DC Motor

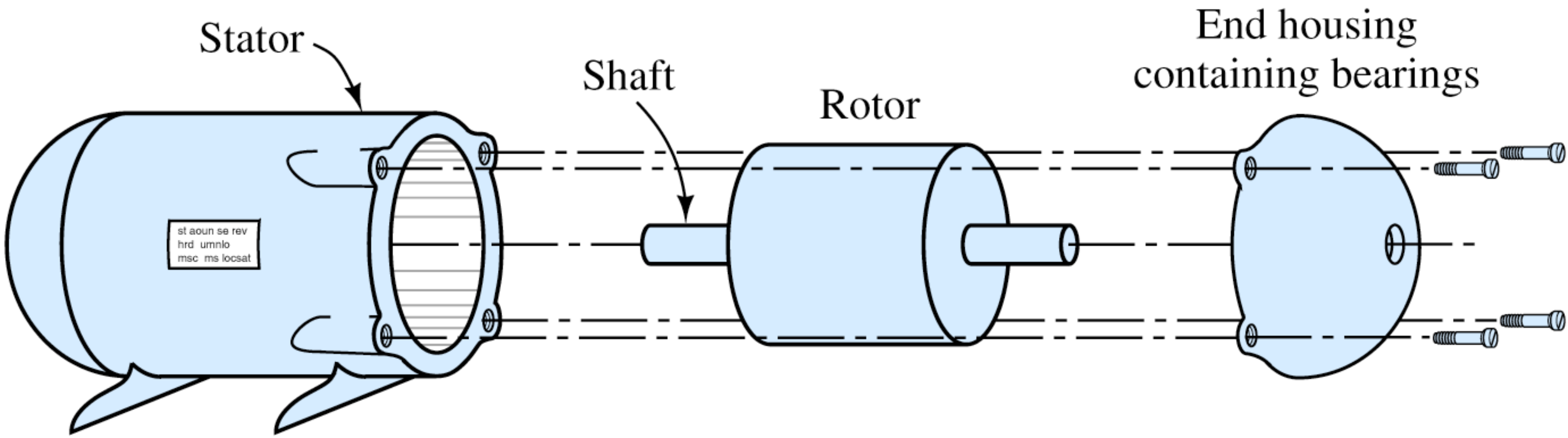


Figure 16.1 An electrical motor consists of a cylindrical rotor that spins inside a stator.

A Two Pole DC Motor

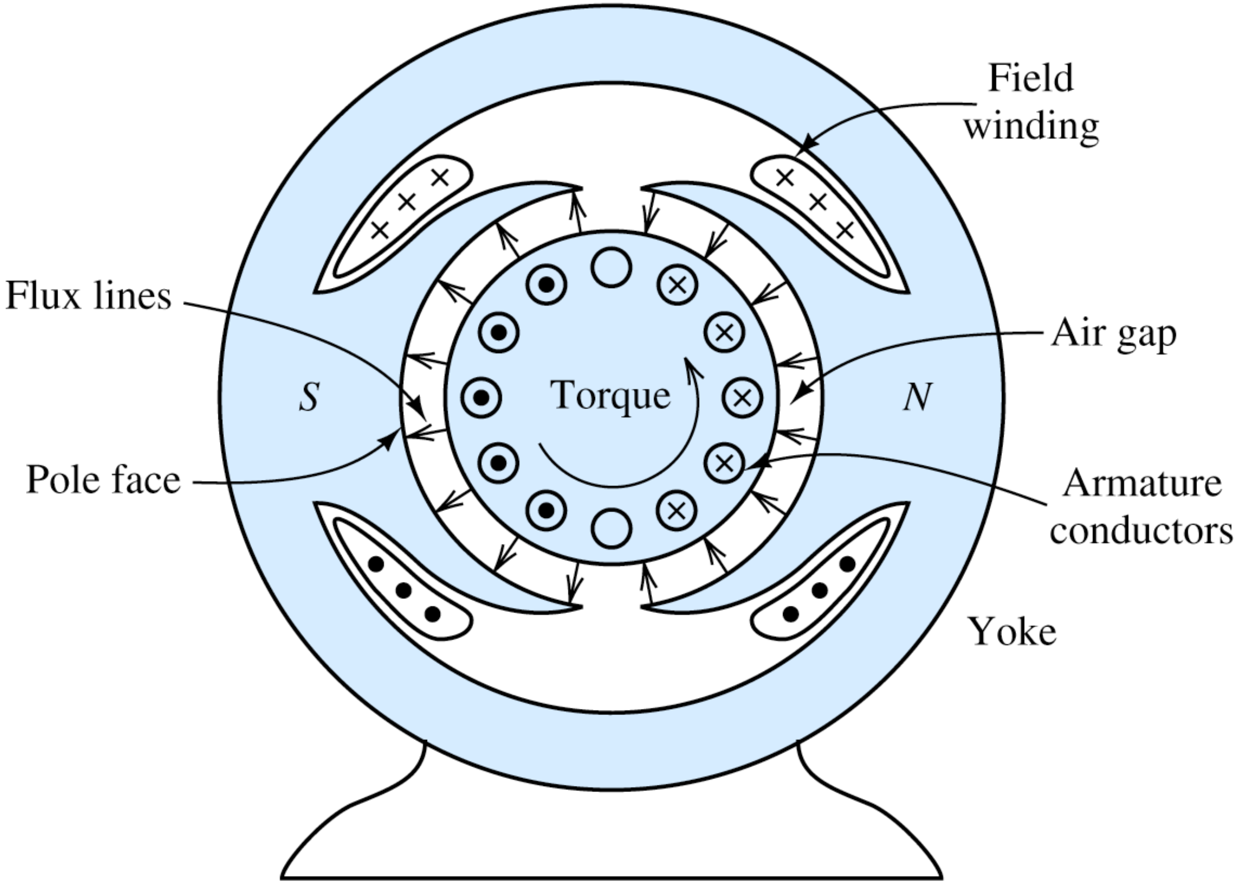


Figure 16.10 Cross section of a two-pole dc machine.

A Four Pole DC Motor

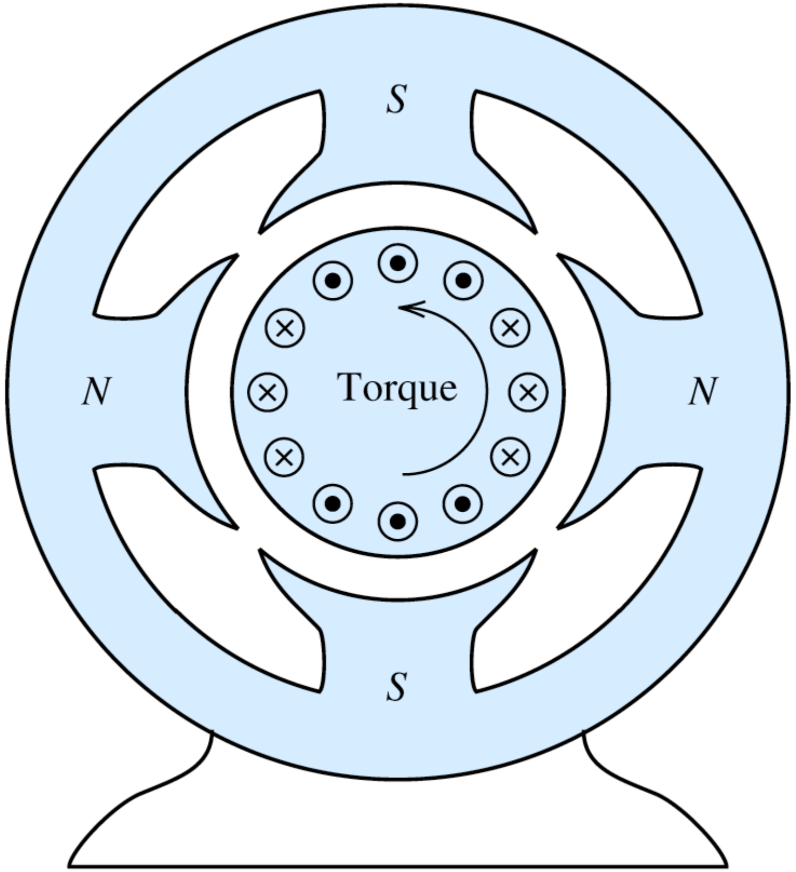


Figure 16.11 Cross section of a four-pole dc machine.

Operating Principle of a DC Machine

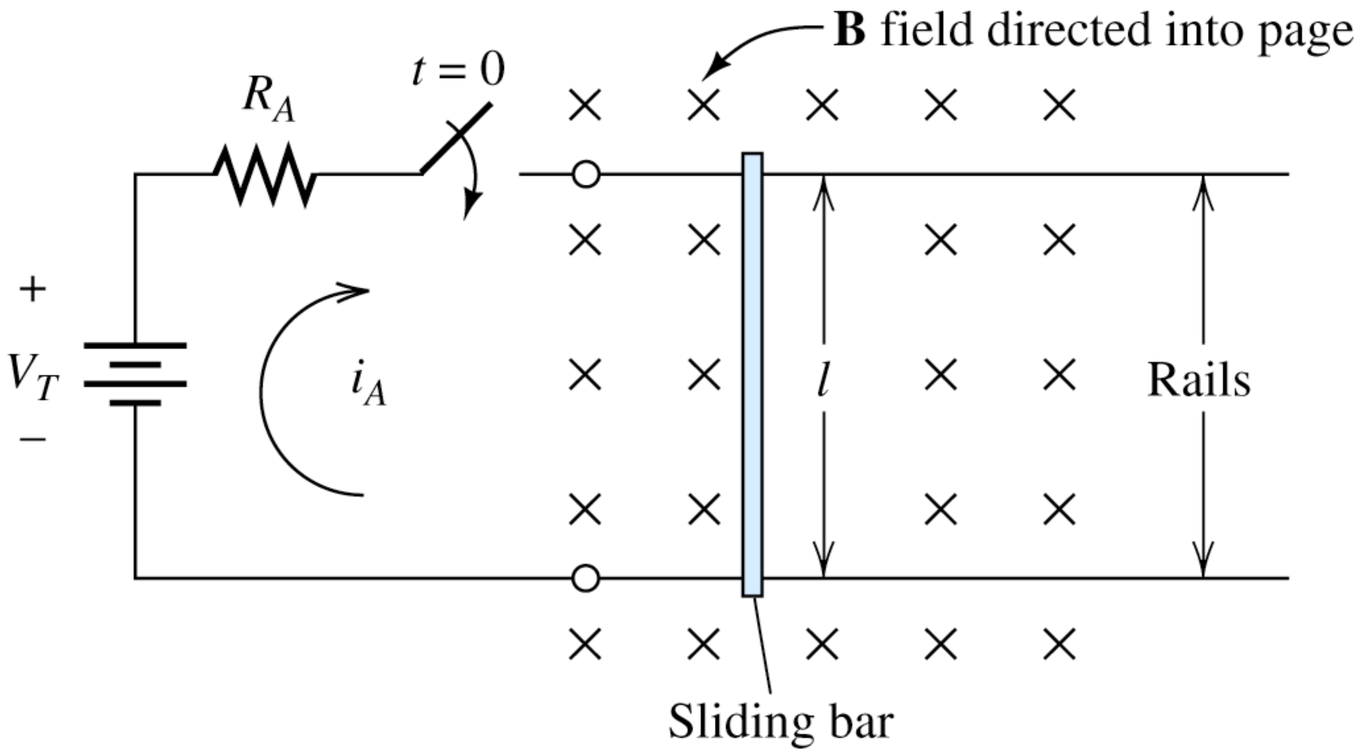
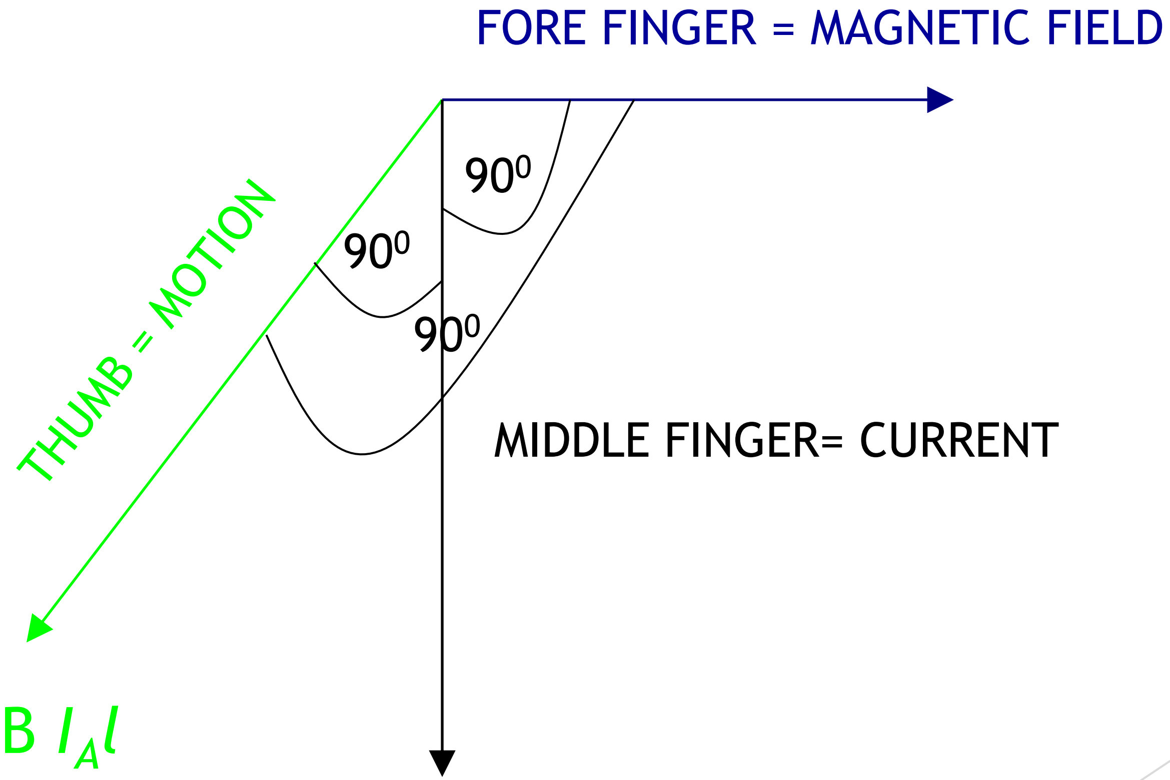


Figure 16.6 A simple dc machine consisting of a conducting bar sliding on conducting rails.

Fleming's Left Hand Rule Or Motor Rule



FORE FINGER = MAGNETIC FIELD

90^0

90^0

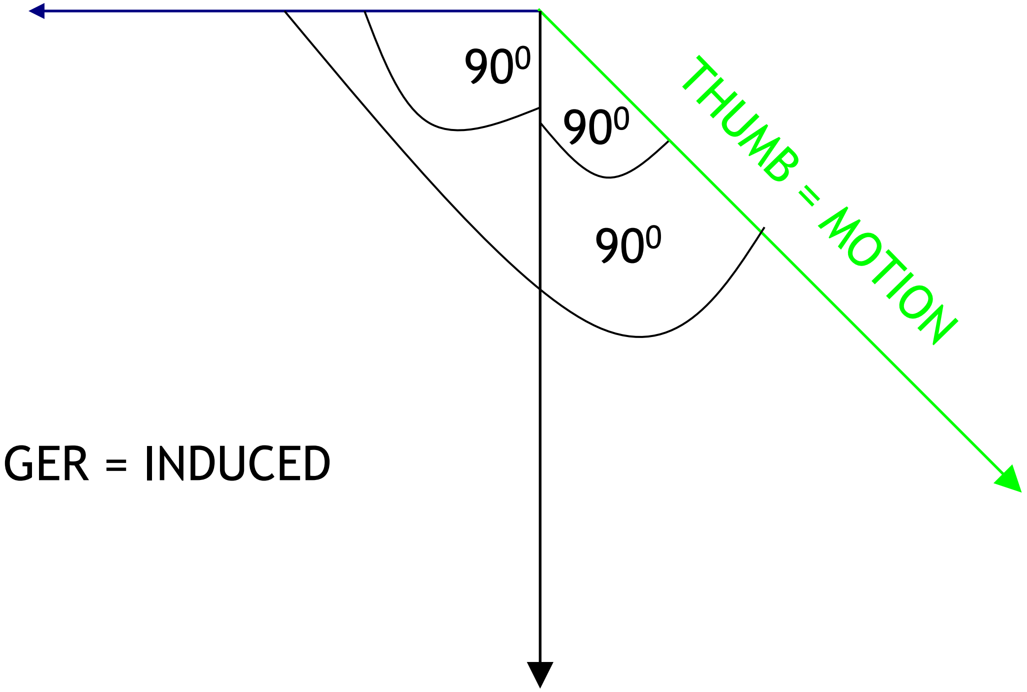
90^0

THUMB = MOTION

MIDDLE FINGER= CURRENT

FORCE = B $I_A l$

Fleming’s Right Hand Rule Or Generator Rule



FORE FINGER = MAGNETIC FIELD

THUMB = MOTION

MIDDLE FINGER = INDUCED VOLTAGE

VOLTAGE = $B\ l\ u$

Action of a Commutator

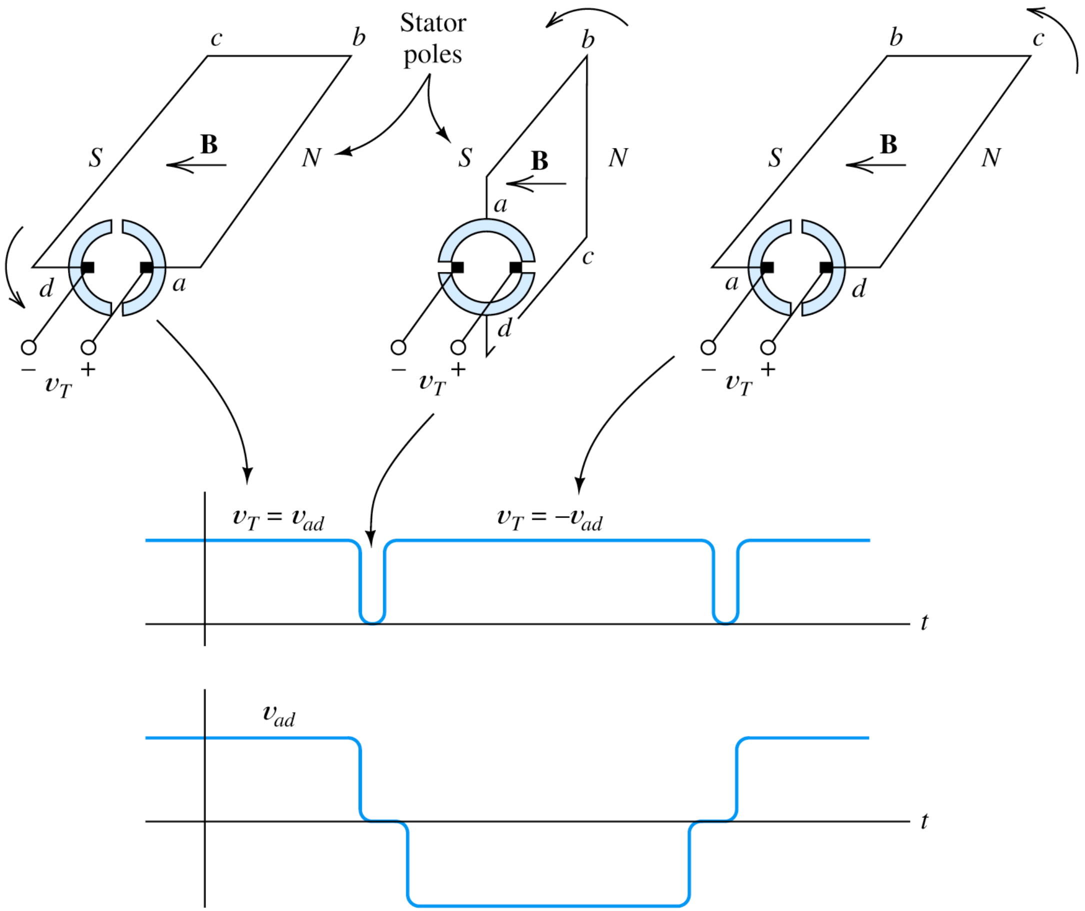


Figure 16.12 Commutation for a single armature winding.

Armature of a DC Motor

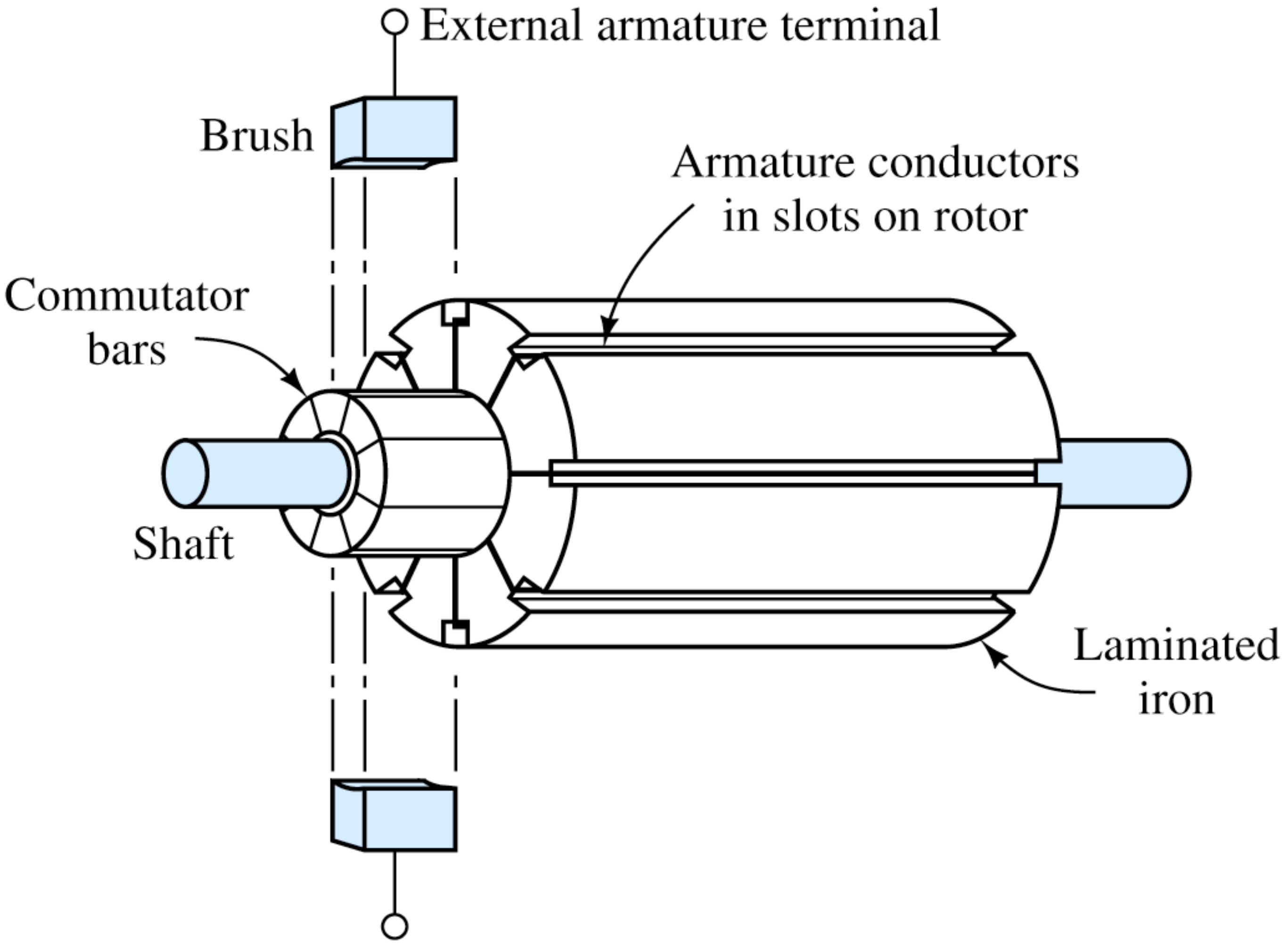


Figure 16.9 Rotor assembly of a dc machine.

Generated Voltage in a DC Machine

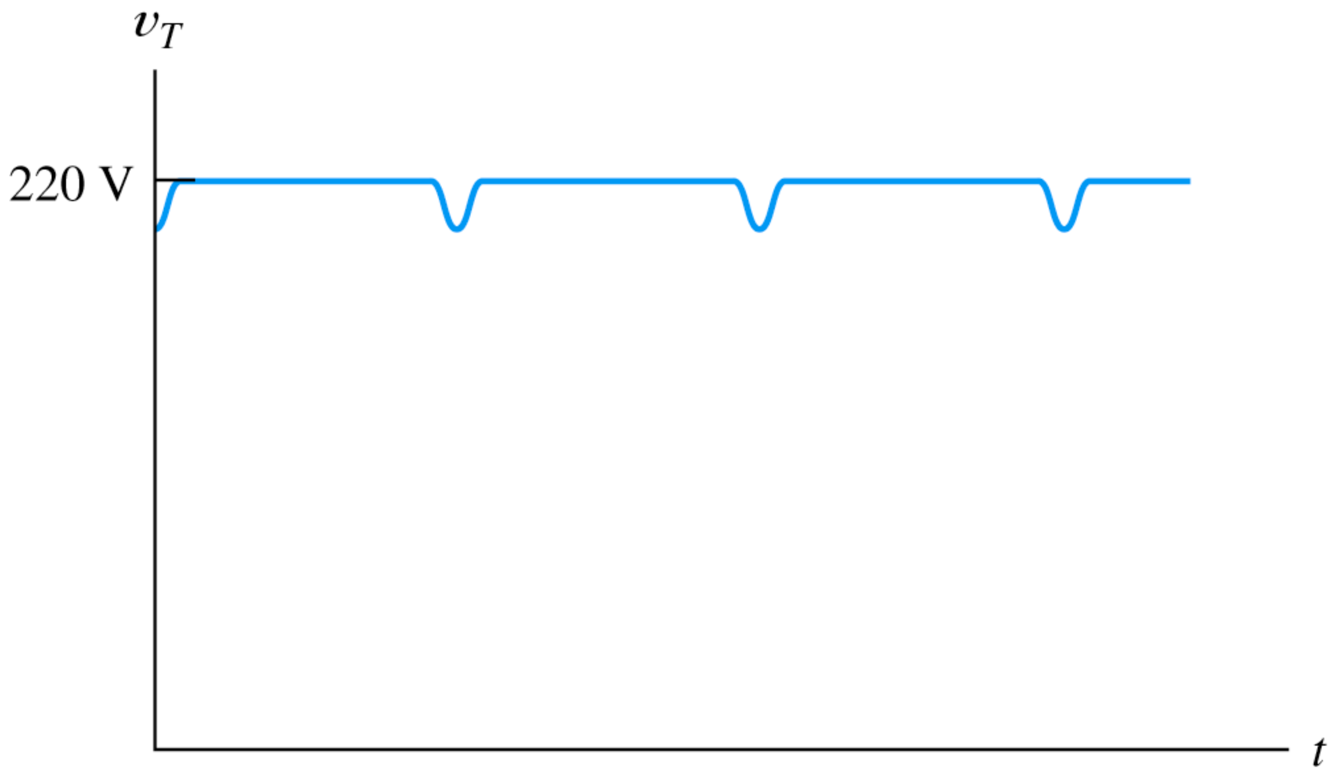


Figure 16.13 Voltage produced by a practical dc machine. Because only a few (out of many) conductors are commutated (switched) at a time, the voltage fluctuations are less pronounced than in the single-loop case illustrated in Figure 16.12.

Armature Winding in a DC Machine

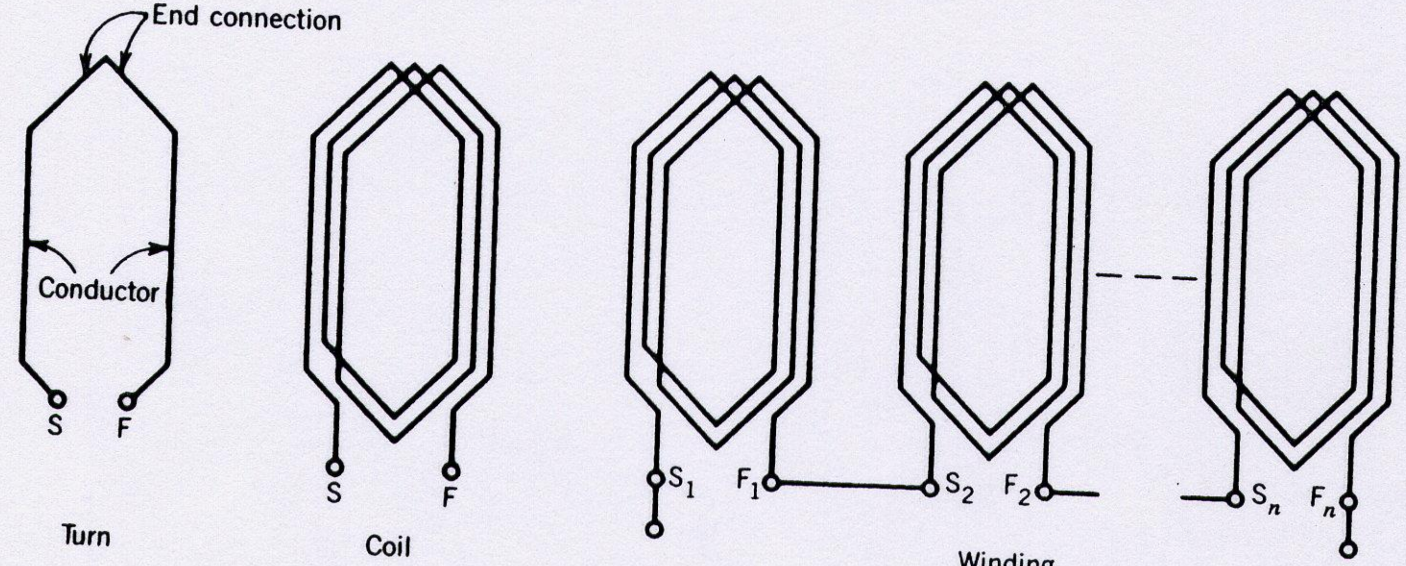


FIGURE 4.15 Turn, coil, and winding.

Lap Winding of a DC Machine

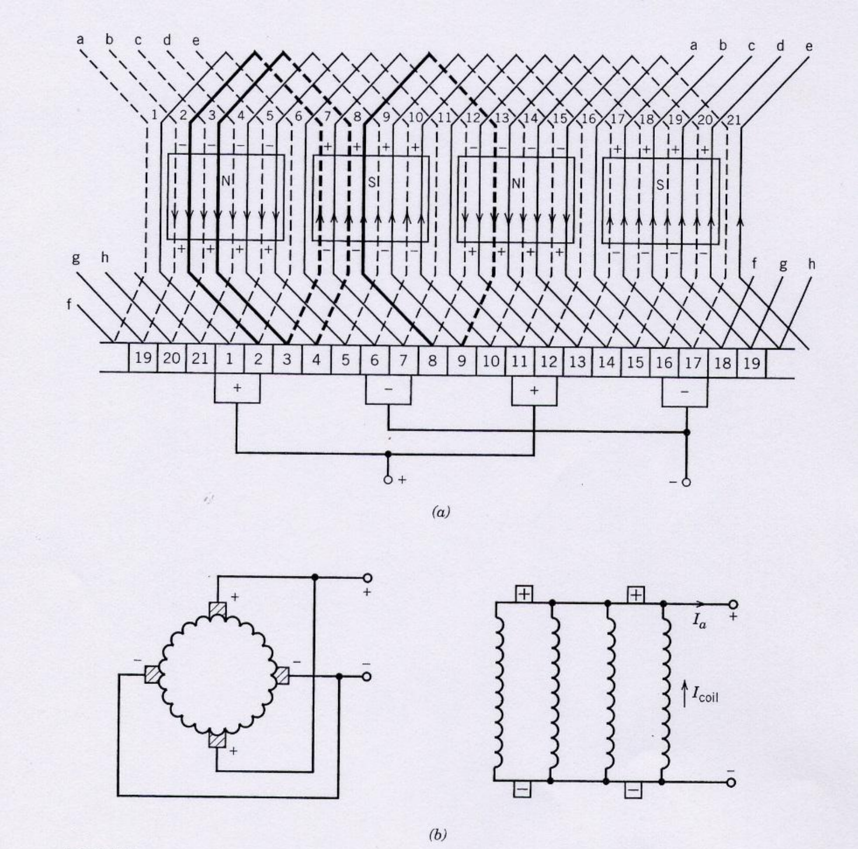


FIGURE 4.17 Lap winding. (*a*) Unrolled winding. (*b*) Equivalent coil representation.

- Used in high current low voltage circuits
- Number of parallel paths equals number of brushes or poles

Wave Winding of a DC Machine

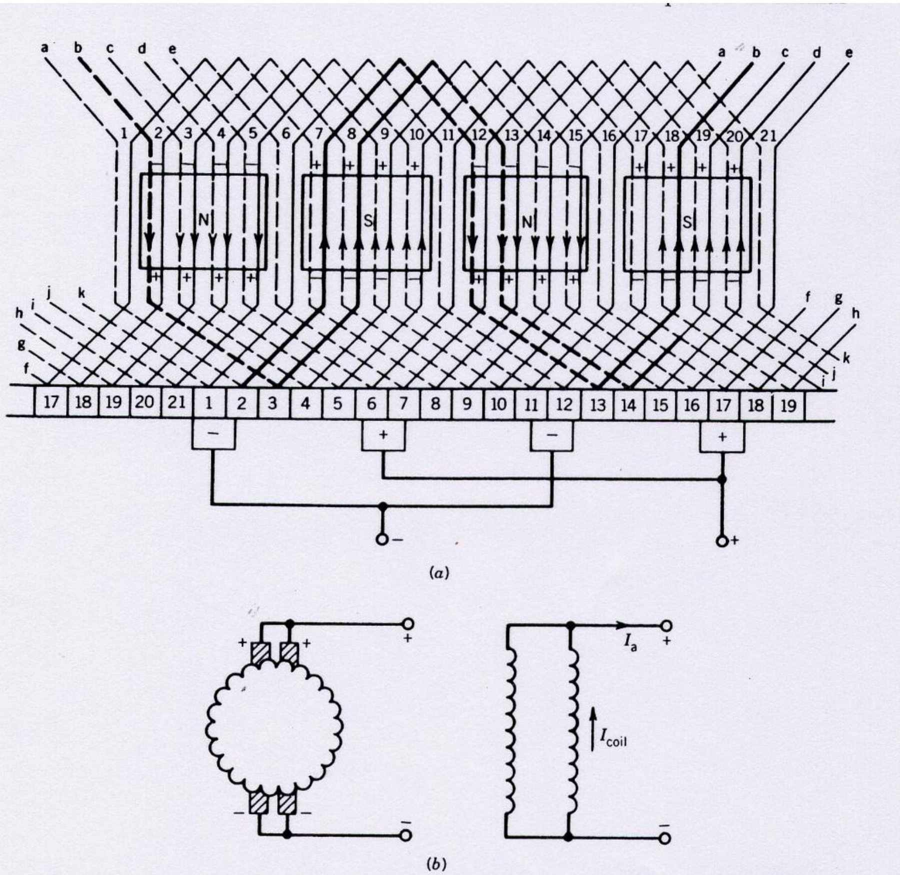
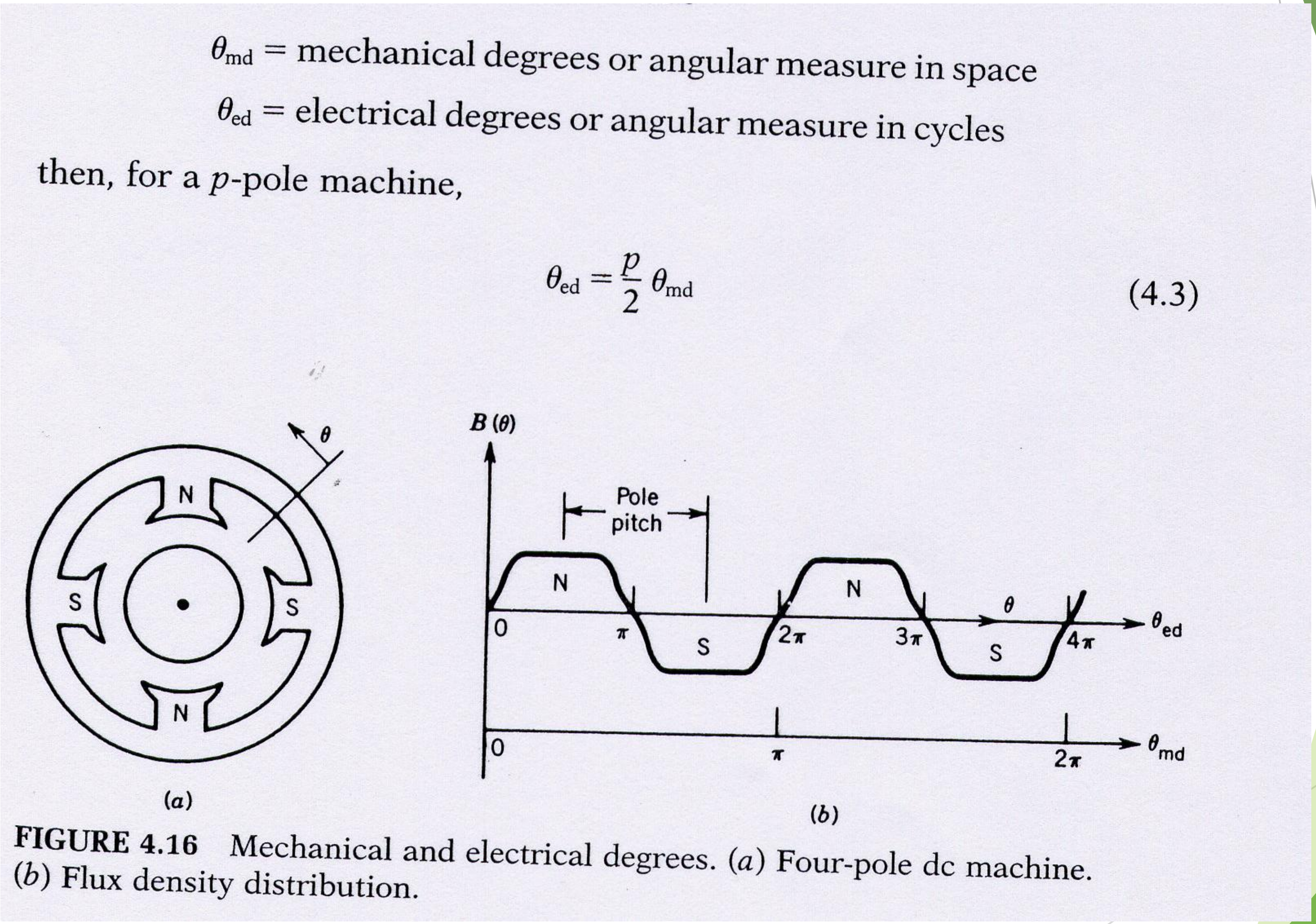


FIGURE 4.18 Wave winding. (*a*) Unrolled winding. (*b*) Equivalent coil representation.

- Used in high voltage low current circuits

- Number of parallel paths always equals 2

Magnetic circuit of a 4 pole DC Machine



θ_{md} = mechanical degrees or angular measure in space

θ_{ed} = electrical degrees or angular measure in cycles

then, for a *p*-pole machine,

$$\theta_{ed} = \frac{p}{2}\theta_{md} \tag{4.3}$$

FIGURE 4.16 Mechanical and electrical degrees. (*a*) Four-pole dc machine. (*b*) Flux density distribution.

Magnetic circuit of a 2 pole DC Machine

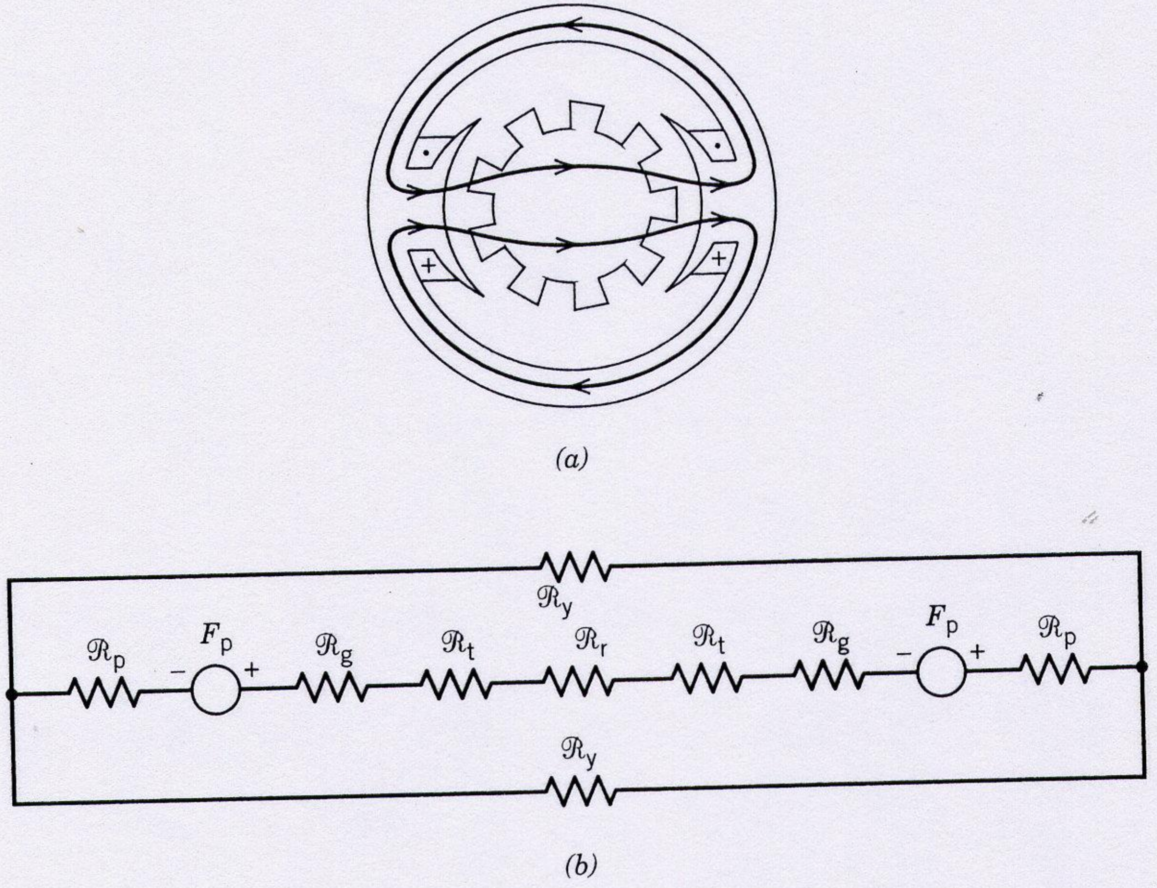


FIGURE 4.21 Magnetic circuit. (*a*) Cross-sectional view. (*b*) Equivalent circuit.

Summary of a DC Machine

- Basically consists of

1. An electromagnetic or permanent magnetic structure called field which is static
2. An Armature which rotates

- The Field produces a magnetic medium
- The Armature produces voltage and torque under the action of the magnetic field

Deriving the induced voltage in a DC Machine

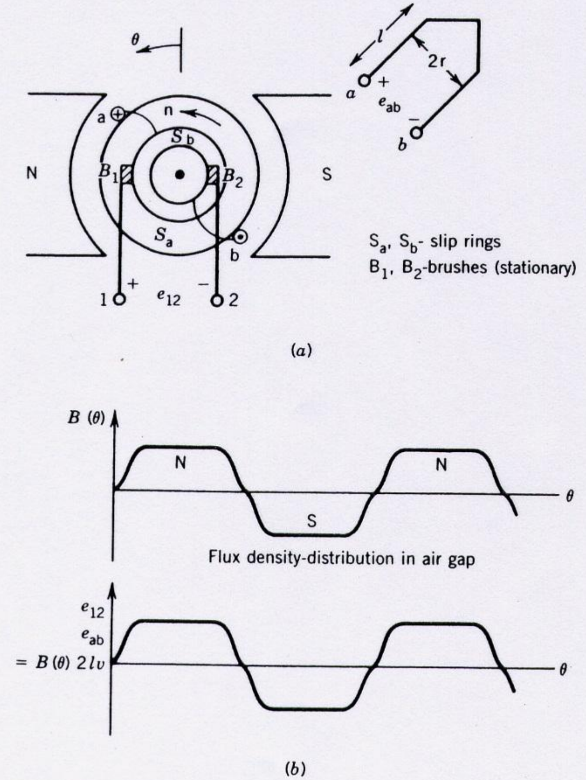


FIGURE 4.12 Induced voltage in a dc machine. (*a*) Two-pole dc machine. (*b*) Induced voltage in a turn.

Deriving the electromagnetic torque in a DC Machine

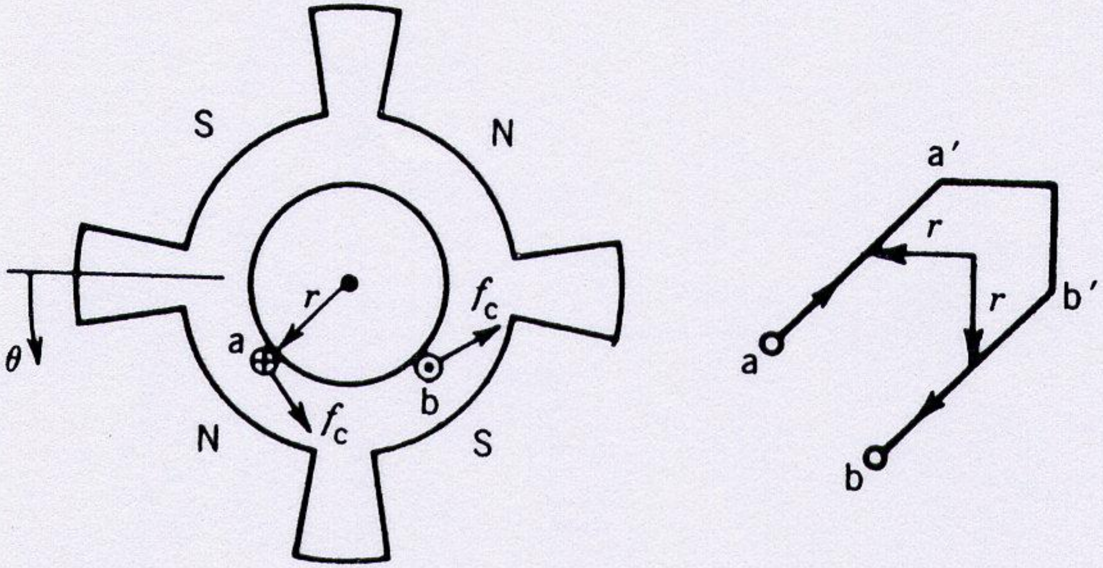


FIGURE 4.19 Torque production in dc machine.

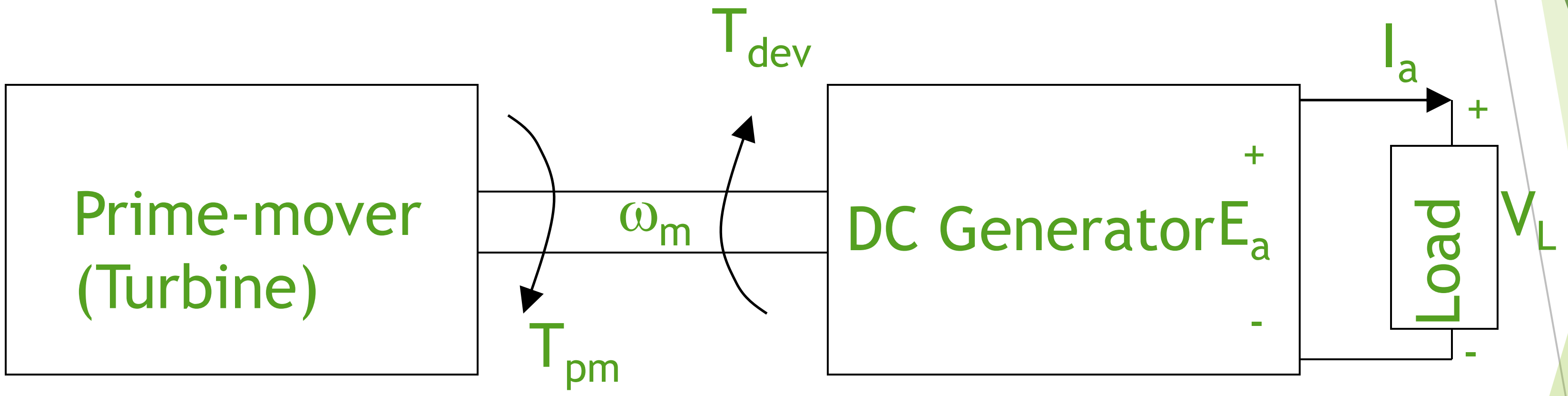
Voltage and Torque developed in a DC Machine

- Induced EMF, $E_a = K_a \Phi \omega_m$ (volts)

- Developed Torque, $T_{dev} = K_a \Phi I_a$ (Newton-meter or Nm)

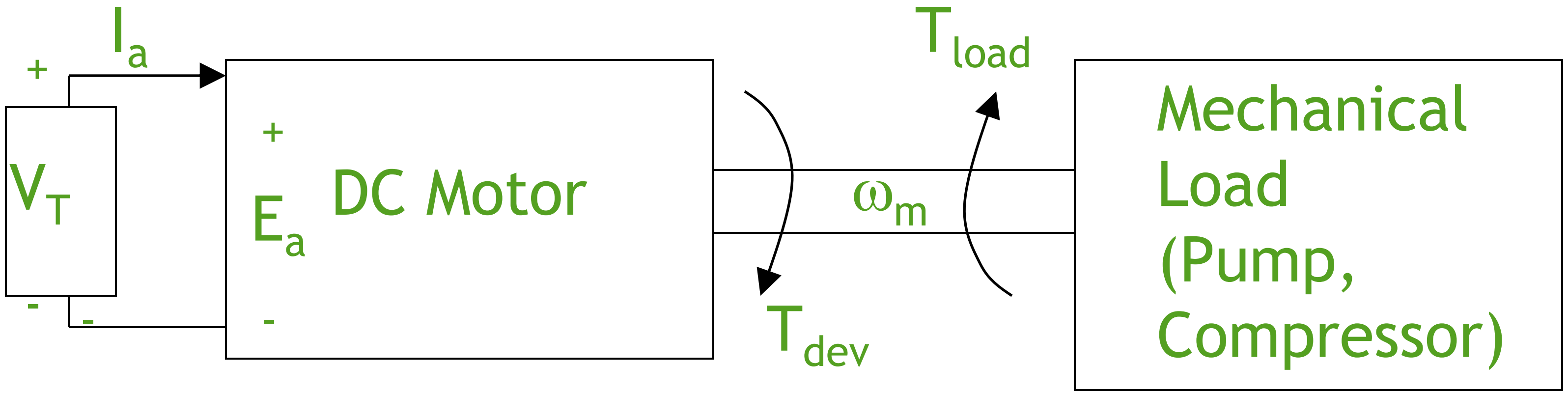
where ω_m is the speed of the armature in rad/sec., Φ is the flux per pole in weber (Wb)
I_a is the Armature current
K_a is the machine constant

Interaction of Prime-mover DC Generator and Load



E_a is Generated voltage
V_L is Load voltage
T_{pm} is the Torque generated by Prime Mover
T_{dev} is the opposing generator torque

Interaction of the DC Motor and Mechanical Load



E_a is Back EMF
V_T is Applied voltage
T_{dev} is the Torque developed by DC Motor
T_{load} is the opposing load torque

Power Developed in a DC Machine

Neglecting Losses,

- *Input mechanical power* to dc generator

$= T_{dev}\,\omega_m = K_a\Phi I_a\omega_m = E_a\,I_a$

= *Output electric power* to load

- *Input electrical power* to dc motor

$= E_a\,I_a = K_a\Phi\,\omega_m\,I_a = T_{dev}\,\omega_m$

= *Output mechanical power* to load

Equivalence of motor and generator

- In every generator there is a motor (T_{dev} opposes T_{pm})
- In every motor there is a generator (E_a opposes V_T)

Example of winding specific motor and generator

Worked out on greenboard

Magnetization Curve

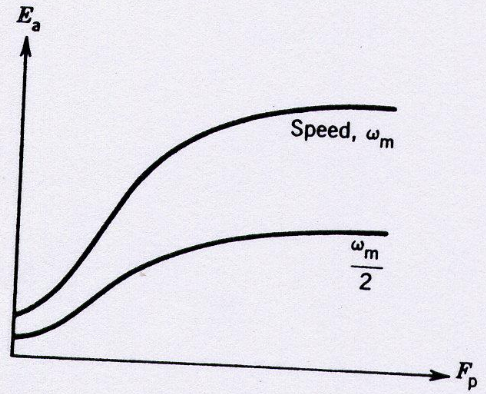


FIGURE 4.23 Magnetization curve.

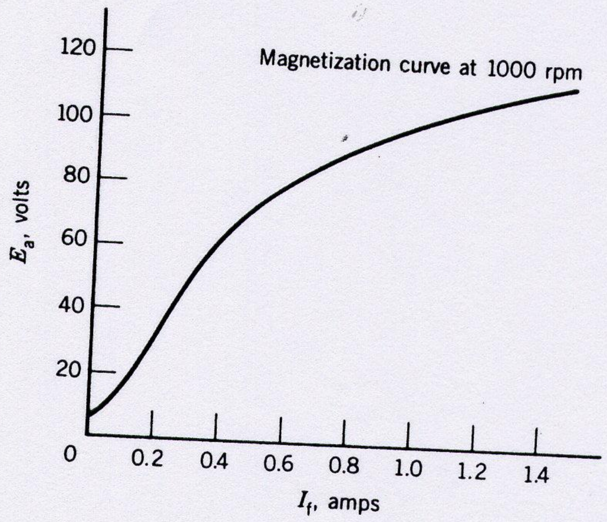


FIGURE 4.24 Test result: magnetization curve.

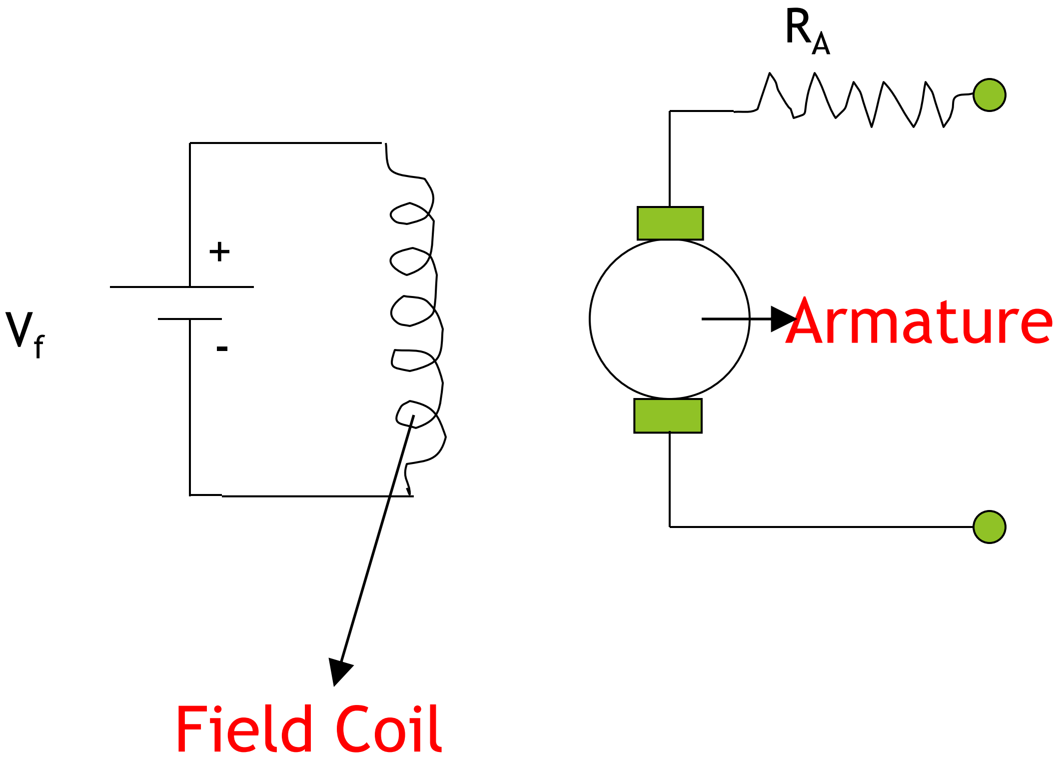
$$E_a = K_a \Phi \omega_m$$

- Flux is a non-linear function of field current and

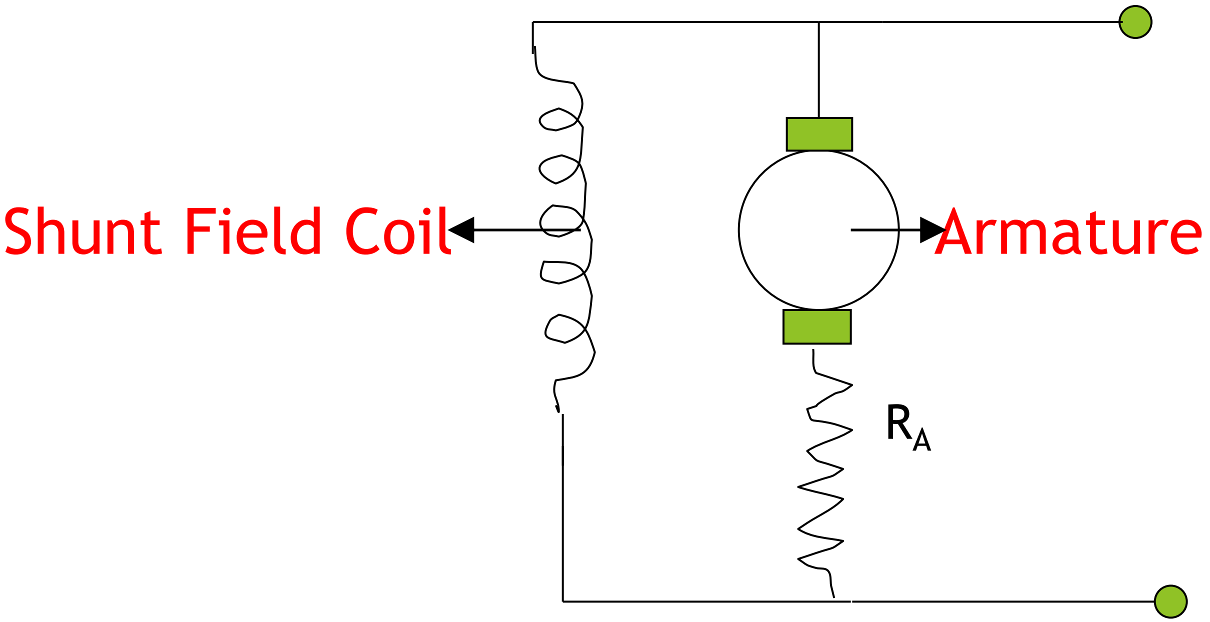
  hence E_a is a non-linear function of field current

- For a given value of flux E_a is directly proportional to ω_m

Separately Excited DC Machine

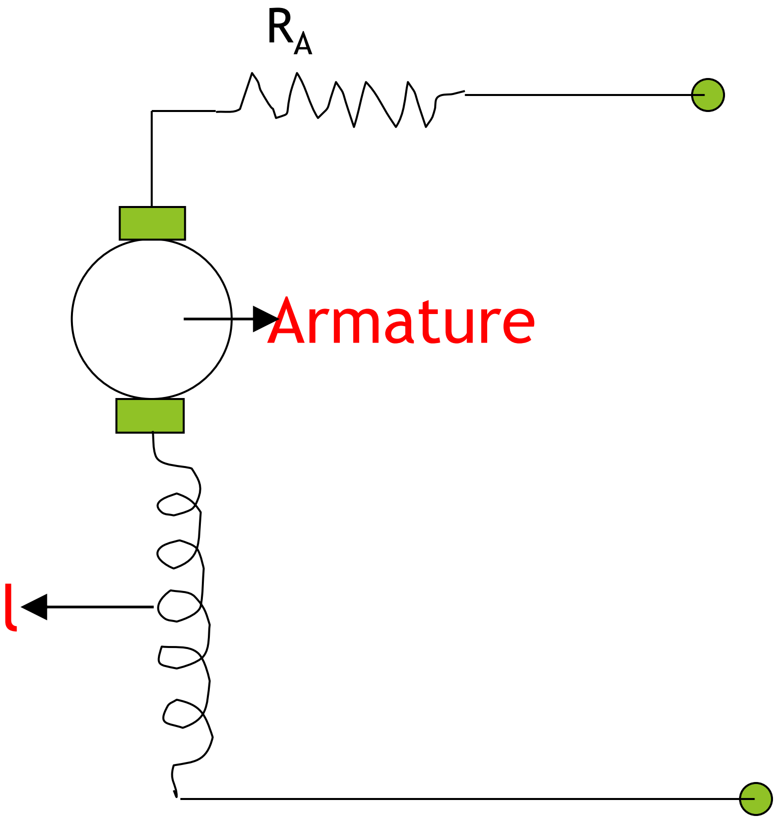


Shunt Excited DC Machine


Shunt Field Coil

Armature

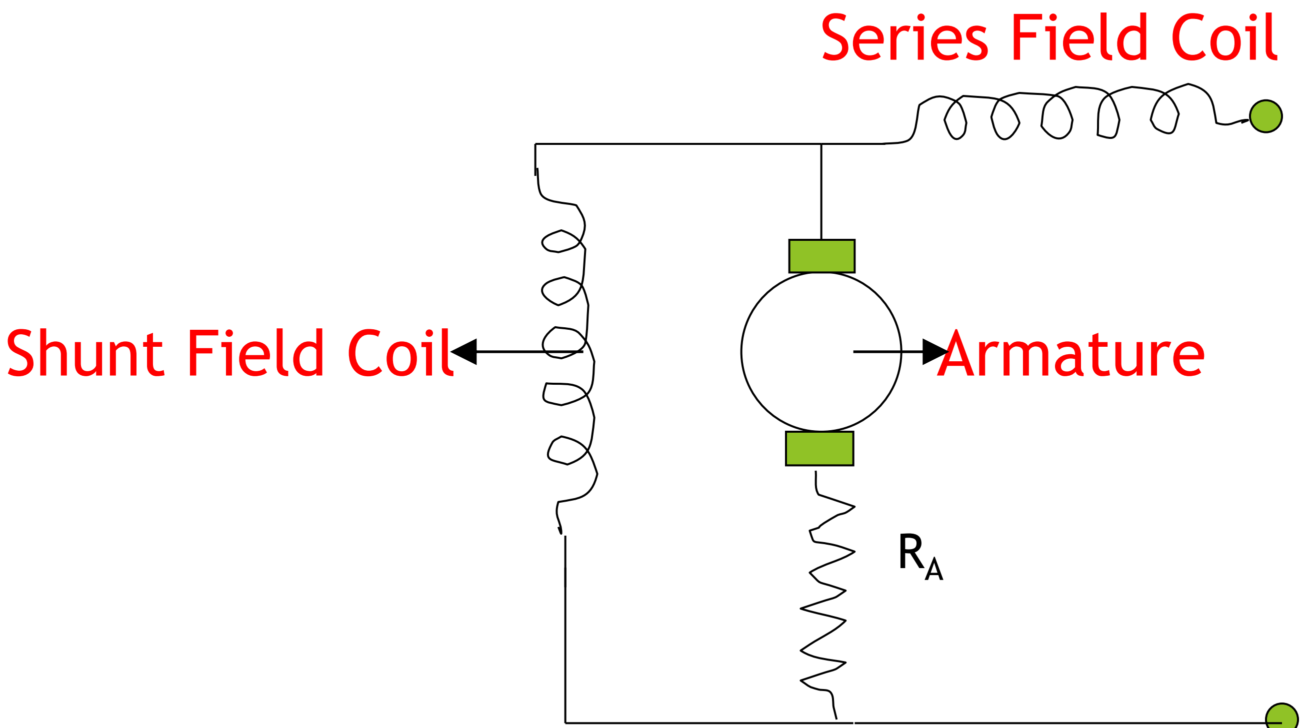
Series Excited DC Machine



Armature

Series Field Coil

Compound Excited DC Machine



- If the shunt and series field aid each other it is called a cumulatively excited machine
- If the shunt and series field oppose each other it is called a differentially excited machine

Armature Reaction(AR)

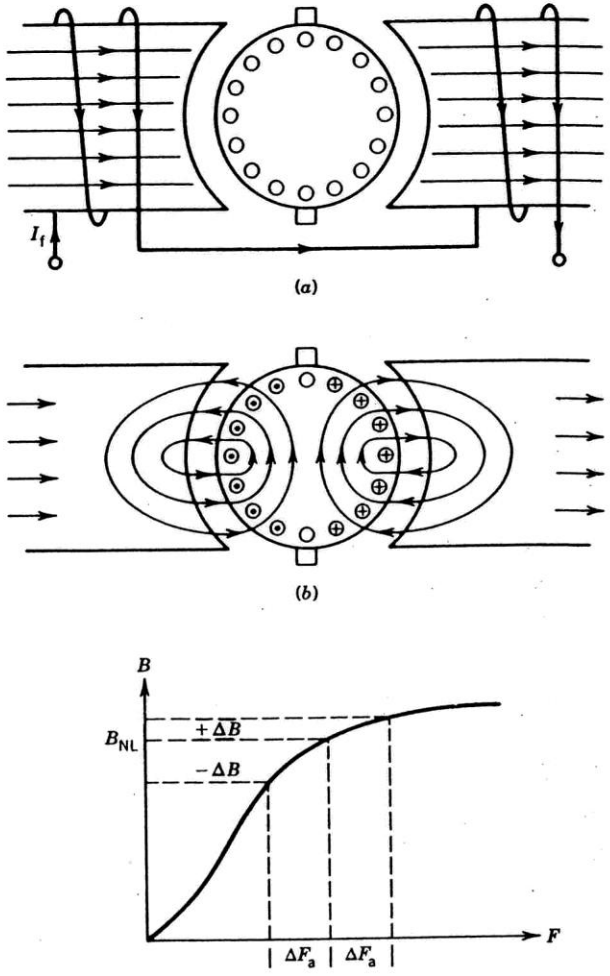


FIGURE 4.30 Armature reaction effects.

- AR is the magnetic field produced by the armature current

- AR aids the main flux in one half of the pole and opposes the main flux in the other half of the pole

- However due to saturation of the pole faces the net effect of AR is demagnetizing

Effects of Armature Reaction

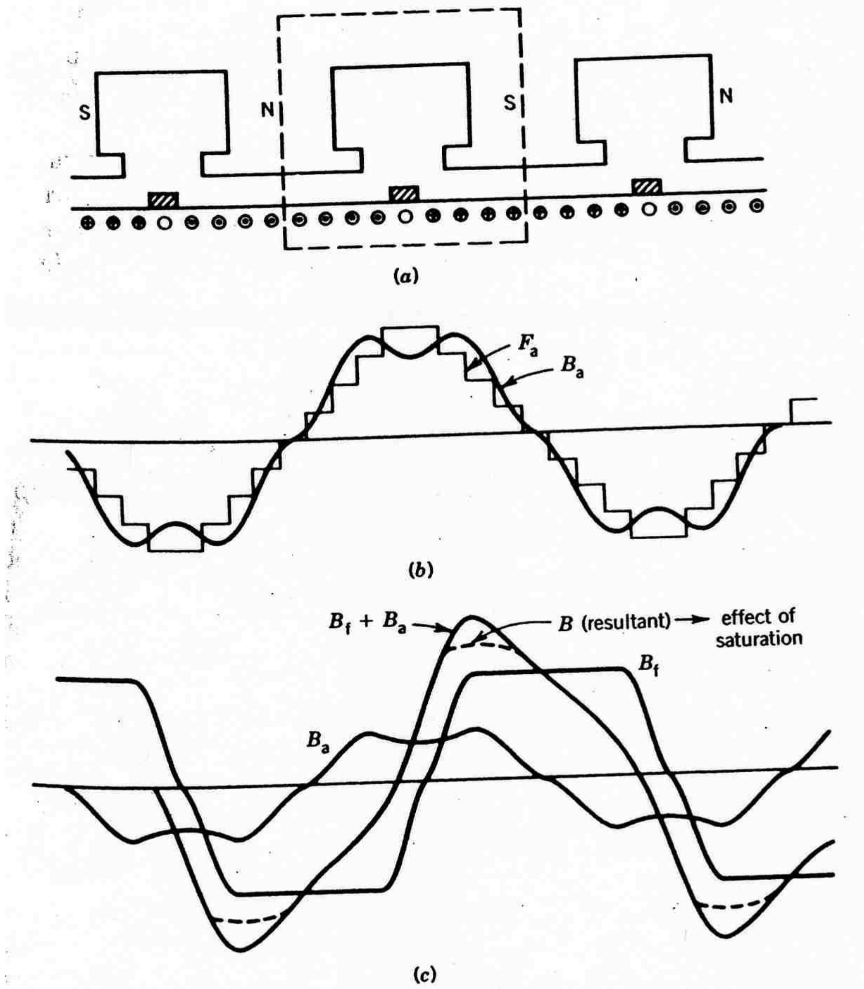


FIGURE 4.31 MMF and flux density distribution.

- The magnetic axis of the AR is 90^0 electrical (cross) out-of-phase with the main flux. This causes commutation problems as zero of the flux axis is changed from the interpolar position.

Minimizing Armature Reaction

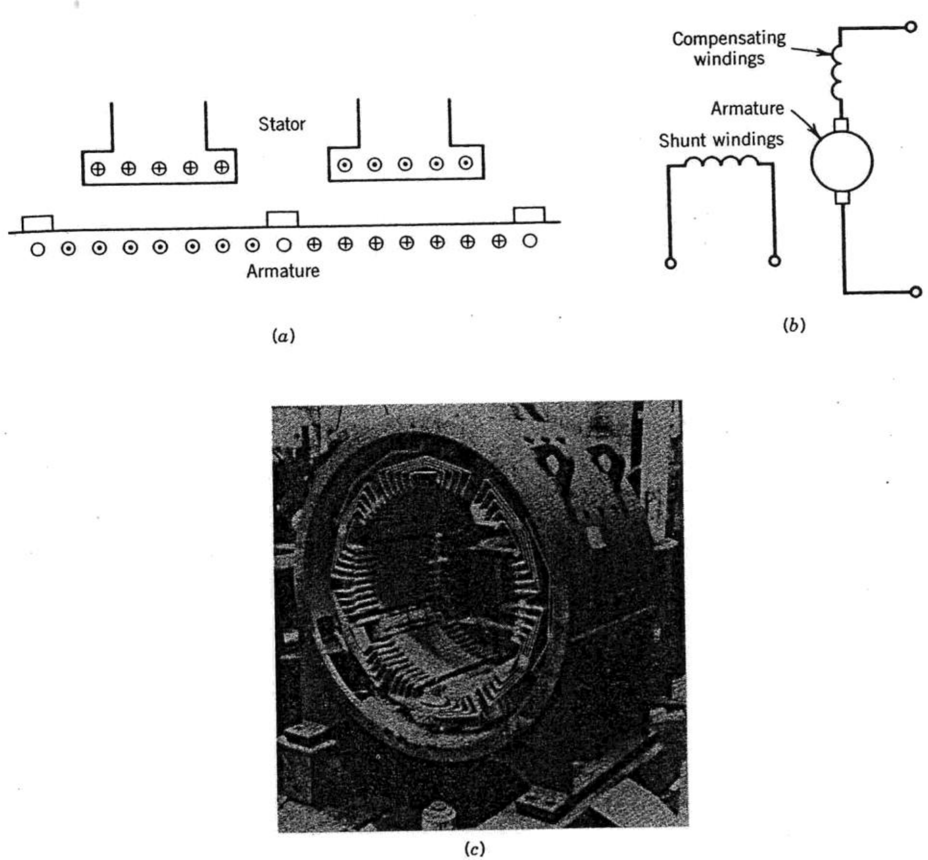
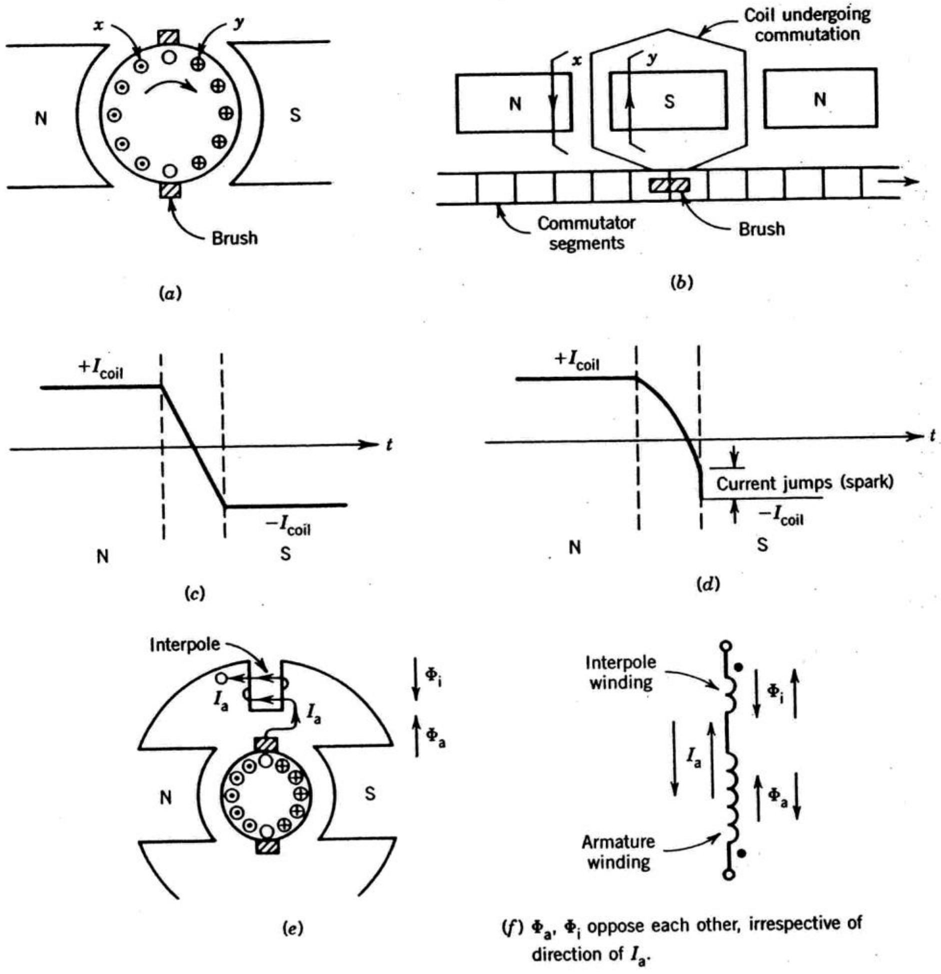


FIGURE 4.33 Compensating winding. (*a*) Developed diagram. (*b*) Schematic diagram. (*c*) Photograph. (Courtesy of General Electric Canada Inc.)

•Since AR reduces main flux, voltage in generators and torque in motors reduces with it. This is particularly objectionable in steel rolling mills that require sudden torque increase.

•Compensating windings put on pole faces can effectively negate the effect of AR. These windings are connected in series with armature winding.

Minimizing commutation problems



(f) Φ_a, Φ_i oppose each other, irrespective of direction of I_a.

FIGURE 4.46 Current communication in dc machine.

- Smooth transfer of current during commutation is hampered by
a) coil inductance and
b) voltage due to AR flux in the interpolar axis. This voltage is called reactance voltage.

- Can be minimized using interpoles. They
produce an opposing field that cancels out the AR in the interpolar region. Thus this winding is also connected in series with the armature winding.

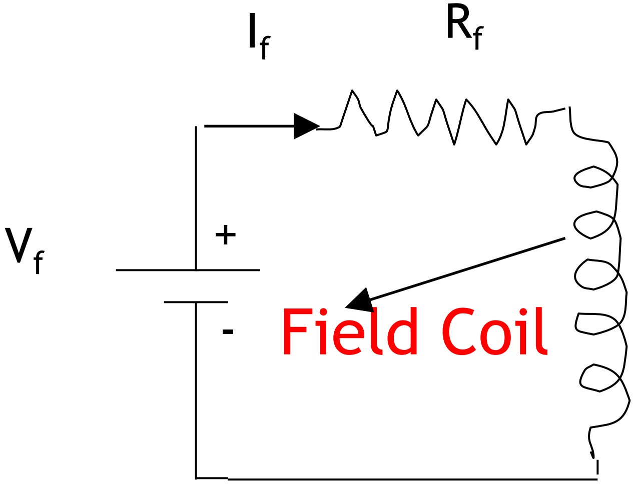
Note: The UVic lab motors have interpoles in them. This should be connected in series with the armature winding for experiments.

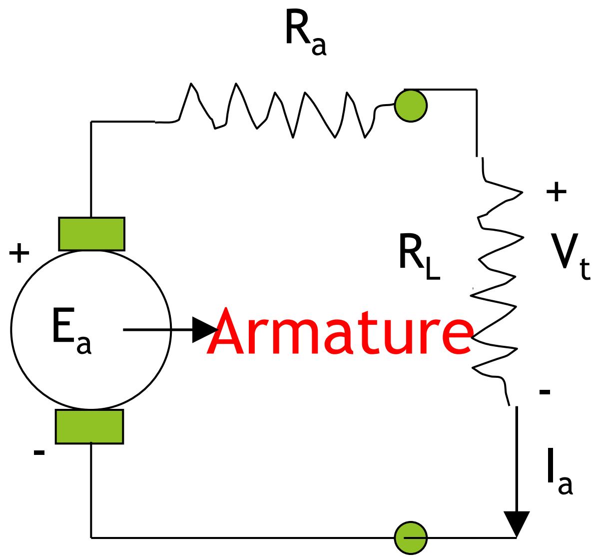
Question:

Can interpoles be replaced by compensating windings and vice-versa?

Why or why not?

Separately Excited DC Generator



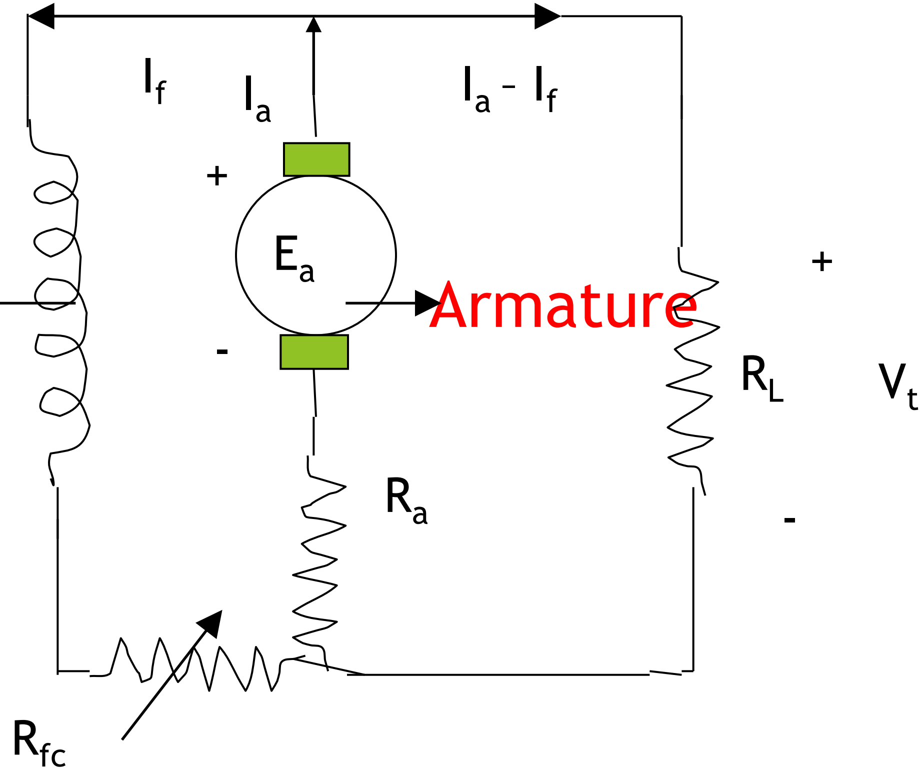


Field equation: $V_f=R_fI_f$

Armature equation: $V_t=E_a-I_aR_a$

$V_t=I_aR_L$, $E_a=K_a\Phi\omega_m$

Shunt Generators



Shunt Field Coil

Armature

Field coil has R_{fw} :
Implicit field resistance

Field equation: $V_t = R_f I_f$

$R_f = R_{fw} + R_{fc}$

Armature equation: $V_t = E_a - I_a R_a$

$V_t = (I_a - I_f) R_L$, $E_a = K_a \Phi \omega_m$

Voltage build-up of shunt generators

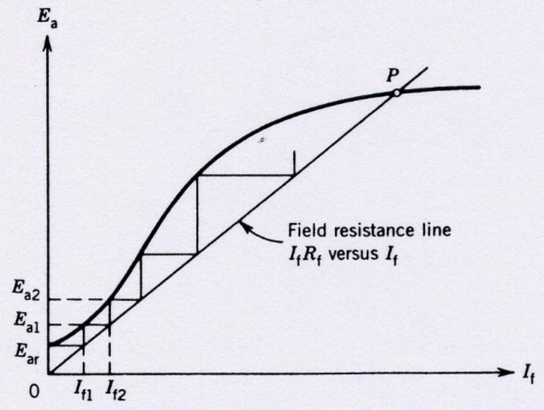


FIGURE 4.35 Voltage buildup in a self-excited dc generator.

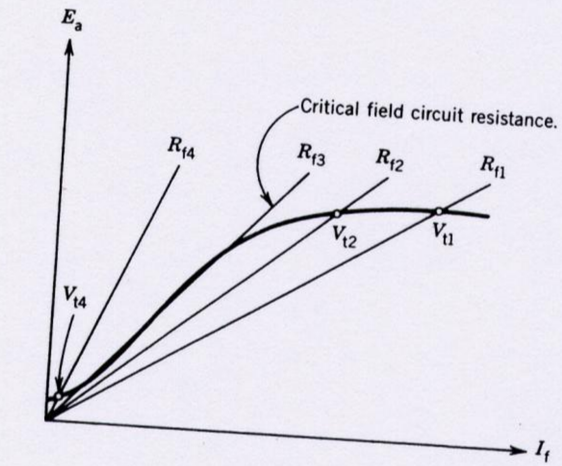


FIGURE 4.36 Effect of field resistance.

Example on shunt generators’ buildup

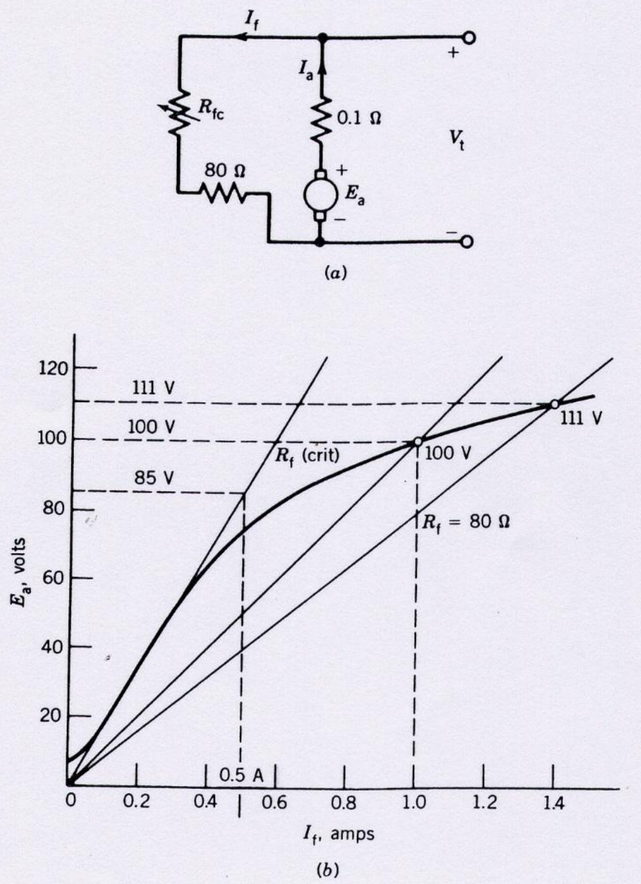
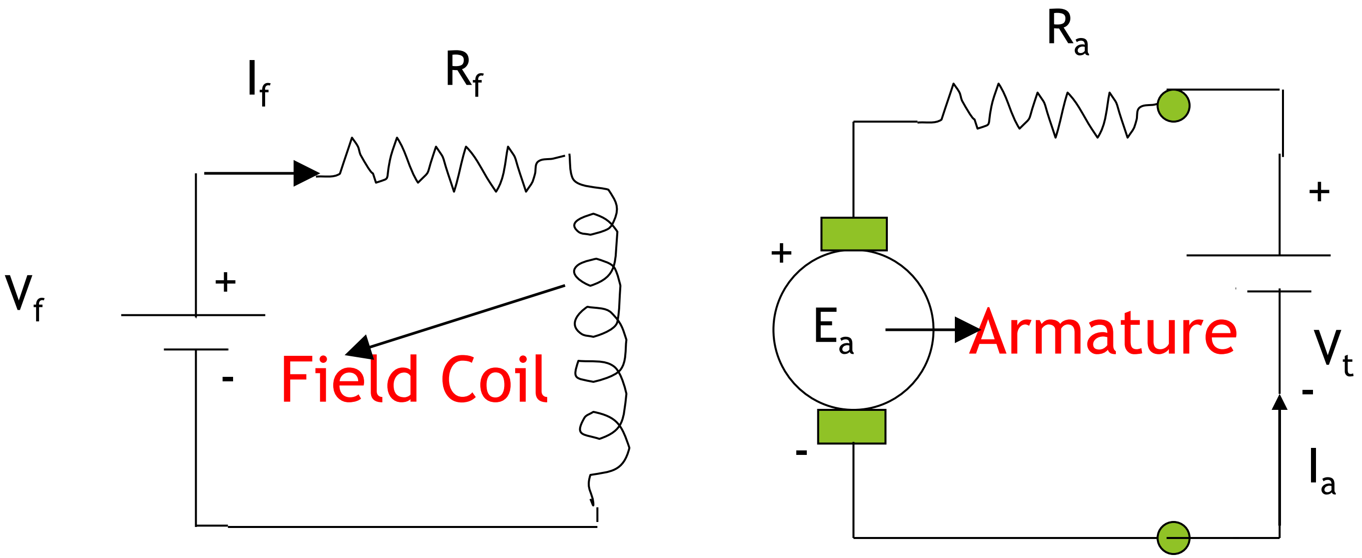


FIGURE E4.3

For proper voltage build-up the following are required:

- Residual magnetism
- Field MMF should aid residual magnetism
- Field circuit resistance should be less than critical field circuit resistance

Separately Excited DC Motor

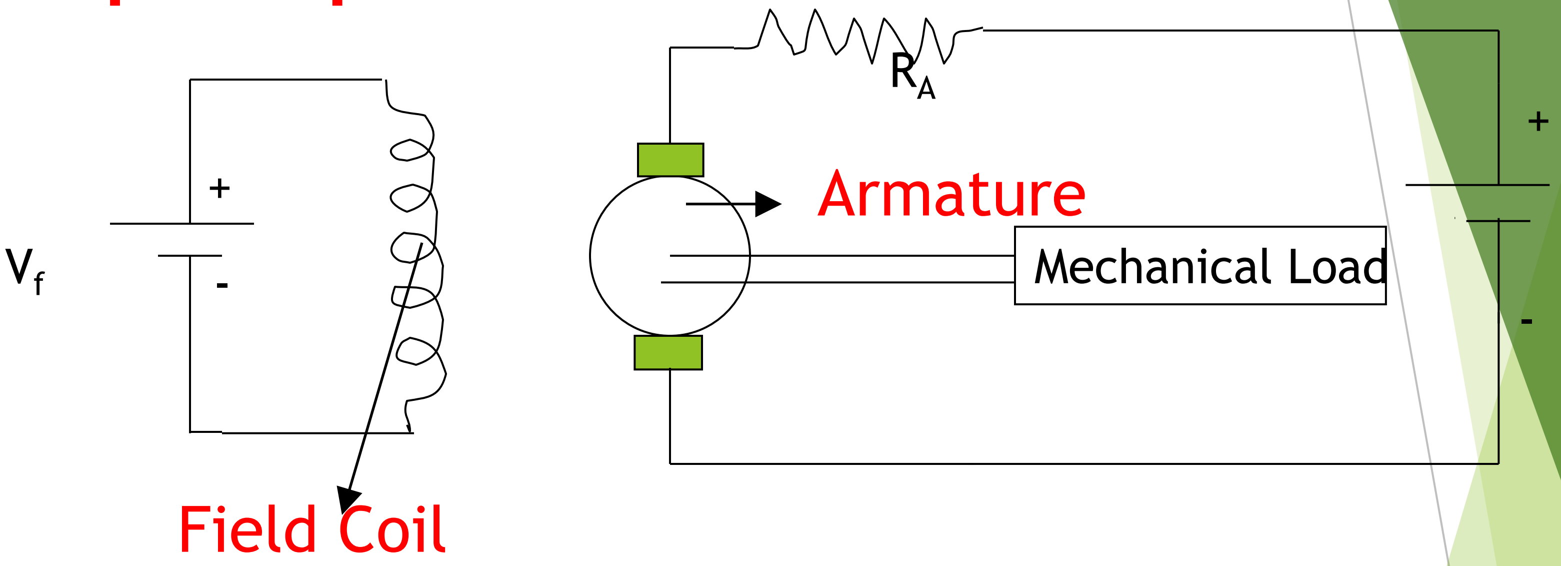


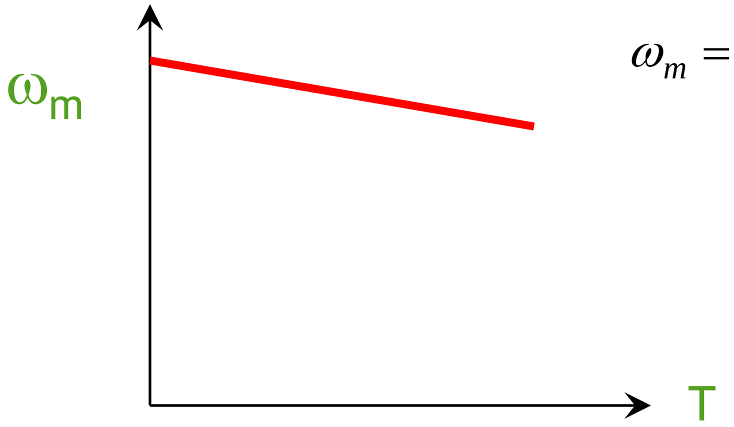
Field equation: $V_f=R_fI_f$

Armature equation: $E_a=V_t-I_aR_a$

$E_a=K_a\Phi\omega_m$

Separately Excited DC Motor Torque-speed Characteristics





$$\omega_m = \frac{V_t}{K_a\Phi} - \frac{R_a}{(K_a\Phi)^2}T$$

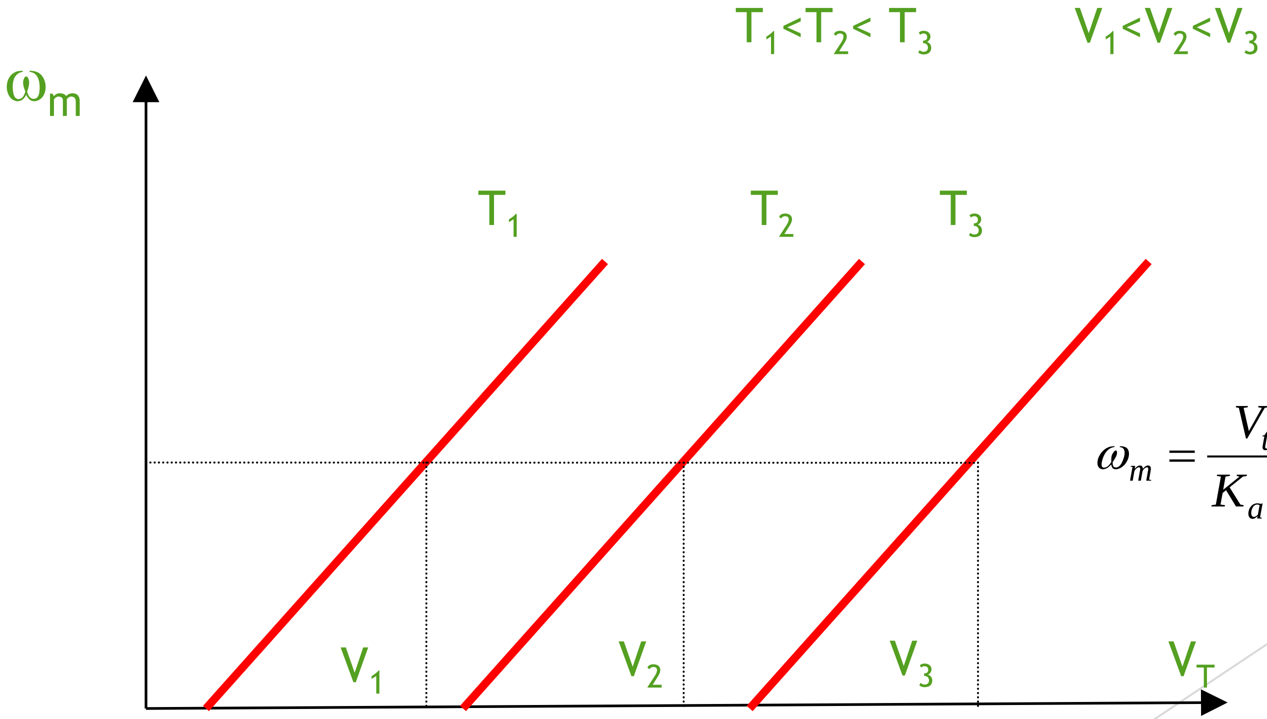
Separately excited DC Motor-Example I

A dc motor has R_a =2 Ω, I_a=5 A, E_a = 220V, N_m = 1200 rpm. Determine i) voltage applied to the armature, developed torque, developed power . ii) Repeat with N_m = 1500 rpm. Assume same I_a.

Solution on Greenboard

Speed Control of Separately Excited DC Motor(2)

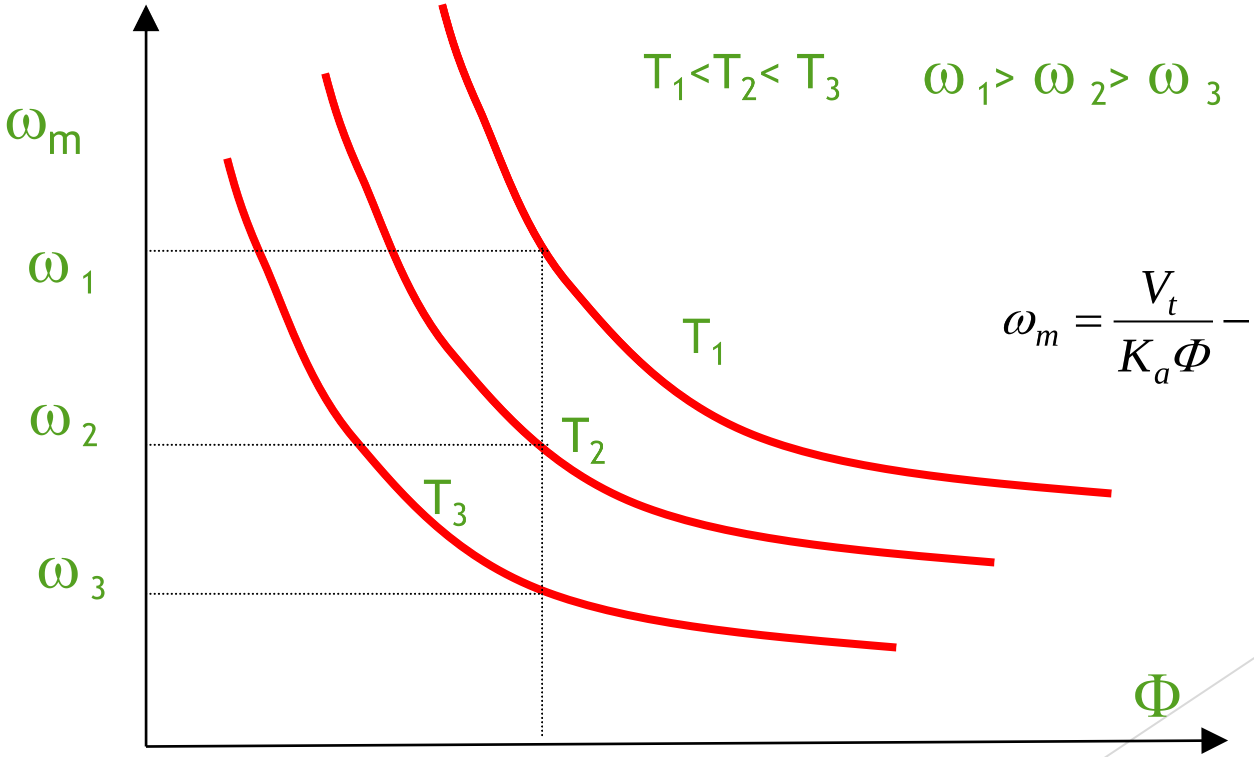
- By *Controlling* Terminal Voltage V_t and keeping I_f or Φ constant at rated value .This method of speed control is applicable for speeds below rated or base speed.



$$\omega_m = \frac{V_t}{K_a \Phi} - \frac{R_a}{(K_a \Phi)^2} T$$

Speed Control of Separately Excited DC Motor

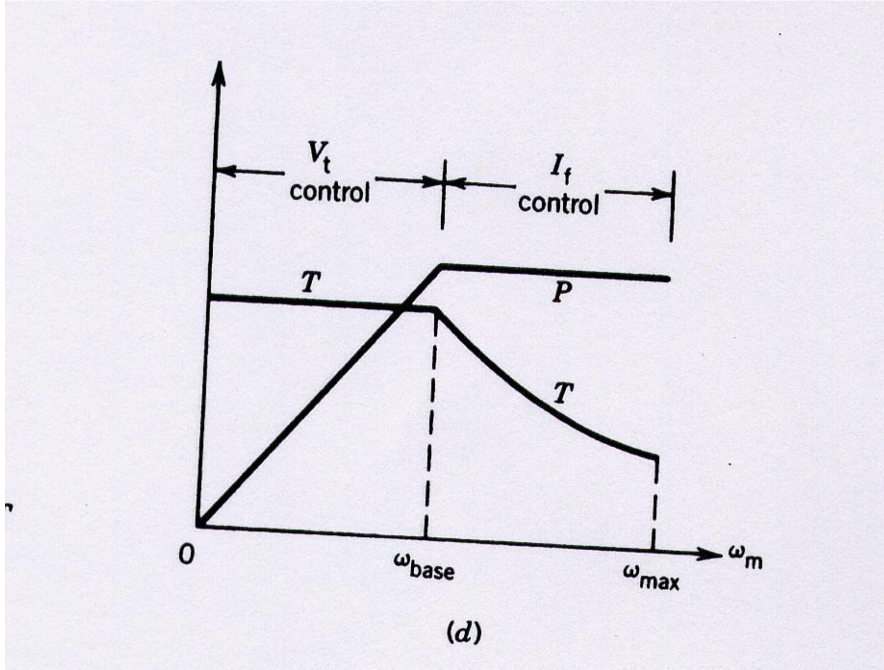
- By *Controlling*(reducing) Field Current I_f or Φ and keeping V_t at rated value. This method of speed control is applicable for speeds above rated speed.



$T_1 < T_2 < T_3$ $\omega_1 > \omega_2 > \omega_3$

$$\omega_m = \frac{V_t}{K_a \Phi} - \frac{R_a}{(K_a \Phi)^2} T$$

Regions of operation of a Separately Excited DC Motor



Separately excited dc motor –Example 2

A separately excited dc motor with negligible armature resistance operates at 1800 rpm under no-load with V_t =240V(rated voltage). The rated speed of the motor is 1750 rpm.

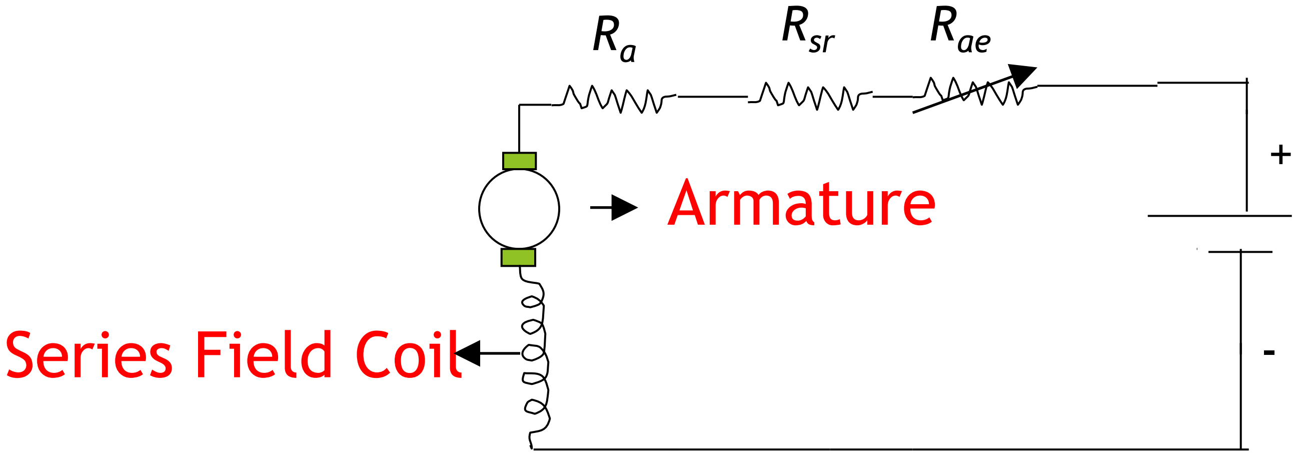
i) Determine V_t if the motor has to operate at 1200 rpm under no-load.

ii) Determine Φ(flux/pole) if the motor has to operate at 2400 rpm under no-load; given that $K = 400/\pi$.

iii) Determine the rated flux per pole of the machine.

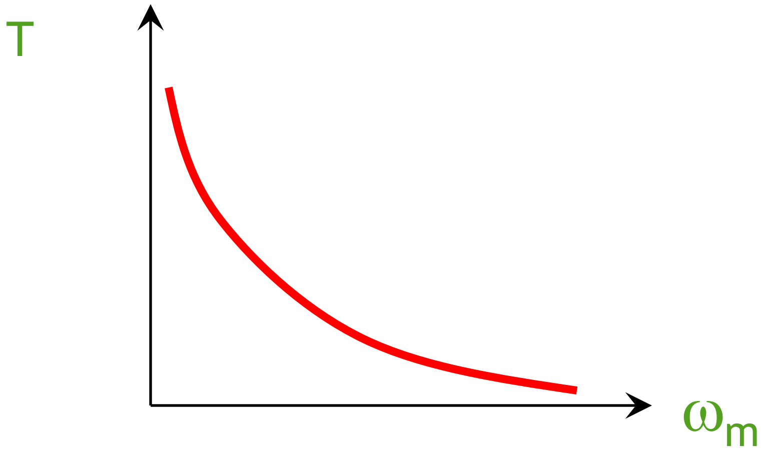
Solution on Greenboard

Series Excited DC Motor Torque-Speed Characteristics



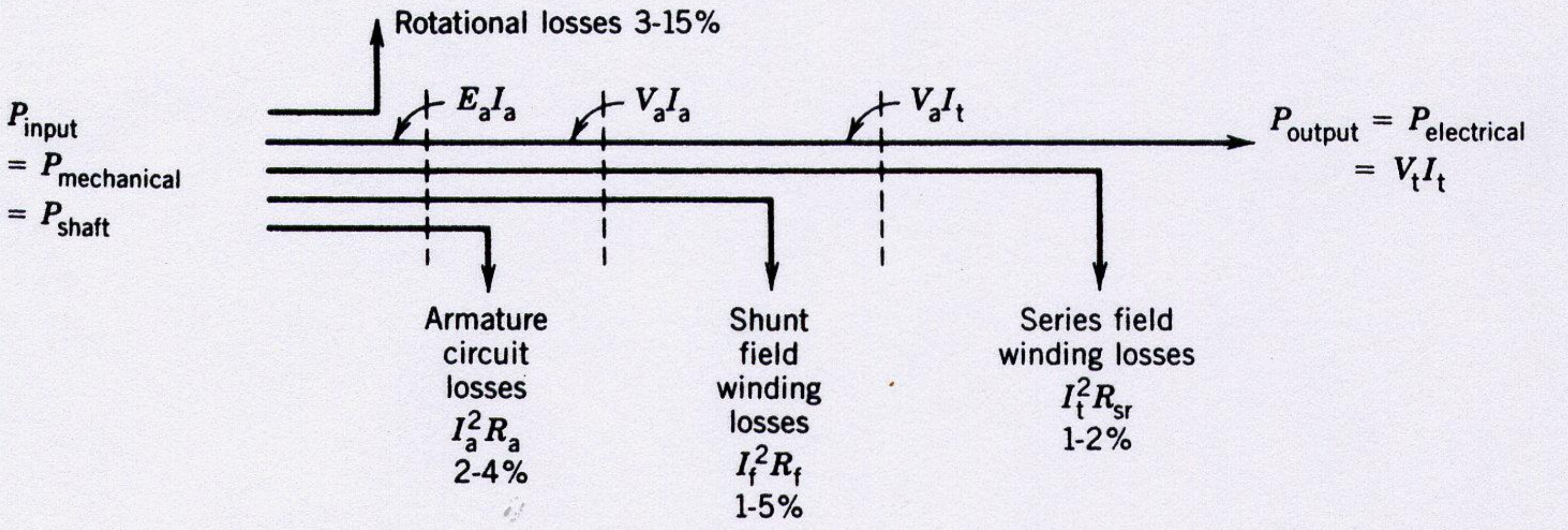
Armature

Series Field Coil

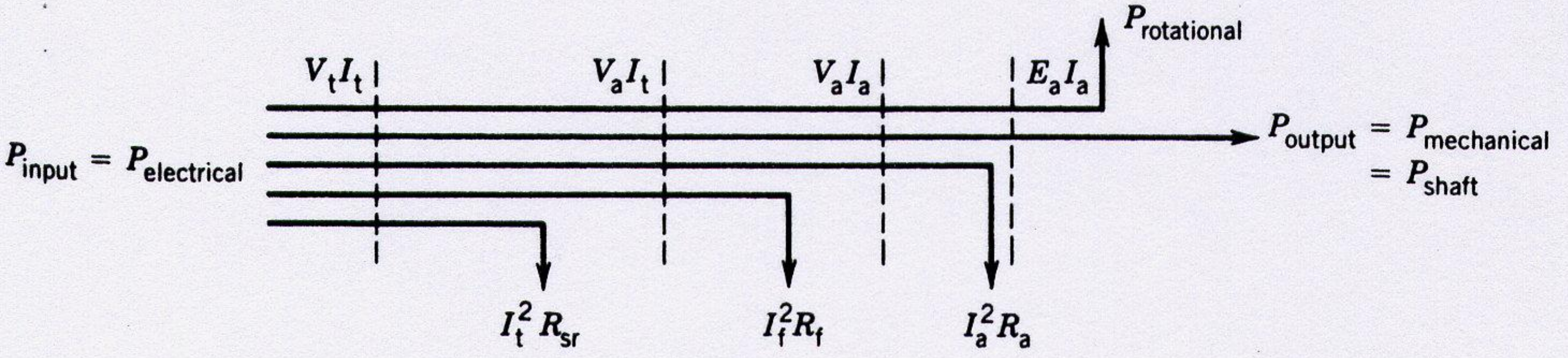


$$\omega_m = \frac{V_t}{\sqrt{K_{sr}T}} - \frac{R_a + R_{sr} + R_{ae}}{K_{sr}}$$

Losses in dc machines

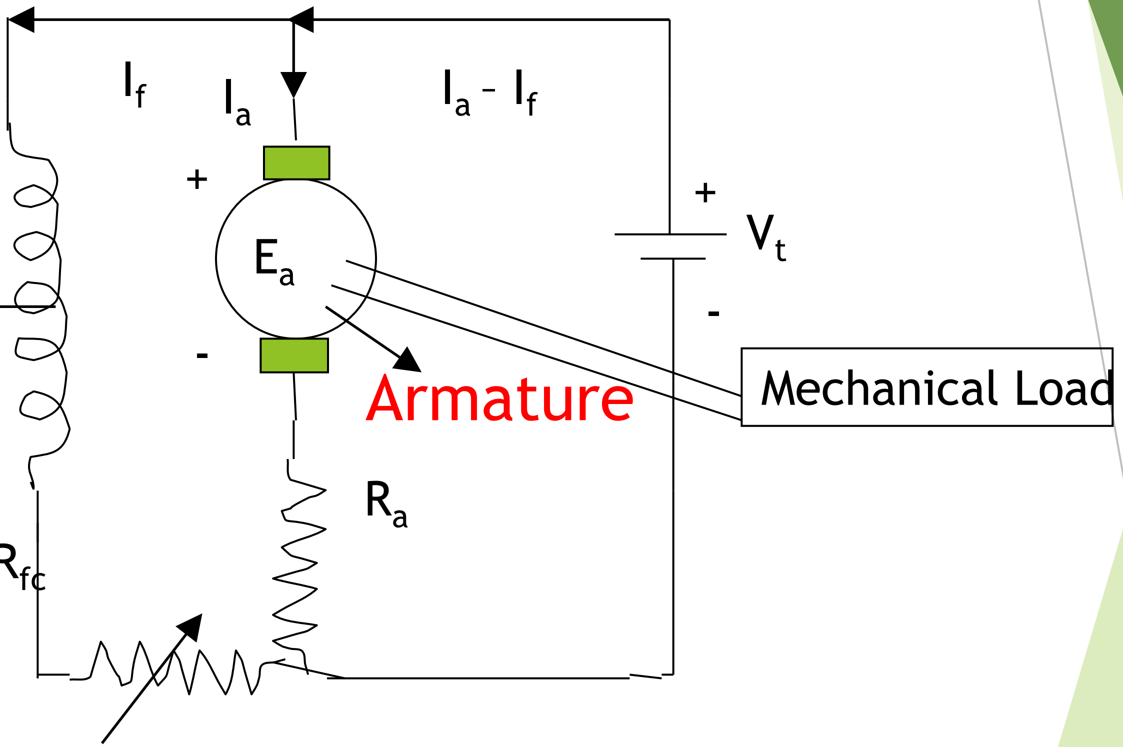


(*b*) Generator



(*c*) Motor

Losses in dc machines-shunt motor example



Shunt Field Coil

Armature

Field coil has R_{fw} :
Implicit field resistance

Field equation: $V_t = R_f I_f$

$R_f = R_{fw} + R_{fc}$

Armature equation: $V_t = E_a + I_a R_a$

$E_a = K_a \Phi \omega_m$