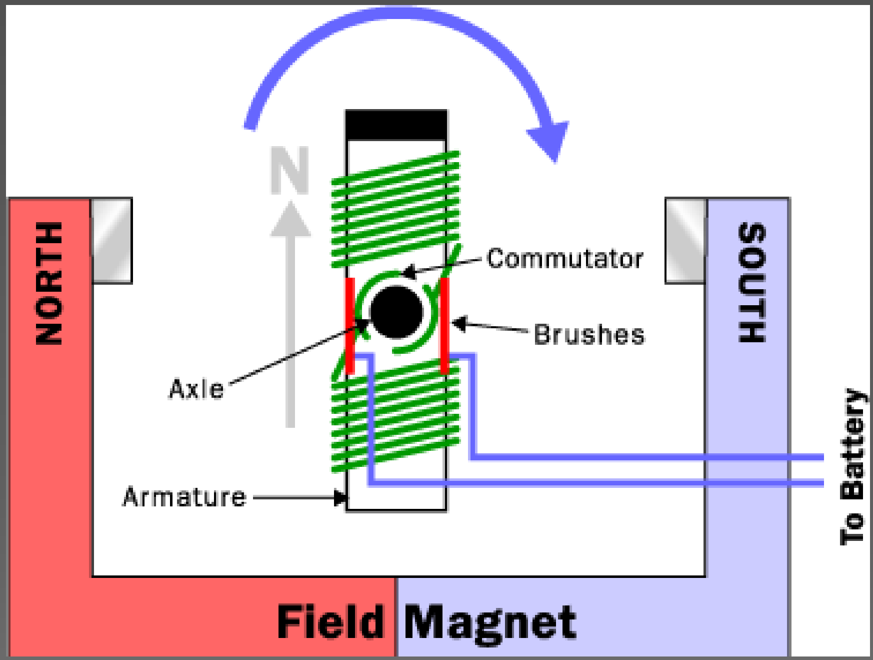
SECTION-D

DC MOTOR and its Applications

DC Motor Principles

DC motors consist of rotor-mounted windings (armature) and stationary windings (field poles). In all DC motors, except permanent magnet motors, current must be conducted to the armature windings by passing current through carbon brushes that slide over a set of copper surfaces called a commutator, which is mounted on the rotor.



Parts of an electric motor

The commutator bars are soldered to armature coils. The brush/commutator combination makes a sliding switch that energizes particular portions of the armature, based on the position of the rotor.

This process creates north and south magnetic poles on the rotor that are attracted to or repelled by north and south poles on the stator, which are formed by passing direct current through the field windings. It's this magnetic attraction and repulsion that causes the rotor to rotate.

Advantages

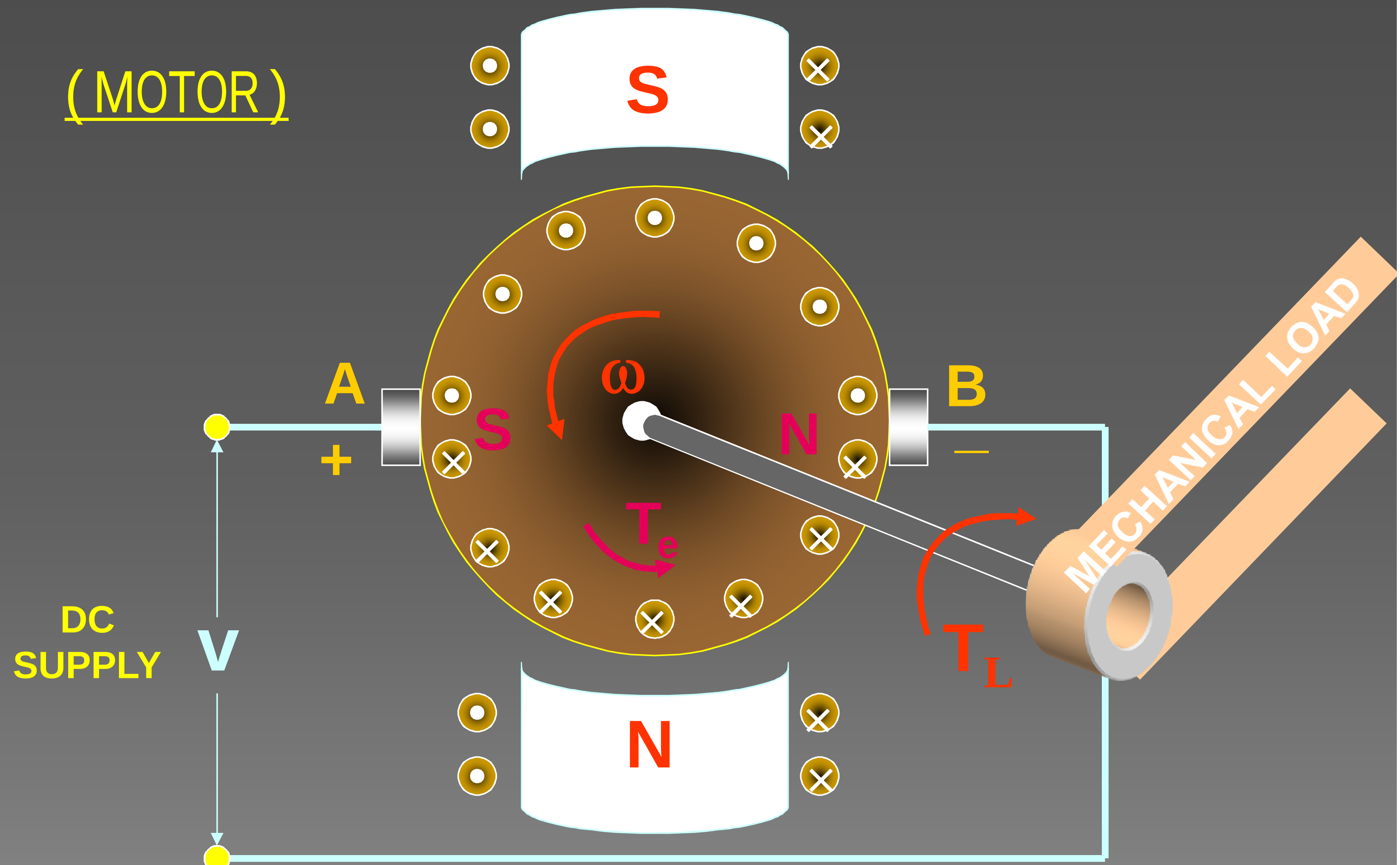
- The greatest advantage of DC motors may be speed control. Since speed is directly proportional to armature voltage and inversely proportional to the magnetic flux produced by the poles, adjusting the armature voltage and/or the field current will change the rotor speed.
- Today, adjustable frequency drives can provide precise speed control for AC motors, but they do so at the expense of power quality, as the solid-state switching devices in the drives produce a rich harmonic spectrum. The DC motor has no adverse effects on power quality.

Drawbacks

- Power supply, initial cost, and maintenance requirements are the negatives associated with DC motors
- Rectification must be provided for any DC motors supplied from the grid. It can also cause power quality problems.
- The construction of a DC motor is considerably more complicated and expensive than that of an AC motor, primarily due to the commutator, brushes, and armature windings. An induction motor requires no commutator or brushes, and most use cast squirrel-cage rotor bars instead of true windings — two huge simplifications.

DC MACHINES

(MOTOR)



A Two Pole DC Motor

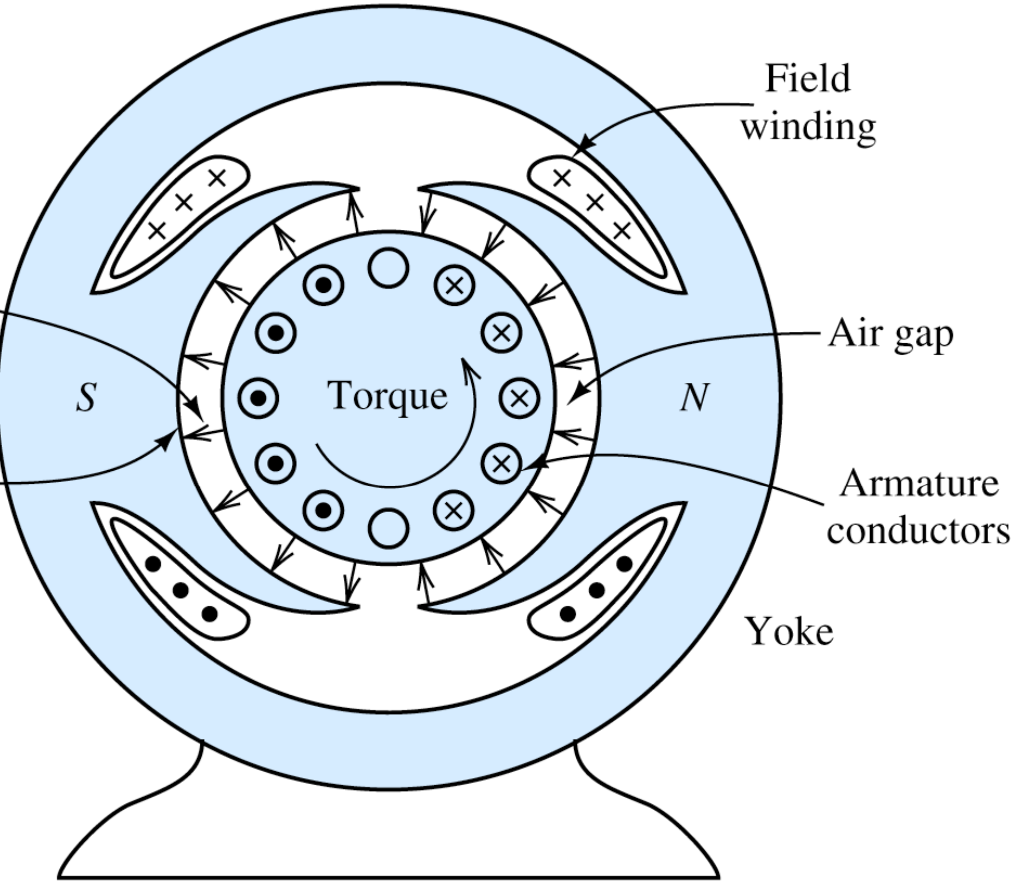


Figure 16.10 Cross section of a two-pole dc machine.

A Four Pole DC Motor

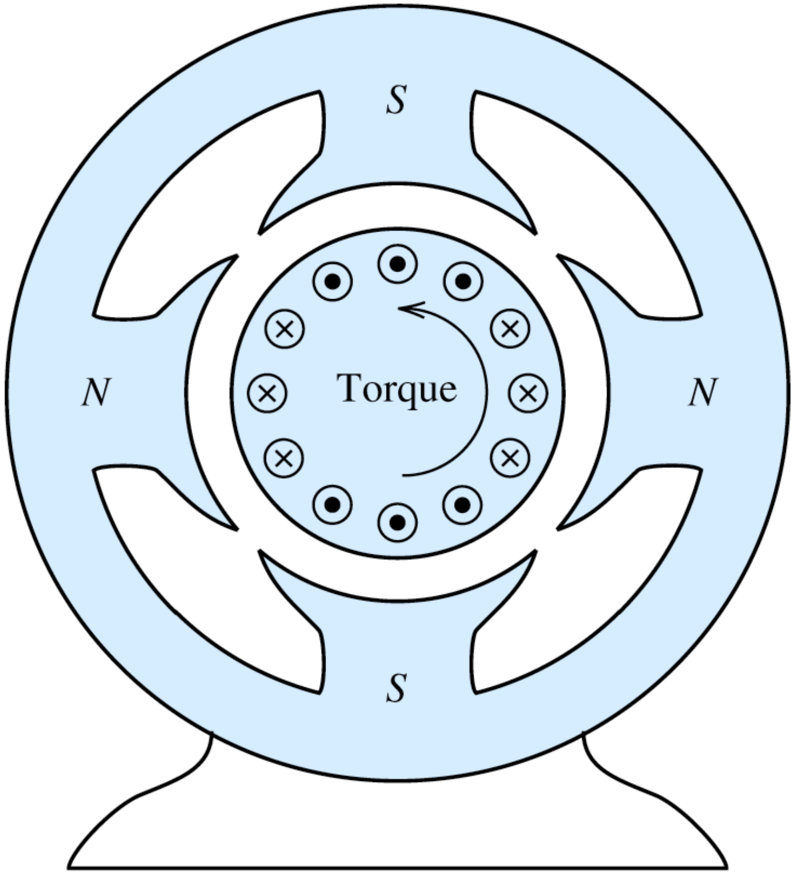
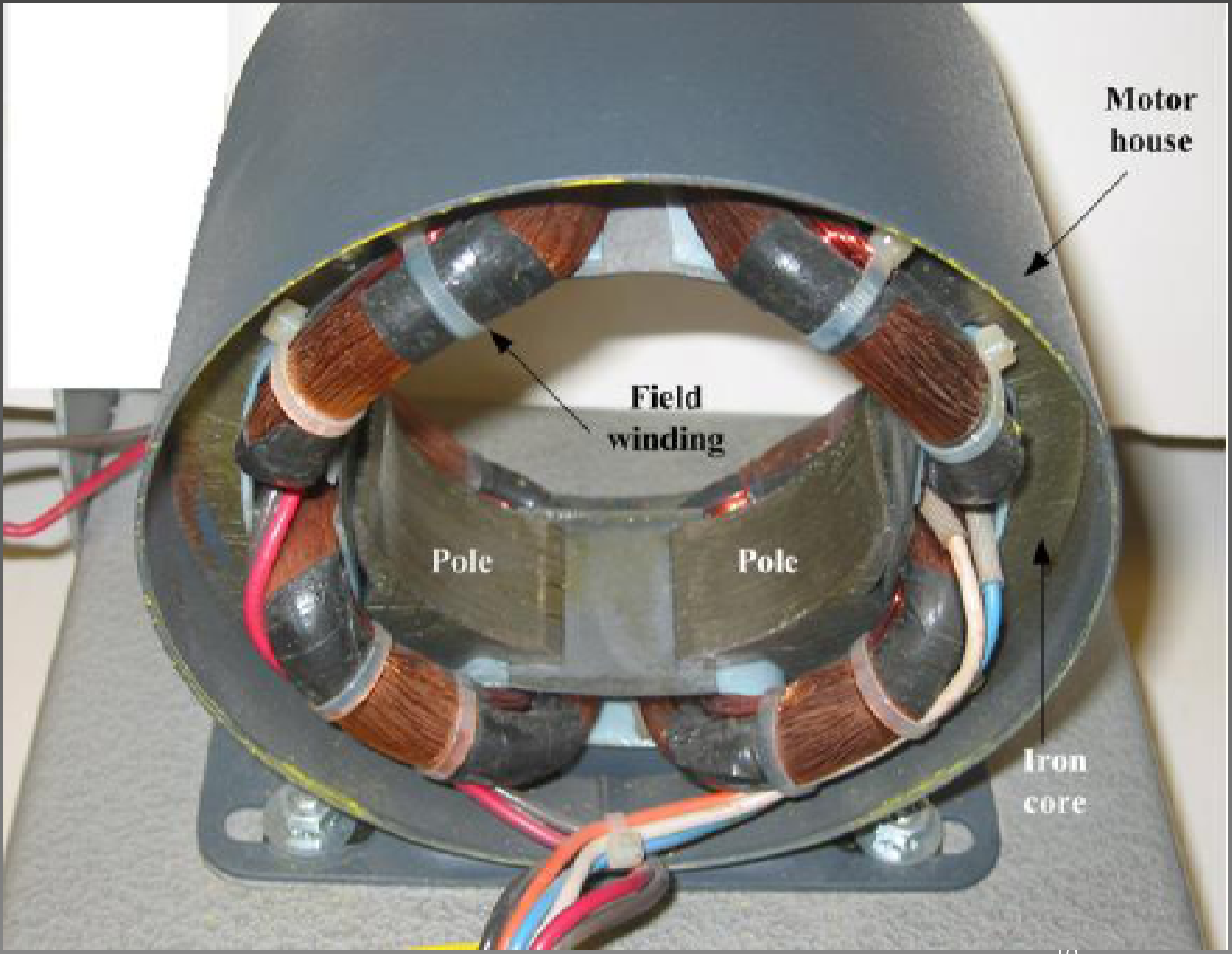
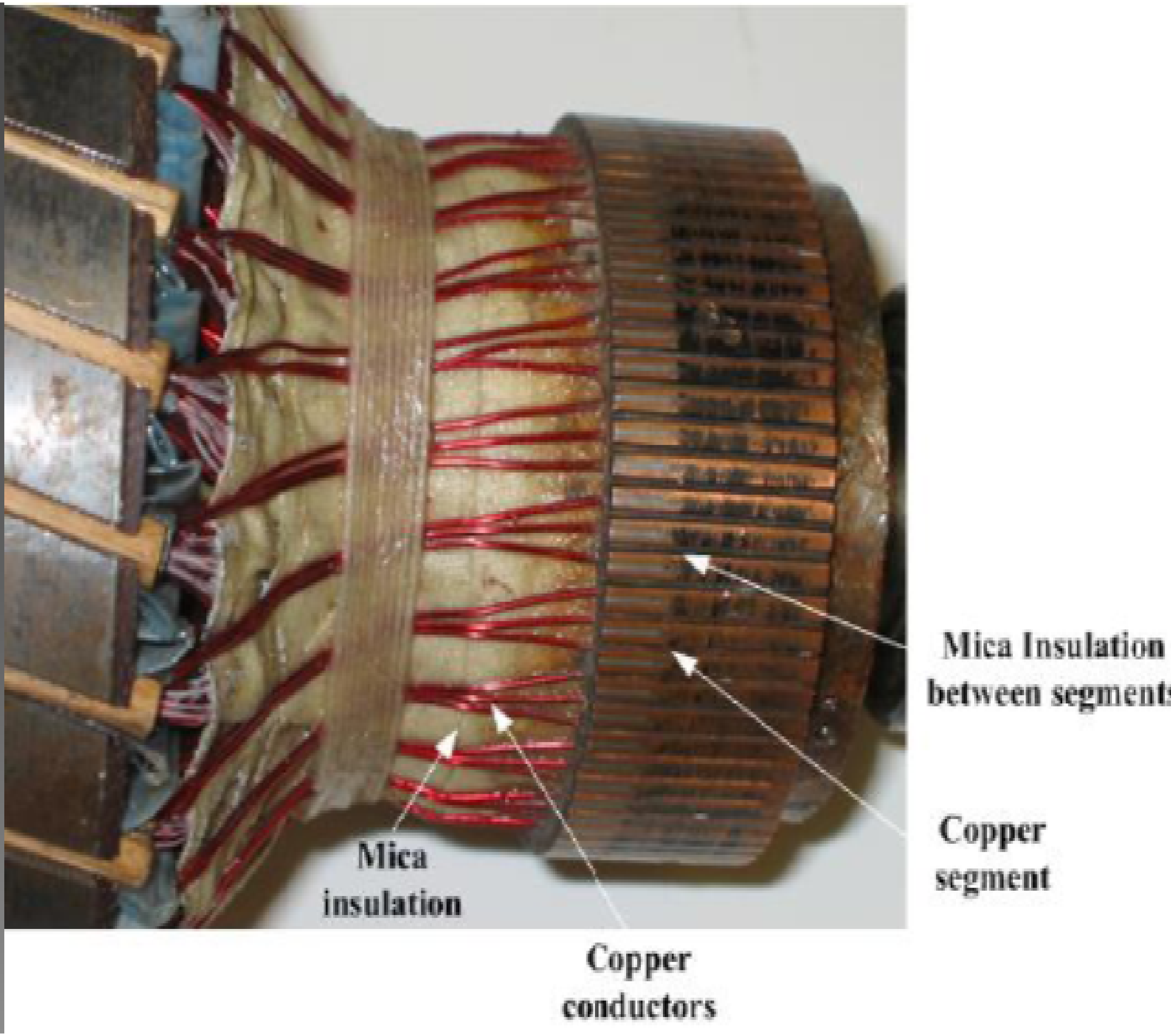
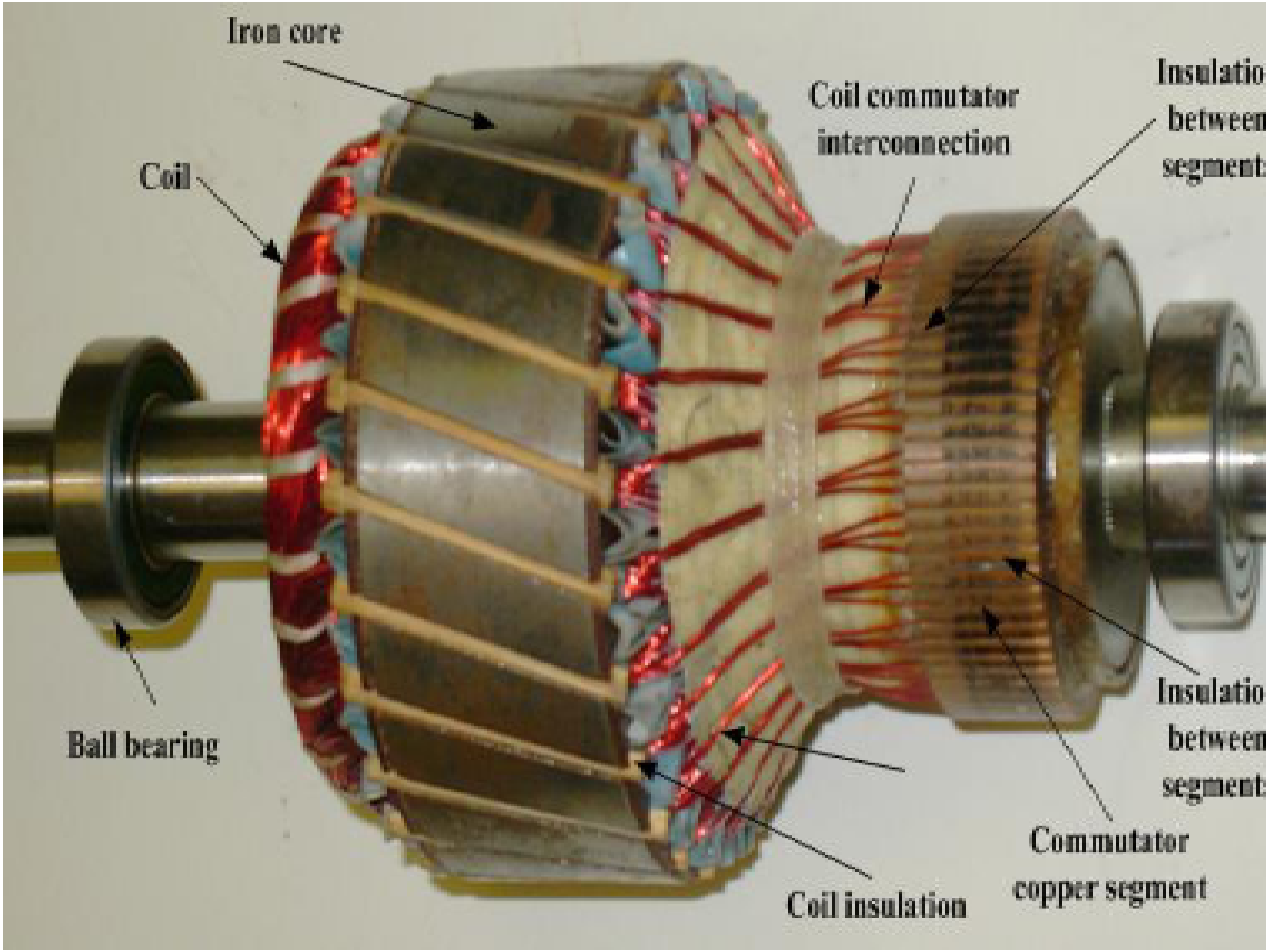


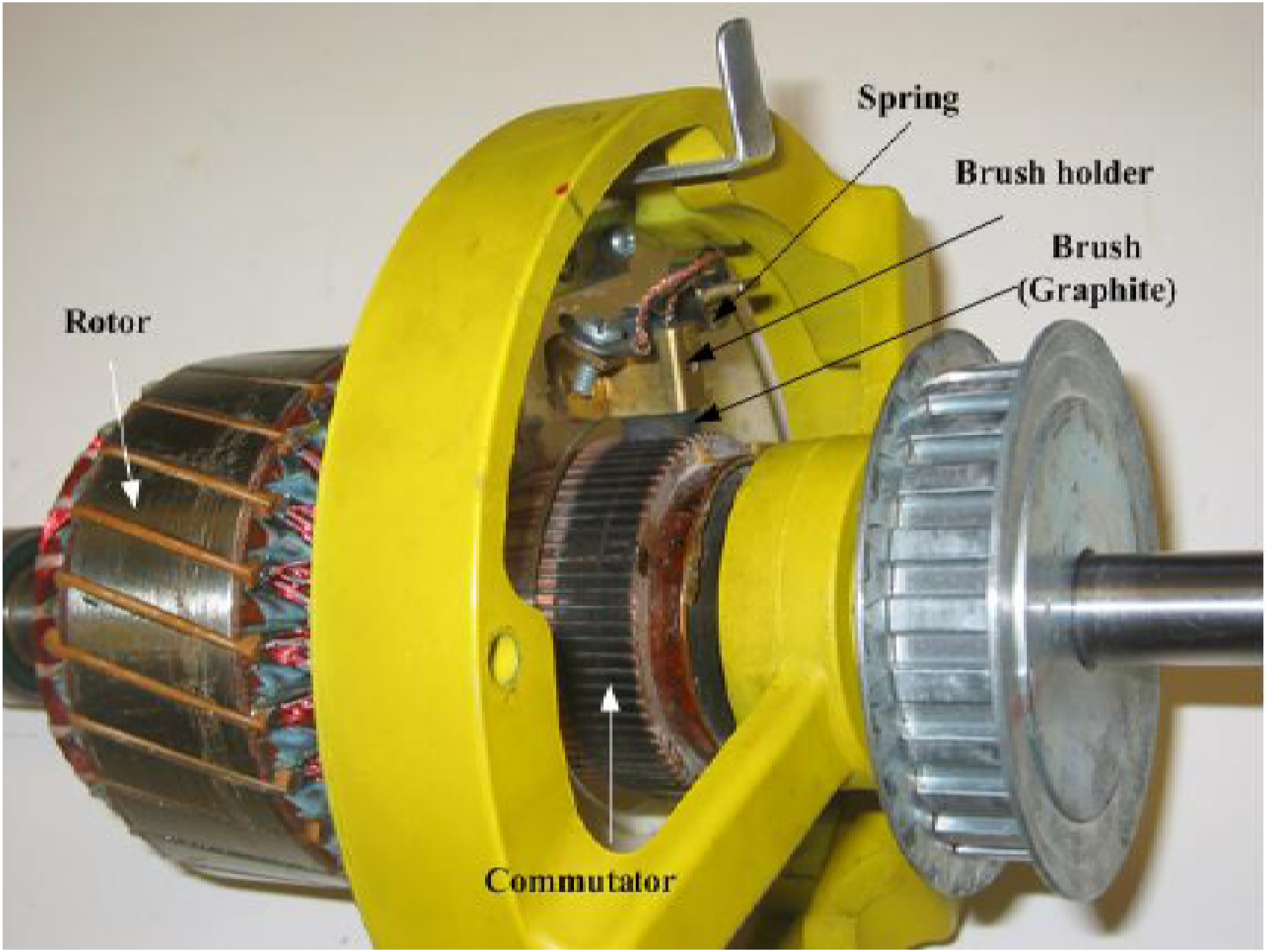
Figure 16.11 Cross section of a four-pole dc machine.


Motor
house
Field
winding
Pole
Pole
Iron
core


Mica Insulation between segments
Copper segment
Mica insulation
Copper conductors



Iron core
Coil commutator
interconnection
Insulatio
between
segment
Coil
Ball bearing
Insulatio
between
segment
Commutator
copper segment
Coil insulation


Spring
Brush holder
Brush
(Graphite)
Rotor
Commutator

Armature of a DC Motor

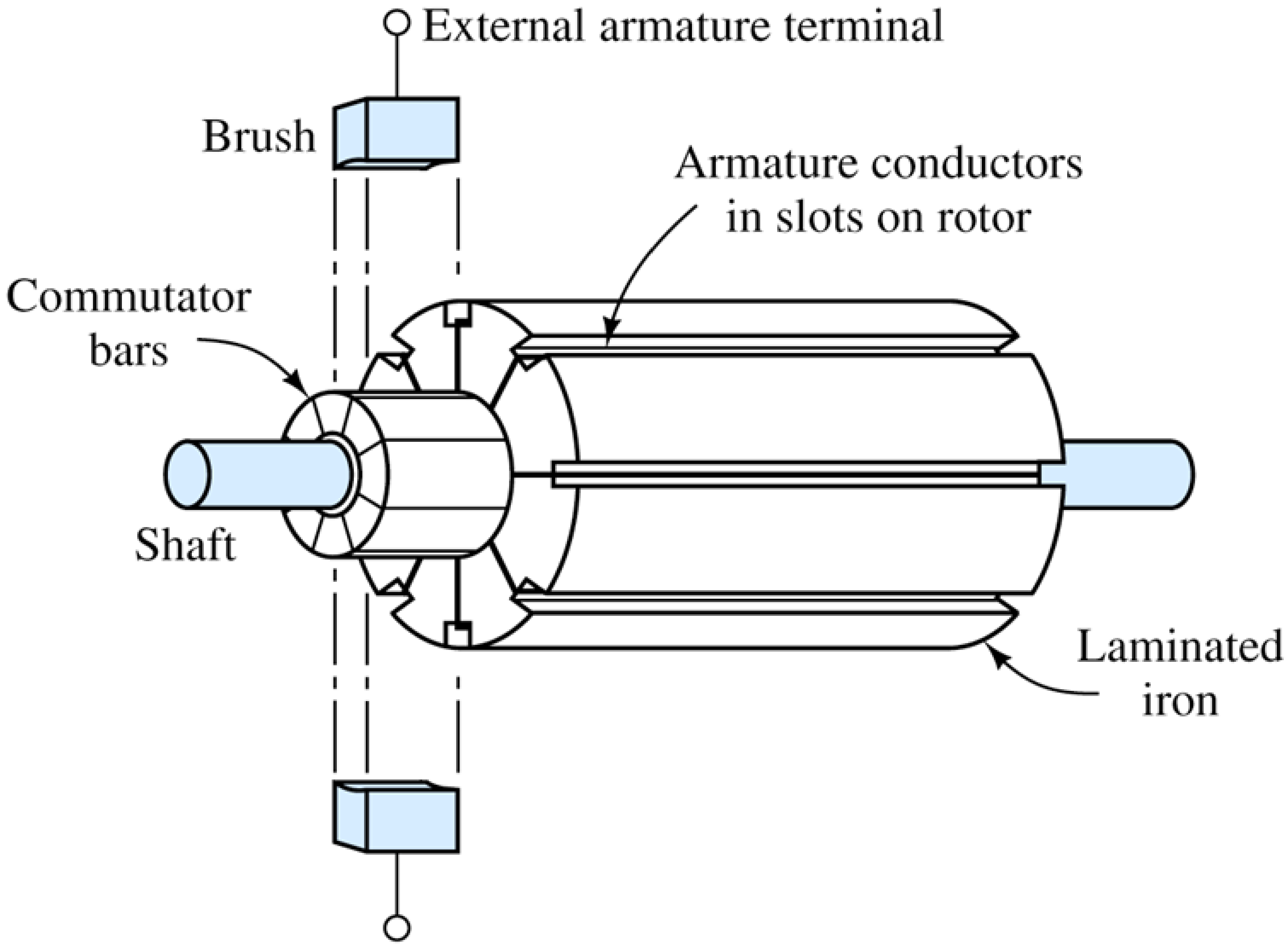


Figure Rotor assembly of a dc machine.

Generated Voltage in a DC Machine

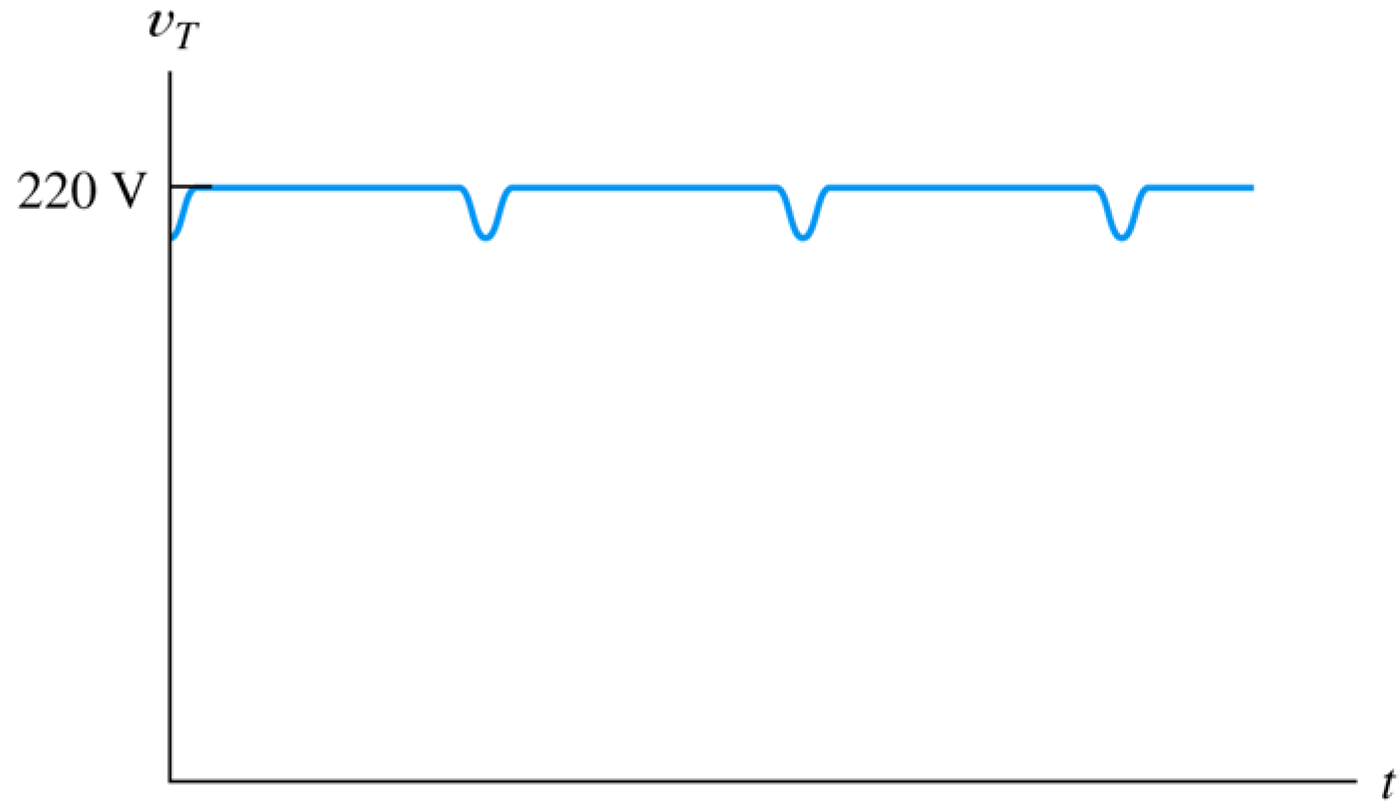


Figure Voltage produced by a practical dc machine. Because only a few (out of many) conductors are commutated (switched) at a time, the voltage fluctuations are less pronounced than in the single-loop case

Armature Winding in a DC Machine

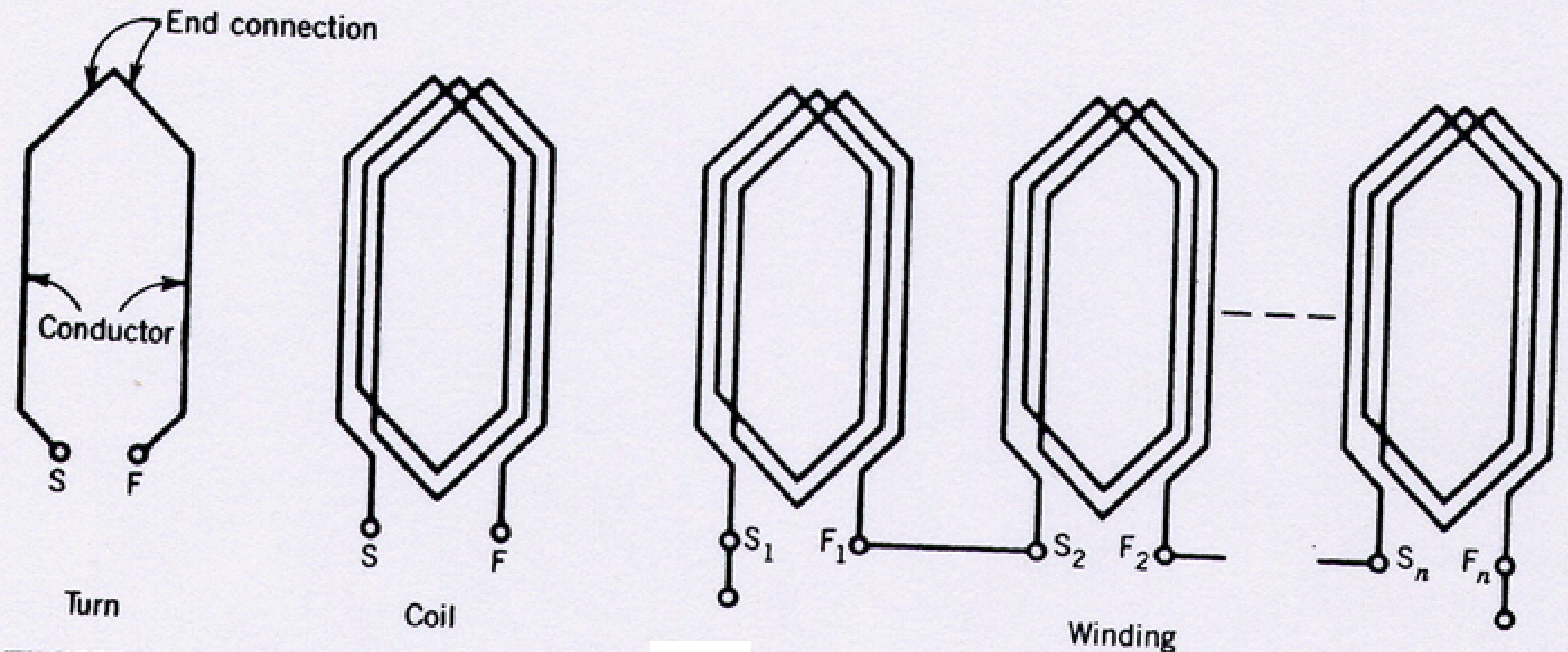


FIGURE Turn, coil, and winding.

Lap Winding of a DC Machine

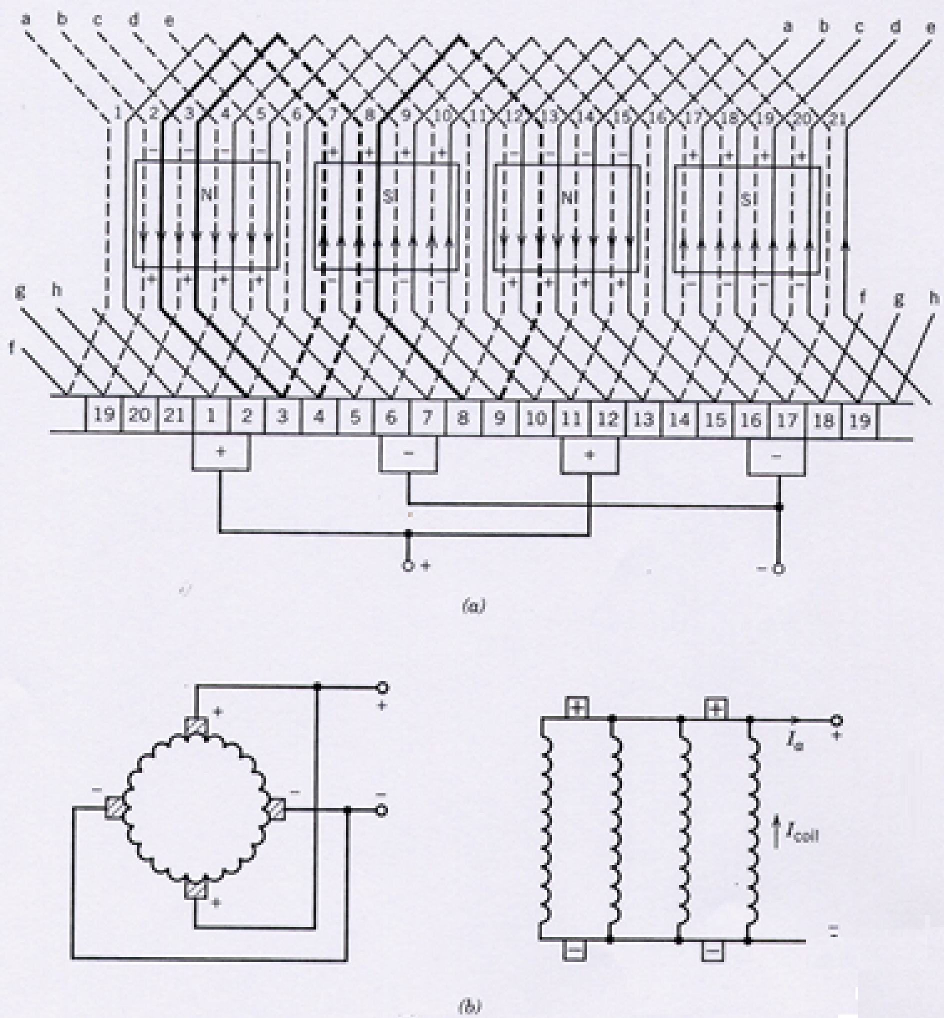


FIGURE Lap winding. (a) Unrolled winding. (b) Equivalent coil representation.

Used in high current low voltage circuits

Number of parallel paths equals number of brushes or poles

Wave Winding of a DC Machine

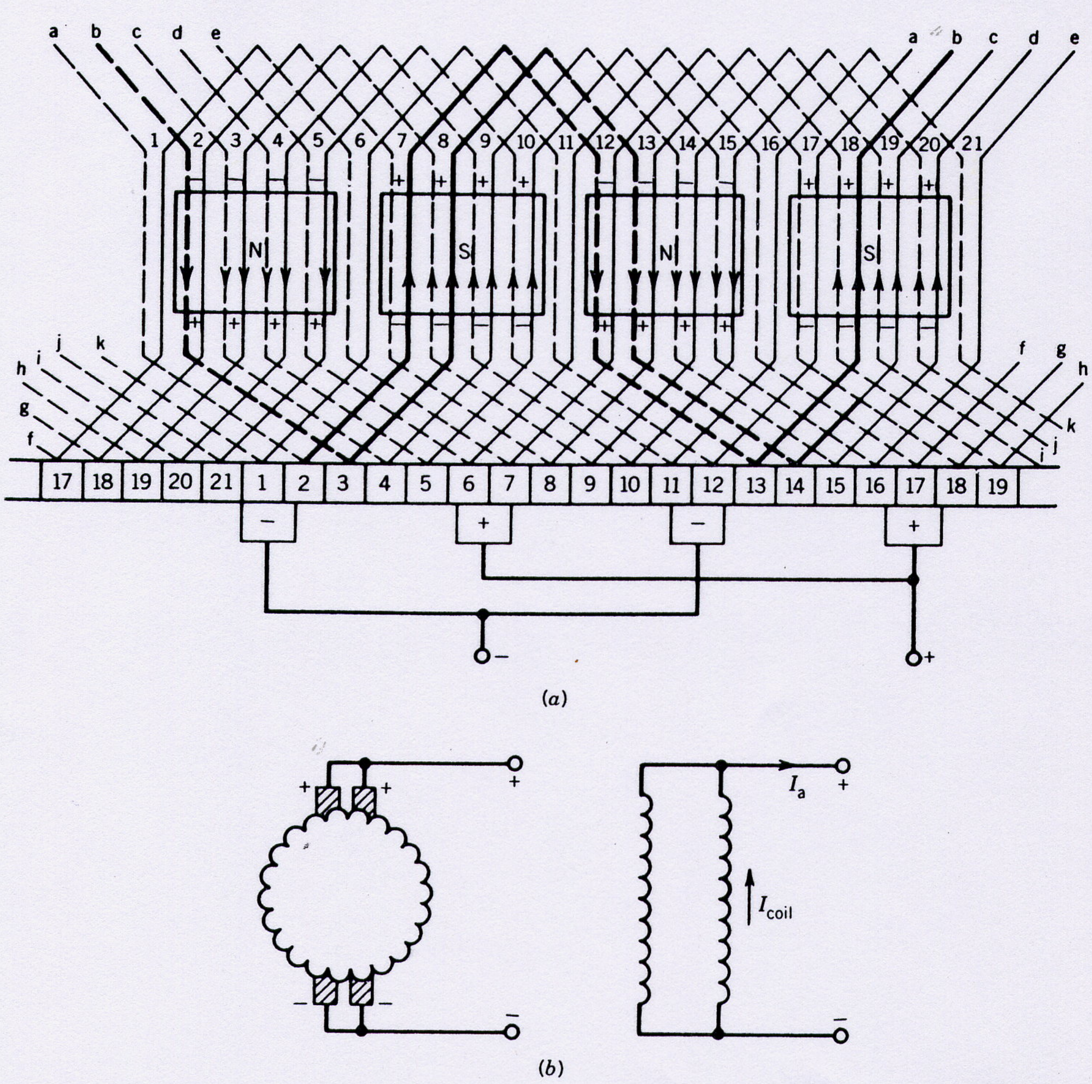


FIGURE 4.18 Wave winding. (*a*) Unrolled winding. (*b*) Equivalent coil representation.

- Used in high voltage low current circuits
- Number of llal 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,

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

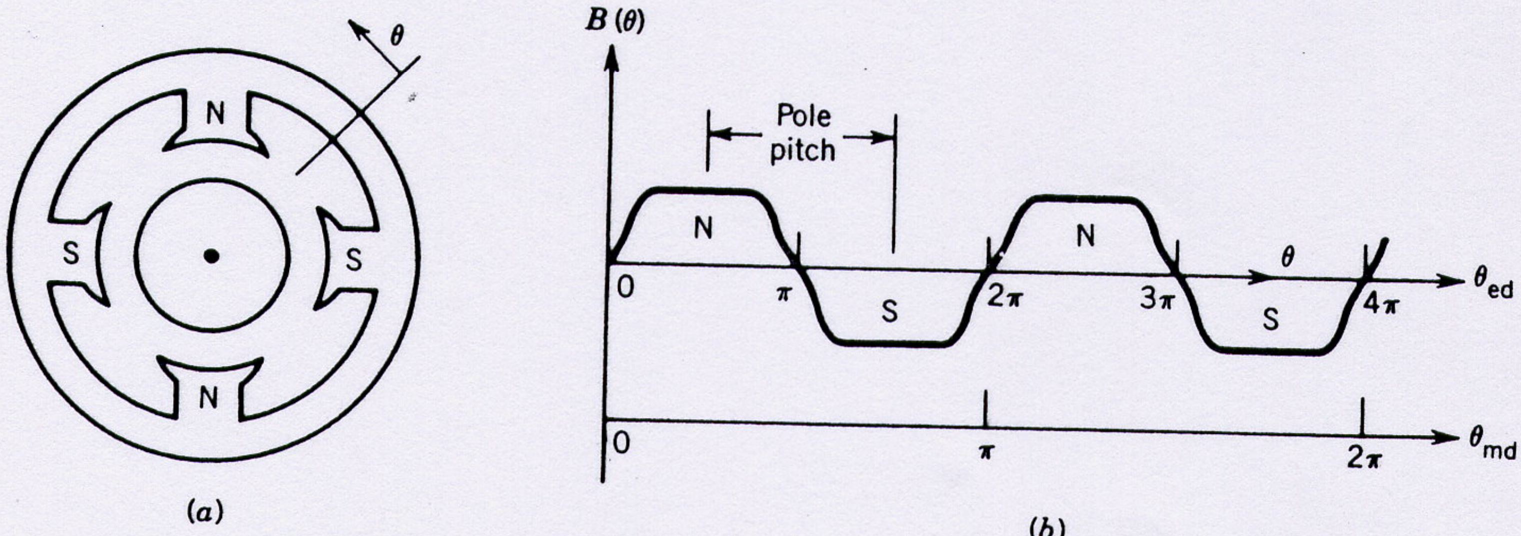


FIGURE 4.16 Mechanical and electrical degrees. (*a*) Four-pole dc machine. (*b*) Flux density distribution.

Magnetic circuit of a 2 pole DC Machine

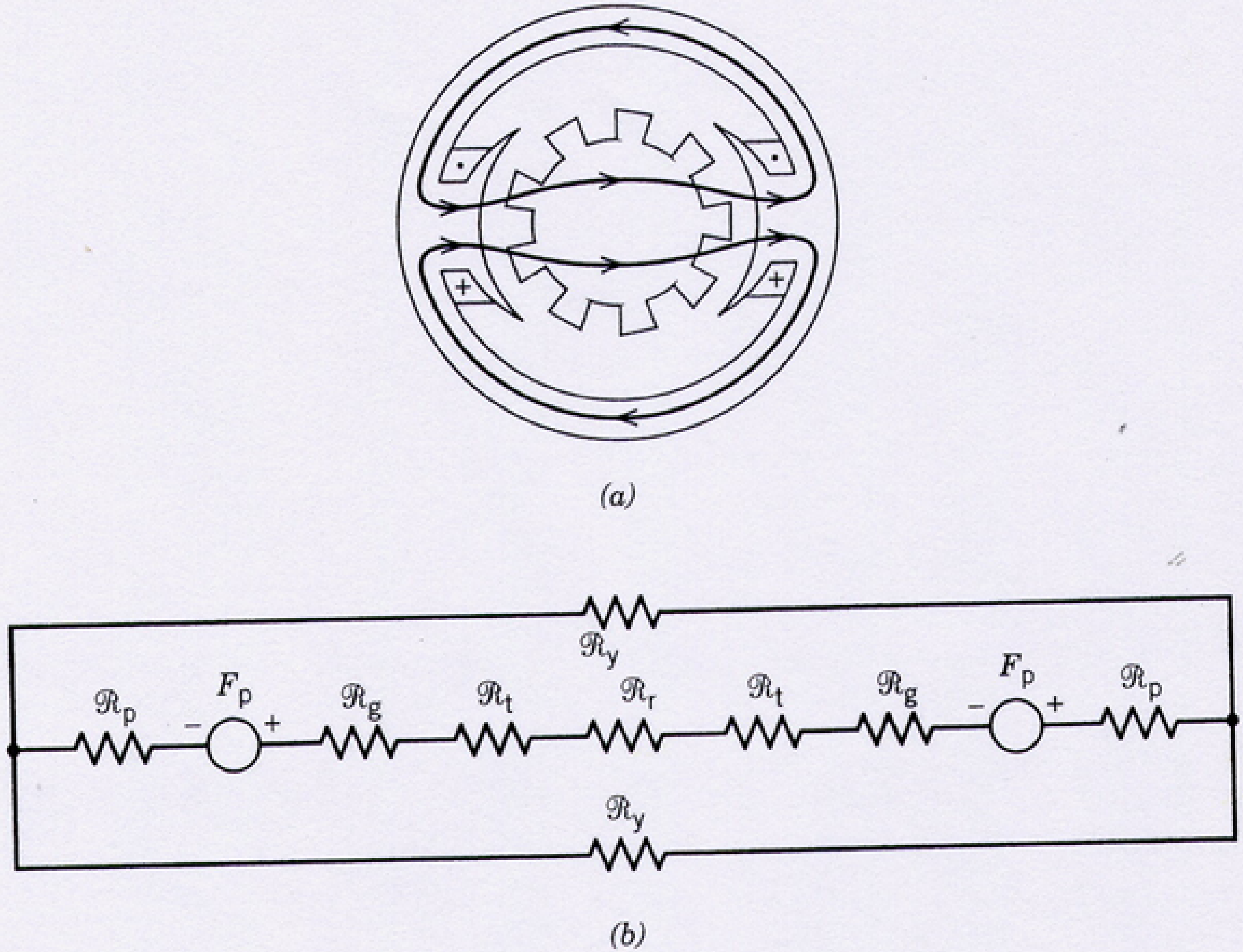


FIGURE .Magnetic circuit. (*a*) Cross-sectional view. (*b*) Equivalent circuit.

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

Expression for induced voltage in a DC Machine

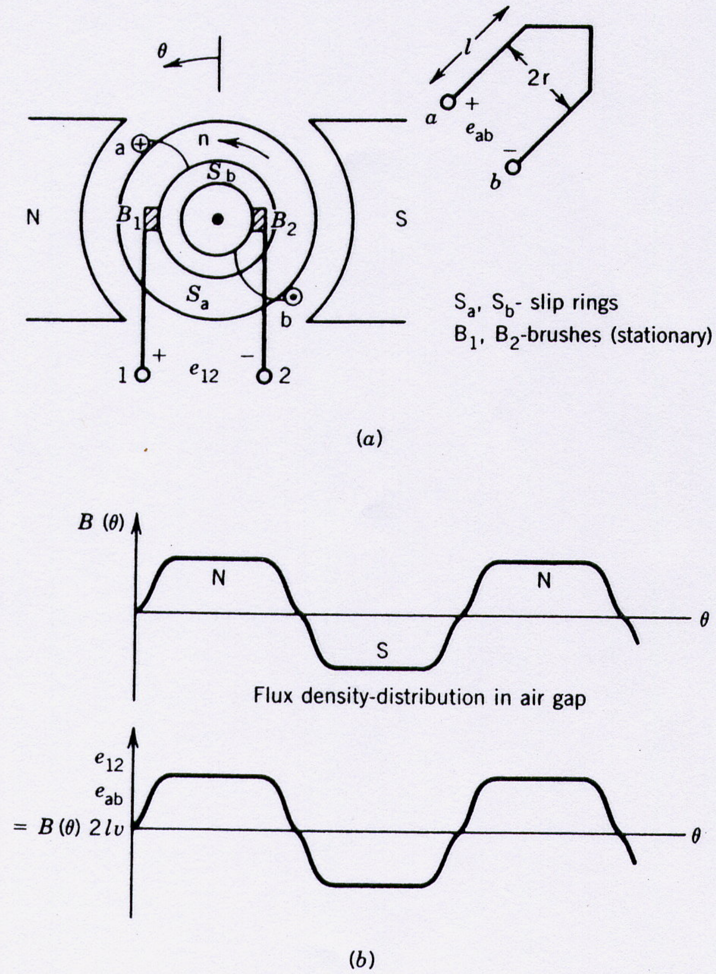


FIGURE 4.12 Induced voltage in a dc machine. (*a*) Two-pole dc machine. (*b*) Induced voltage in a turn.

Deriving the electromagnetic torque in a DC Machine

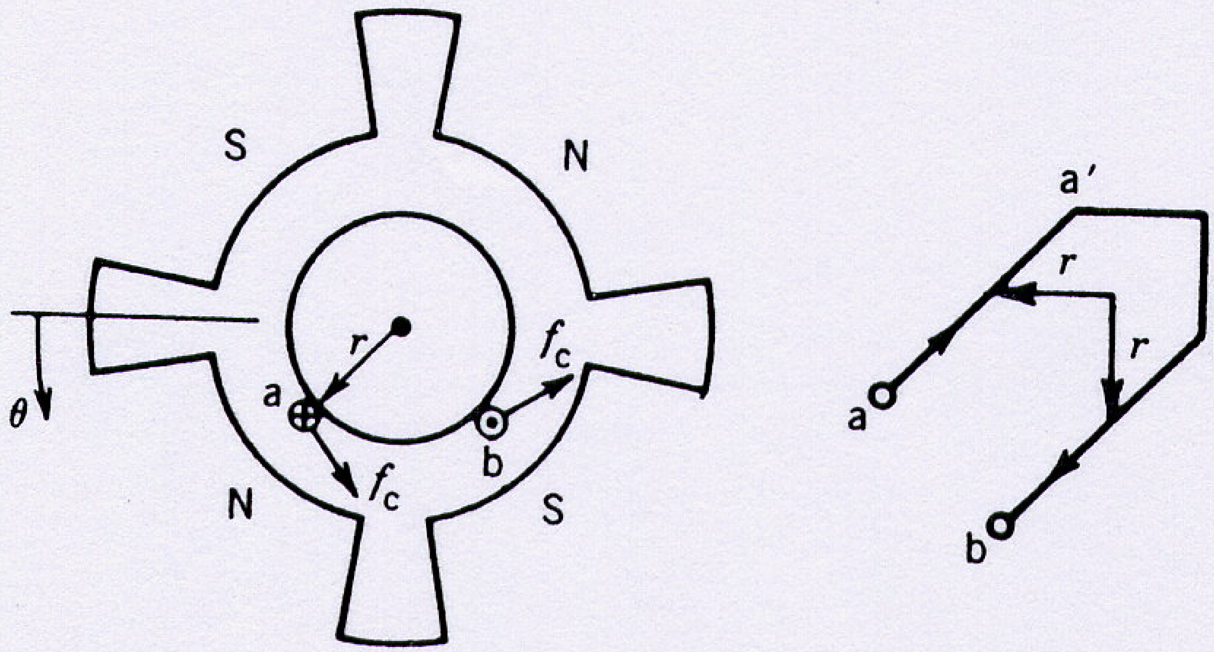


FIGURE 4.19 Torque production in dc machine.

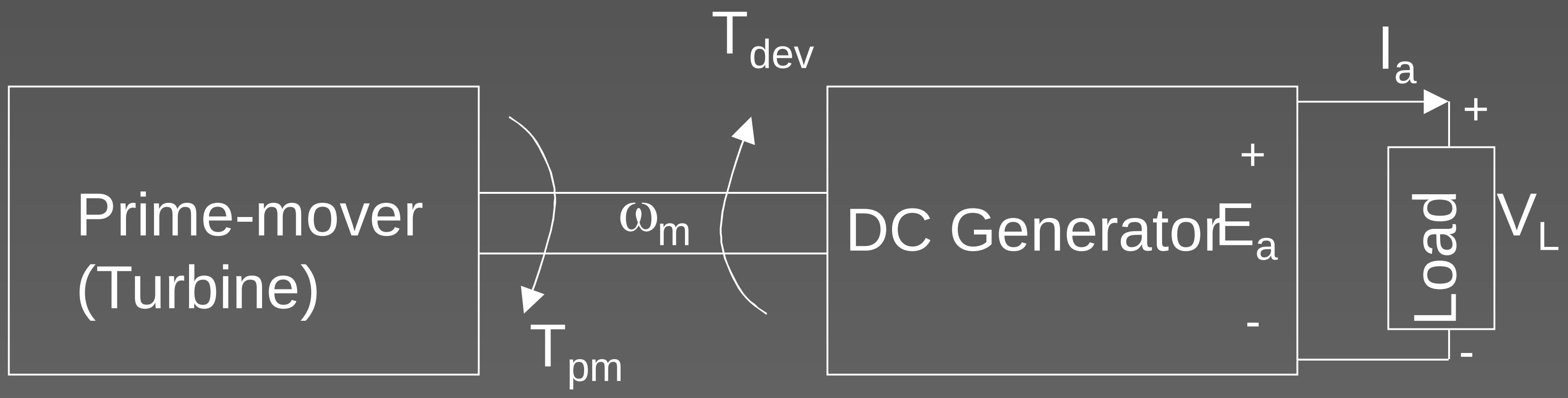
Voltage and Torque developed in a DC Machine

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

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

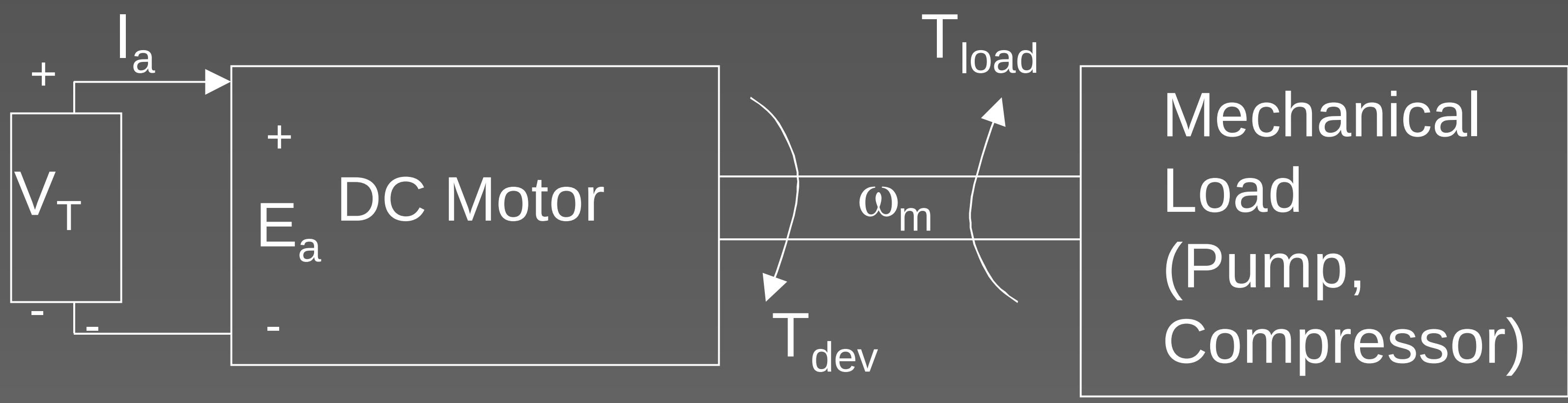
where ω_m is the speed of the armature in rad/sec., Φ is the flux per pole in weber (Wb)
I_a is the Armature current
K_a is the machine constant

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)

TYPES OF EXCITATIONS (DC MOTORS)

Depending upon the type if excitation to the field winding , The dc machine can be classified into three categories viz.

- Machines with permanent field,
- separately excited
- and self excited type dc machines.

TYPES OF EXCITATIONS (DC MOTORS)

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.

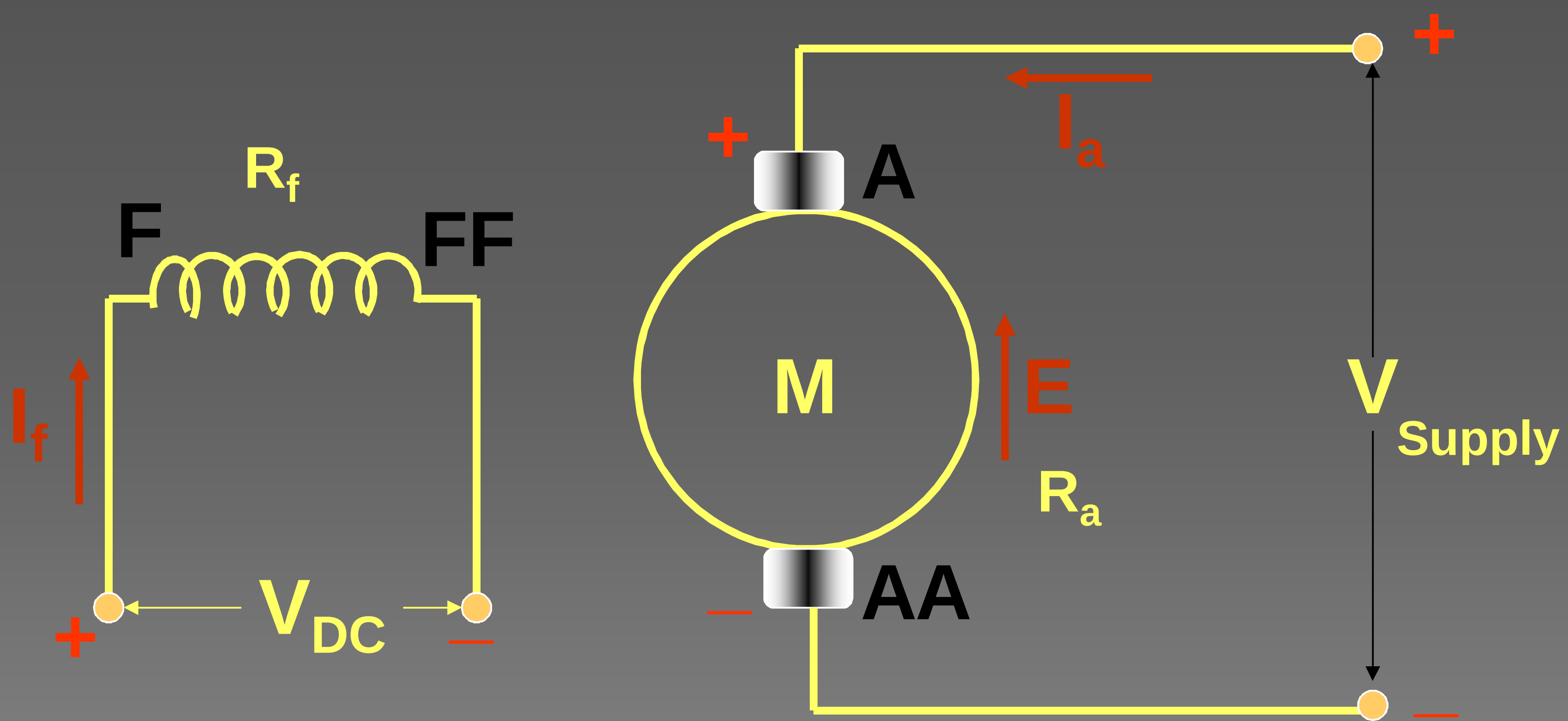
TYPES OF EXCITATIONS (DC MOTORS)

Depending upon the type of connections to the field winding for excitation , the dc motors can be classified into two categories :

1) Separately excited dc motors

2) Self excited dc motors.

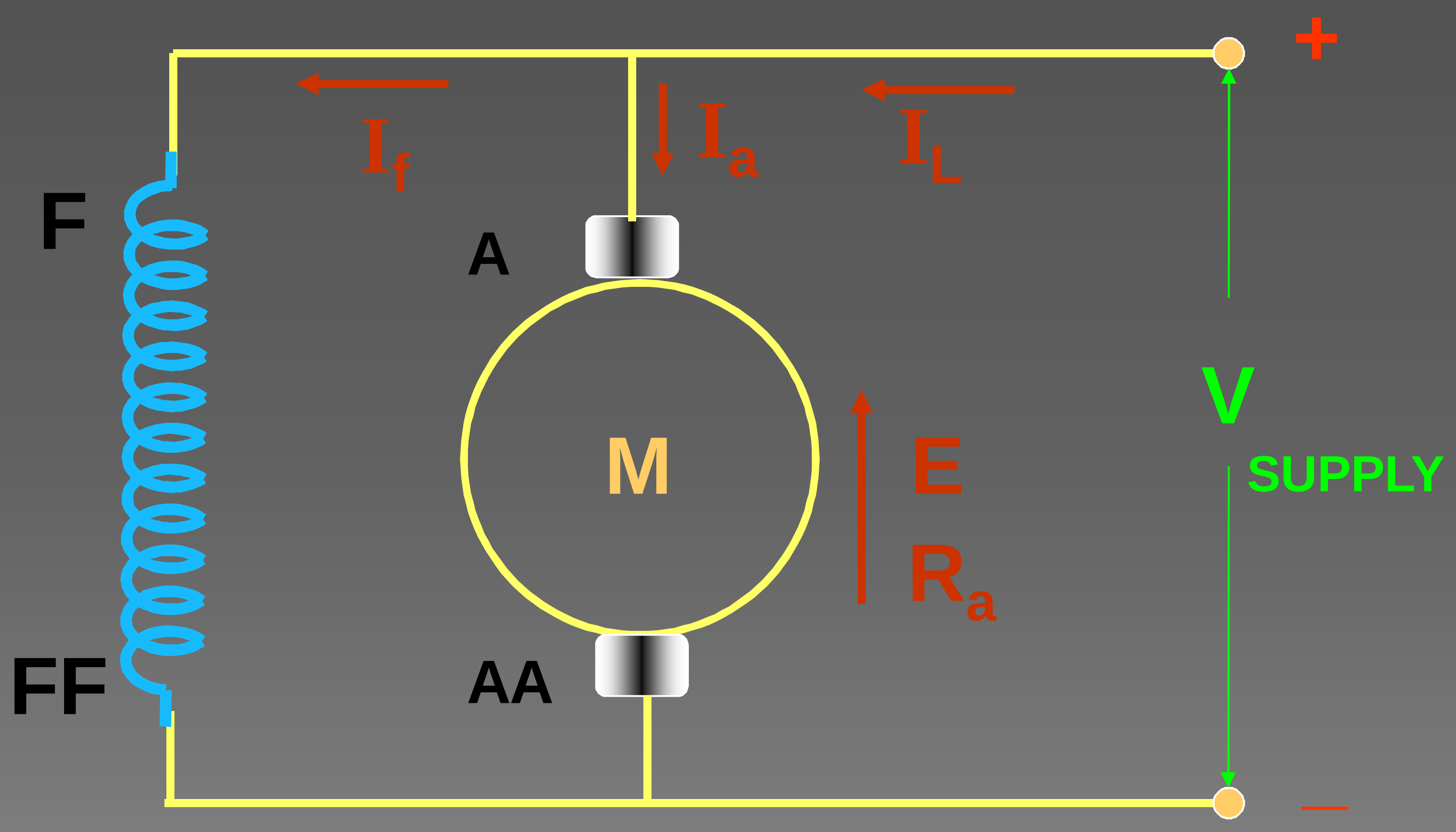
SEPARATELY EXCITED DC MOTORS



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. $Ø \propto I_f$

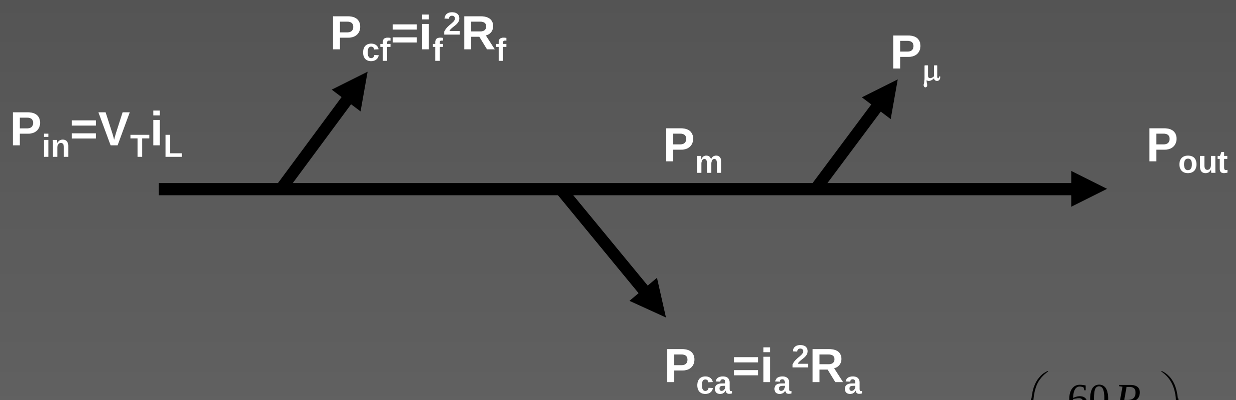
SELF EXCITED DC SHUNT MOTORS



SELF EXCITED DC 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. As shown in fig.

Shunt Motor (power flow diagram)



P_μ is normally given

$P_{in} = P_{out}$ + total losses

Where,

P_{ca} =armature copper loss
P_{cf} =field copper loss
$P\mu$=stray, mech etc

$P_m = E_a\, i_a$

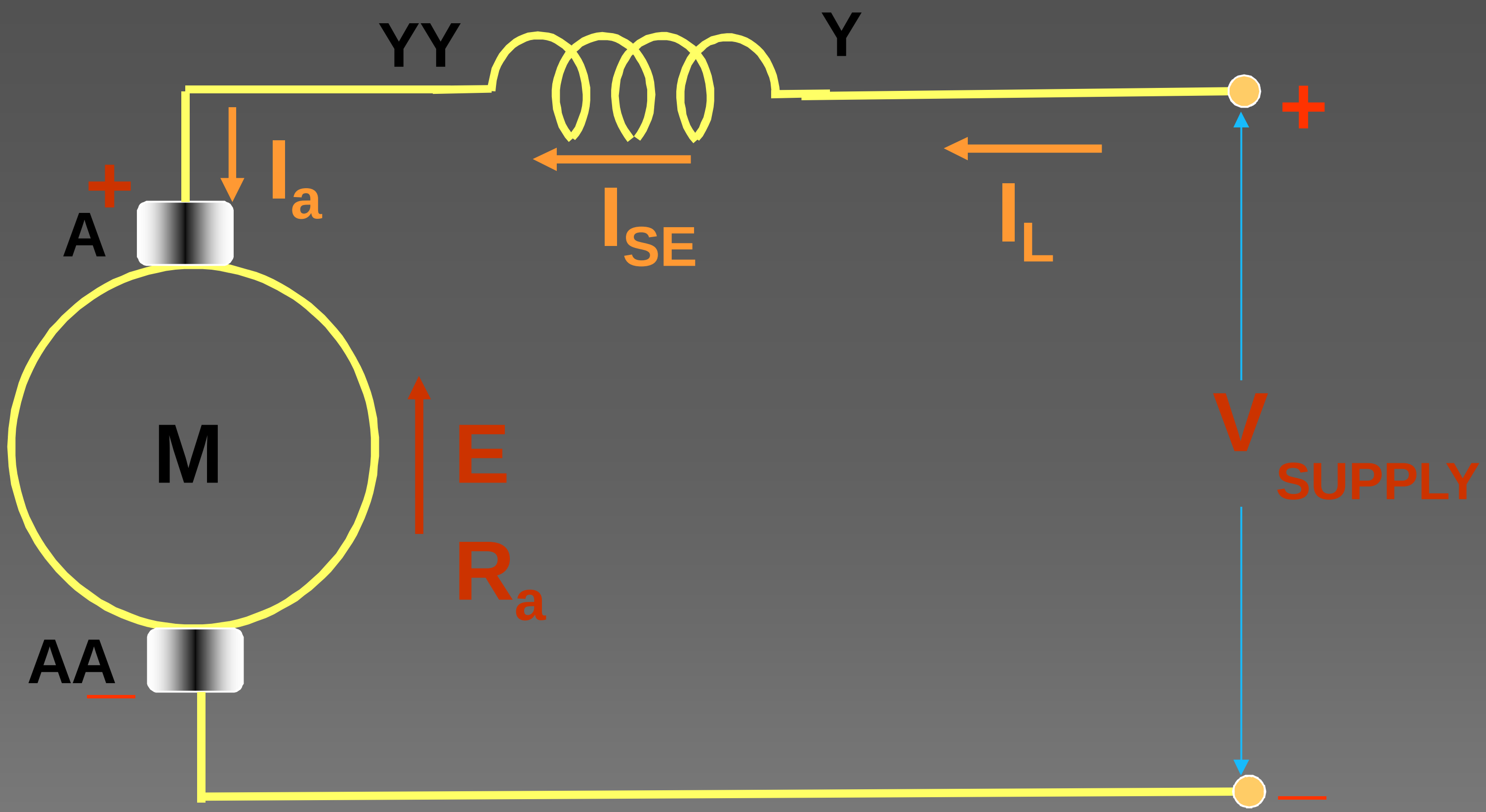
$$\tau = \left(\frac{60\,P}{2\pi\; N}\right)$$

$$for\ output\ /\ load\ torque\ ,\tau_o = \left(\frac{60\,P_o}{2\pi\; N}\right)$$

$$for\ mechanical\ \ torque\ ,\tau_m = \left(\frac{60\,P_m}{2\pi\; N}\right)$$

$$Efficiency\ ,\ \eta = \left(\frac{P_{out}}{P_{in}}\right)$$

SELF EXCITED DC SERIES MOTORS



SELF EXCITED DC 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 , $\varnothing \propto I_f \propto I_a$.

SELF EXCITED DC SERIES MOTORS

The relationship between induced e.m.f. and terminal voltage is as follows:

$$V = E + I_a R_a + I_a R_{se}$$

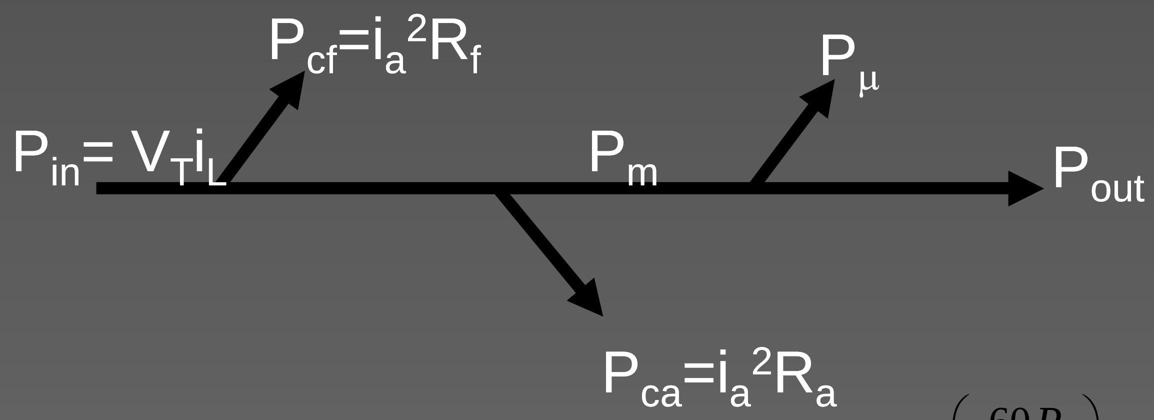
or

$$E = V - I_a (R_a + R_{se})$$

and

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

Series Motor Power Flow Diagram



P_μ is normally given

$P_{in} = P_{out}$ + total losses

Where,

P_{ca} =armature copper loss

P_{cf} =field copper loss

P_μ=stray, mech etc

$P_m= E_a i_a$

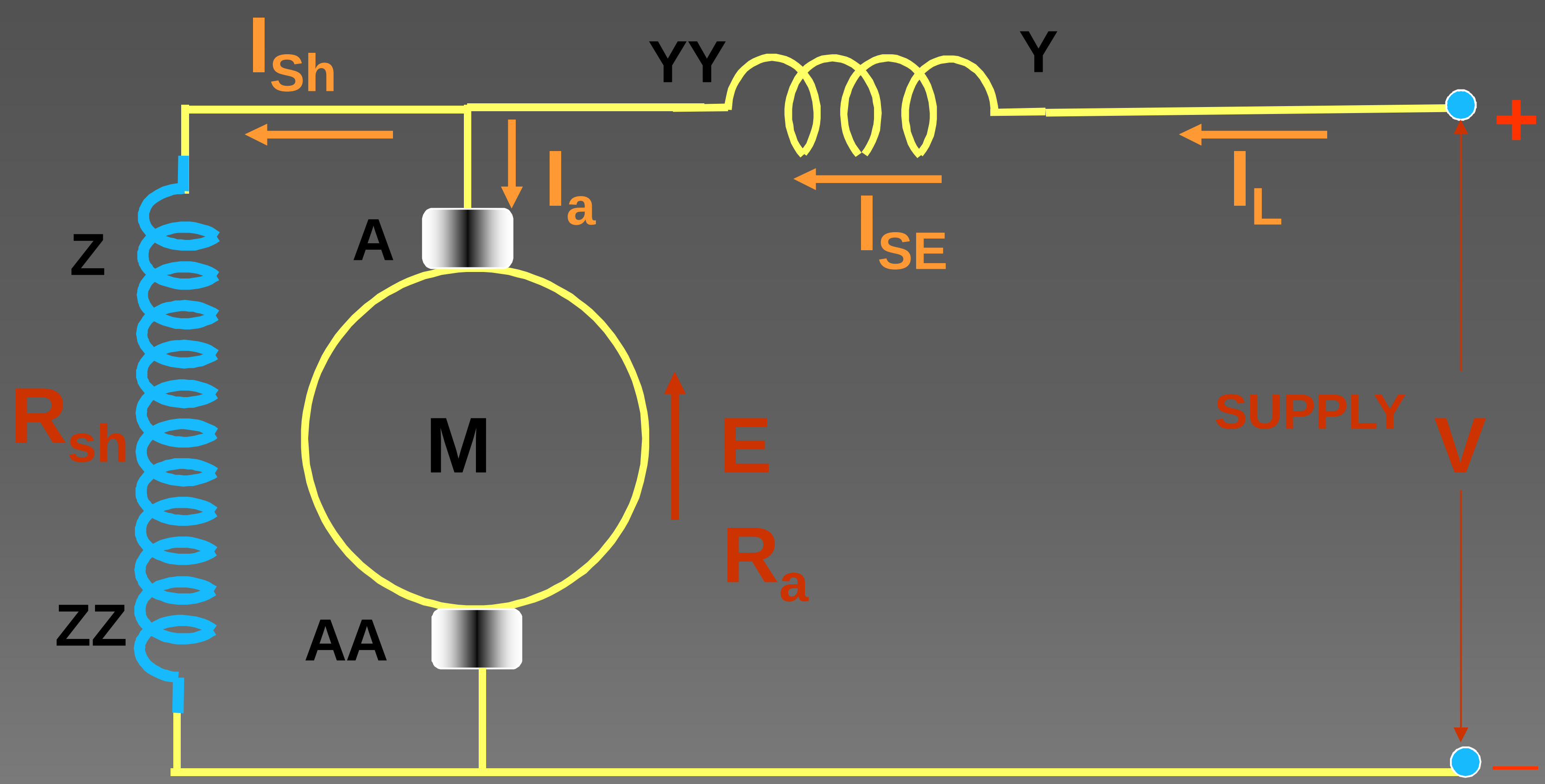
$$\tau = \left(\frac{60P}{2\pi N} \right)$$

$$\textit{for output / load torque}, \tau_o = \left(\frac{60P_o}{2\pi N} \right)$$

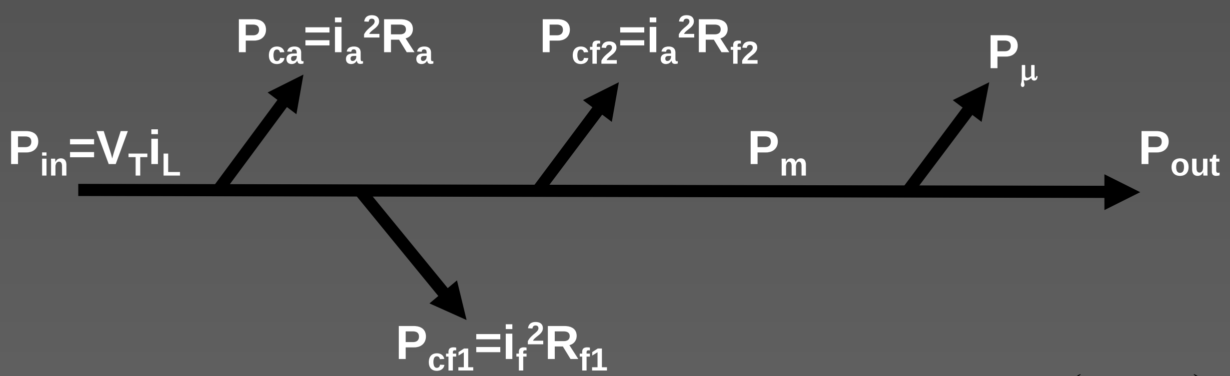
$$\textit{for mechanical torque}, \tau_m = \left(\frac{60P_m}{2\pi N} \right)$$

$$\textit{Efficiency}, \eta = \left(\frac{P_{out}}{P_{in}} \right)$$

SELF EXCITED DC COMPOUND MOTORS



Compound motor (power flow diagram)



P_μ is normally given

$P_{in} = P_{out}$ + total losses

Where,

P_{ca} =armature copper loss
P_{cf} =field copper loss
$P\mu$=stray, mech etc

$P_m= E_a\, i_a$

$$\tau = \left(\frac{60P}{2\pi N} \right)$$

$$\textit{for output / load torque}, \tau_o = \left(\frac{60P_o}{2\pi N} \right)$$

$$\textit{for mechanical torque}, \tau_m = \left(\frac{60P_m}{2\pi N} \right)$$

$$\textit{Efficiency}, \eta = \left(\frac{P_{out}}{P_{in}} \right)$$

SELF EXCITED DC COMPOUND 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 .

SELF EXCITED DC COMPOUND MOTORS

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.

SELF EXCITED DC COMPOUND MOTORS

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

SELF EXCITED DC COMPOUND MOTORS

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.

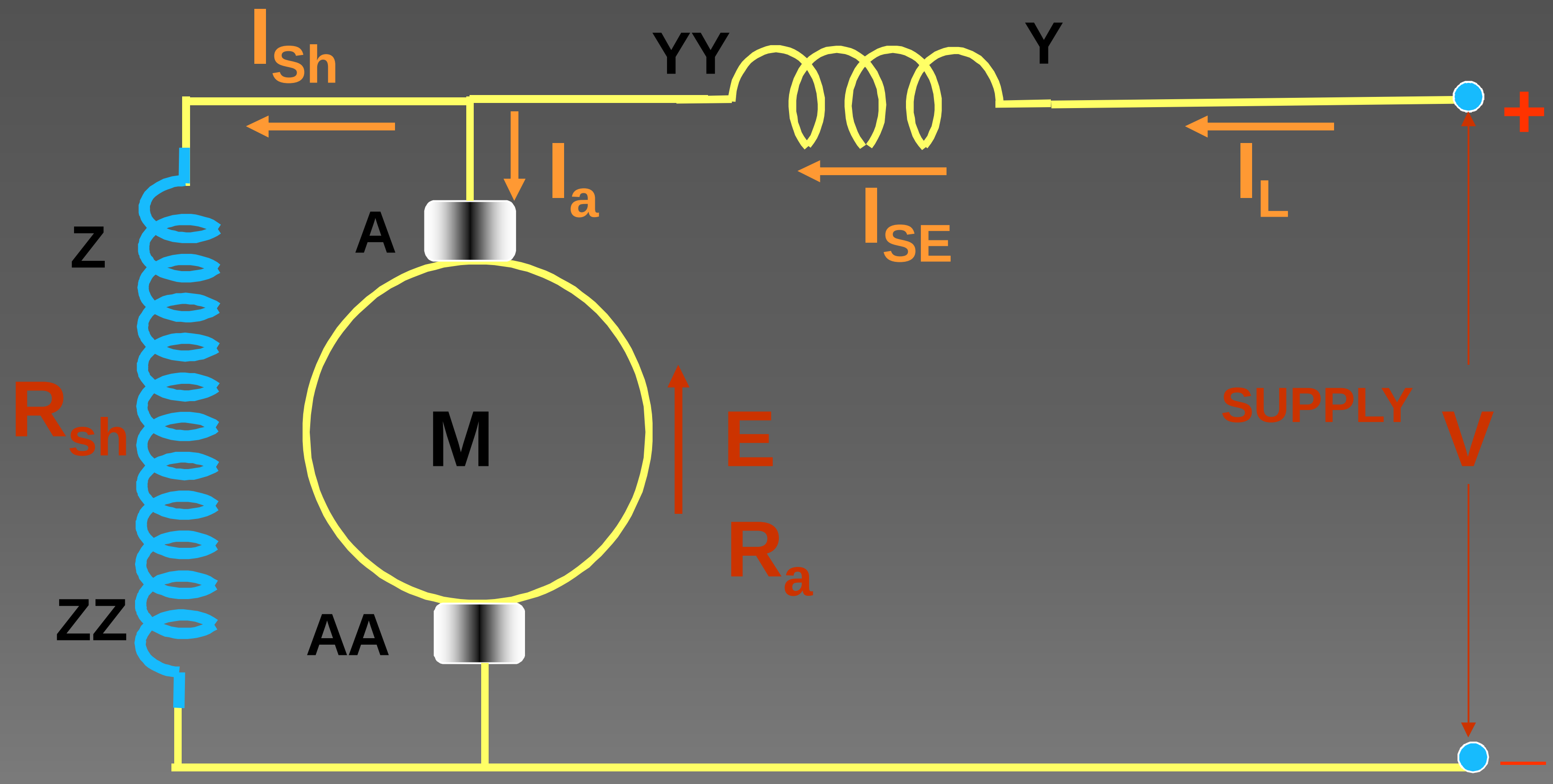
SELF EXCITED DC COMPOUND MOTORS

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 TYPE (DC COMPOUND MOTORS)



SHORT SHUNT TYPE (DC COMPOUND MOTORS)

<u>i) SHORT SHUNT DC COMPOUND MOTORS</u>

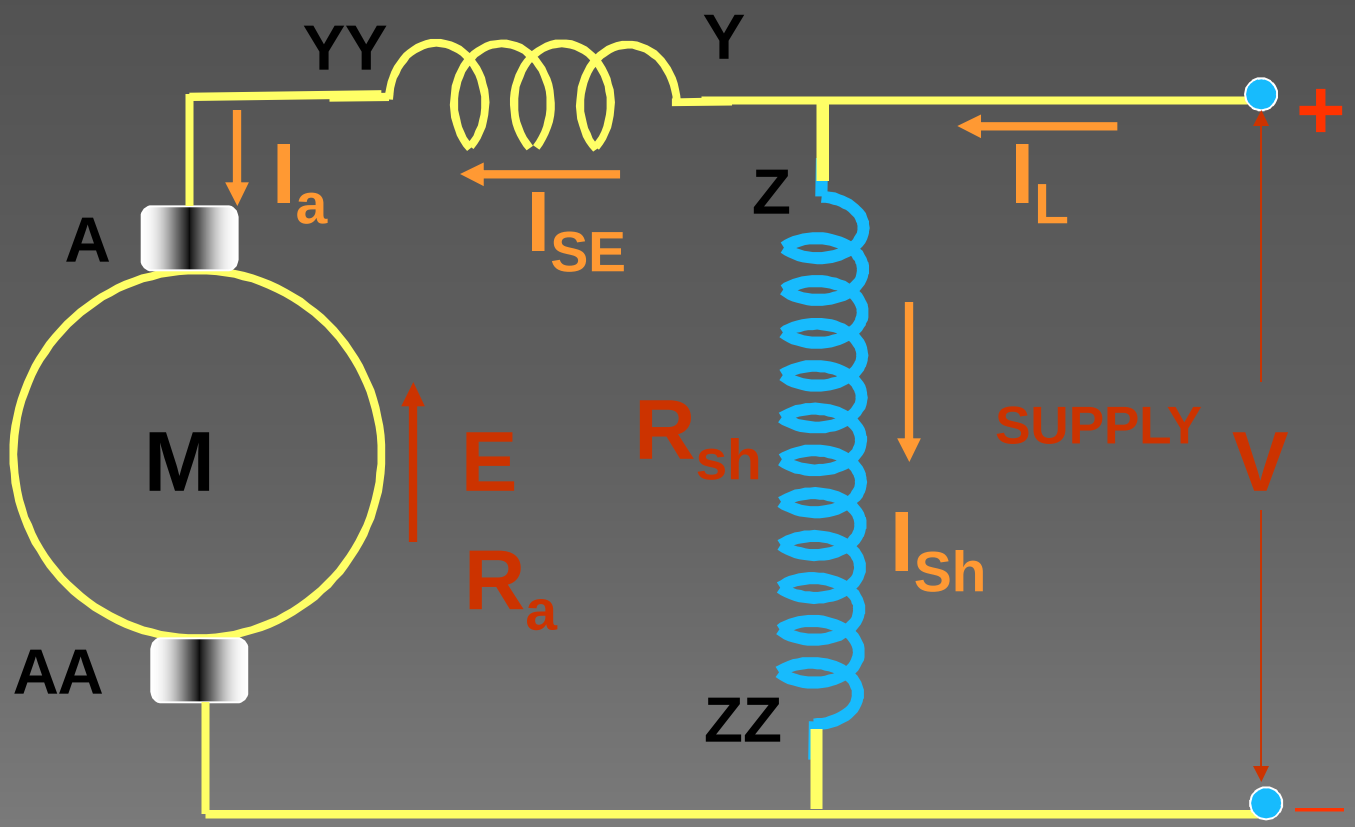
In this case the shunt field winding is connected across the armature winding only as shown in the fig of slide no.

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

$$V = E + I_a R_a + I_{se} R_{se}$$

$$= E + I_a R_a + (I_a + I_{sh}) R_{se}$$

LONG SHUNT TYPE (DC COMPOUND MOTORS)



LONG SHUNT TYPE (DC COMPOUND MOTORS)

ii) LONG SHUNT DC COMPOUND MOTORS

In this case the shunt field winding is connected across the combination of armature and series field winding as shown in the fig.

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

$$V = E + I_a R_a + I_{se} R_{se}$$
$$= I_{sh} R_{sh}$$

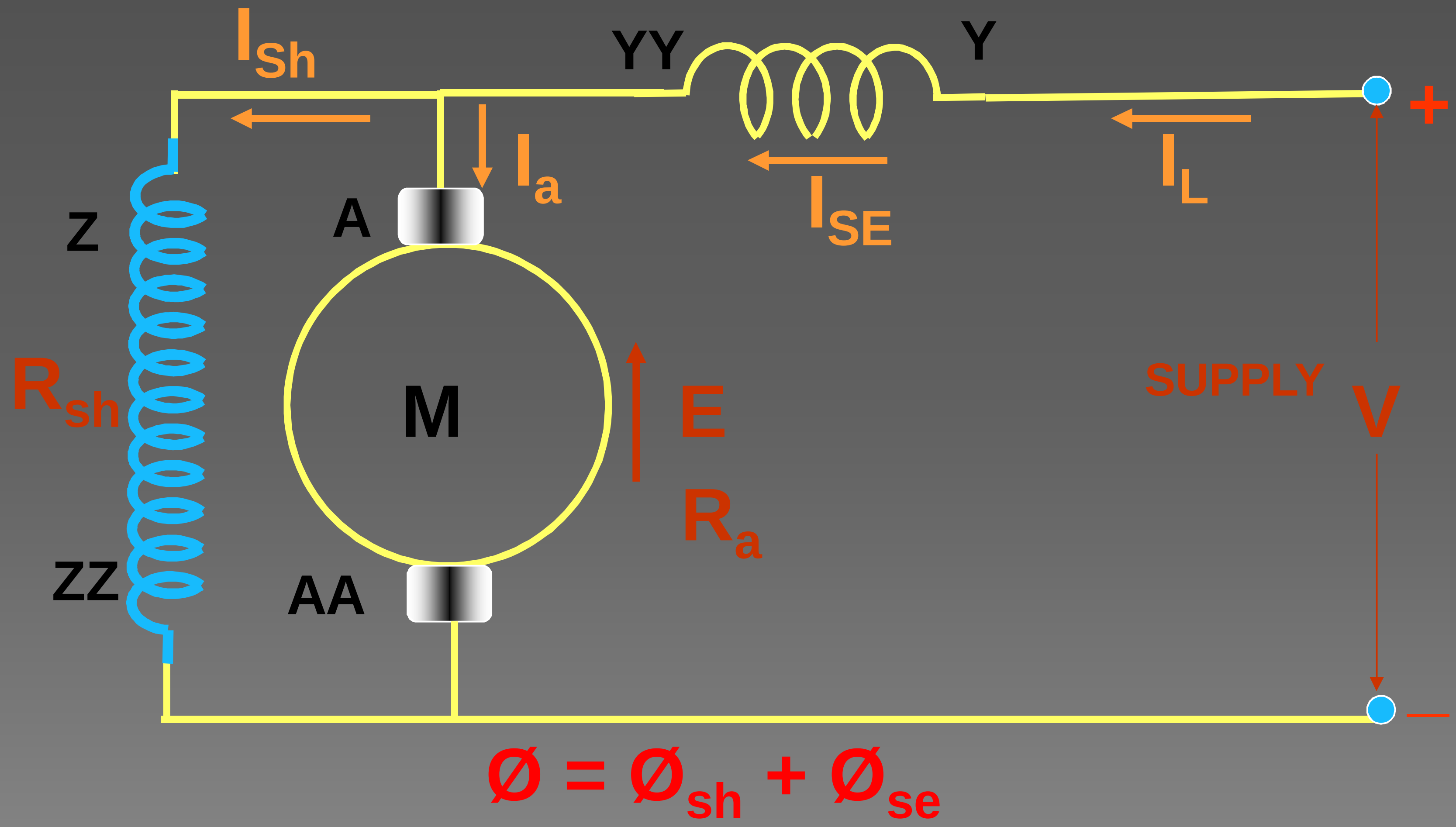
SELF EXCITED DC MOTORS (DC COMPOUND MOTORS)

Depending upon the direction of flow of current through series field, we can classify dc compound motors into two categories namely ;

I) Cumulative compound dc motors

II) differential compound dc motors

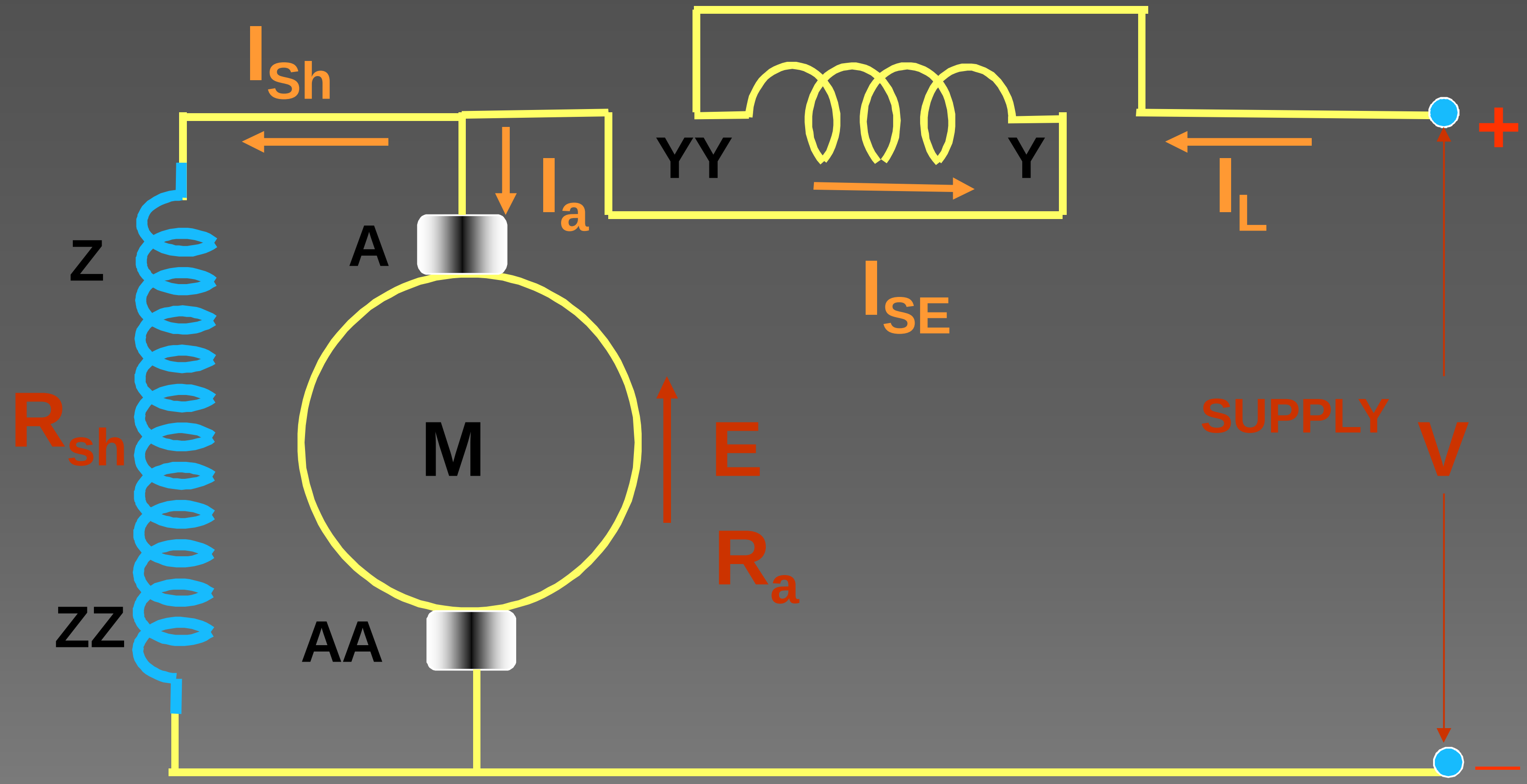
CUMULATIVE TYPE (DC COMPOUND MOTORS)



CUMULATIVE TYPE (DC COMPOUND MOTORS)

The direction of current in the series field winding is such that magnetic field produced by it is in the direction to that of shunt field. Total magnitude of the field is the sum of shunt field and series field so that $\text{Ø} = \text{Ø}_{sh} + \text{Ø}_{se}$.

DIFFERENTIAL TYPE (DC COMPOUND MOTORS)



$$Ø = Ø_{sh} - Ø_{se}$$

DIFFERENTIAL TYPE (DC COMPOUND MOTORS)

The direction of current in the series field winding is such that magnetic field produced by it is in the opposite direction to that of shunt field. Total magnitude of the field is the difference of shunt field and series field so that

$$Ø = Ø_{sh} - Ø_{se}.$$

FACTORS DETERMINING THE SPEED OF DC MOTOR

The expression for back e.m.f. developed in the armature of a dc motor is given as follows :

$$E = \frac{P \, Ø \, Z \, N}{60 \, A} \qquad \ldots\ldots(i)$$

$$E = V - I_a R_a \qquad \ldots\ldots(ii)$$

FACTORS DETERMINING THE SPEED OF DC MOTOR

Comparing expressions (i) and (ii)

$$\frac{P\,\varnothing\,Z\,N}{60\,A} = V - I_a R_a$$

OR

$$K\,\varnothing\,N = V - I_a R_a$$

$$N = \frac{V - I_a R_a}{K\,\varnothing}$$

FACTORS DETERMINING THE SPEED OF DC MOTOR

Where K is the constant of proportionality and equal to PZ / 60 A

Now in the above expression for speed, the speed can be varied by varying the applied voltage ‘V’ , field flux Ø and resistance of the armature .

FACTORS DETERMINING THE SPEED OF DC MOTOR

It is clear that speed is directly proportional to the supply voltage ‘V’. So the speed increases with increase in voltage ‘V’ and vice versa.

The speed is inversely proportional to the field flux Ø . So speed decreases as the Flux Ø increases and vice versa.

CHARACTERISTICS OF DC MOTORS

The important characteristics of dc motors are :

1) Speed - armature current (Load) characteristics

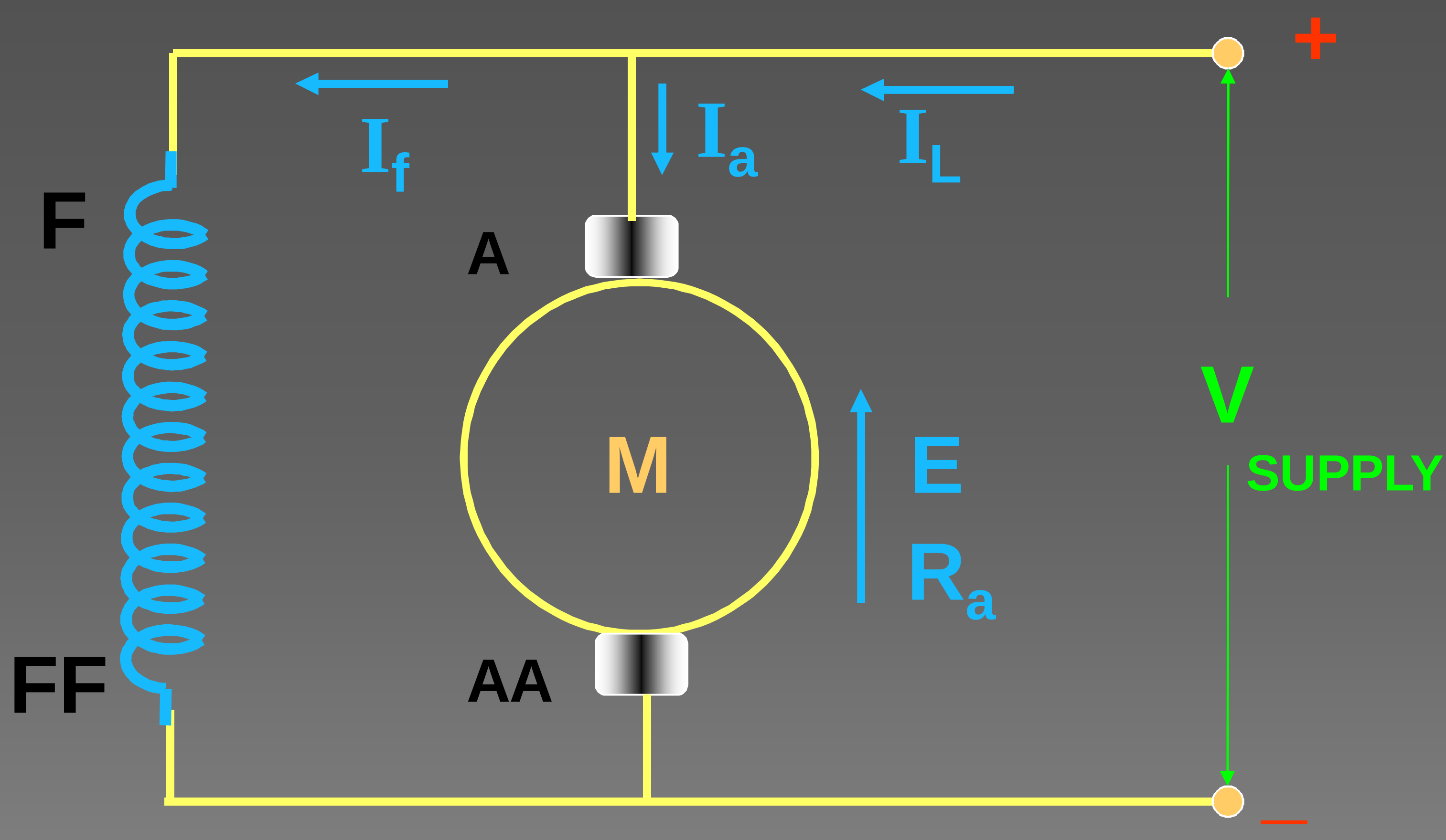
2) Torque - armature current (Load) characteristics

3) Speed - Torque characteristics

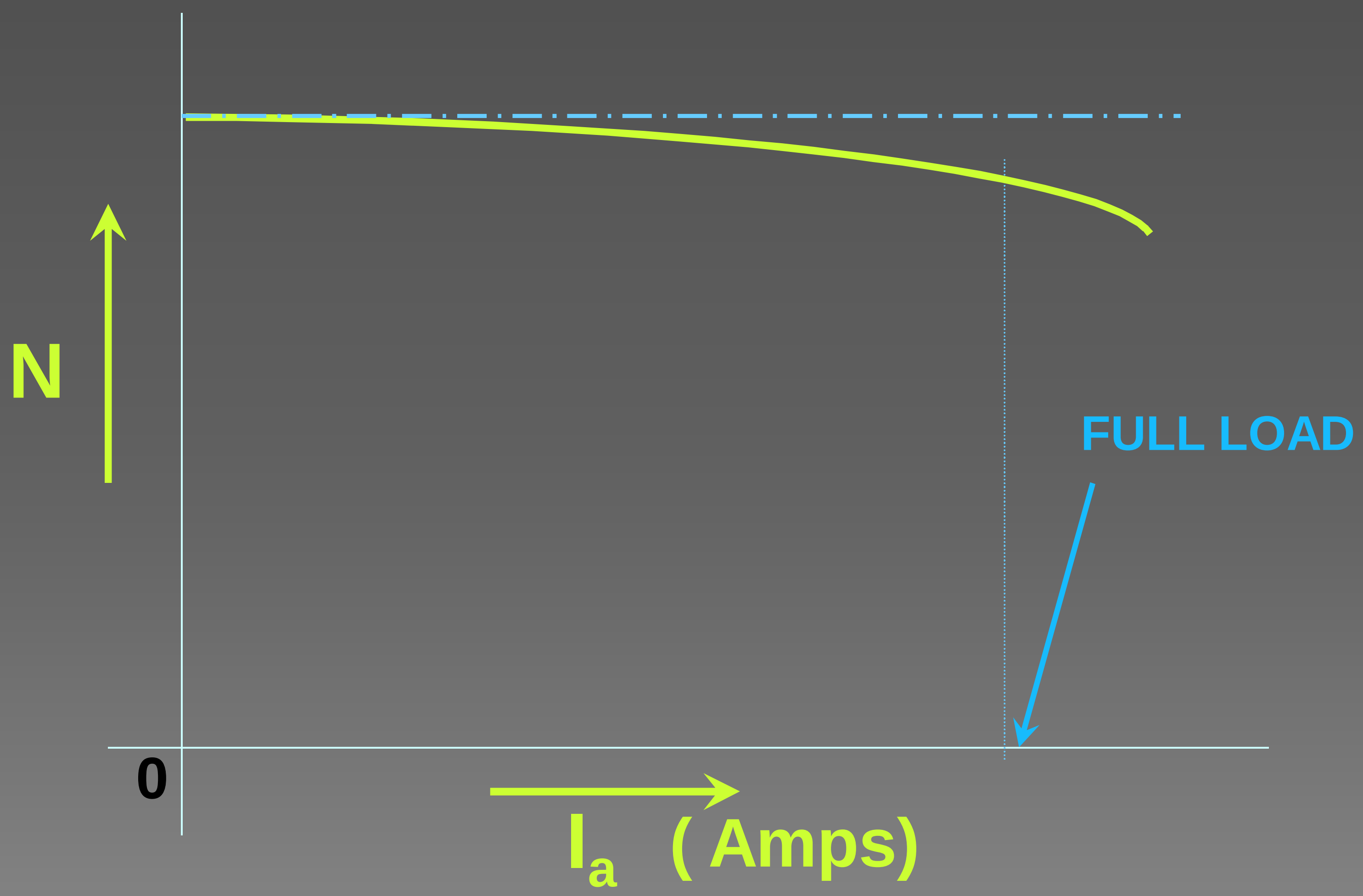
CHARACTERISTICS OF DC MOTORS

It is very much important to know the characteristics mentioned above for different types of dc motors because it enables the selection of a specific type of dc motor for specific purpose.

CHARACTERISTICS OF DC SHUNT MOTORS



CHARACTERISTICS OF DC SHUNT MOTORS

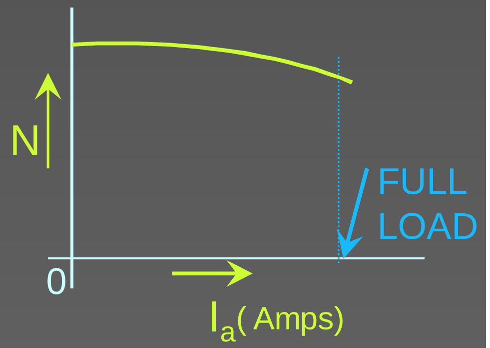


CHARACTERISTICS OF DC SHUNT MOTORS

1. Speed - Armature current (Load) characteristics

For a dc motor , we know that ;

$$N = \frac{V - I_a R_a}{K Ø}$$



A dc shunt motor is connected across the mains having supply voltage ‘V’ .

CHARACTERISTICS OF DC SHUNT MOTORS

Speed - Armature current (Load) characteristics

This supply voltage is assumed to be constant. The field winding is connected across the armature as shown in Fig. The magnetic flux Ø produced by field current I_f will be constant as V remains constant.

CHARACTERISTICS OF DC SHUNT MOTORS

1. Speed - Armature current (Load) characteristics

But in actual practice, the air gap flux is slightly reduced due to the effect of armature reaction. From the expression for the speed mentioned earlier, it is evident that as the armature current I_a ……

CHARACTERISTICS OF DC SHUNT MOTORS

1. Speed - Armature current (Load) characteristics

increases , speed will decrease by a small amount due to an increase in $I_a R_a$ drop is very small as compared to V . The speed verses armature current characteristics is shown in Fig.

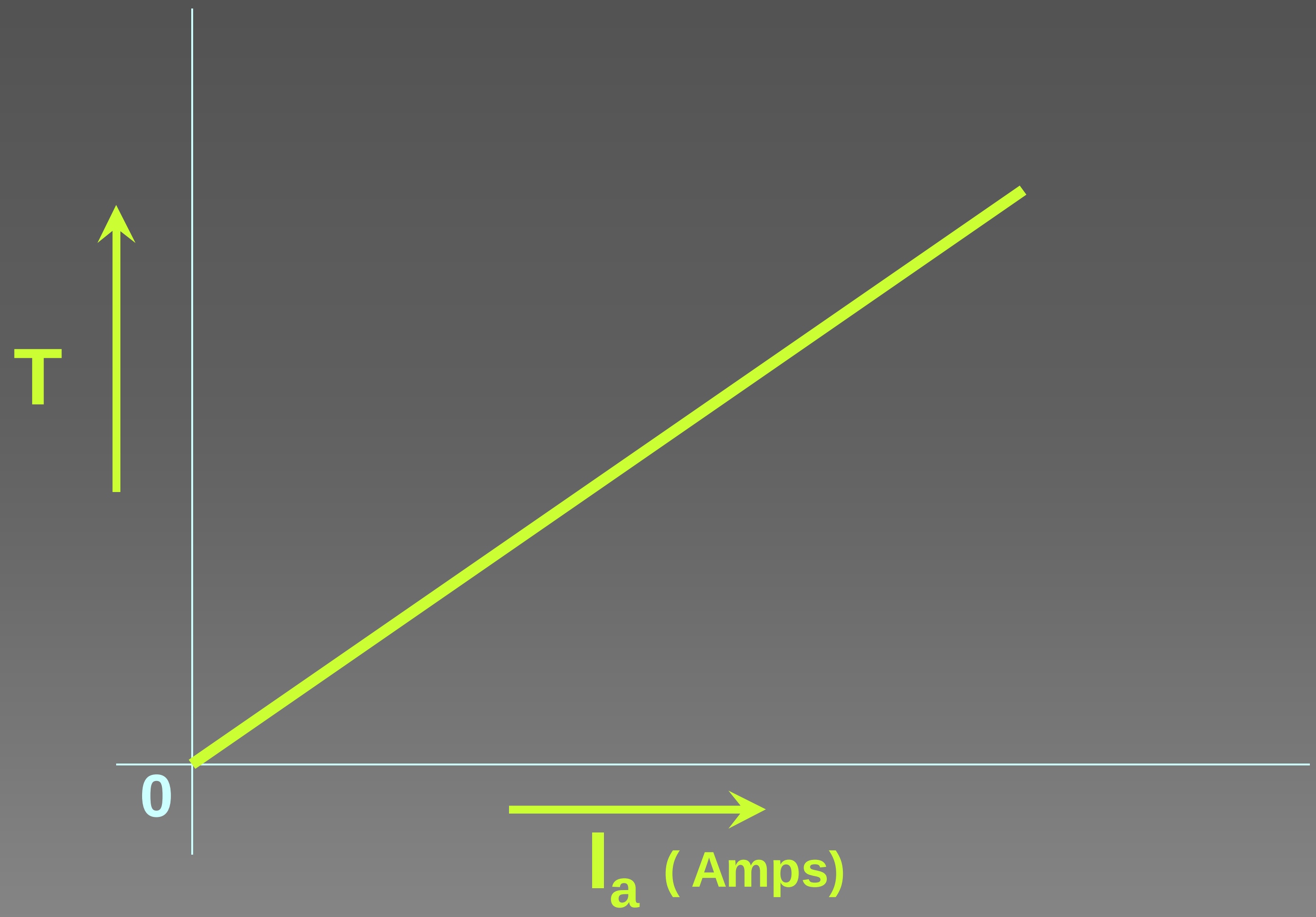
CHARACTERISTICS OF DC SHUNT MOTORS

1. Speed - Armature current (Load) characteristics

The shunt motor being thus more or less a constant speed motor , can be used in the applications such as driving of line shafts, lathes conveyors etc.

CHARACTERISTICS OF DC SHUNT MOTORS

2. Torque - Armature current (Load) characteristics



CHARACTERISTICS OF DC SHUNT MOTORS

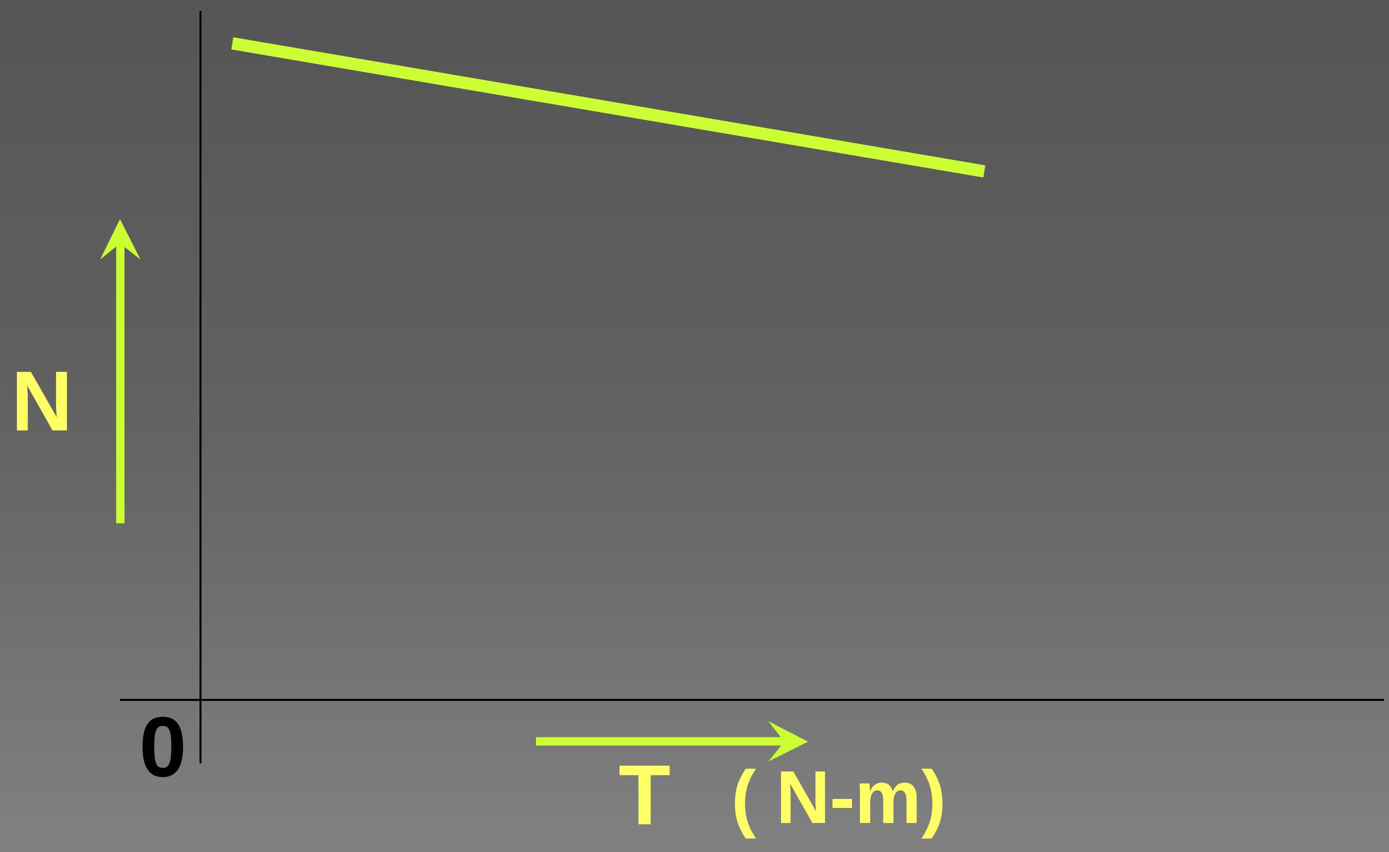
2. Torque - Armature current (Load) characteristics

The equation for torque can be written as follows ; $\boxed{T = k_t \, Ø \, I_a}$

If flux Ø is taken as constant, the torque T becomes directly proportional to armature current (Load current) I_a . It is a straight line passing through the origin.

CHARACTERISTICS OF DC SHUNT MOTORS

3. Speed - Torque characteristics



CHARACTERISTICS OF DC SHUNT MOTORS

3. Speed - Torque characteristics

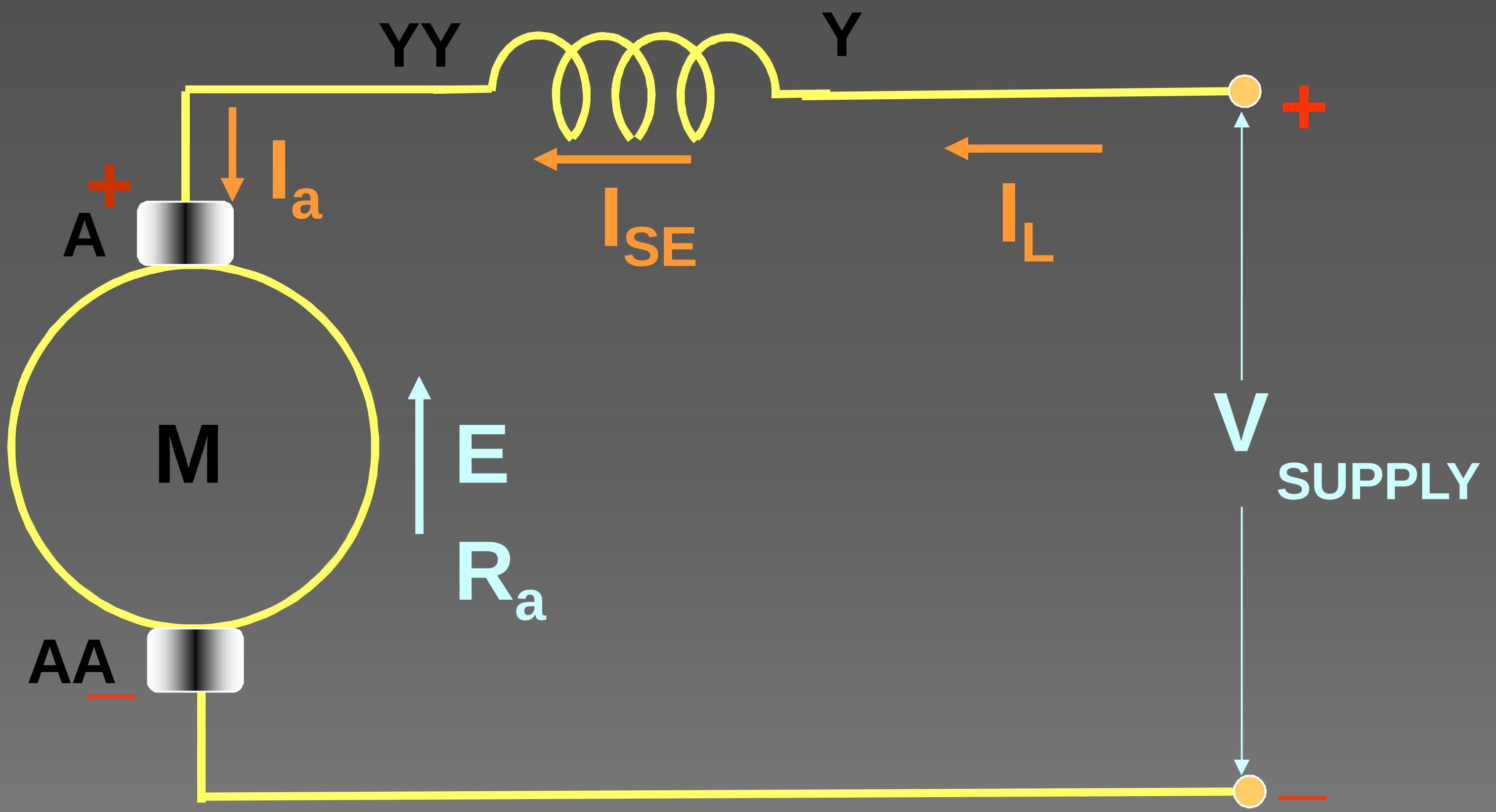
The relation between T and I_a and N and I_a are as under ;

$$T = k_t \text{Ø} I_a$$

$$N = \frac{V - I_a R_a}{K \text{Ø}}$$

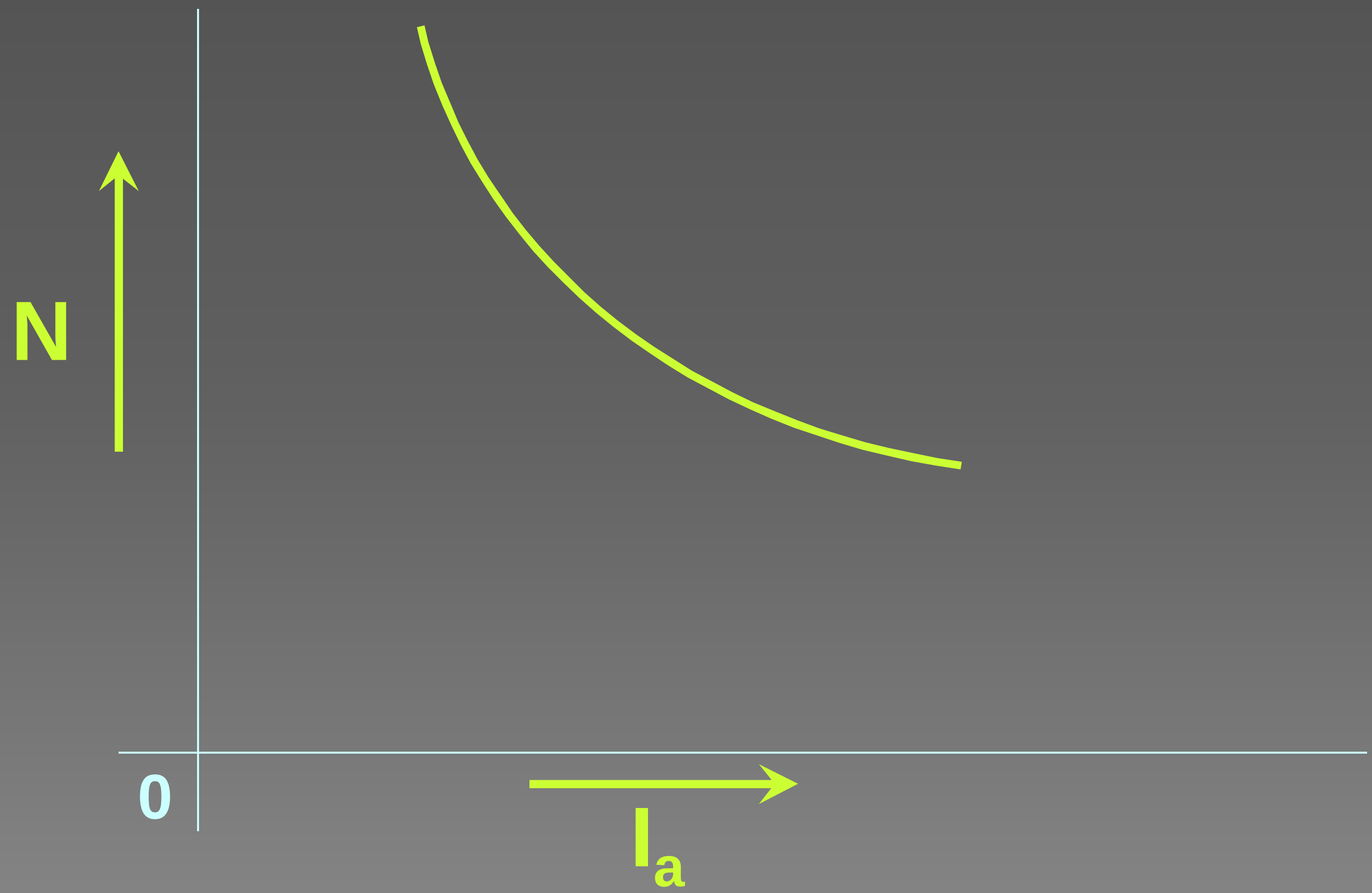
And The relationship between speed and torque can be drawn as shown in Fig .

CHARACTERISTICS OF DC SHUNT MOTORS



CHARACTERISTICS OF DC SERIES MOTORS

1. Speed - Load characteristics



CHARACTERISTICS OF DC SERIES MOTORS

1. Speed - Load characteristics

From the expression ;

$$N = \frac{V - I_a R_a}{K Ø}$$

It is seen that the speed N is inversely proportional to flux Ø

For a dc series motor ,magnetic flux Ø is proportional to I_a.

CHARACTERISTICS OF DC SERIES MOTORS

1. Speed - Load characteristics

Thus , if V is constant, N is inversely proportional to I_a. The N verses I_a characteristics is therefore a rectangular hyperbola as shown in Fig . It is seen from the characteristics that ….

CHARACTERISTICS OF DC SERIES MOTORS

1. Speed - Load characteristics

the speed decreases as the load on the motor increases. At a very low load , the speed is dangerously high . Thus if a dc series motor is allowed to run on very light load or at No- Load , its speed will become much higher than its ….

CHARACTERISTICS OF DC SERIES MOTORS

1. Speed - Load characteristics

normal speed which may cause damage to the motor. For this reason , dc series motors are never started on No- Load and are not used in the applications where there is a chance of Load being completely removed , when the motor ....

CHARACTERISTICS OF DC SERIES MOTORS

1. Speed - Load characteristics

remains connected to the supply. The load on the dc series motor is connected through the gears and not through the belt pulley arrangement.This is because, in case of failure of belt , the load will be removed from the motor and thereby the

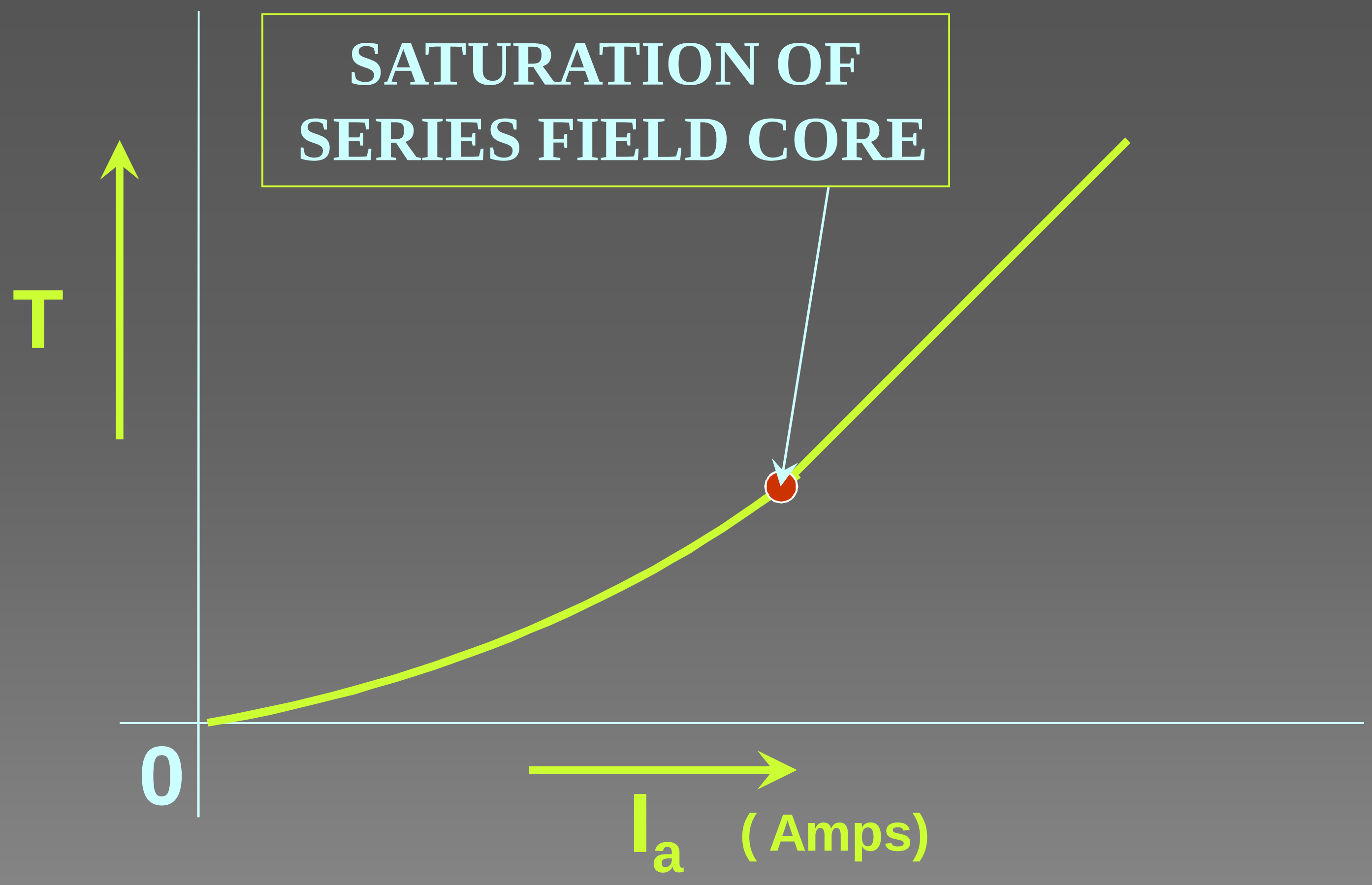
CHARACTERISTICS OF DC SERIES MOTORS

1. Speed - Load characteristics

motor will attain a dangerously high speed . In case of load connected through the gears, however in the event of an accidental release of load, gears will provide some load on account of the frictional resistance of the gear teeth.

CHARACTERISTICS OF DC SERIES MOTORS

1. Torque - Load characteristics



CHARACTERISTICS OF DC SERIES MOTORS

1. Torque - Load characteristics

The equation for the torque for dc motor is given by ; $T = k_t \text{Ø} I_a$

The magnetic flux for a dc series motor is proportional to armature current I_a. Thus the torque $T = k_t I_a I_a$.

Or $T \propto I_a^2$

CHARACTERISTICS OF DC SERIES MOTORS

1. Torque - Load characteristics

The relationship between torque and armature current , is therefore of the form of a parabola . With increase in I_a , the field flux increases linearly but due to saturation of the core, beyond a certain magnitude of I_a the increase in flux is

CHARACTERISTICS OF DC SERIES MOTORS

1. Torque - Load characteristics

negligible.. Thus T is proportional to the square of I_a up to the saturation point beyond which T varies linearly with I_a. From the torque load characteristics , it can be observed that a dc series motor ….

CHARACTERISTICS OF DC SERIES MOTORS

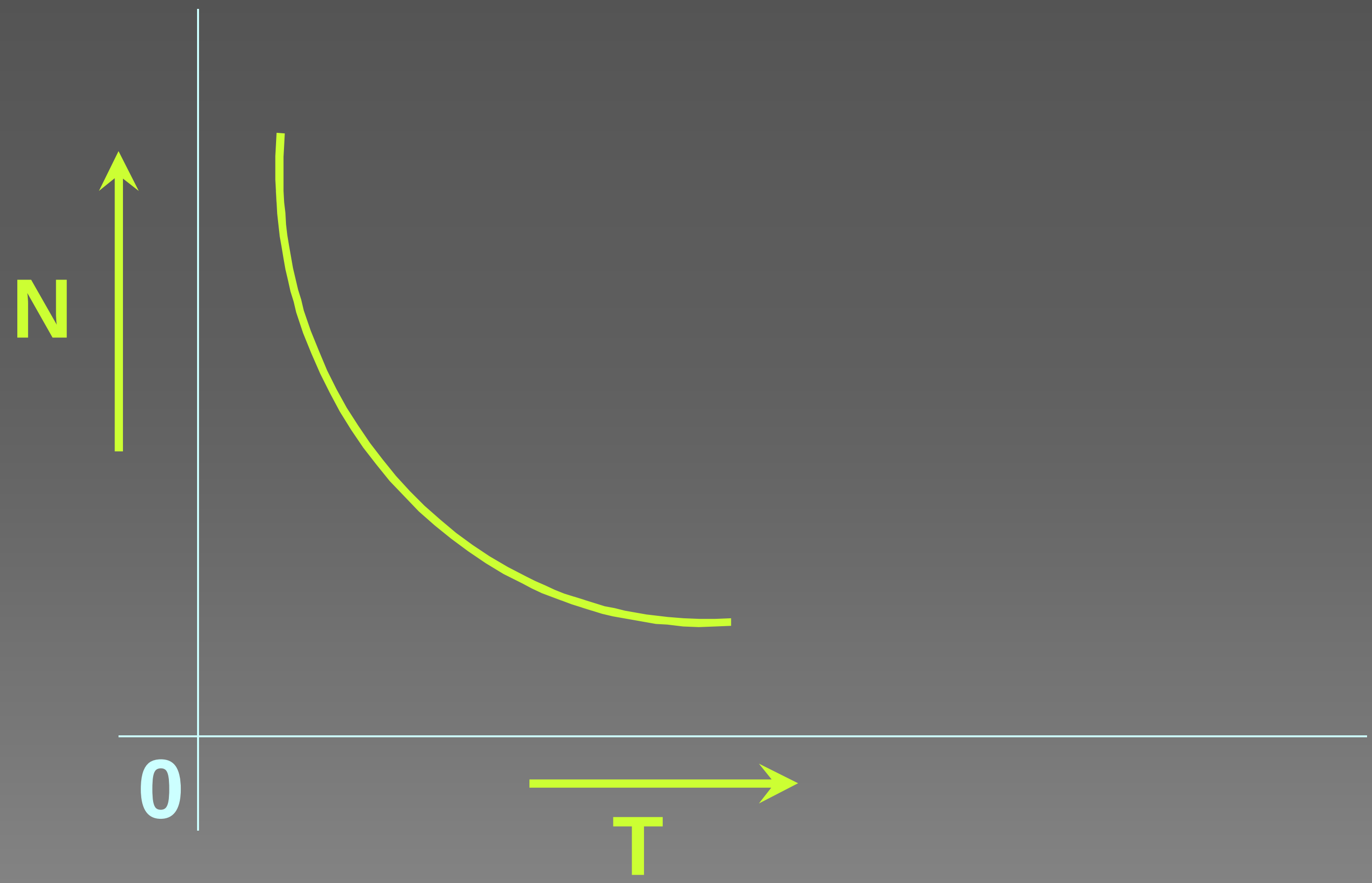
1. Torque - Load characteristics

started on-load , develops a very high starting torque.

Hence dc series motors are used in applications where high starting torque is required such as in electric trains , hoists, trolleys etc.

CHARACTERISTICS OF DC SERIES MOTORS

1. Torque - Speed characteristics

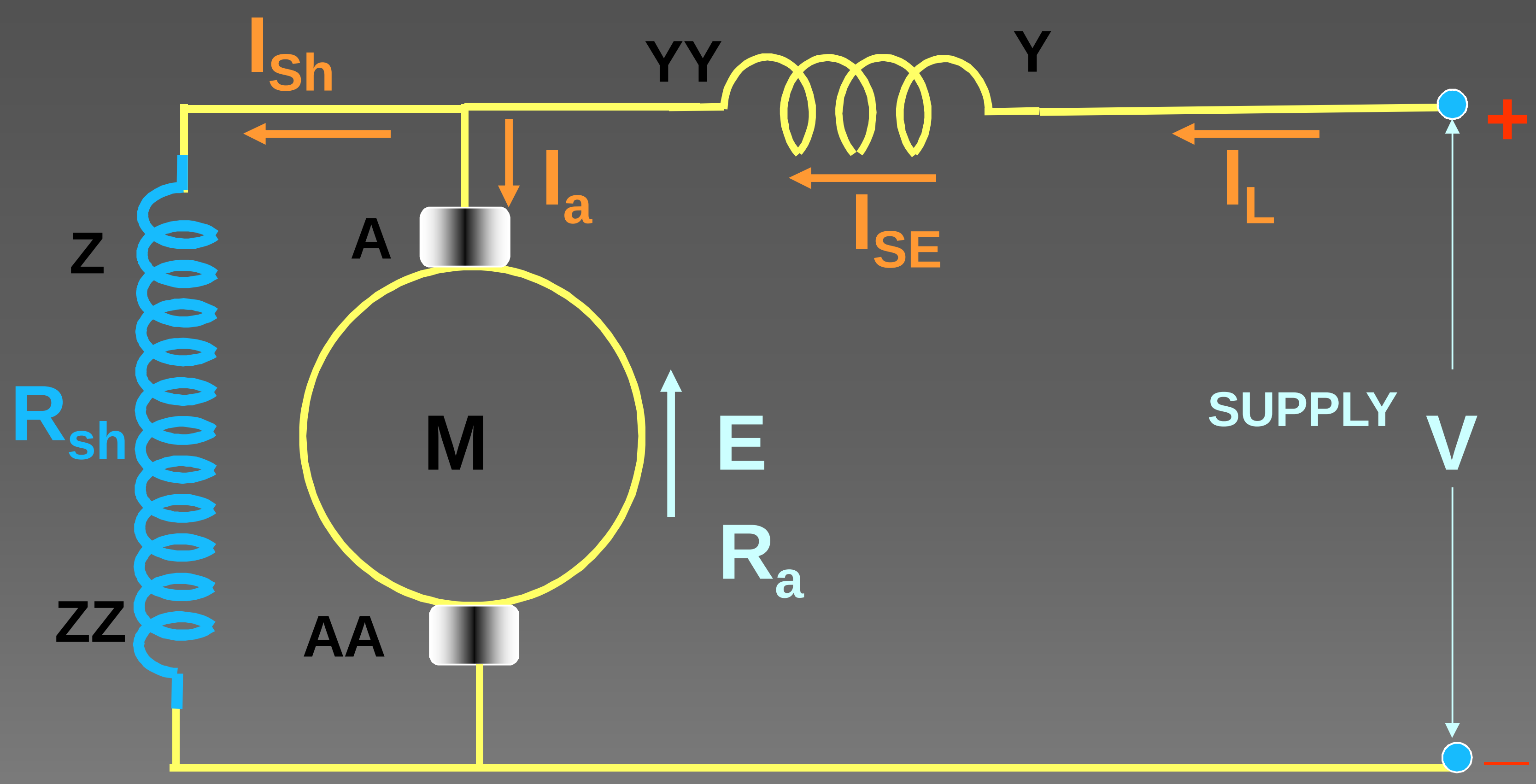


CHARACTERISTICS OF DC SERIES MOTORS

1. Torque - Speed characteristics

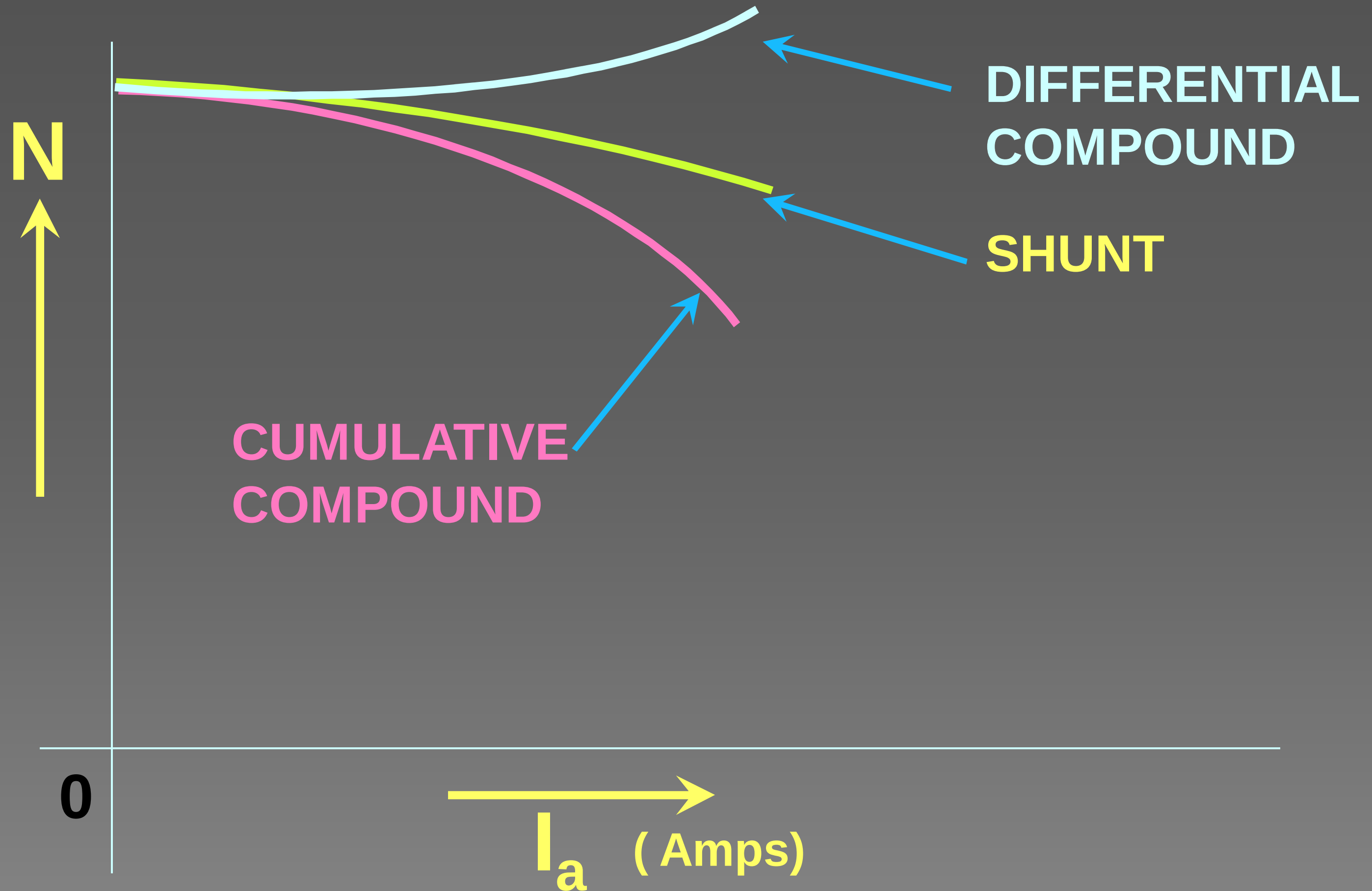
From the characteristics shown in slide no. , it can be seen that for low speeds , the torque is high and for high speeds the torque is very small. This is why dc series motor is widely used in the applications where motor is to be started on bulk loads such as electric loco- motive.

CHARACTERISTICS OF DC COMPOUND MOTORS



CHARACTERISTICS OF DC COMPOUND MOTORS

1. Speed - Load characteristics



CHARACTERISTICS OF DC COMPOUND MOTORS

1. Speed - Load characteristics

In cumulative compound motors , series field winding is connected in such a way that magnetic flux produced by it helps the flux produced by shunt field winding. Series field is directly proportional to the load current ,....

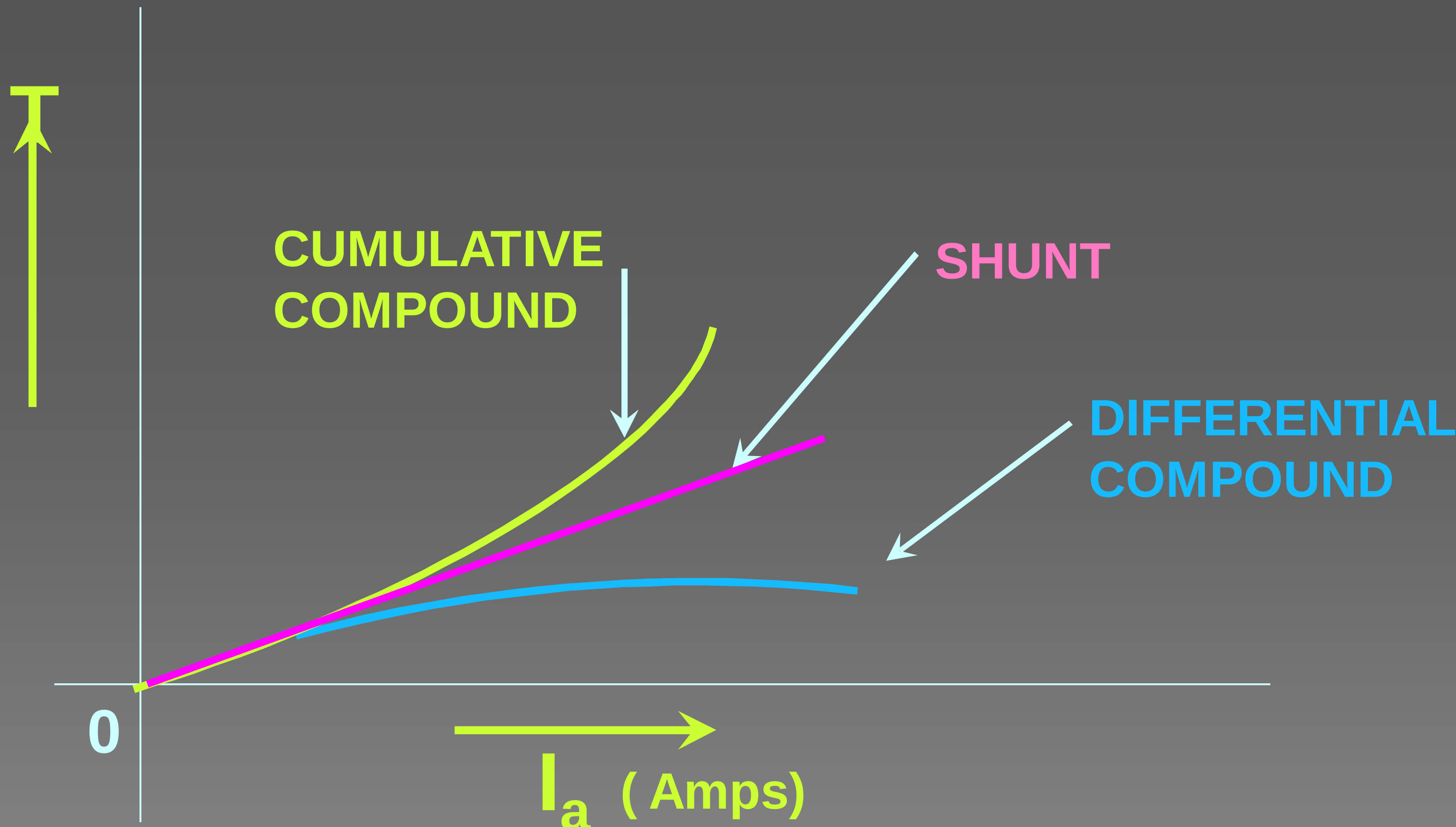
CHARACTERISTICS OF DC COMPOUND MOTORS

1. Speed - Load characteristics

therefore total flux increases with increase in load current / armature current due to the series field in addition to the voltage drop in the armature winding. The speed of dc motor is inversely proportional to the total main flux Ø . Therefore speed drops more sharply as compared to dc shunt motor. Refer Fig.

CHARACTERISTICS OF DC COMPOUND MOTORS

2. Torque - Load characteristics



CHARACTERISTICS OF DC COMPOUND MOTORS

2. Torque - Load characteristics

The torque developed by a cumulative compound motor increases with sudden increase in load and at no-load , it has a definite speed. Cumulative compound motors are therefore, suitable where there is sudden application . . . .

CHARACTERISTICS OF DC COMPOUND MOTORS

2. Torque - Load characteristics

of heavy loads like sheers, punches, rolling mills etc. The speed of differential compound motors remains more or less constant. With increase in load but its torque decreases with load. Since the dc shunt motor develops a good torque and

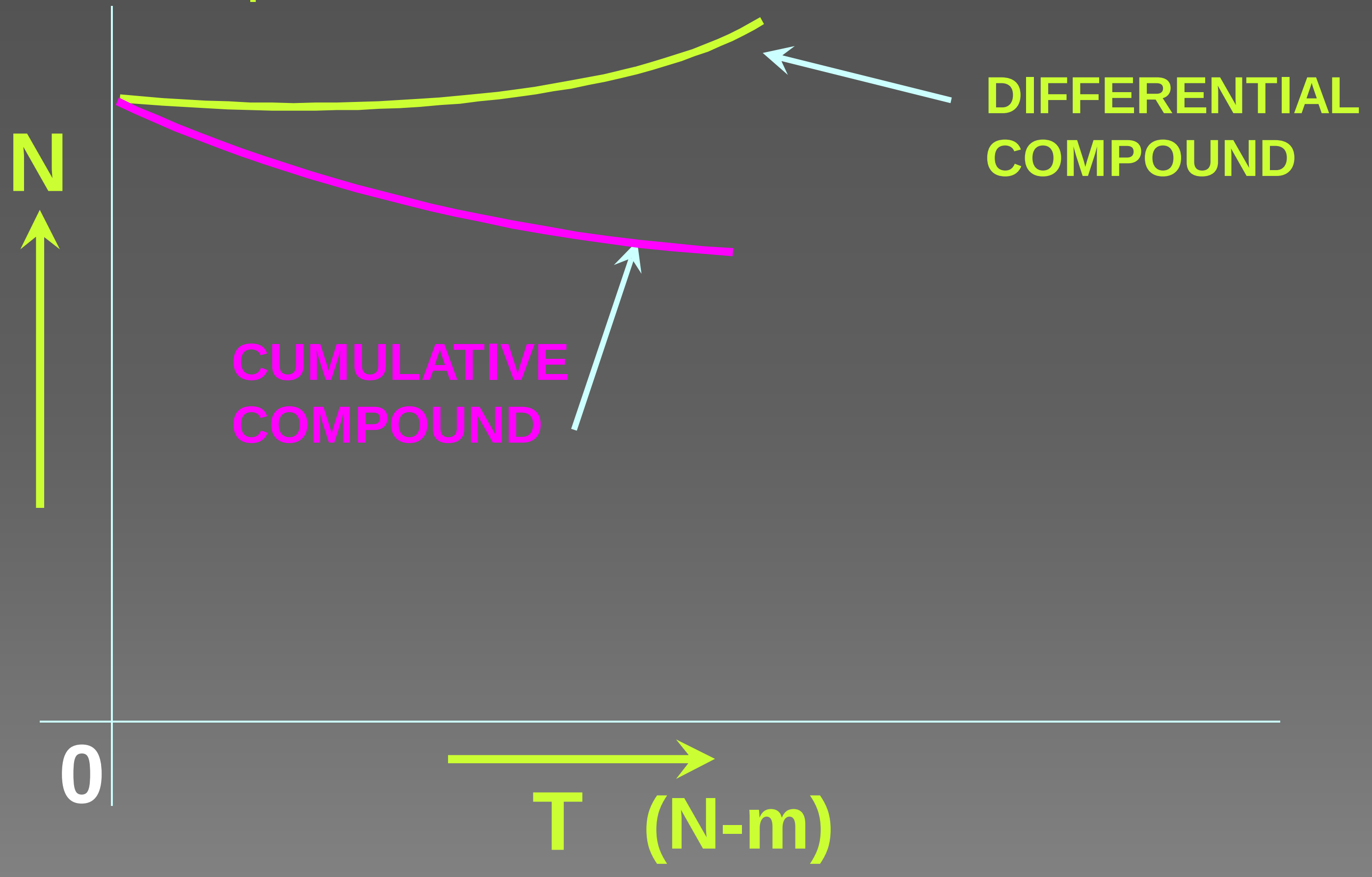
CHARACTERISTICS OF DC COMPOUND MOTORS

2. Torque - Load characteristics

its speed does not vary appreciably with increase in load, differential compound motors are not preferred over dc shunt motors and hence are rarely used.

CHARACTERISTICS OF DC COMPOUND MOTORS

3. Speed - Torque characteristics



Speed Control for shunt motor and separately excited dc motor

- Torque –speed characteristic for shunt and separately excited dc motor

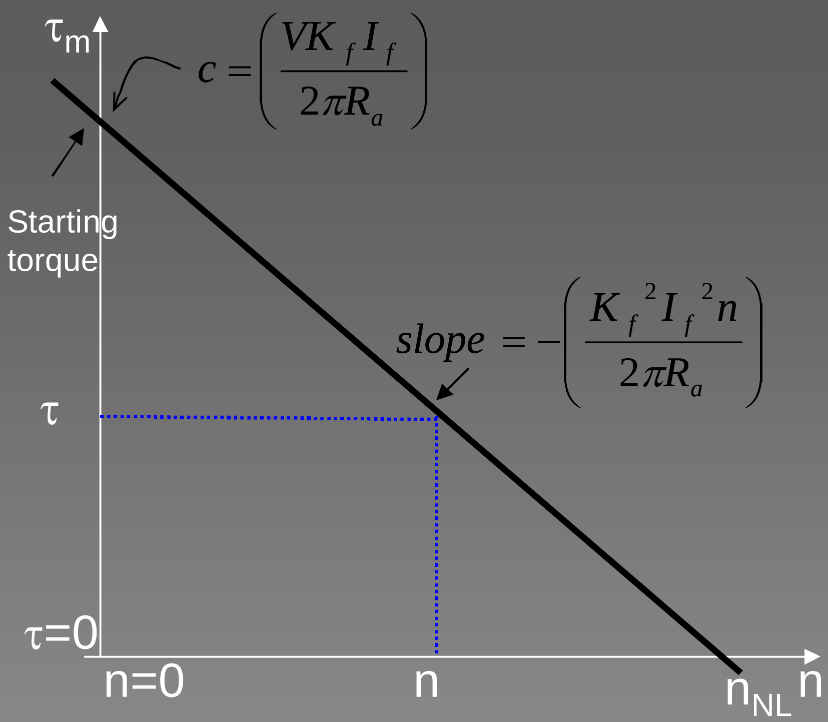
$$Developed\ torque, \tau = \left(\frac{E_a I_a}{\varpi}\right)$$

$$\tau = \left(\frac{E_a I_a}{2\pi n}\right)$$

$$= \left(\frac{V - E_a}{R_a}\right)\left(\frac{E_a}{2\pi n}\right)$$

same as separately excited ,

$$\tau = \left(\frac{VK_f I_f}{2\pi R_a}\right) - \left(\frac{K_f^{\ 2} I_f^{\ 2} n}{2\pi R_a}\right)$$



Speed Control for shunt motor and separately excited dc motor

- By referring to the Torque –speed characteristic for shunt and separately excited dc motor

$$\tau = \left(\frac{VK_f I_f}{2\pi R_a}\right) - \left(\frac{K_f{}^2 I_f{}^2 n}{2\pi R_a}\right)$$

- note that, there are three variables that can influence the speed of the motor,

$$\left.\begin{array}{l} V \\ I_f \\ R_a \end{array}\right\} \text{Variables}$$

- Thus, there are three methods of controlling the speed of the shunt and separately excited dc motor,
  i. Armature terminal – voltage speed control
  ii. Field speed control
  iii. Armature resistance speed control

Speed Control for shunt motor and separately excited dc motor

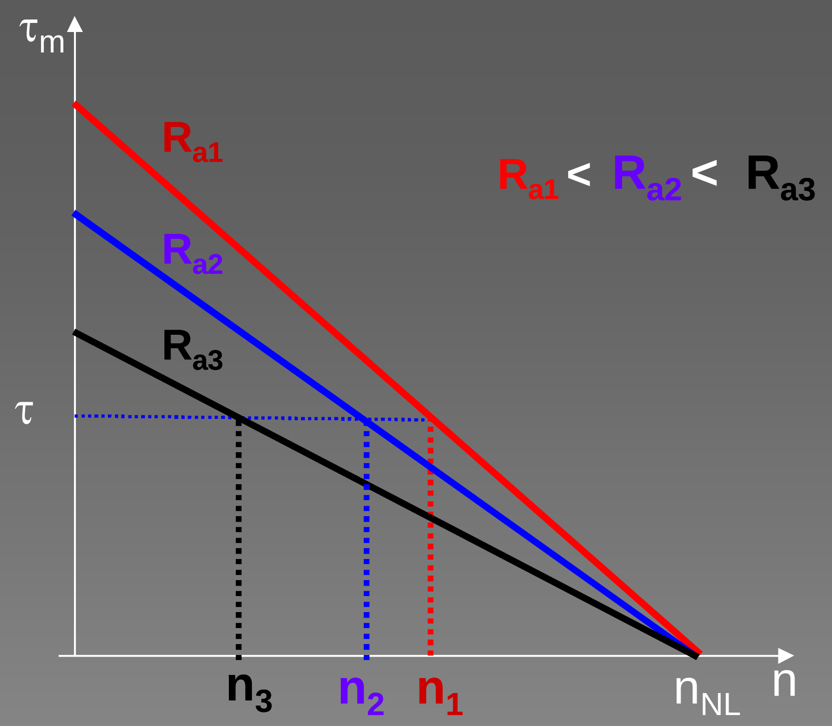
i. **Armature resistance speed control**

- Speed may be controlled by changing R_a
- The total resistance of armature may be varied by means of a rheostat in series with the armature
- The armature speed control rheostat also serves as a starting resistor.
- From τ-n characteristic,

$$\left.\begin{aligned} \tau_{start} &= c = \left(\frac{VK_f I_f}{2\pi R_a}\right) \\ slope &= -\left(\frac{K_f^{\,2} I_f^{\,2} n}{2\pi R_a}\right) \end{aligned}\right\} \text{Will be changed}$$

Speed Control for shunt motor and separately excited dc motor

- Torque –speed characteristic



Speed Control for shunt motor and separately excited dc motor

- Advantages armature resistance speed control:
  i. Starting and speed control functions may be combined in one rheostat
  ii. The speed range begins at zero speed
  iii. The cost is much less than other system that permit control down to zero speed
  iv. Simple method

- Disadvantages armature resistance speed control :
  i. Introduce more power loss in rheostat
  ii. Speed regulation is poor (S.R difference n_{Loaded} & $n_{no\ loaded}$)
  iii. Low efficiency due to rheostat

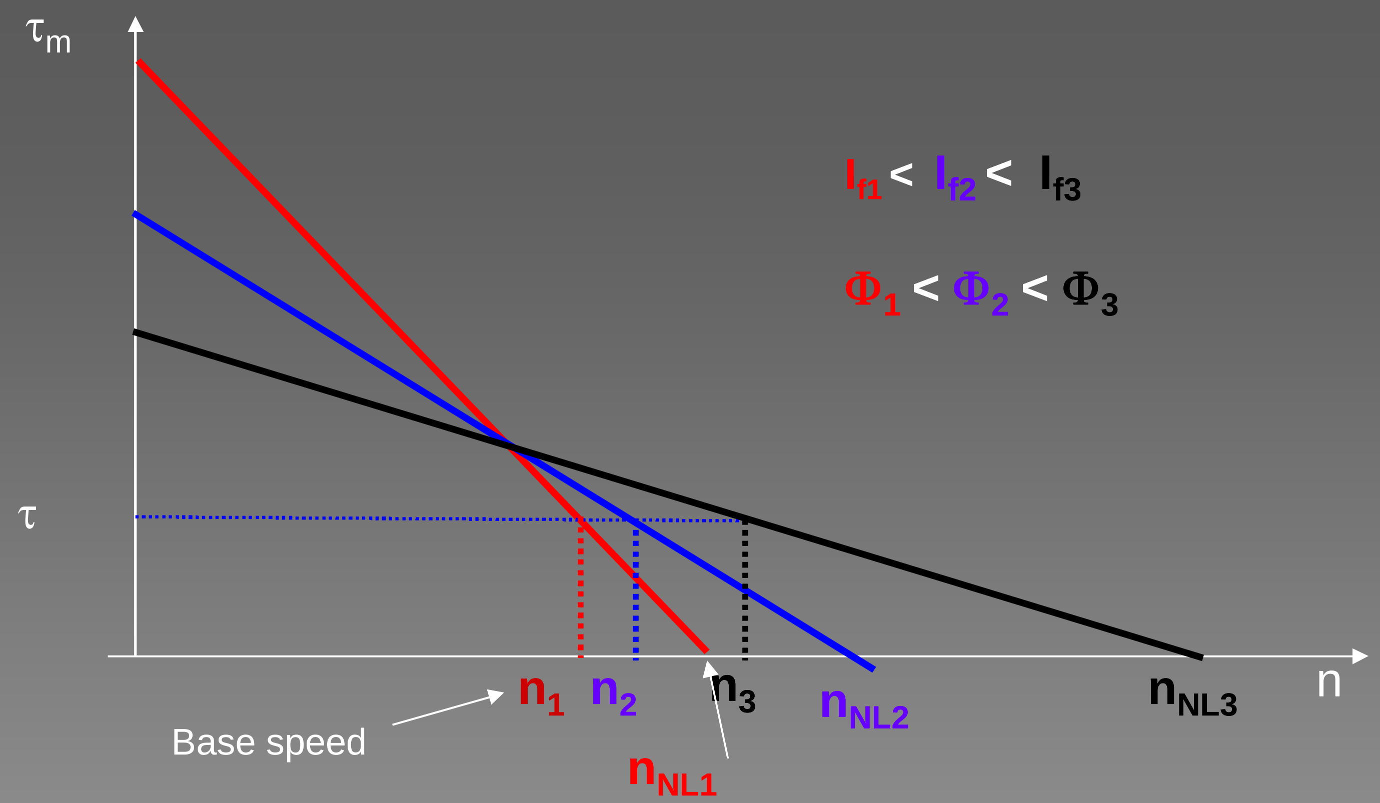
Speed Control for shunt motor and separately excited dc motor

ii. **Field Speed Control**

- Rheostat in series with field winding (shunt or separately ect.)
- If field current, I_f is varied, hence flux is also varied
- Not suitable for series field
- Refer to τ-n characteristic,
  - Slope and n_{NL} will be changed

Speed Control for shunt motor and separately excited dc motor

- Torque –speed characteristic



Speed Control for shunt motor and separately excited dc motor

- Advantages field speed control:
  1. Allows for controlling at or above the base speed
  2. The cost of the rheostat is cheaper because I_f is small value

- Disadvantages field speed control :
  1. Speed regulation is poor (S.R difference n_{Loaded} & $n_{no\ loaded}$)
  2. At high speed, flux is small, thus causes the speed of the machines becomes unstable
  3. At high speed also, the machines is unstable mechanically, thus there is an upper speed limit

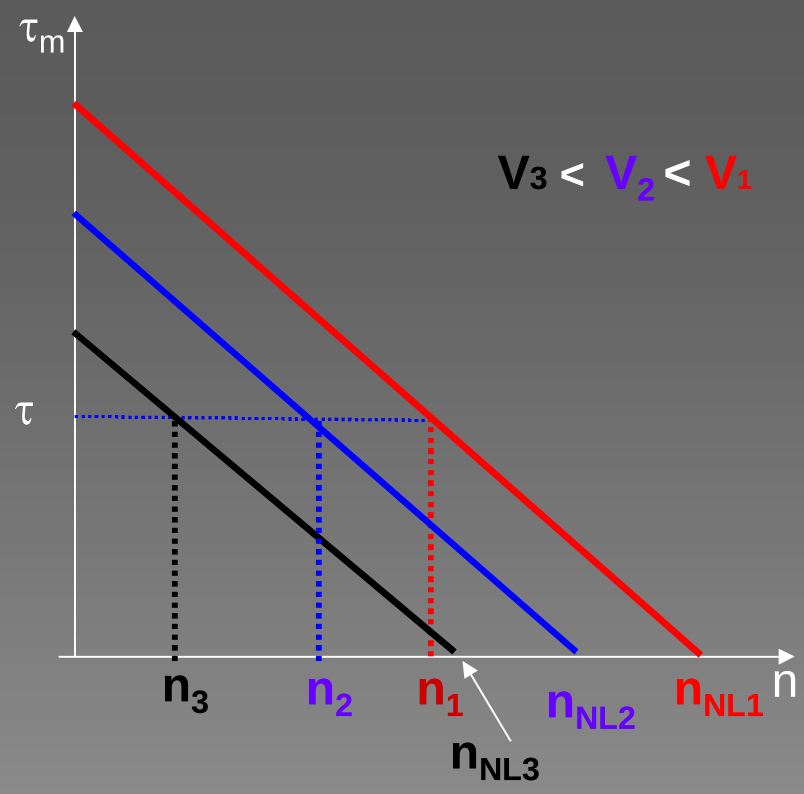
Speed Control for shunt motor and separately excited dc motor

iii. **Armature terminal – voltage speed control**

- Use power electronics controller
    - AC supply ➔rectifier
    - DC supply ➔chopper
- Supply voltage to the armature is controlled
- Constant speed regulation
- From τ-n characteristic,
    - C and n_{NL} will be change
    - Slope constant

Speed Control for shunt motor and separately excited dc motor

- Torque –speed characteristic



Speed Control for shunt motor and separately excited dc motor

- Advantages armature terminal voltage speed control:
  1. Does not change the speed regulation
  2. Speed is easily controlled from zero to maximum safe speed

- Disadvantages armature terminal voltage speed control :
  1. Cost is higher because of using power electronic controller

FACTORS AFFECTING THE PERFORMANCE OF DC MACHINE

- There are two factors affecting the performance of dc machine

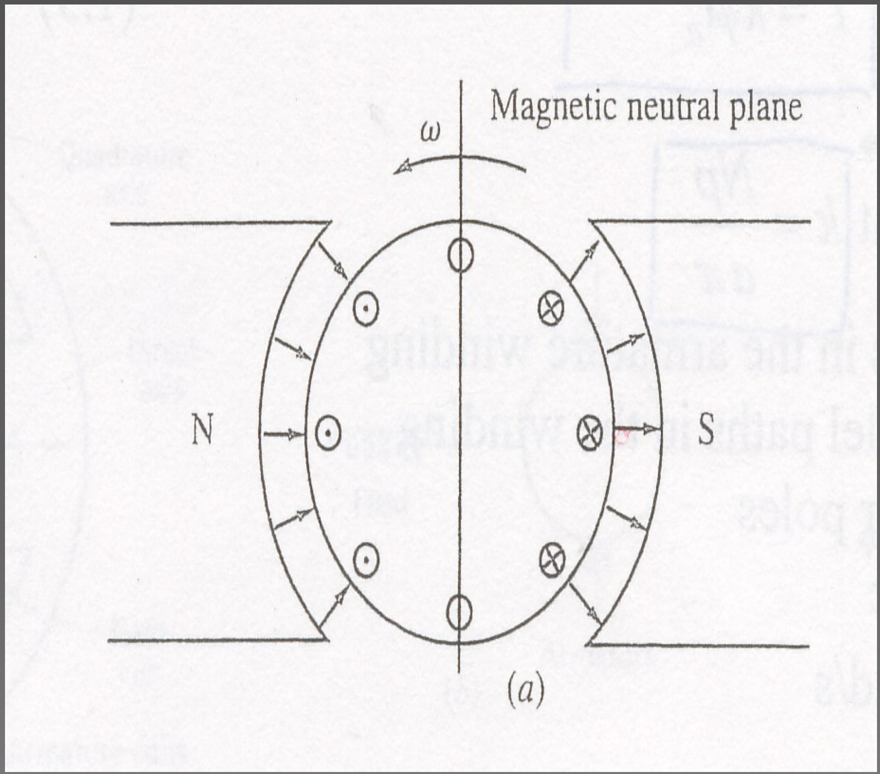
1. Armature reaction
2. Armature inductance

Armature Reaction

- Definition of armature reaction:
  1. It is the term used to describe the effects of the armature mmf on the operation of a dc machine as a "generator" no matter whether it is a generator or motor.
  2. It effects both the flux distribution and the flux magnitude in the machine.
  3. The distortion of the flux in a machine is called armature reaction
- Two effects of armature reaction:
  1. Neutral Plane Shift
  2. Flux Weakening

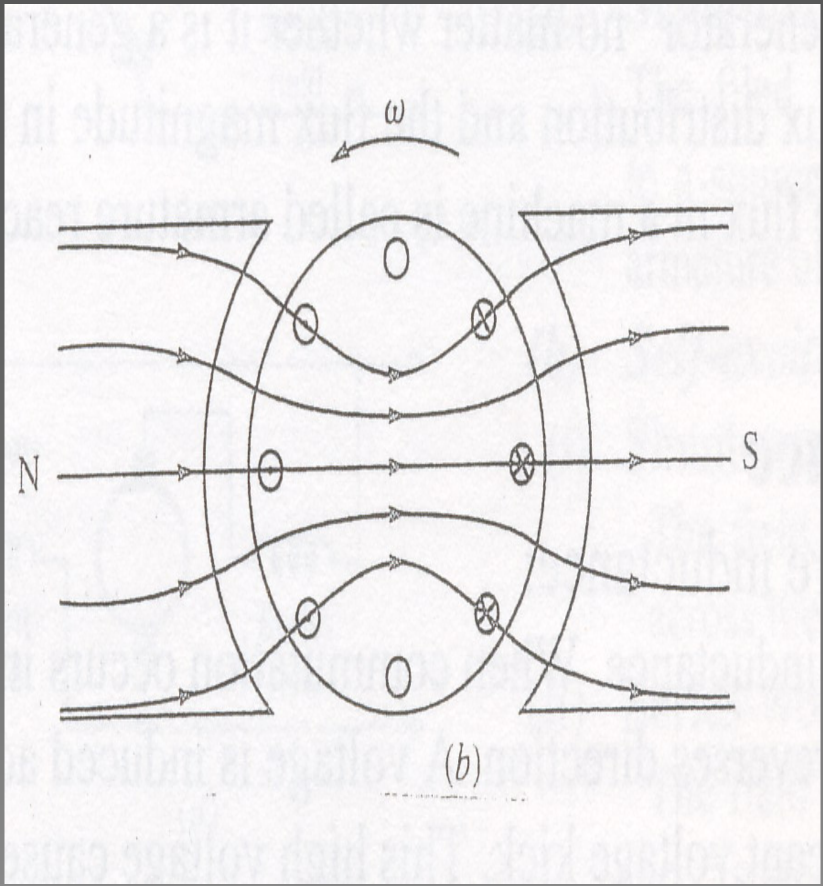
Armature Reaction

- Effect on flux distribution: *Neutral plane shift*
  - When current is flowing in the field winding, hence a flux is produced across the machine which flows from the North pole to the South pole.
  - Initially the pole flux is uniformly distributed and the magnetic neutral plane is vertical



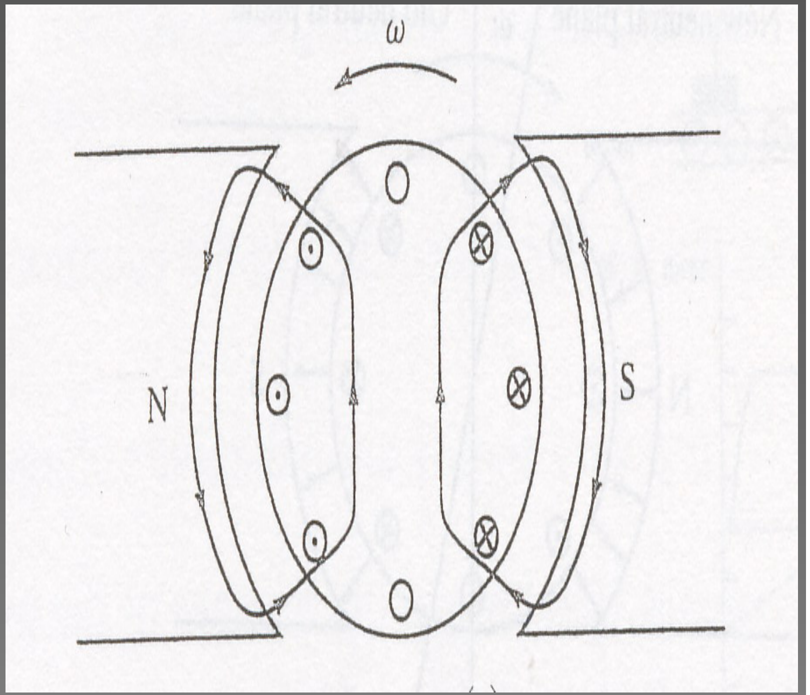
Armature Reaction

- Effect on flux distribution: *Neutral plane shift*
  - Effect by the air gap on the flux field causes the distribution of flux is no longer uniform across the rotor.
  - There are two points on the periphery of the rotor where B= 0.



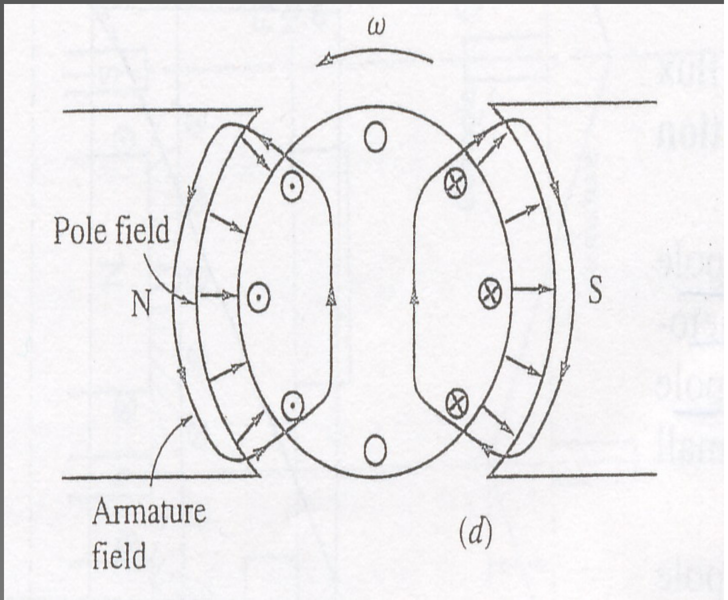
Armature Reaction

- Effect on flux distribution: *Neutral plane shift*
  - when a load connected to the machines a resulting magnetic field produced in the armature
  - If the armature is rotated at a speed ω by an external torque each armature coil experiences a change in flux $\partial\phi/\partial t$ as it rotates.
  - A voltage is generated across the terminals of each winding according to the equation $e = \partial\phi/\partial t$



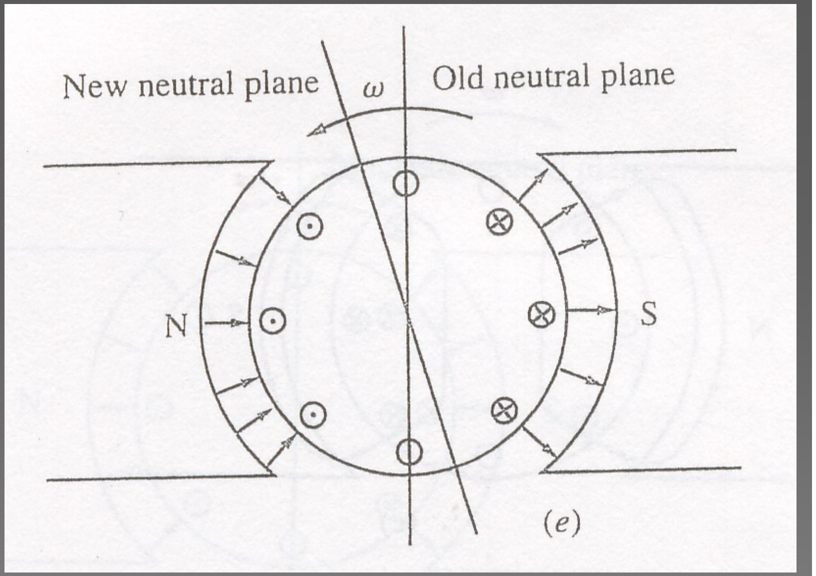
Armature Reaction

- Effect on flux distribution: *Neutral plane shift*
  - Both rotor and pole fluxes (flux produced by the field winding and the flux produced by the armature winding) are added and subtracted together accordingly
  - The fields interact to produce a different flux distribution in the rotor.
  - Thus, the flux on the middle line, between the two field poles, is no longer zero.



Armature Reaction

- Effect on flux distribution: *Neutral plane shift*
- The combined flux in the machine has the effect of strengthening or weakening the flux in the pole. Neutral axis is therefore shifted in the direction of motion.
- The result is current flow circulating between the shorted segments and large sparks at the brushes. The ending result is arcing and sparking at the brushes.
- **Solution to this problem:**
  - placing an additional poles on the neutral axis or mid-point that will produce flux density component, which counter-acts that produced by the armature.



Armature Inductance

- When rotor turns, thus we have inductance value, $e_1 = L(di/dt)$. Let say current i_{a1}.
- That means, we have ability to store energy
- If the machine is turn ‘off’, thus, e_1 will decreased. This will affect the current as well. Say i_{a2}.
- When the machine is turn ‘on’ again, it will produce e_2 while e_1 is still inside. The current now is reversed direction from previous (decreasing) current.
- Thus, it will cause sparking → resulting the same aching problem caused by neutral plane shift.

APPLICATIONS OF DC MOTORS

(a) DC SHUNT MOTORS

(i) Shunt motors are used in situations, such as driving a line shafting etc. where the speed as to be maintained approximately constant between no-load and full-load.

(ii) In situations where variable load is to be driven at different speeds but at each load, the speed is to be kept constant. Such as driving a lathe.

APPLICATIONS OF DC MOTORS

(b) DC SERIES MOTORS

DC Series Motors are used in applications such as driving hoists, cranes, trains, etc., as in these cases a large starting torque is required. They are also used where the motor can be permanently coupled to the load, such as

(b) DC SERIES MOTORS

Fans , whose torque increases with speed. Where constancy in speed is not essential, the decrease of speed with increase of load has the advantage that the power absorbed by the motor does not increase as rapidly as the torque .

APPLICATIONS OF DC MOTORS

(b) DC SERIES MOTORS

Series motors acquire very high speed at no-load or at very light load . That is why they should not be used for a belt drive where there is a possibility of the load decreasing to very small value.

APPLICATIONS OF DC MOTORS

(c) DC COMPOUND MOTORS

DC Compound Motors are used in application where large starting torque are required but where the load may fall to such a small value that a series motor would reach a dangerously high speed.

APPLICATIONS OF DC MOTORS

(c) DC COMPOUND MOTORS

Where the supply voltage may fluctuate , for instance on a traction system, the series winding reduces the fluctuation of armature current partly by its inductance and partly by its influence on the value of

(c) DC COMPOUND MOTORS

flux and therefore on that of the induced e.m.f.

When the load is of a fluctuating nature , e.g. for driving stamping processes, etc. the shunt excitation prevents the speed …

(c) DC COMPOUND MOTORS

Becoming excessive on light load, and the decrease of speed with increase of load enables the flywheel, usually fitted to such a machine, to assist the motor in in dealing with the peak load by giving up some of its kinetic energy.