Welcome to

# Electric Machines & Drives

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UNIVERSITY OF SOUTH FLORIDA POLYTECHNIC

**Session 3:**
**DC Motors**

**Fall 2011**

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## Session 3

- **Chapter 5 – DC Motors**



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## Chapter 5 – DC Motors



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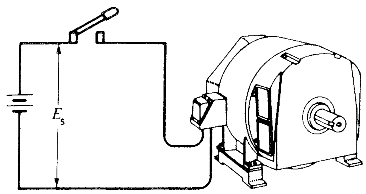
## Chapter 5 – DC Motors

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



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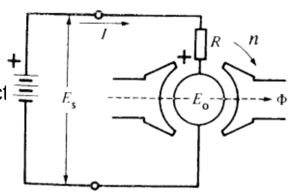
## Chapter 5

$E_O = Z\, n\, \Phi / 60$

$E_O$ proportional to speed
At rest $E_O = 0$
At steady state
$E_O = E_S - I*R$
EO = counter-elect
force (CEMF)



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## Chapter 5

Starting Current many times running current
Speed ceases to increase when
Tload = Tmotor

I = (Es – Eo) / R

I = Es / R (during start)

## Example 5-1

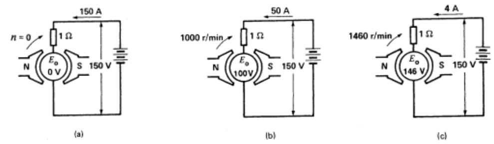
The armature of a permanent magnet DC generator has a resistance of 1 Ω and generates a voltage of 50V when the speed is 500 rpm. If the armature is connected to a source of 150V, calculate the following;

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



## Example 5-1

Solution






## Chapter 5

Mechanical Power & Torque

P = n T / 9.55 = Eo I

Eo = Z n Φ / 60

P = mechanical power developed by motor (W)
Eo = induced voltage in armature (cemf) (V)
I = total current suppied 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 |



## Chapter 5

Speed of Rotation – Proportional to Es and inversely proportional to flux (field current)
Bonus Question, what happens to DC motor on Loss of Field Current?

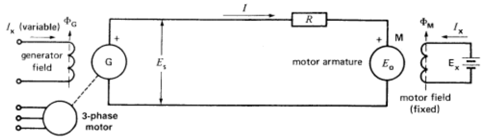
N = 60 Es / (Z Φ) [approximately]

N = speed of rotation (rpm)
Es = armature voltage (V)
Z = total number of armature conductors



## Chapter 5

Speed control from MG set – controlling ES
- controlling Ix
- 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 mΩ. The motor turns at a nominal speed of 300 rpm, when Eo is 500V. Calculate

a. The motor torque and speed when Es = 400V and Eo = 380V
b. The motor torque and speed when Es = 350V and Eo = 380V

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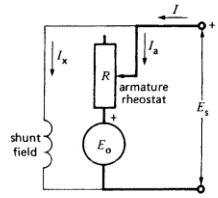
Rheostat allows control of EO -> speed control

Efficiency very poor

Small motors only.

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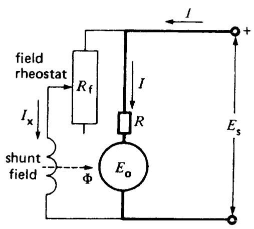
Speed control via field control
Flux increase -> speed decrease
Operate above base speed

(a)

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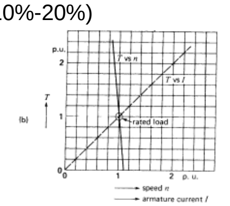
As load increases, Tload increases, causing armature current to increase causing speed to drop
Speed regulation good (10%-20%)

(b)

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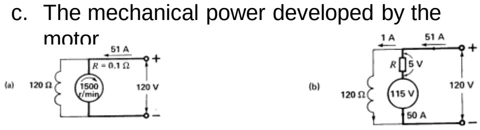
## Example 5-4

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 Ω. If the armature resistance is 0.1Ω, calculate the following;

a. The current in the armature
b. The counter emf
c. The mechanical power developed by the motor

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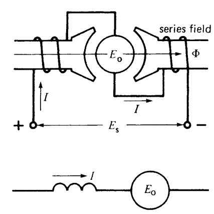
Series Motor – Different torque speed characteristic

Starting torque higher

Reduction in load = reduced flux = higher speed

Bonus Question – what happens if load removed?

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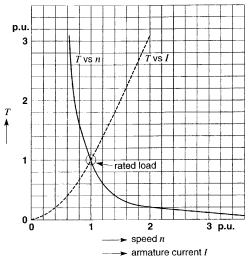
## Chapter 5

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

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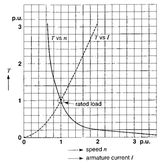
## Example 5-5

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

a. The current and speed when the load torque is 24 N m
b. 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

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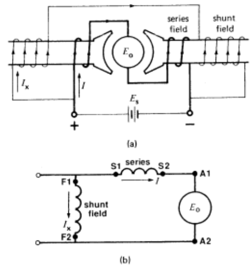


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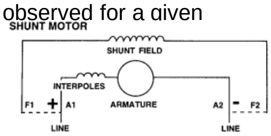
## Chapter 5

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.

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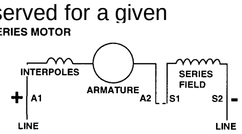


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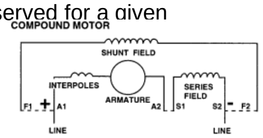
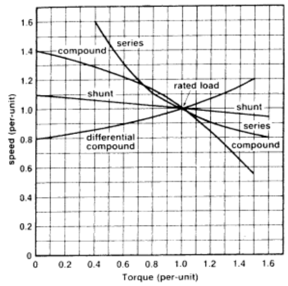





## Chapter 5

Speed Torque

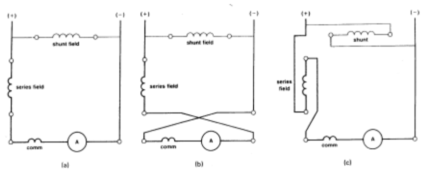





## Chapter 5

Direction of Rotation – Reverse Armature or Field

Commutation polarity associated with Armature polarity





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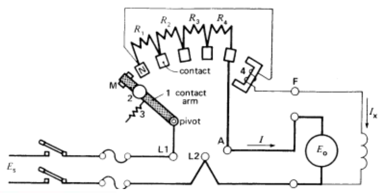
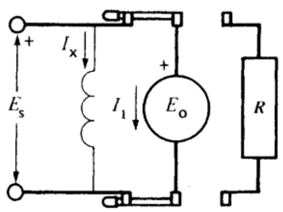
Current limitation during start –
Rheostat or resistor, solid state RVS






## Chapter 5

Dynamic Breaking –
Speed proportional to $E_O$



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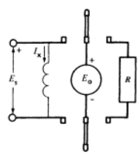
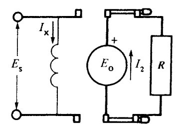
Motor becomes generator (direction of I reverses) – $E_O$ dissipates into R

-Torque reversed

-Brings machine to quicker stop





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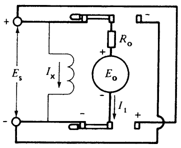
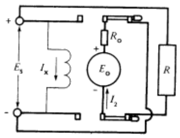
Plugging – I is reversed on motor – resistor limit current
When motor stop, open circuit



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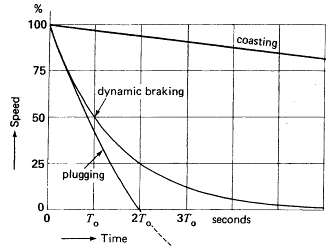
Comparison of Dynamic Breaking vs Plugging






## Chapter 5

Time Constant for Dynamic Breaking
T = time to reach 36.8% initial speed
TO = time to reach 50% speed
Excludes windage and friction effects

$To = 0.693\ T = J\ n1^2 / (131.5\ P1)$

To = time for the motor speed to fall to ½ previous value (s)
J = moment of inertia referred to motor shaft (kg $m^2$)
n1 = initial speed (rpm)
P1 = initial power on brake resistor (W)



## 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 $m^2$. 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 To 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 -> $t_S$ = 2 * $T_O$

$t_S$ = stopping time using plugging (s)
To = time constant



## Example 5-7

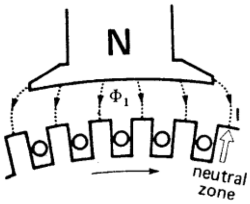
The motor of example 5-6 is plugged and the braking resistor is increased to 0.4 Ω so that the initial braking current is the same as before. Calculate

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

## Chapter 5

Armature reaction
–
Neutral shift &
Field weakening
$\Phi_3 < \Phi_1$
Commutating
Poles

No load flux
distribution

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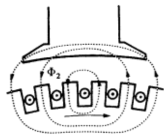
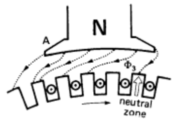
## Chapter 5

Flux created by
armature current




Resulting flux

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## Chapter 5

Variable Speed Control – (use PU values)
From base speed & torque –
To reduce speed, reduce Ea (T remains constant)
“Constant Torque” region.
To raise speed, reduce $\Phi_F$ (T decreases but P constant)
“constant HP” region. ($P \propto T * n$)

$T = \Phi f\ Ia$ $\qquad$ $Ea = n\ \Phi f$

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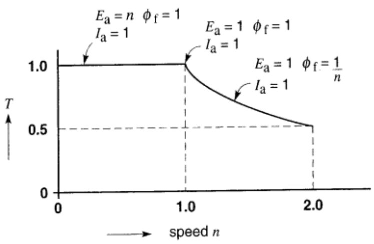
## Chapter 5

Torque vs. Speed Curve

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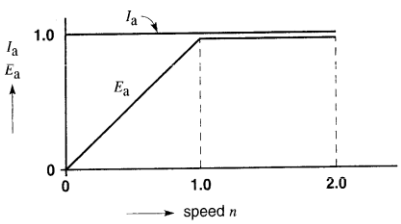
## Chapter 5

Armature voltage & current vs speed curves

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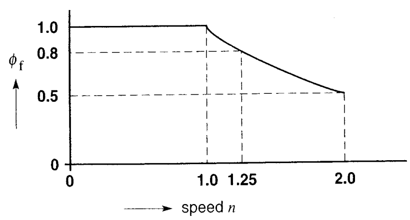
Field flux vs speed curve

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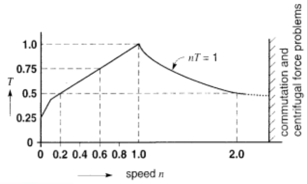
## Chapter 5

Actual Torque vs Speed Curve –
Low speed cooling limitations
High speed commutation losses & centrifugal forces

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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

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## Chapters 6 and 13 next session

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**End of Session 3: DC Motors**

**Spring 2011**