Electrical Drives

Lecture 8 (16/22-01-2024)

Introduction to DC Motor drives

- DC DRIVES: Electric drives that use DC motors as the prime movers
- DC motor: industry workhorse for decades
- Dominated variable speed applications <u>before</u> PE converters were introduced
- Will AC drive replaces DC drive ?
  - Predicted 30 years ago
  - DC strong presence – easy control – huge numbers
  - AC will eventually replace DC – at a slow rate

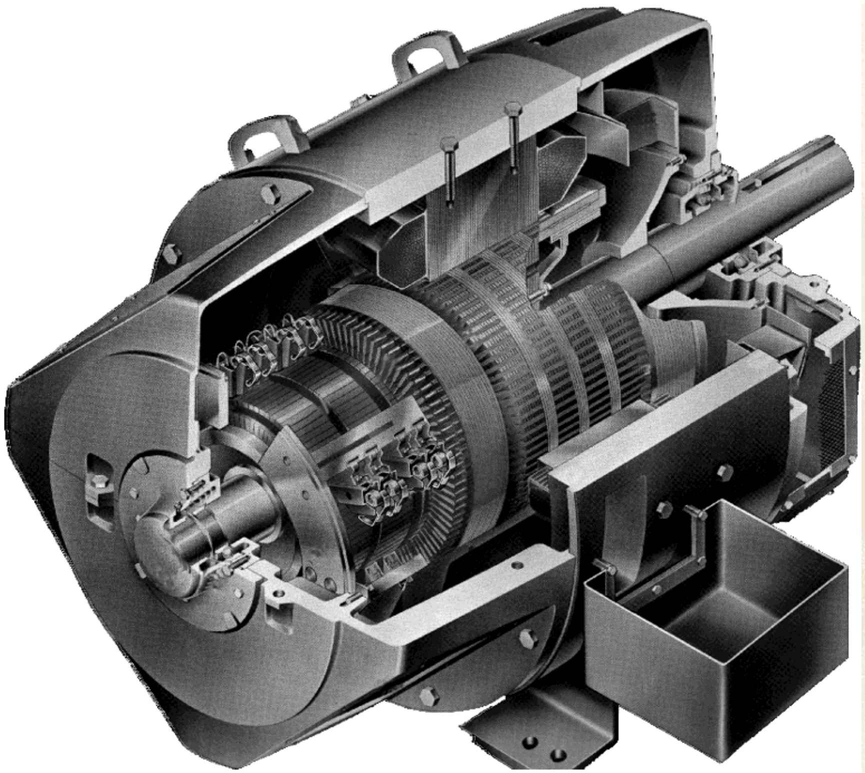
Purpose of a "DC Motor"

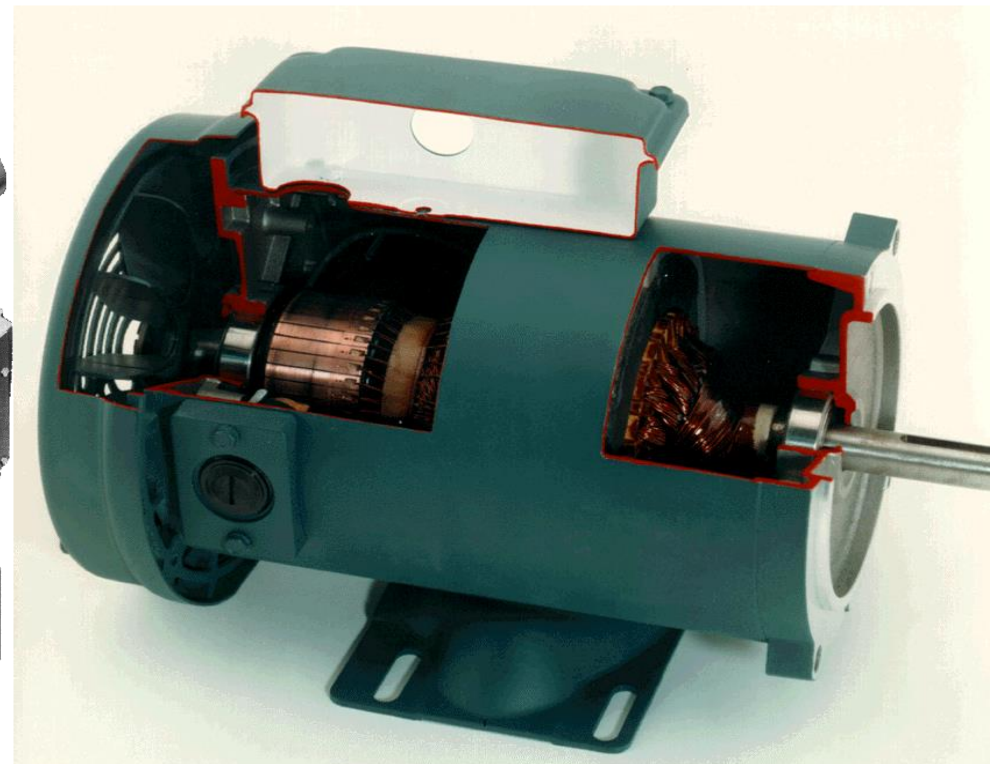
Electrical Energy

Mechanical Energy

The purpose of a DC Motor is to Convert Electrical Energy into Mechanical Energy

Typical DC Motors



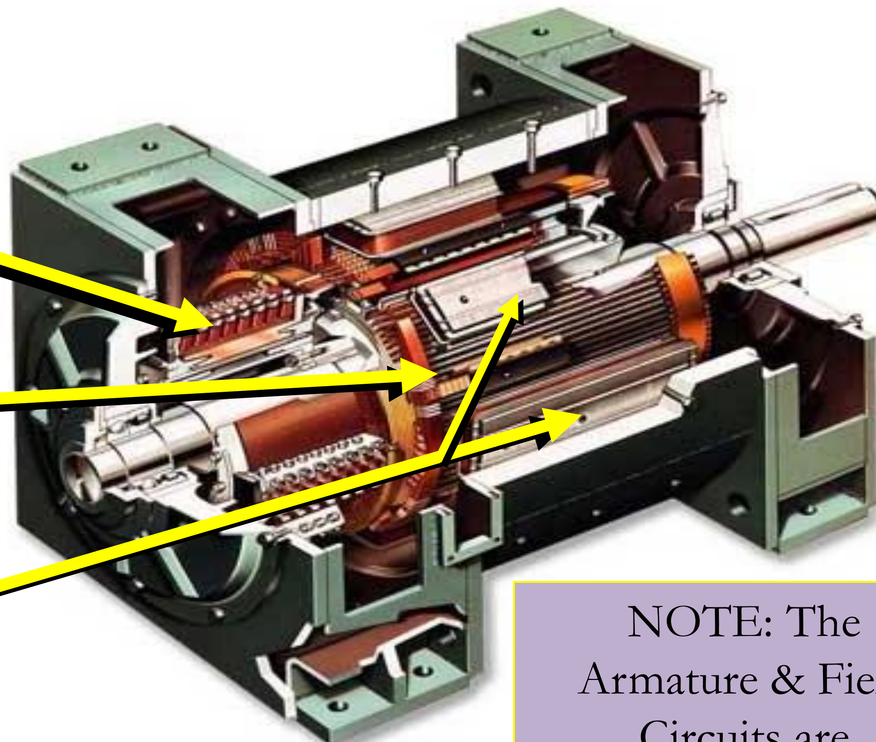


DC MOTOR CONSTRUCTION

Commutator & Brush Assembly

Armature Assembly

Field Poles Assemblies

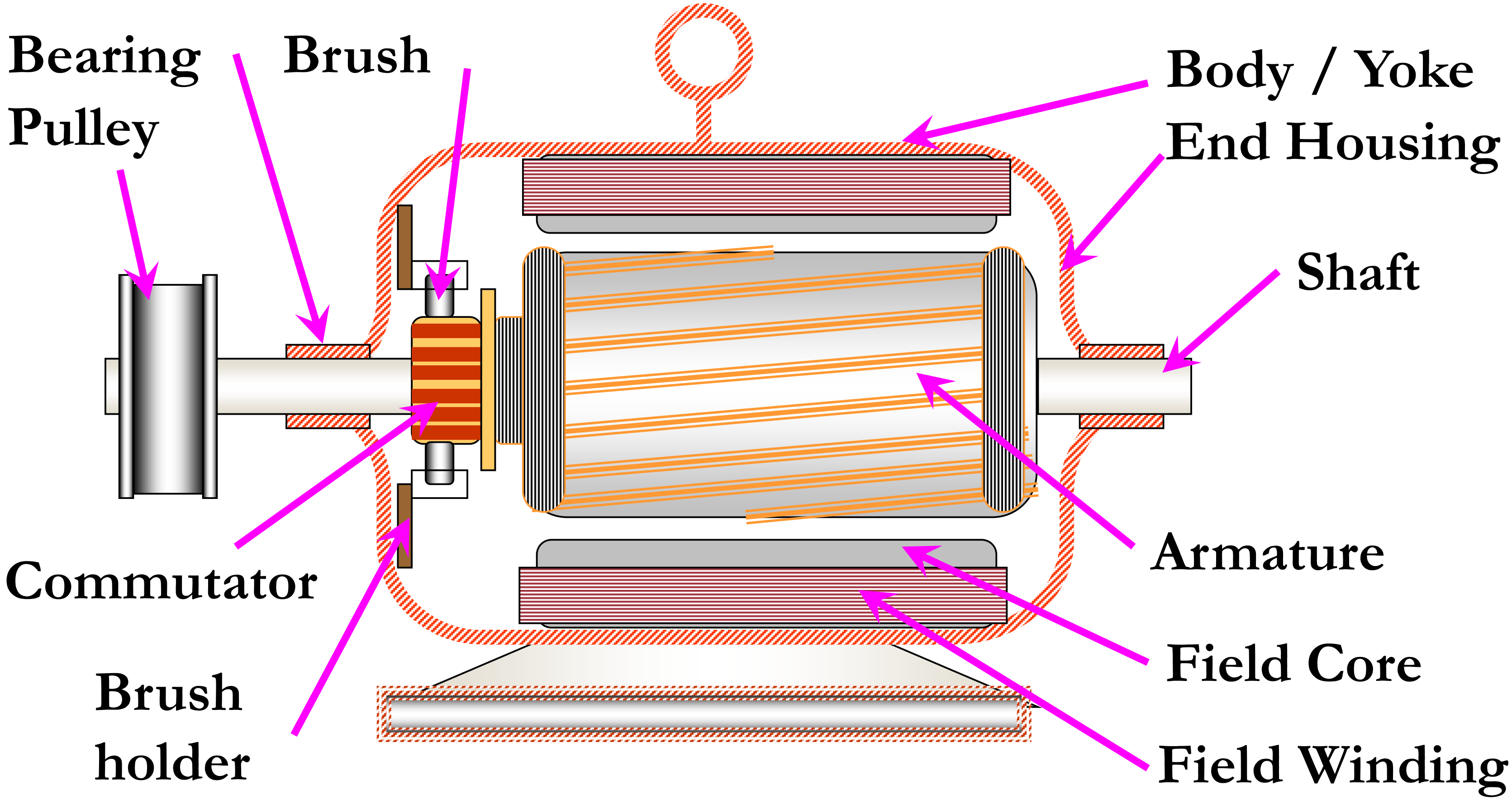


NOTE: The Armature & Field Circuits are mechanically fixed at 90° at all times

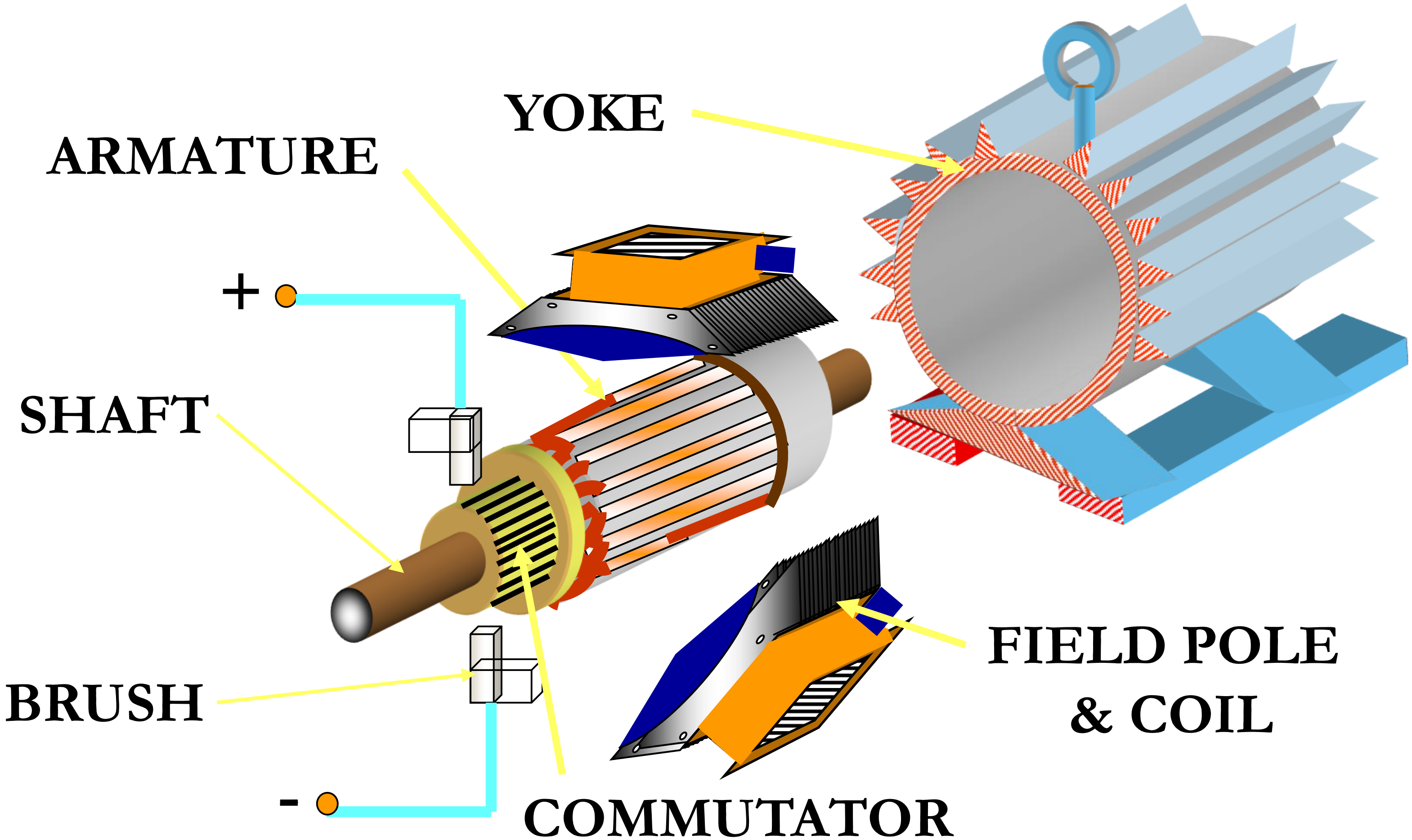
Distinct Armature & Field Circuits

are mechanically separated

MAIN CONSTRUCTIONAL FEATURES



MAIN CONSTRUCTIONAL FEATURES



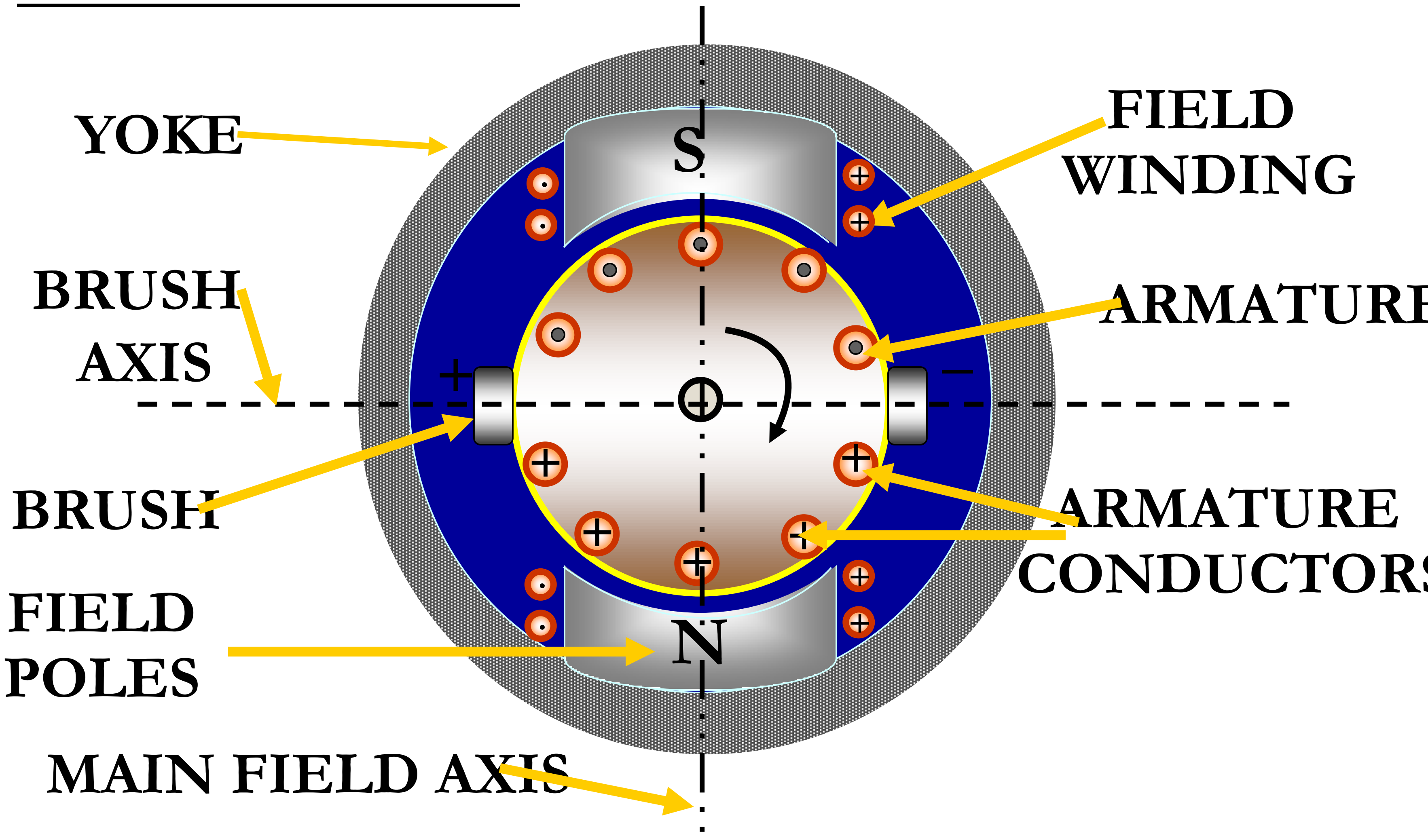
Introduction to DC Motor drives

- <u>DC Motors</u>

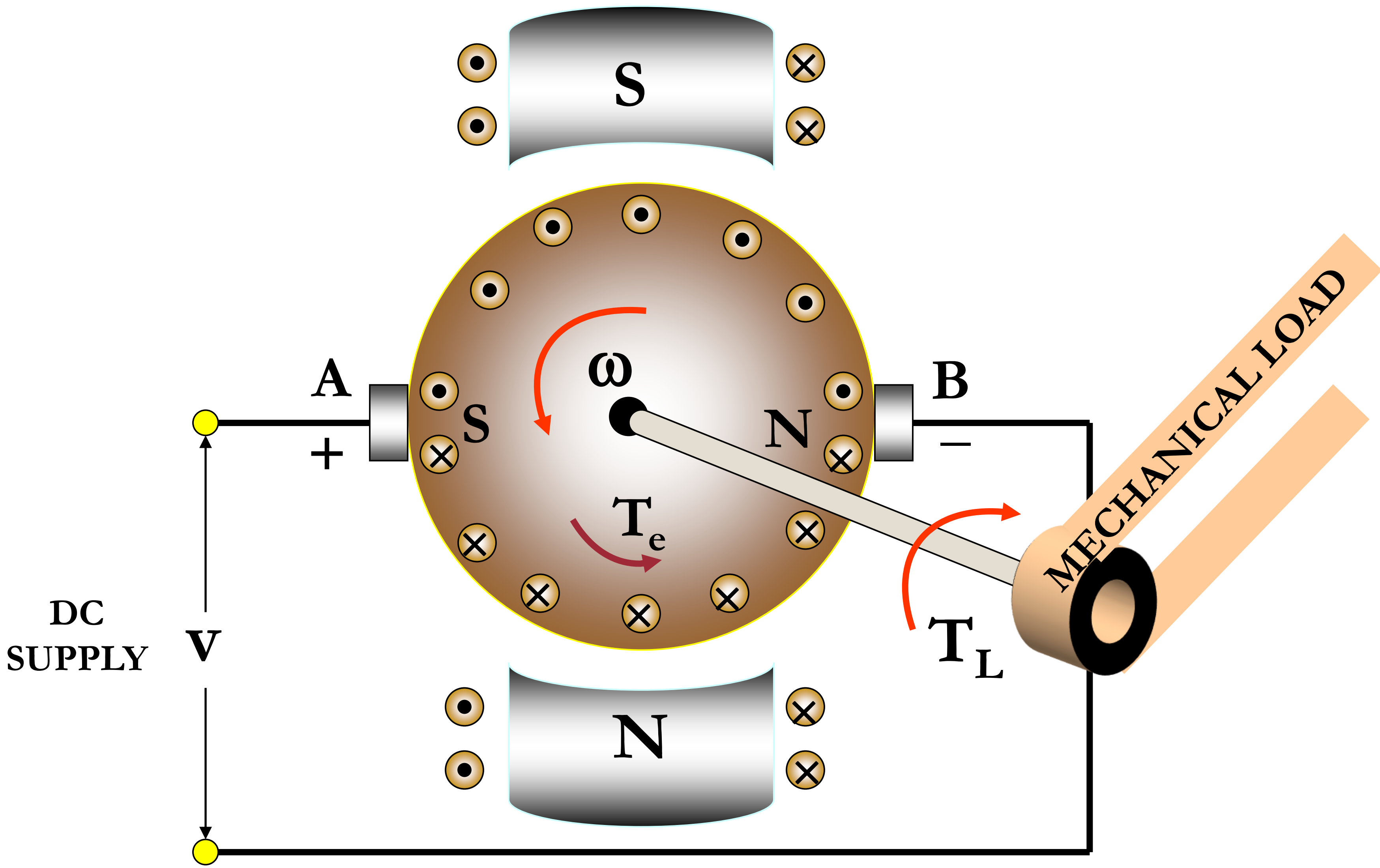
- Advantage: Precise torque and speed control without sophisticated electronics

- Several limitations:
  - Regular Maintenance
  - Heavy
  - Sparking
  - Expensive
  - Speed limitations

DC MACHINES


YOKE
BRUSH AXIS
BRUSH
FIELD POLES
MAIN FIELD AXIS
FIELD WINDING
ARMATURE
ARMATURE CONDUCTORS
S
N
+
−

DC MOTOR

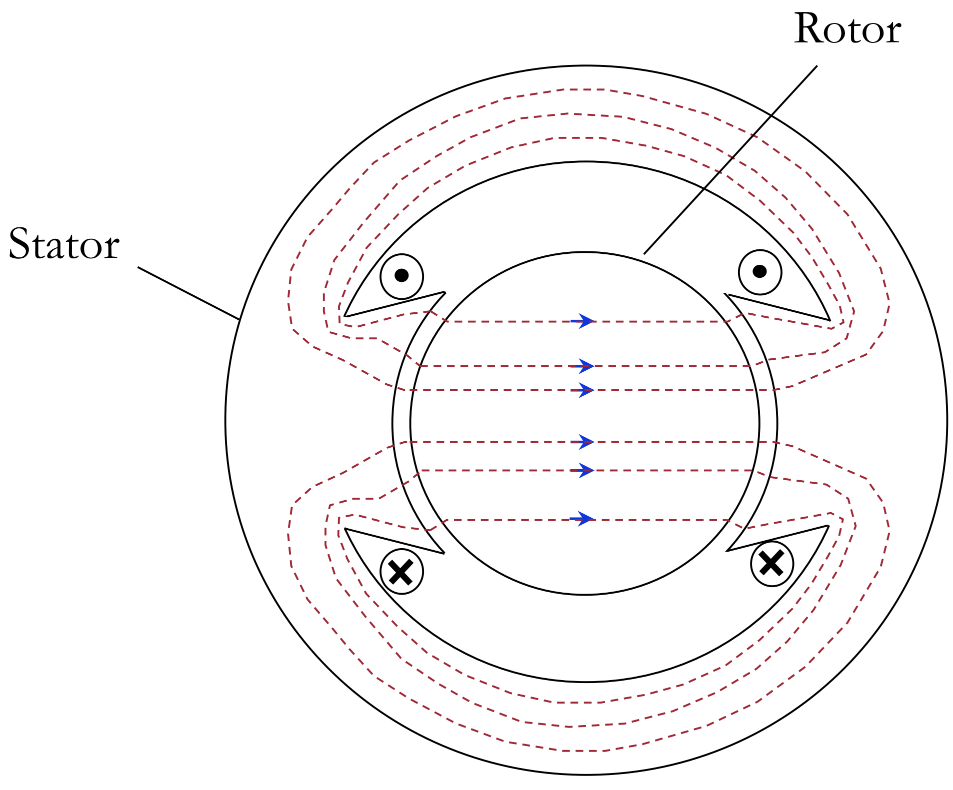


- The field windings are shown as excited from external source. The polarity of electro-magnetic field will depend upon the direction of field current.
- The armature carries conductors in side the slots. Two brushes are placed at the right angle to the main field axis. The brushes are stationary whereas armature is free to rotate.
- The armature is connected across a supply voltage 'V' and the field windings are excited from the same supply or from any external dc source.
- The electro-magnetic torque T_e will be developed in the anti-clockwise direction as opposite poles of armature field and main field will attract each other. The armature will rotate in anti-clockwise direction due to T_e

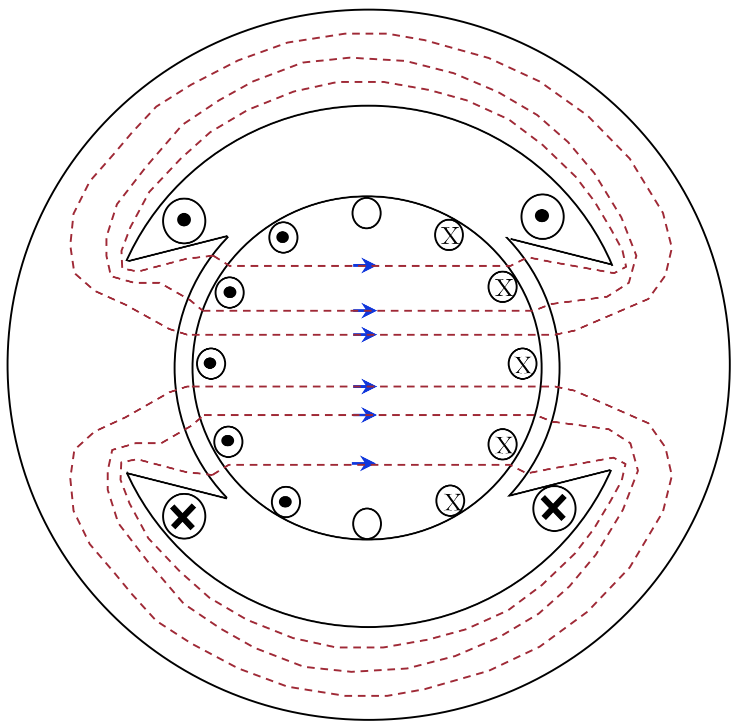
- To reverse the direction of rotation of armature, either the direction of current in the field winding or armature winding will have to be reversed. If the direction of currents in both the windings are reversed, direction of rotation of armature will be unchanged.

- As the mechanical load on the armature i.e. rotor shaft represented by load torque T_L is increased, more and more electro-magnetic torque will be developed by the armature to balance the mechanical torque requirements for which the armature will draw more current from the supply mains.

DC Motors - 2 pole



DC Motors - 2 pole

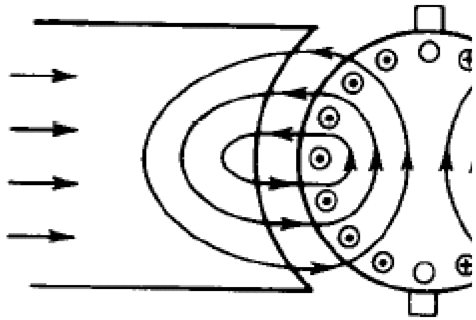


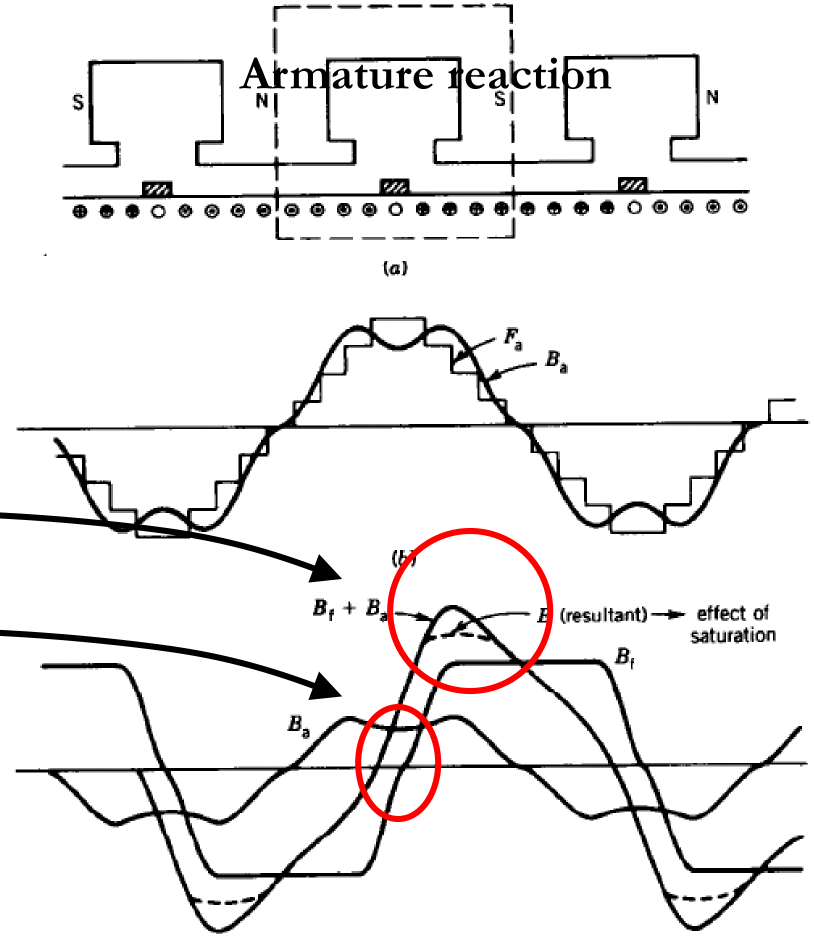
Armature reaction

Armature mmf produces flux which distorts main flux produce by field

- Mechanical commutator to maintain armature current direction

Armature reaction





Flux at one side of the pole may saturate

Zero flux region shifted

Flux saturation, effective flux per pole decreases

- **Armature mmf distorts field flux**

  → Large machine employs compensation windings and interpoles

Type of DC Motors

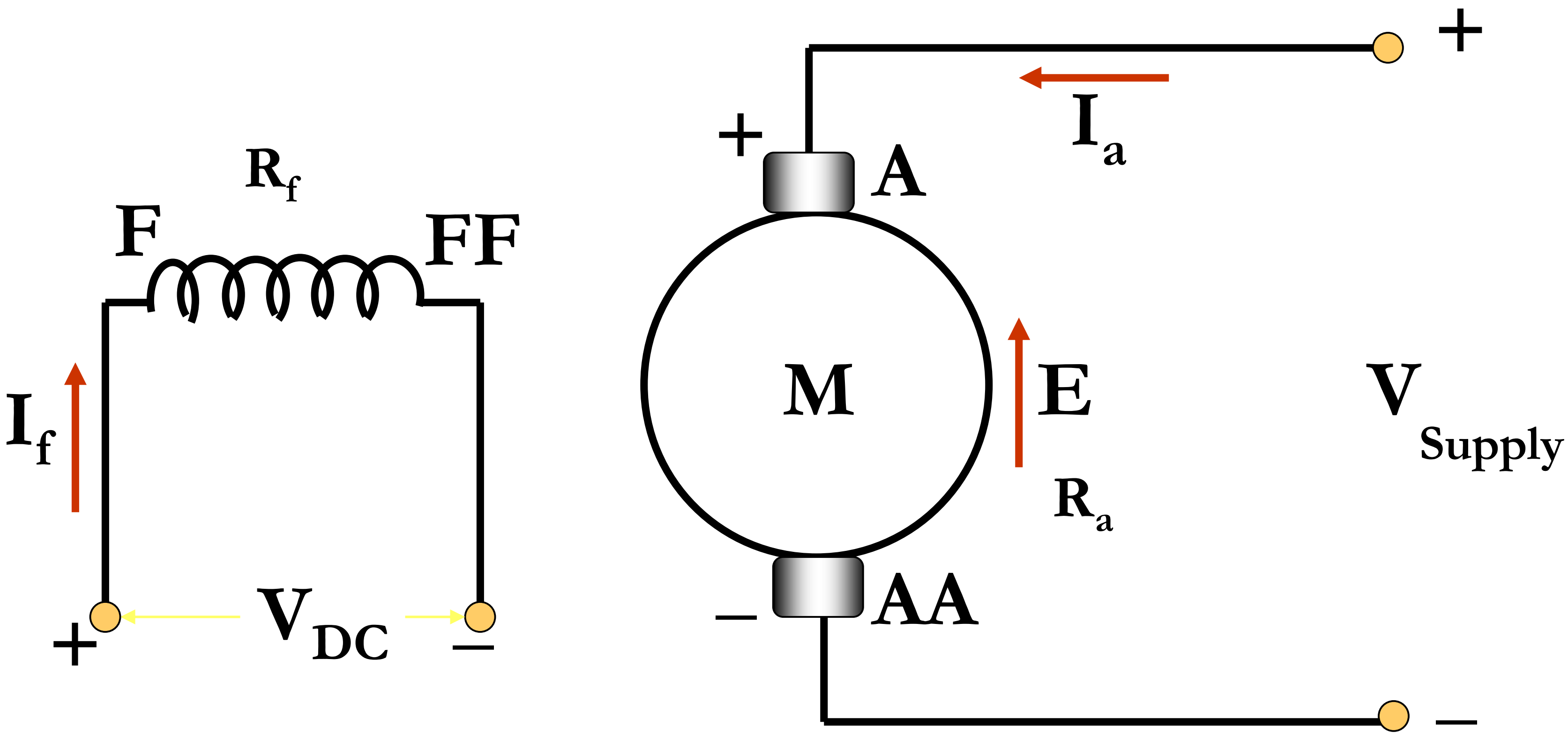
Depending upon the type of excitation to the field winding , The dc machine can be classified into three categories:

- Machines with permanent field,

Dc motors with permanent magnetic field, are manufactured for small rating applications such as toys, cassette tape recorders etc. Large rating DC Motors are constructed with electro-magnetic field i.e field winding is placed on the field core and this winding is supplied with dc current called excitation. Depending upon the type of connections to the field winding for excitation , the dc motors can be classified into two categories ;

- Separately excited DC Motors
- Self excited DC Motors

SEPARATELY EXCITED DC MOTORS



SEPARATELY EXCITED DC MOTORS

- The field winding is excited from a supply which is not connected to the armature winding.

- It may be noted that current flowing through the field winding is independent of load and is equal to V / R_f, where R_f is the field circuit resistance.

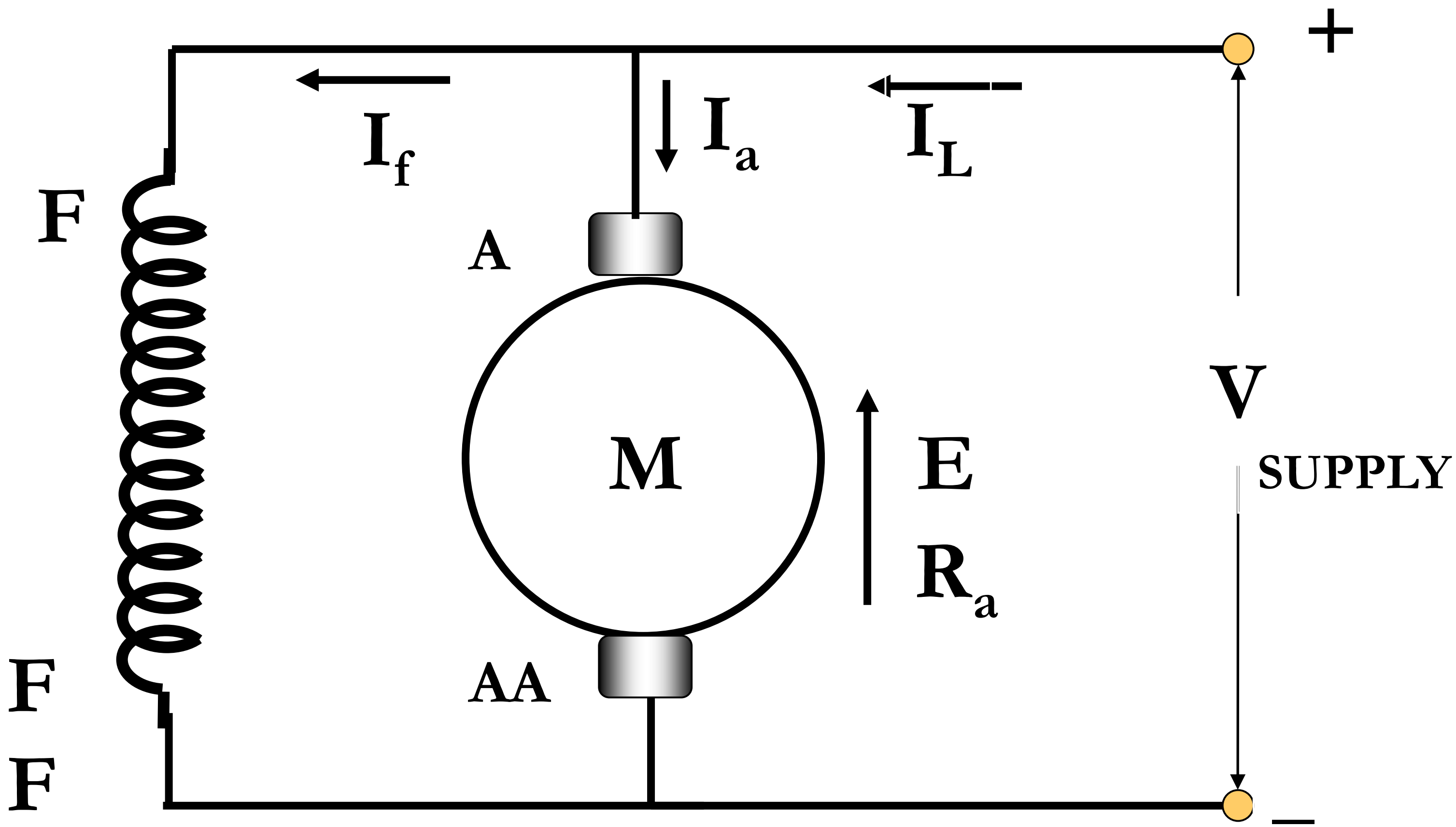
- The flux produced is proportional to the field current i.e. $\varnothing \propto I_f$

SELF EXCITED DC MOTORS

Classified into three types:

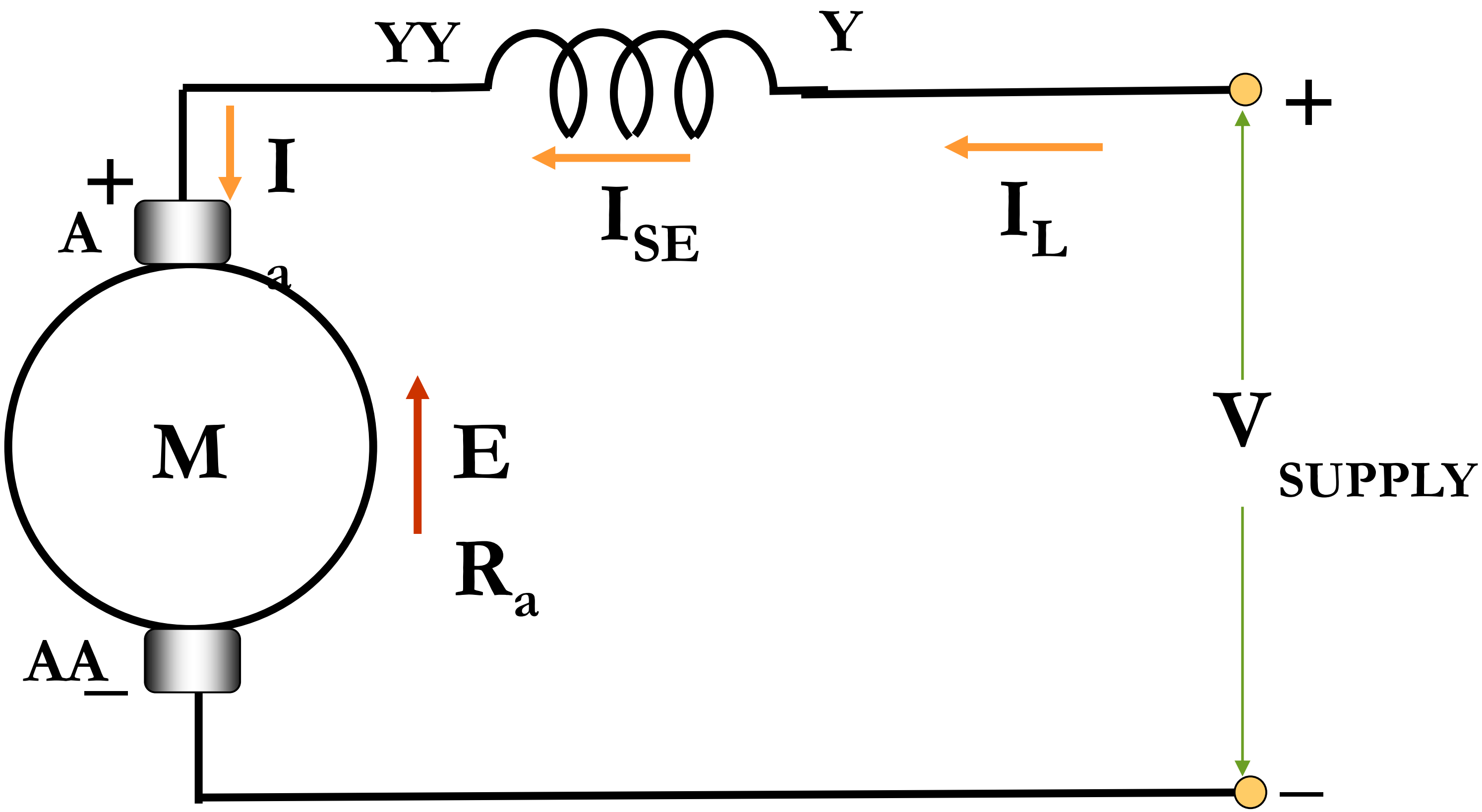
- SHUNT MOTORS
- SERIES MOTORS
- COMPUND MOTORS

SHUNT MOTORS



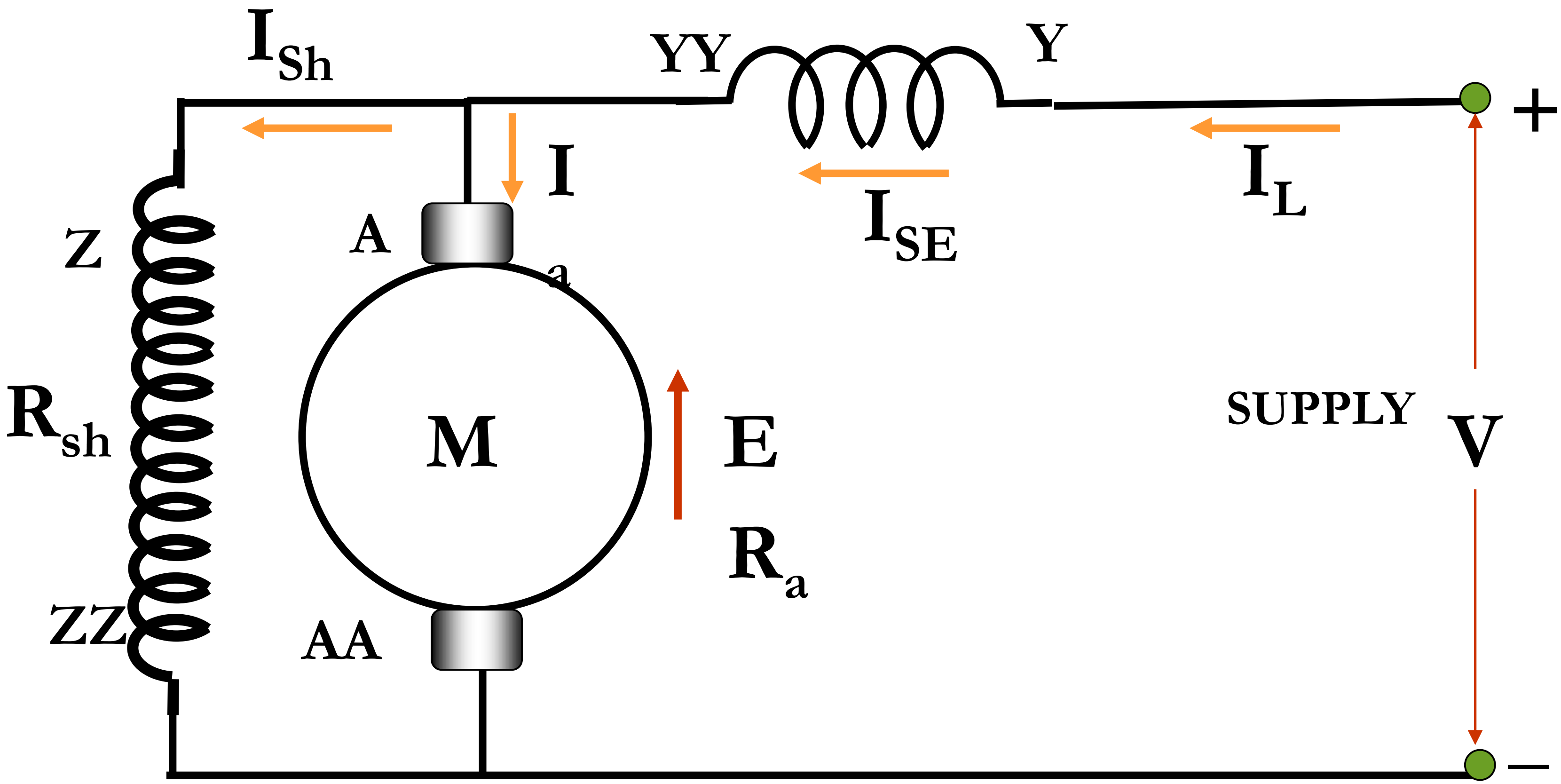
In this type of excitation , armature and field windings are connected across a constant source of supply. The field current I_f is drawn from the same source as that of armature current.

SERIES MOTORS



The field winding is connected in series with the armature so that $I_f = I_a = I_L$. Therefore field winding is made up of thick winding wire of less no. of turns as compared to that of shunt field winding so that armature current can flow through it without overheating. In case of dc series machine , $\emptyset \propto I_f \propto I_a$.

COMPUND MOTORS



There are two field windings , namely a shunt field winding and a series field winding. The shunt field winding is connected in parallel with the armature and series field winding is connected in series with the combination . Series field winding will carry a large armature current I_a or I_L and therefore it is made of wire of large cross section and has a few turns only. The resistance of series field winding is very small.

The shunt field winding is made up of wires of small cross section and has high resistance. Since the resistance of shunt field winding is high , the current flowing through it is very small as compared to that of series field winding or armature current I_a . The main magnetic field flux is produced by the shunt field current / winding but it is modified by the field of series winding. A compound machine therefore combines the best features of dc shunt machines and dc series machines.

Depending up on the connections of shunt field winding in the combination of armature and series field winding, dc compound generators can be named as

i) Short shunt compound generators.

ii) Long shunt compound generators.

SHORT SHUNT DC COMPOUND MOTORS

In this case the shunt field winding is connected across the armature winding only.

$$I_{se} = I_L = I_a + I_{sh}$$

$$\begin{aligned} V &= E + I_a R_a + I_{se} R_{se} \\ &= E + I_a R_a + (I_a + I_{sh}) R_{se} \end{aligned}$$

LONG SHUNT DC COMPOUND MOTORS

In this case the shunt field winding is connected across the combination of armature and series field winding

$$I_{se} = I_a \quad \text{and} \quad I_L = I_a + I_{sh}$$

$$\begin{aligned} V &= E + I_a R_a + I_{se} R_{se} \\ &= I_{sh} R_{sh} \end{aligned}$$

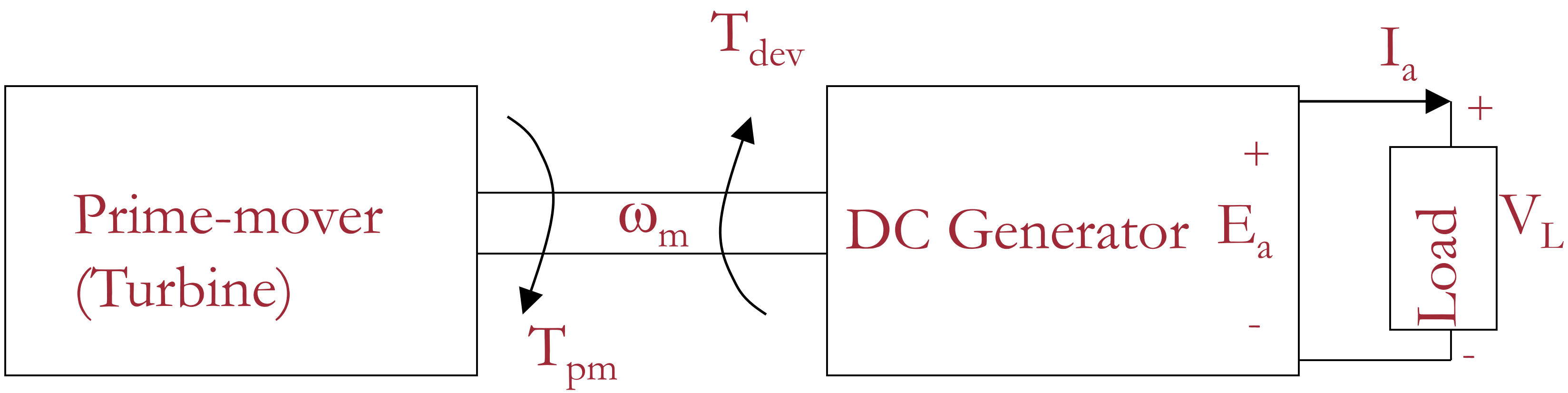
Voltage and Torque developed in a DC Machine

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

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

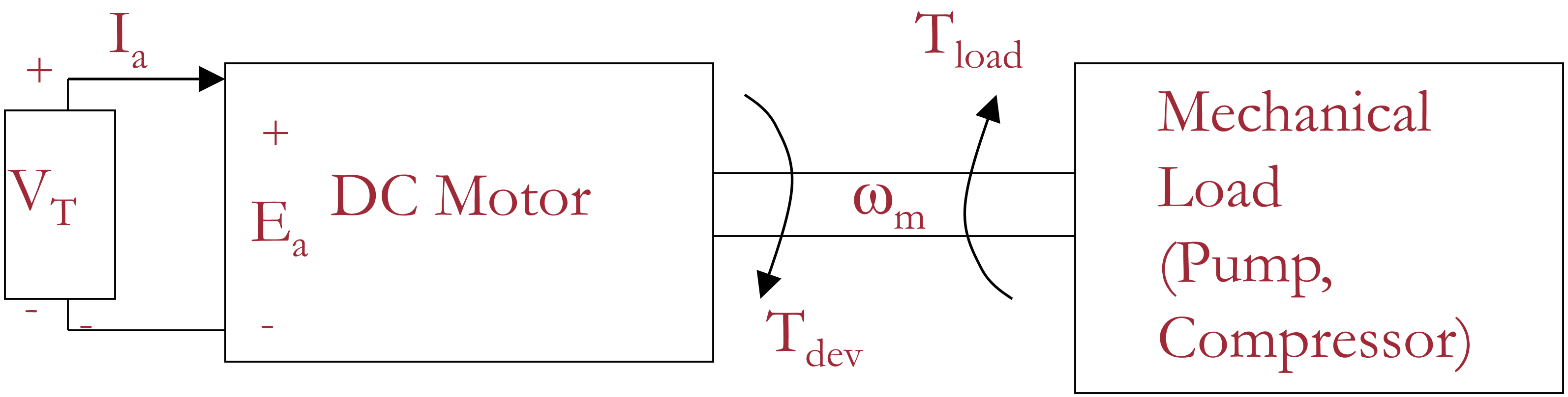
where ω_m is the speed of the armature in rad/sec.,
Φ is the flux per pole in weber (Wb)
I_a is the Armature current
K_a is the machine constant

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

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

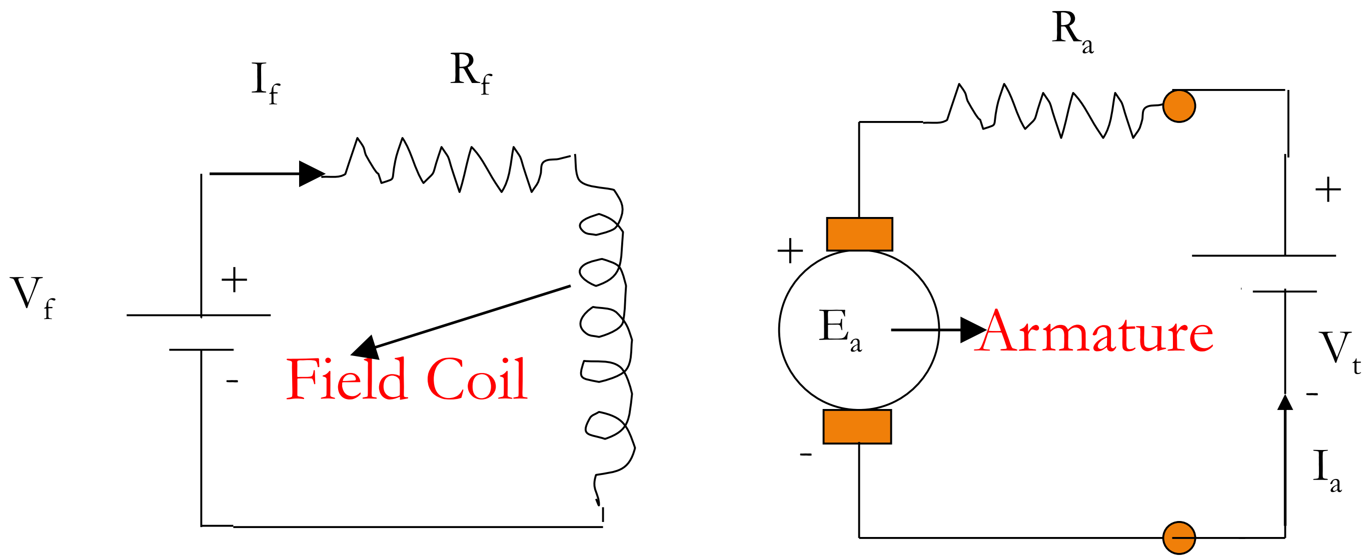
$=$ *Output electric power* to load

- *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

Separately Excited DC Motor

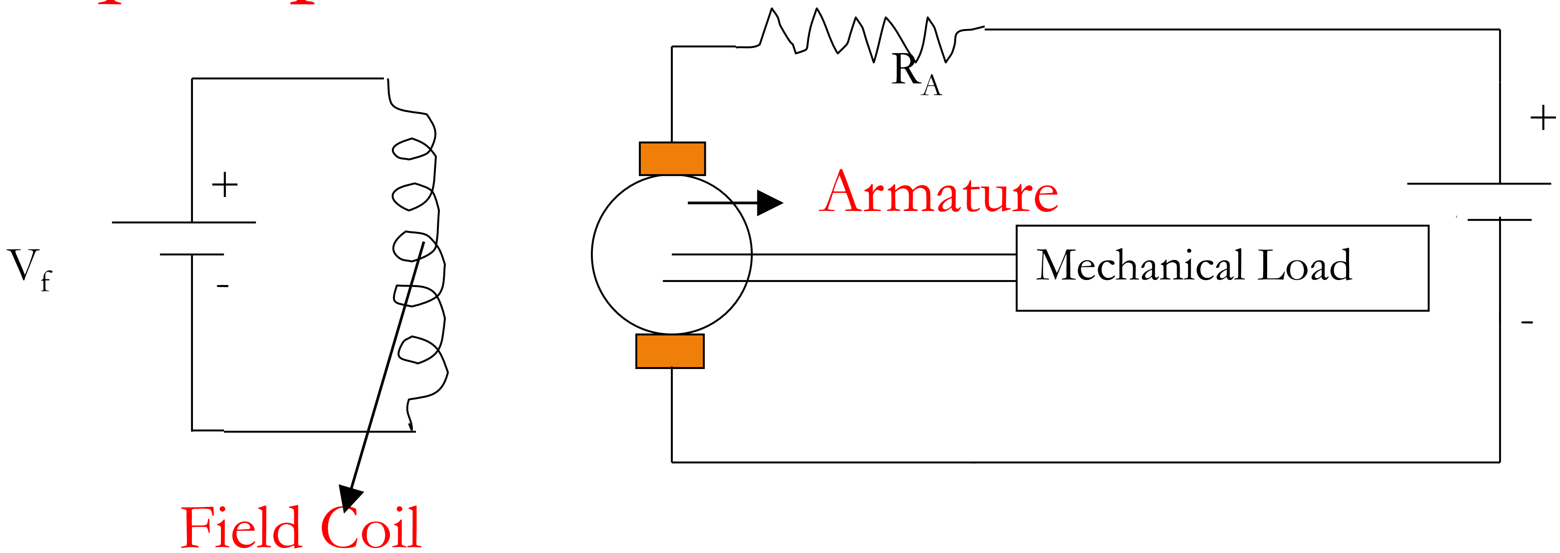


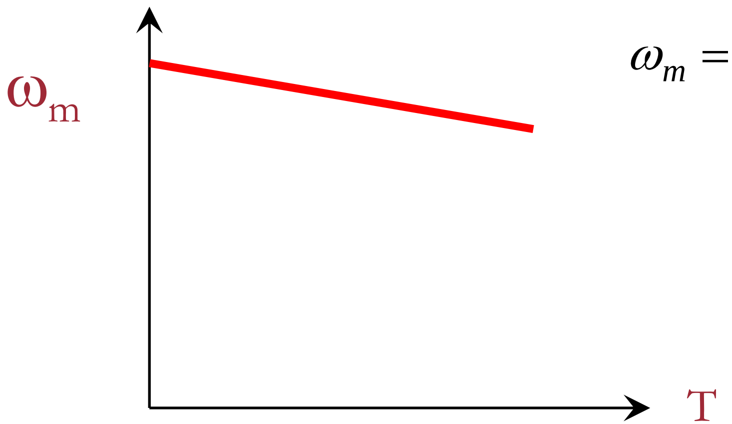
Field equation: $V_f = R_f I_f$

Armature equation: $E_a = V_t - I_a R_a$

$E_a = K_a \Phi \omega_m$

Separately Excited DC Motor
Torque-speed Characteristics





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

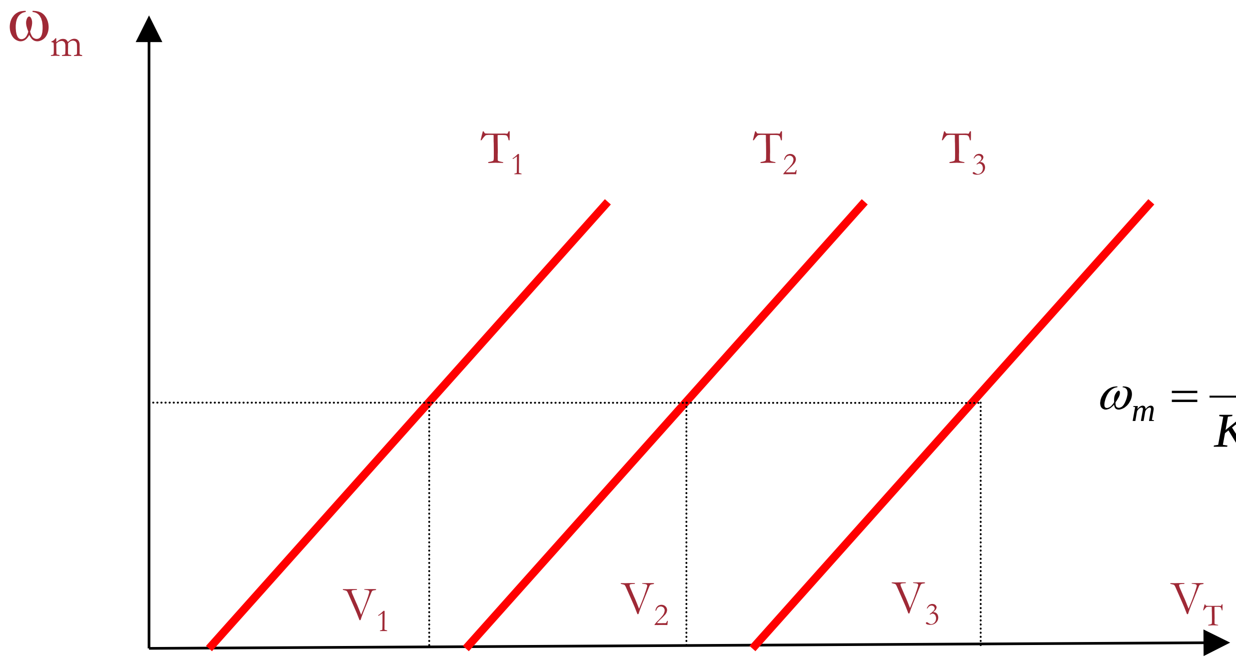
Separately excited DC Motor-Example I

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

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.

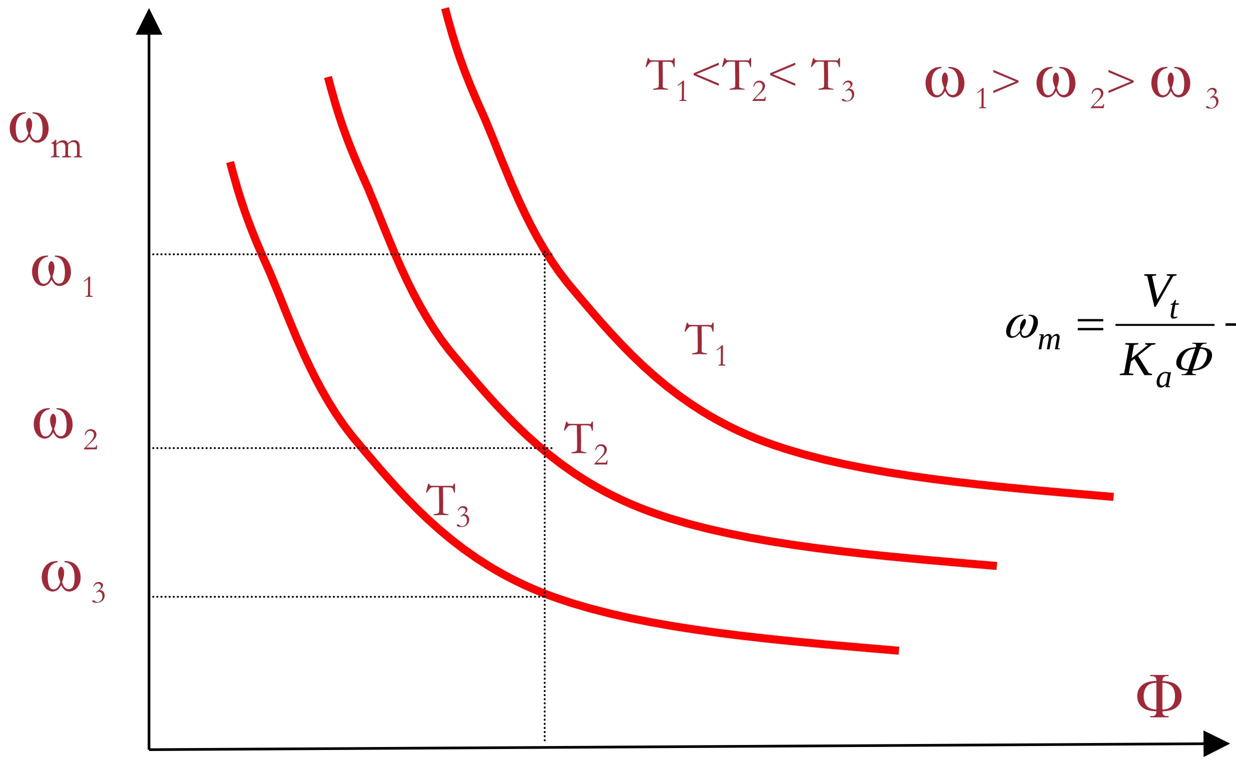
$T_1 < T_2 < T_3$ $V_1 < V_2 < V_3$



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

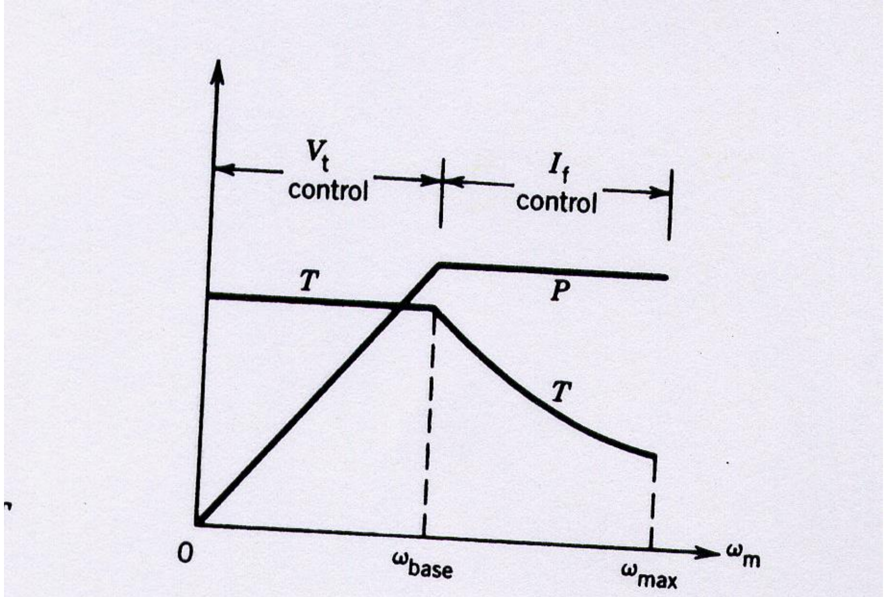
Speed Control of Separately Excited DC Motor

•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.



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

Regions of operation of a Separately Excited DC Motor



(d)

Separately excited dc motor –Example 2

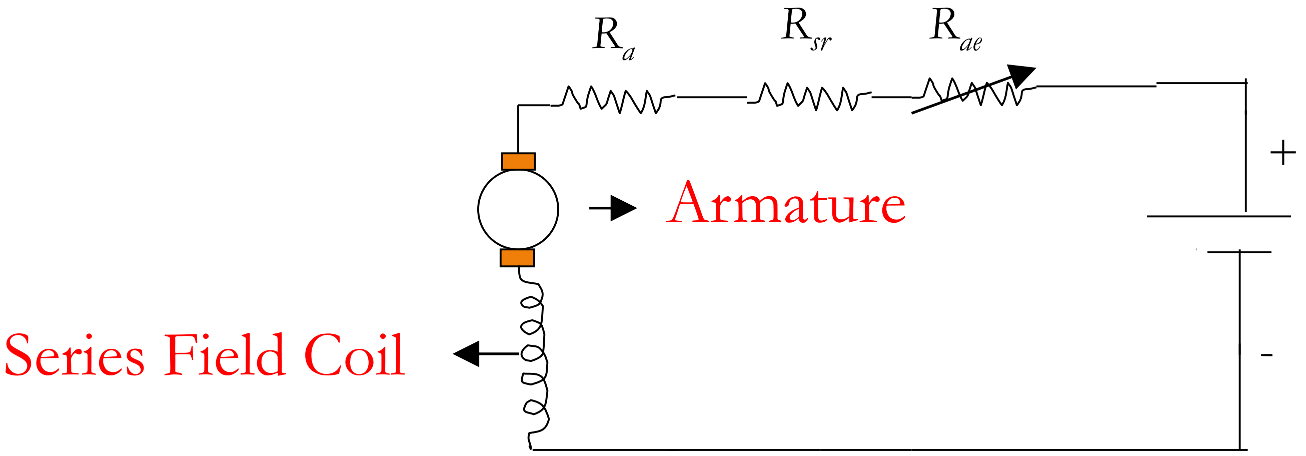
A separately excited dc motor with negligible armature resistance operates at 1800 rpm under no-load with V_t =240V(rated voltage). The rated speed of the motor is 1750 rpm.

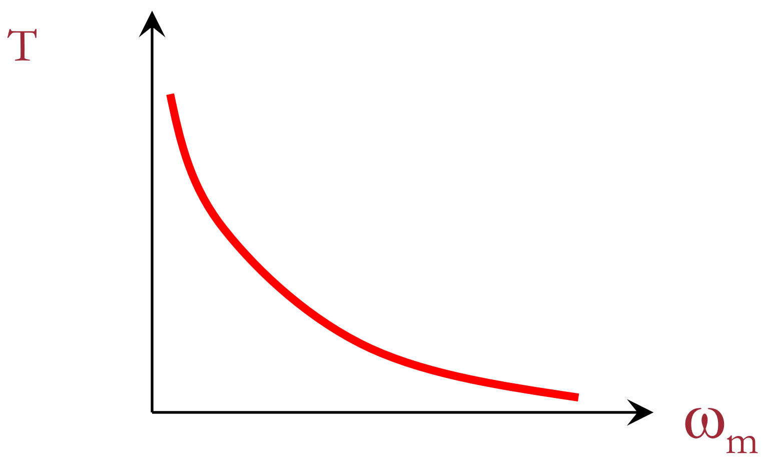
i) Determine V_t if the motor has to operate at 1200 rpm under no-load.

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.

Series Excited DC Motor Torque-Speed Characteristics





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

Losses in dc machines