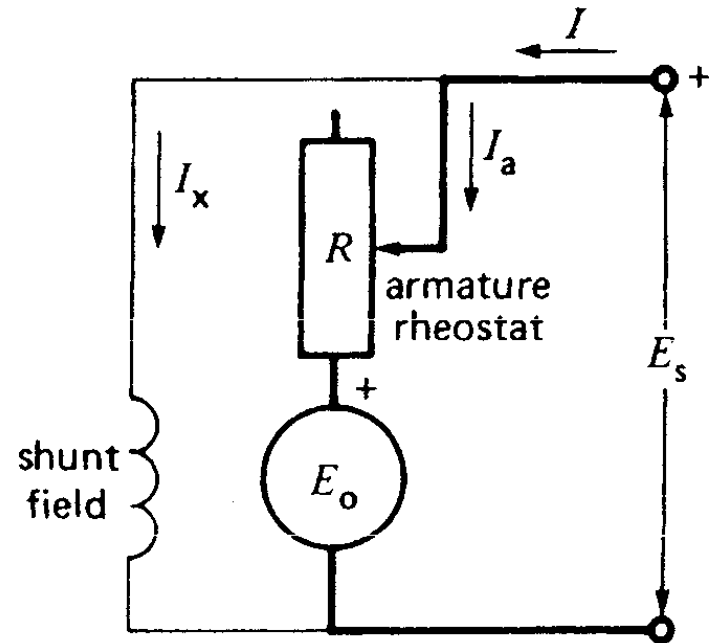
- a. The motor torque and speed when $E_s = 400\text{V}$ and $E_o = 380\text{V}$
- b. The motor torque and speed when $E_s = 350\text{V}$ and $E_o = 380\text{V}$

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Rheostat allows control
of EO \rightarrow speed control

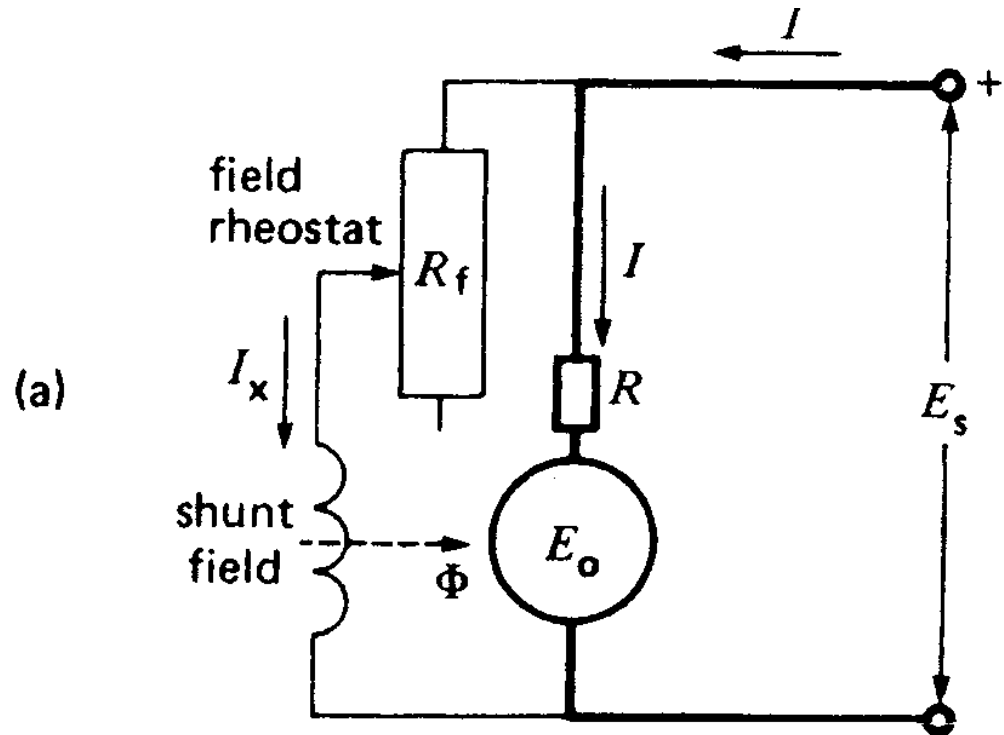
Efficiency very poor

Small motors only.



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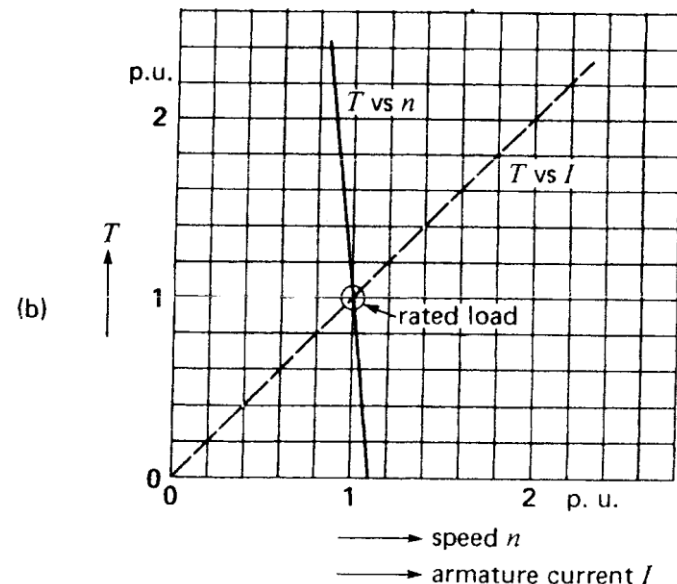
Speed control via
field control
Flux increase \rightarrow
speed decrease
Operate above
base speed



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As load increases, T_{load} increases, causing armature current to increase causing speed to drop

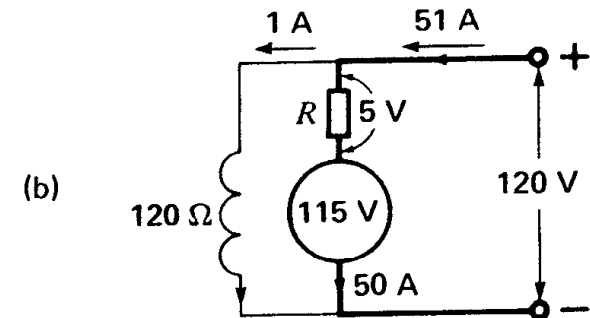
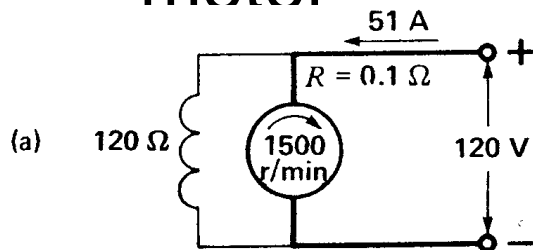
Speed regulation good (10%-20%)



Example 5-4

A shunt motor rotating at 1500 rpm is fed by a 120V source. The line current is 51A and the shunt field resistance is $120\ \Omega$. If the armature resistance is $0.1\ \Omega$, calculate the following;

- The current in the armature
- The counter emf
- The mechanical power developed by the motor



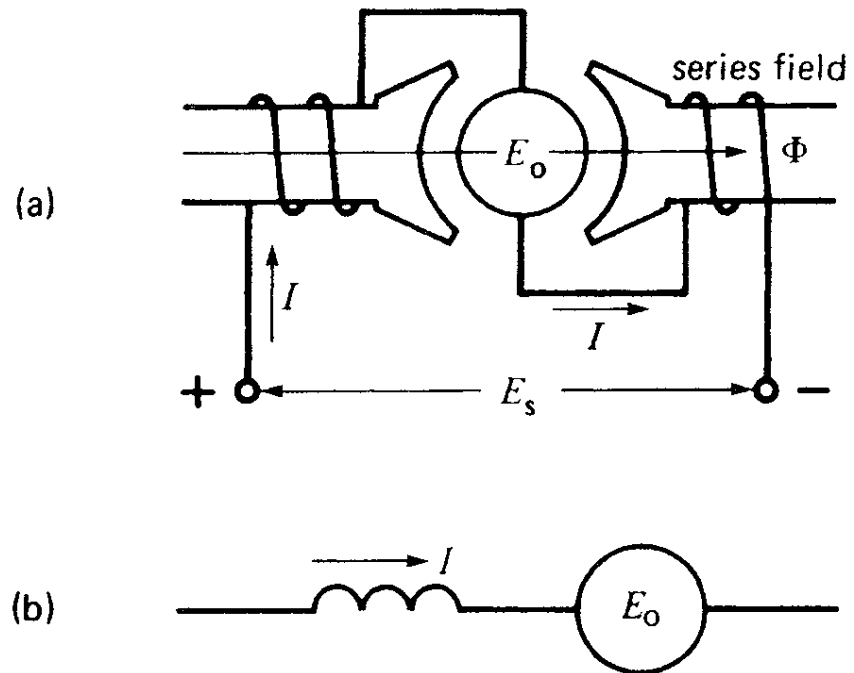
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Series Motor – Different torque speed characteristic

Starting torque higher

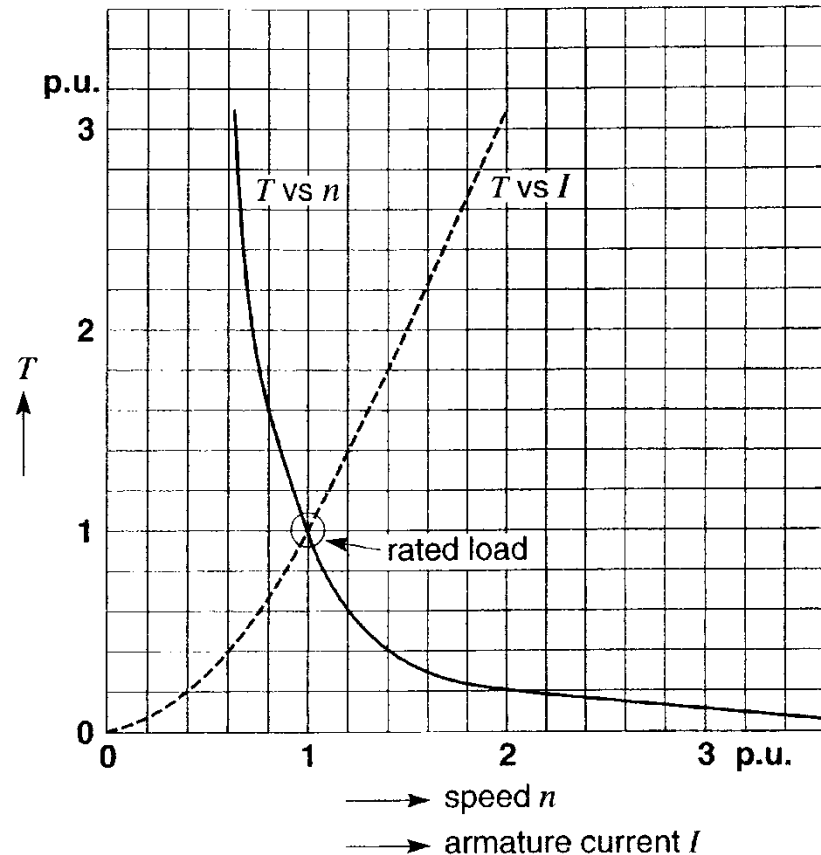
Reduction in load = reduced flux = higher speed

Bonus Question – what happens if load removed?



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As load decreases,
Tload decreases,
causing armature
current to decrease
causing flux to drop
causing speed to
increase rapidly
Speed regulation poor

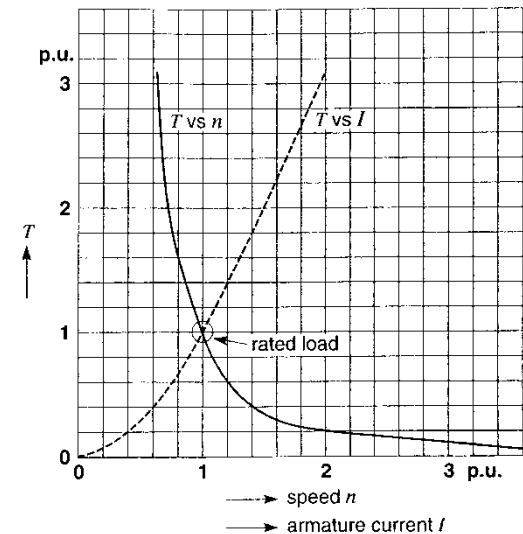


Example 5-5

A 15hp, 240V, 1780 rpm dc series motor has a full load rated current of 54A. Its operating characteristics are given by the per unit curve of Fig 5.11.

Calculate

- The current and speed when the load torque is 24 N m
- The efficiency under these conditions



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Compound DC Motor –

Both series & shunt field

No load, shunt field controls max speed

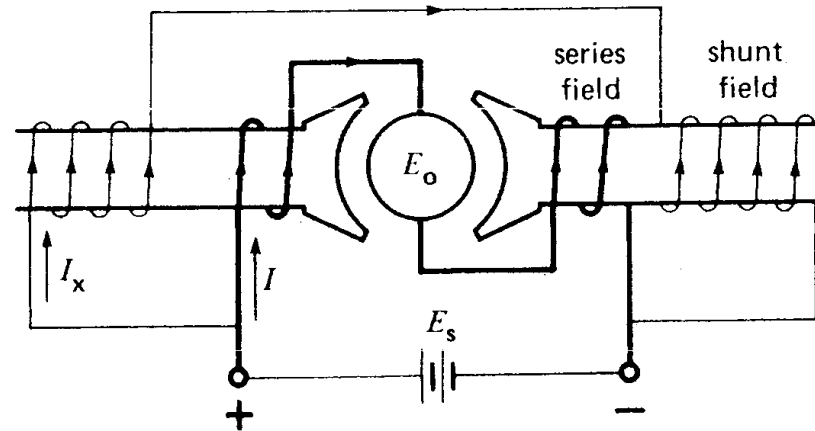
Full load, series field adds to mmf -> increased flux

-> speed decreases

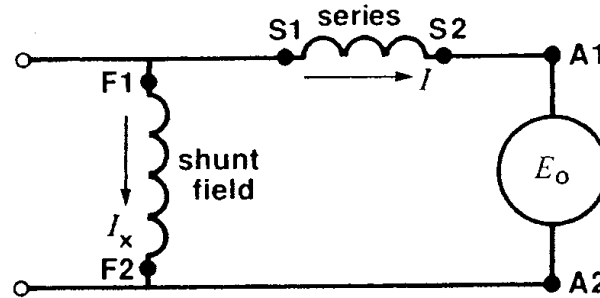
Regulation 10% - 30%

Differential Compound – series field mmf subtracts
from shunt field mmf

Chapter 5



(a)



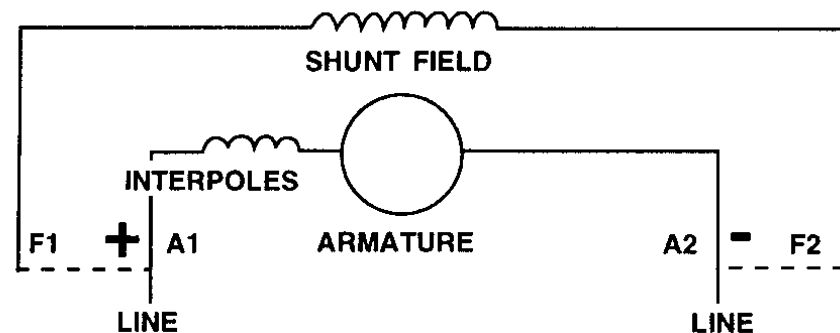
(b)

Chapter 5

All connections CCW rotation facing OE of the drive. For clockwise rotation, interchange A1 and A2. Some manufacturers connect the interpole winding on the A2 side of the armature.

When shunt field is separately excited, same polarities must be observed for a given rotation.

SHUNT MOTOR

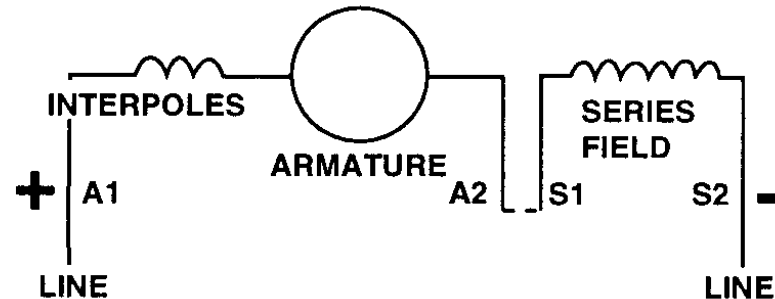


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All connections CCW rotation facing OE of the drive. For clockwise rotation, interchange A1 and A2. Some manufacturers connect the interpole winding on the A2 side of the armature.

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SERIES MOTOR

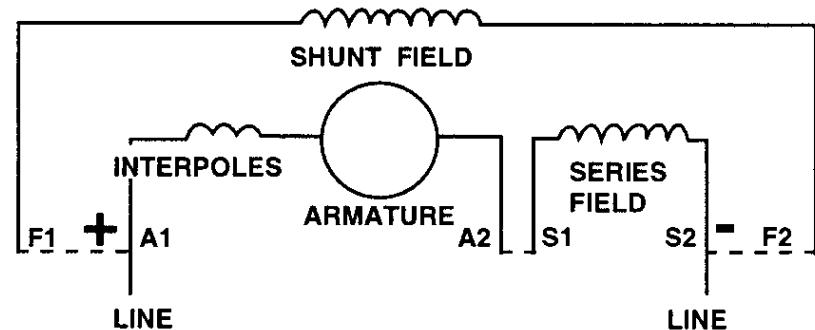


Chapter 5

All connections CCW rotation facing OE of the drive. For clockwise rotation, interchange A1 and A2. Some manufacturers connect the interpole winding on the A2 side of the armature.

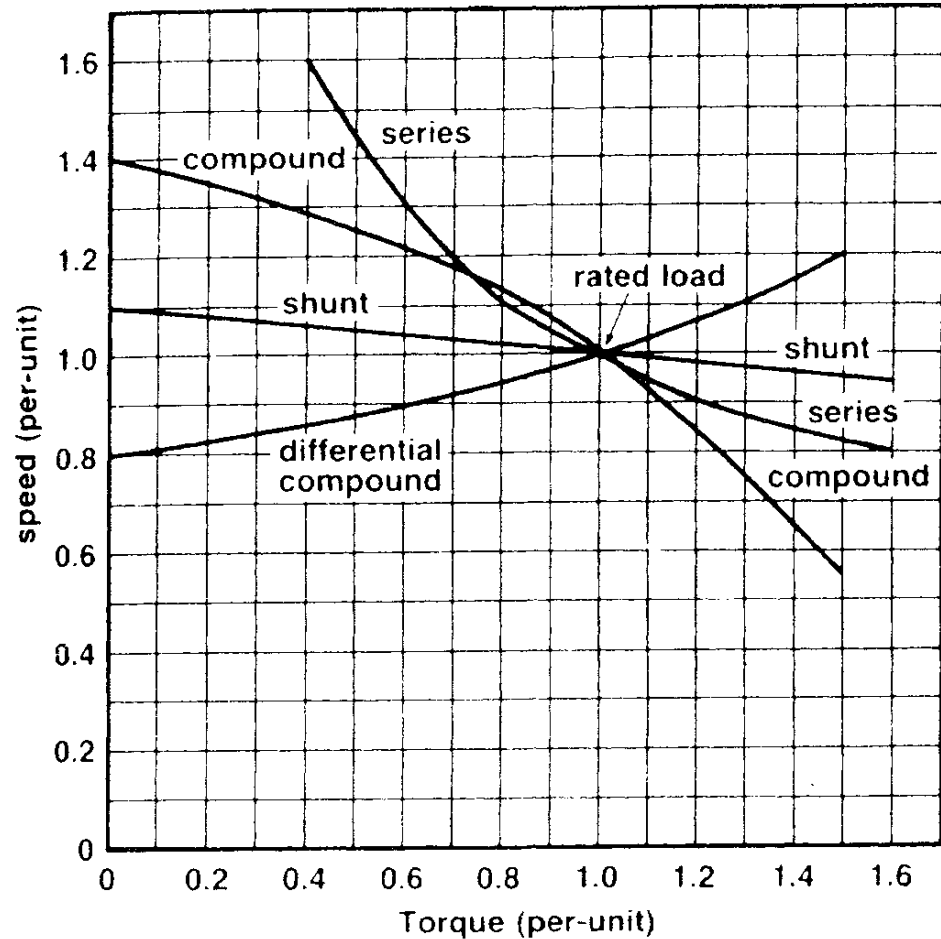
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COMPOUND MOTOR



Chapter 5

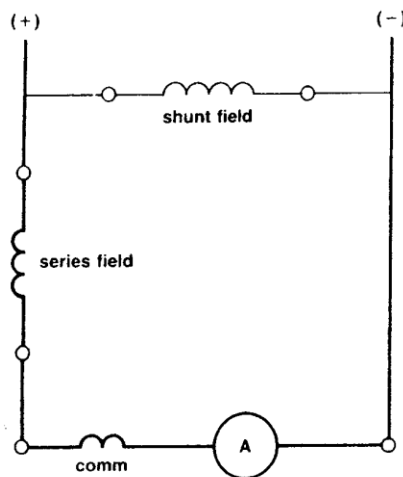
Speed Torque



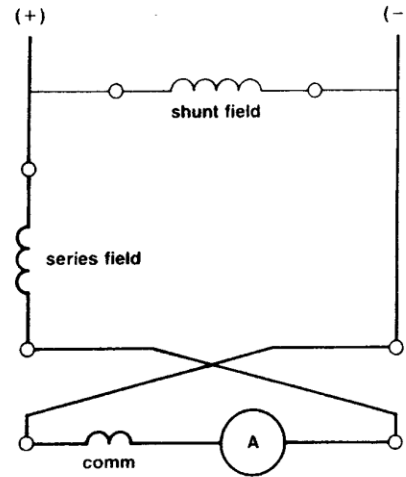
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Direction of Rotation – Reverse Armature or Field

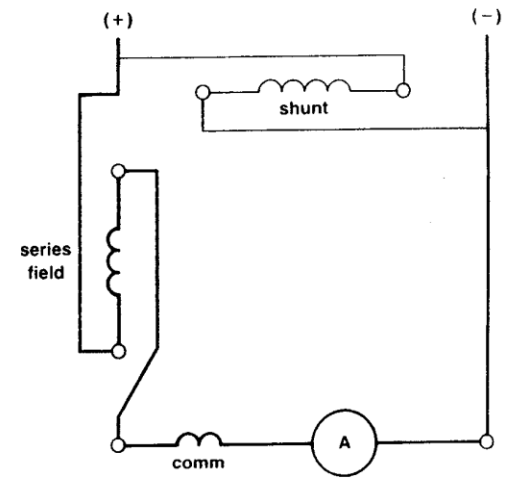
Commutation polarity associated with Armature polarity



(a)



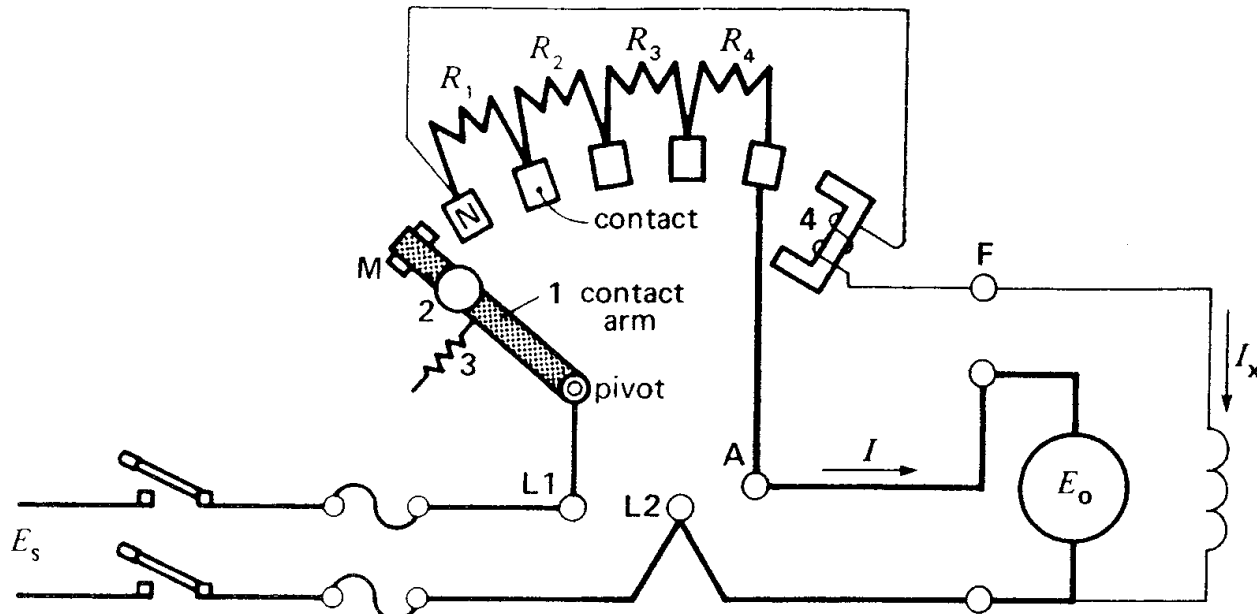
(b)



(c)

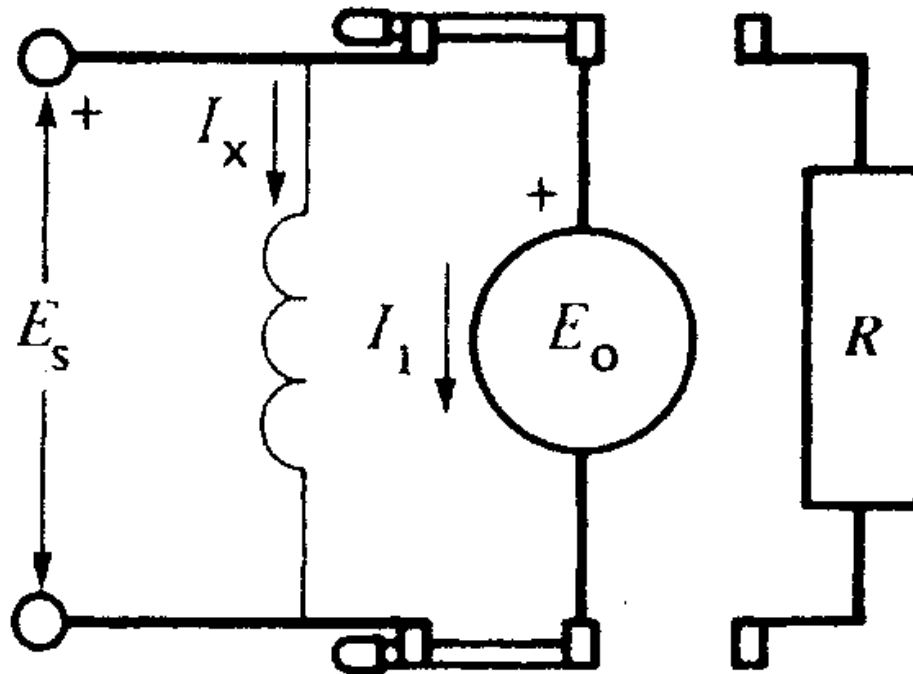
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Current limitation during start –
Rheostat or resistor, solid state RVS



Chapter 5

Dynamic Breaking –
Speed proportional to E_o



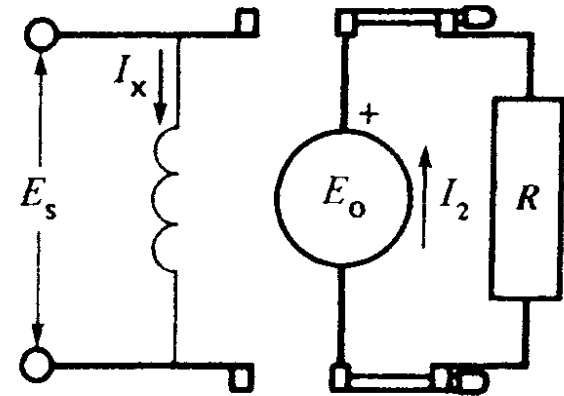
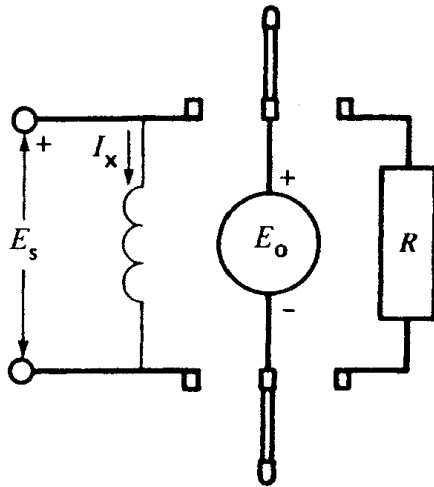
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Motor becomes generator (direction of I reverses)

– E_o dissipates into R

-Torque reversed

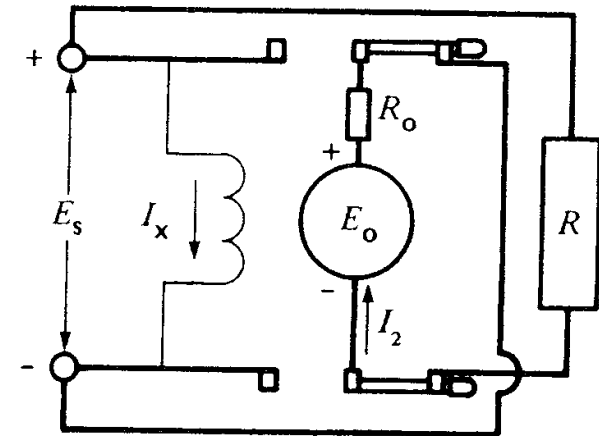
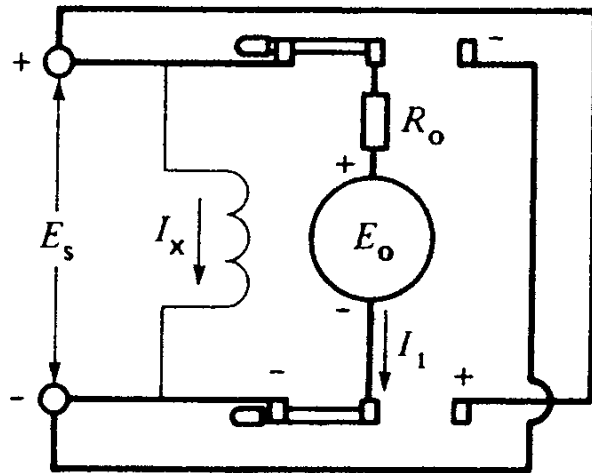
-Brings machine to quicker stop



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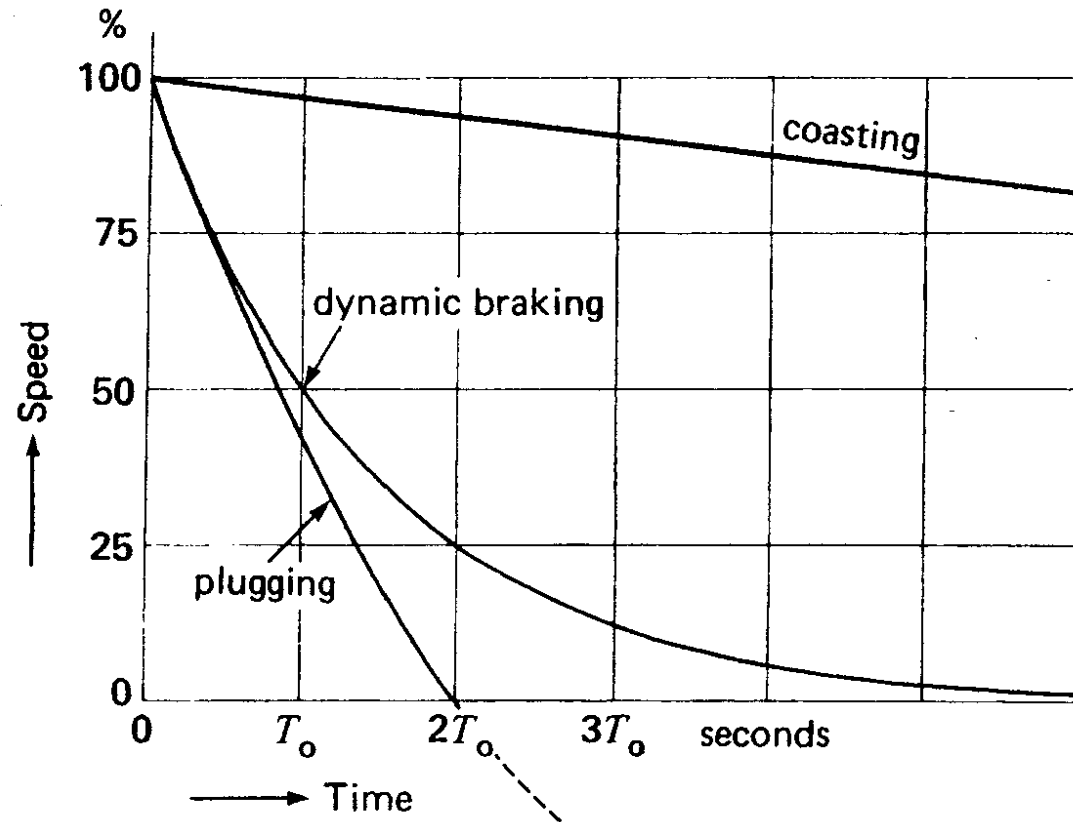
Plugging – I is reversed on motor – resistor
limit current

When motor stop, open circuit



Chapter 5

Comparison of Dynamic Braking vs Plugging



Chapter 5

Time Constant for Dynamic Breaking

T = time to reach 36.8% initial speed

T₀ = time to reach 50% speed

Excludes windage and friction effects

$$T_0 = 0.693 T = J n_1^2 / (131.5 P_1)$$

T₀ = time for the motor speed to fall to ½ previous value (s)

J = moment of inertia referred to motor shaft (kg m²)

n₁ = initial speed (rpm)

P₁ = initial power on brake resistor (W)

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Example 5-6

A 225kW, 250V, 1280 rpm dc motor has windage, friction, and iron losses of 8kw. It drives a large flywheel and the total moment of inertia of the flywheel and armature is 177 kg m². The motor is connected to a 210V dc source, and its speed is 1280 rpm just before the armature is switched across a braking resistor of 0.2 Ω . Calculate

- a. The mechanical time constant T_o of the braking system
- b. The time for the motor speed to drop to 20 rpm
- c. Time for speed to drop to 20 rpm if the only braking force is that due to windage, friction , and iron losses

Chapter 5

For Dynamic Brake t_s approx $5 * T_o$

For Plugging $\rightarrow t_s = 2 * T_o$

t_s = stopping time using plugging (s)

T_o = time constant

Example 5-7

The motor of example 5-6 is plugged and the braking resistor is increased to 0.4Ω so that the initial braking current is the same as before.

Calculate

- a. The initial braking current and braking power
- b. The stopping time

Chapter 5

Armature reaction

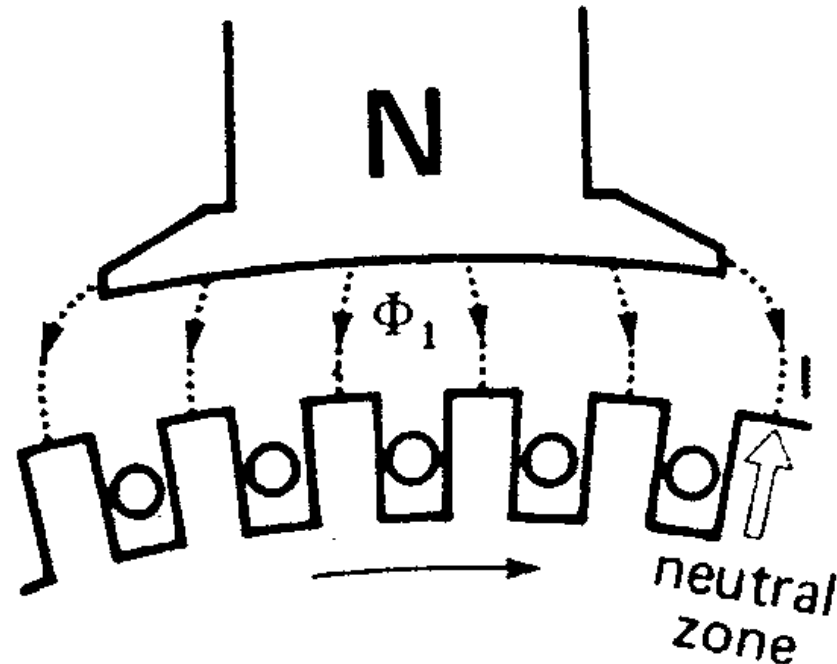
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Neutral shift &
Field weakening

$$\Phi_3 < \Phi_1$$

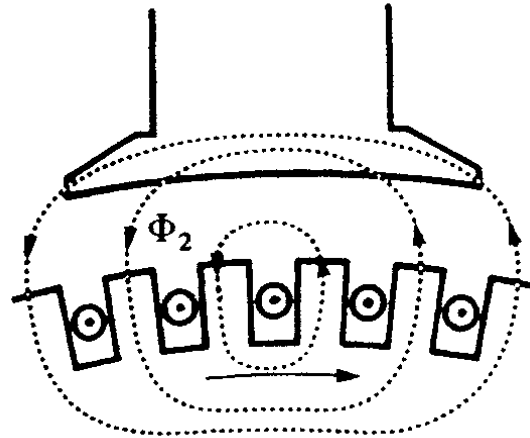
Commutating
Poles

No load flux
distribution

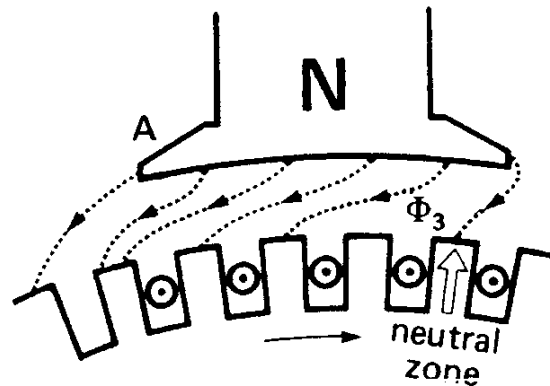


Chapter 5

Flux created by
armature current



Resulting flux



Chapter 5

Variable Speed Control – (use PU values)

From base speed & torque –

To reduce speed, reduce E_a (T remains constant)

“Constant Torque” region.

To raise speed, reduce Φ_F (T decreases but P constant)

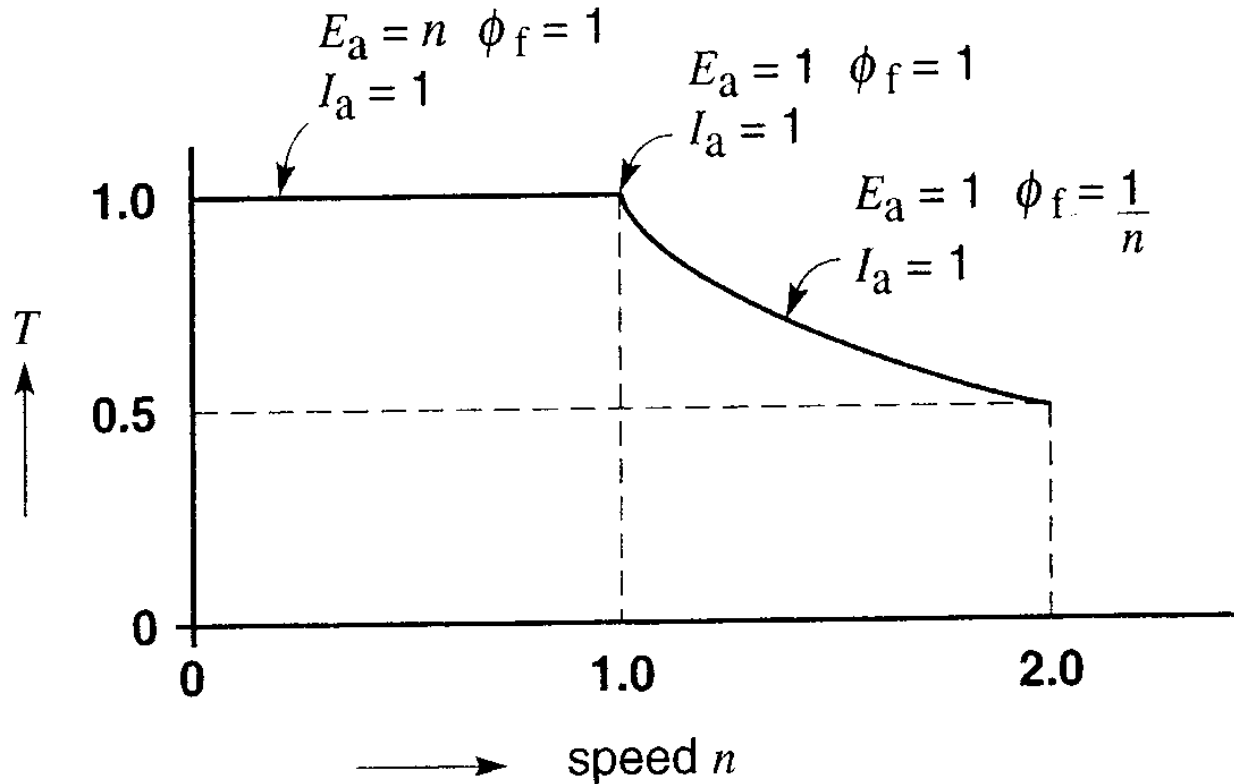
“constant HP” region. ($P \propto T * n$)

$$T = \Phi f I_a$$

$$E_a = n \Phi f$$

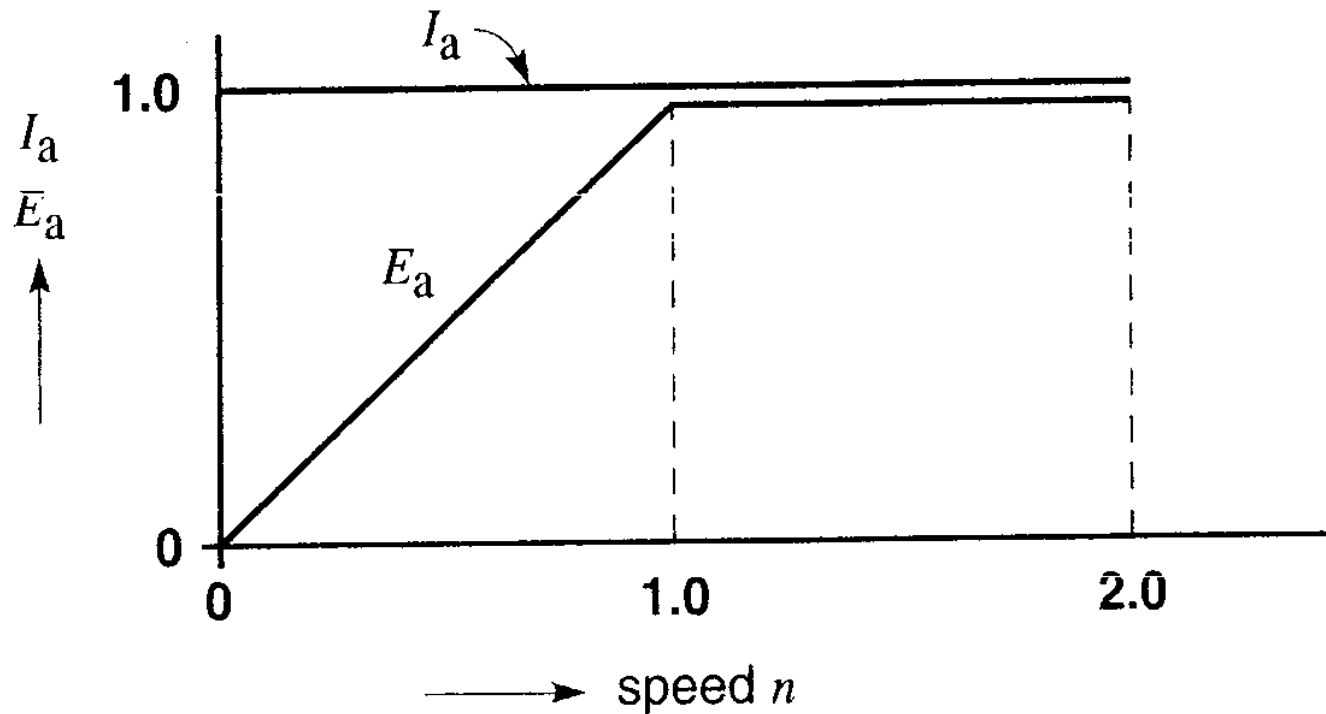
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Torque vs. Speed Curve



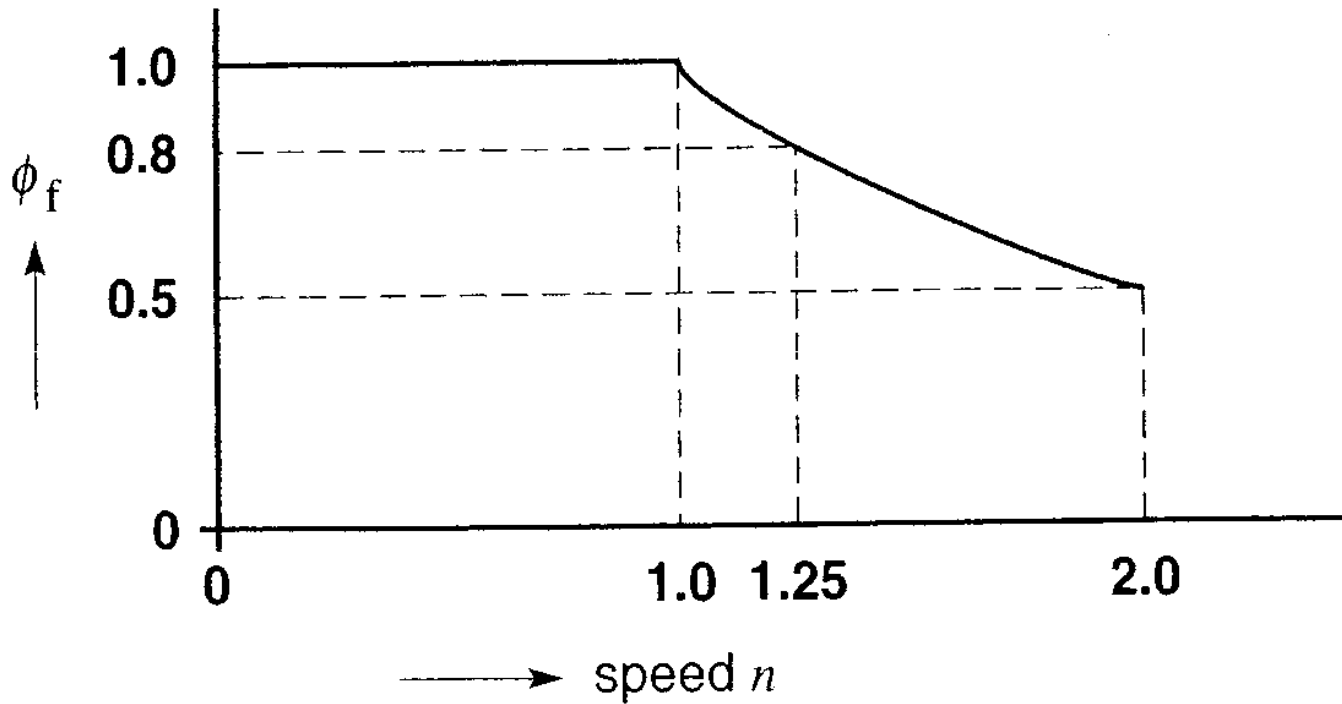
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Armature voltage & current vs speed curves



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Field flux vs speed curve

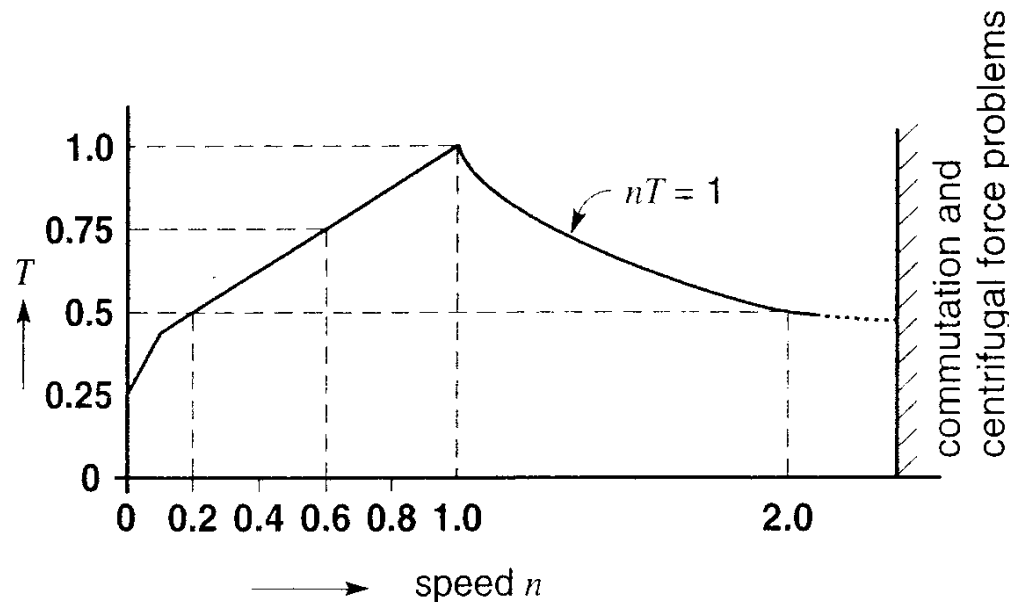


Chapter 5

Actual Torque vs Speed Curve –

Low speed cooling limitations

High speed commutation losses & centrifugal forces



Chapter 5

PM Motors – no separate excitation, no loss of field concern

Magnetic field does not distort like EM field.

High cost & lack of field speed control

Chapters 6 and 13 next session



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**End of Session 3:
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Spring 2011