DC MACHINE

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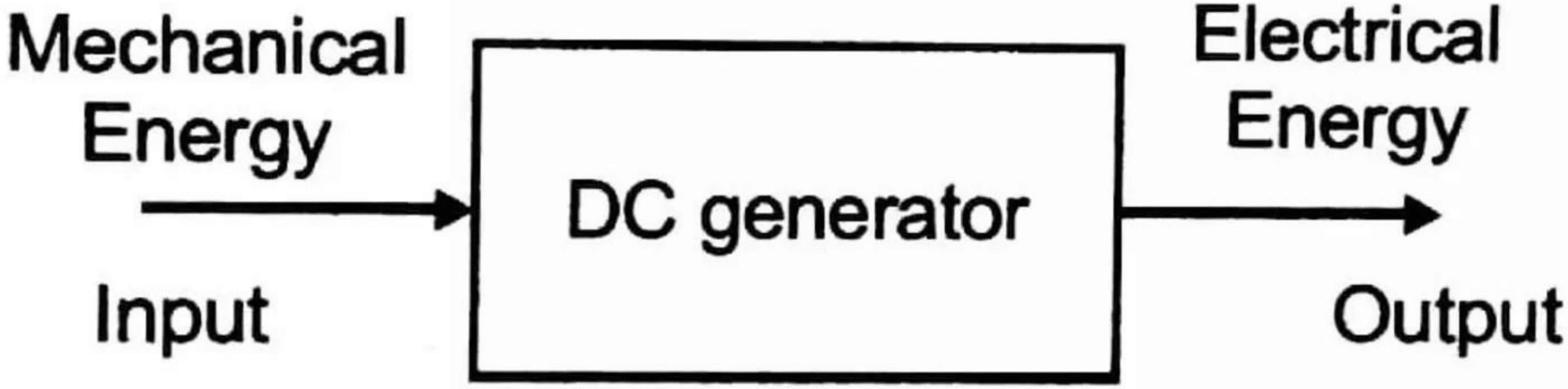
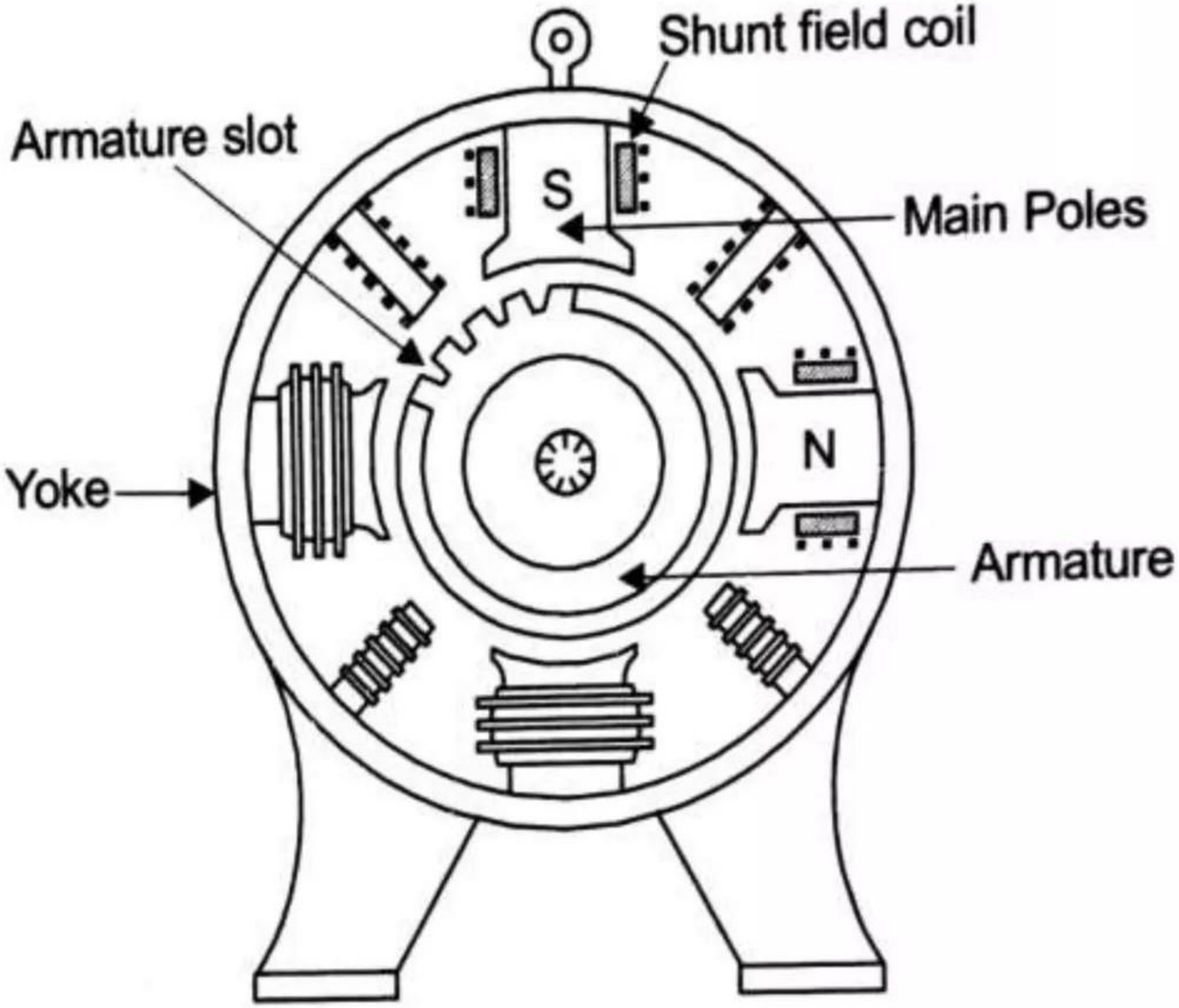
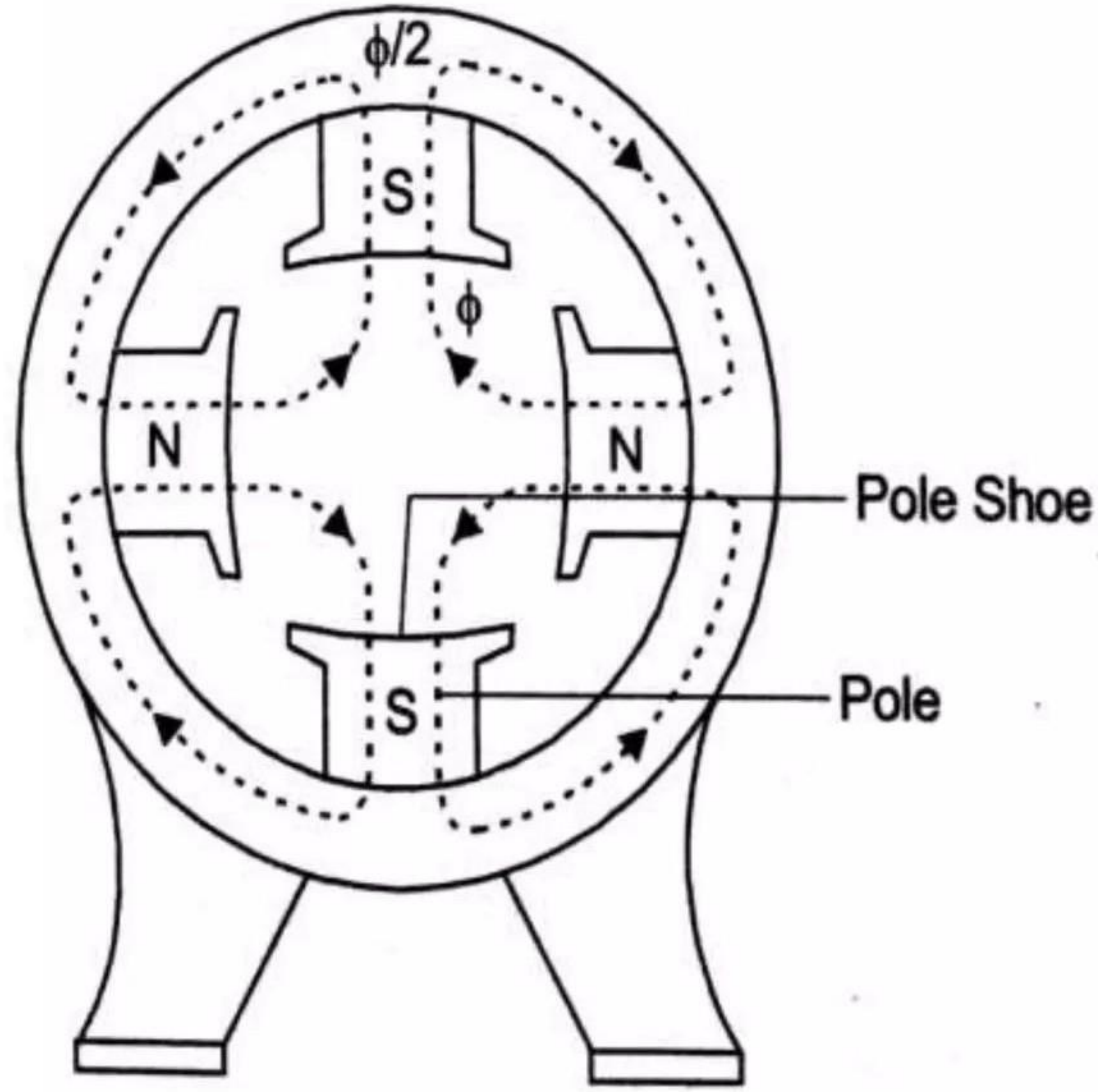
DC Generator



According to faradays law of electromagnetic induction, whenever a conductor is moved in magnetic field, **dynamically induced emf** is produced in the conductor.

Construction





Magnetic frame

Protective cover & mechanical support

Carries magnetic flux produced by the poles

Made up of cast iron and cast steel.

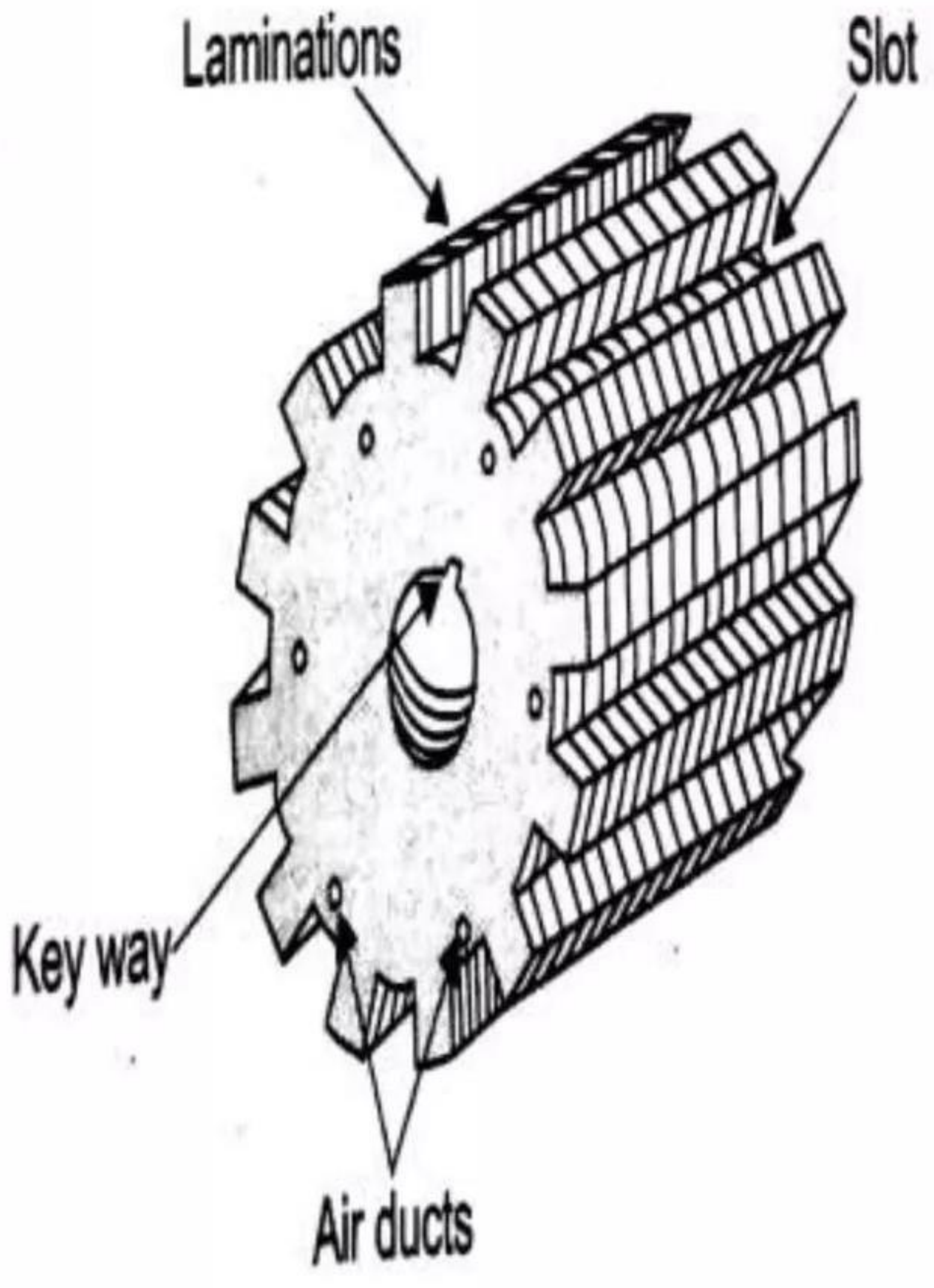
Poles

Made up of copper wire.

Current is passed through coils becomes electromagnet and starts establishing magnetic field in the machine and **flux is distributed through the pole**

Armature

Consists of armature core/ conductors/coils and armature windings



It rotates under poles and **flux produced by field magnets is cut by the armature conductors.**

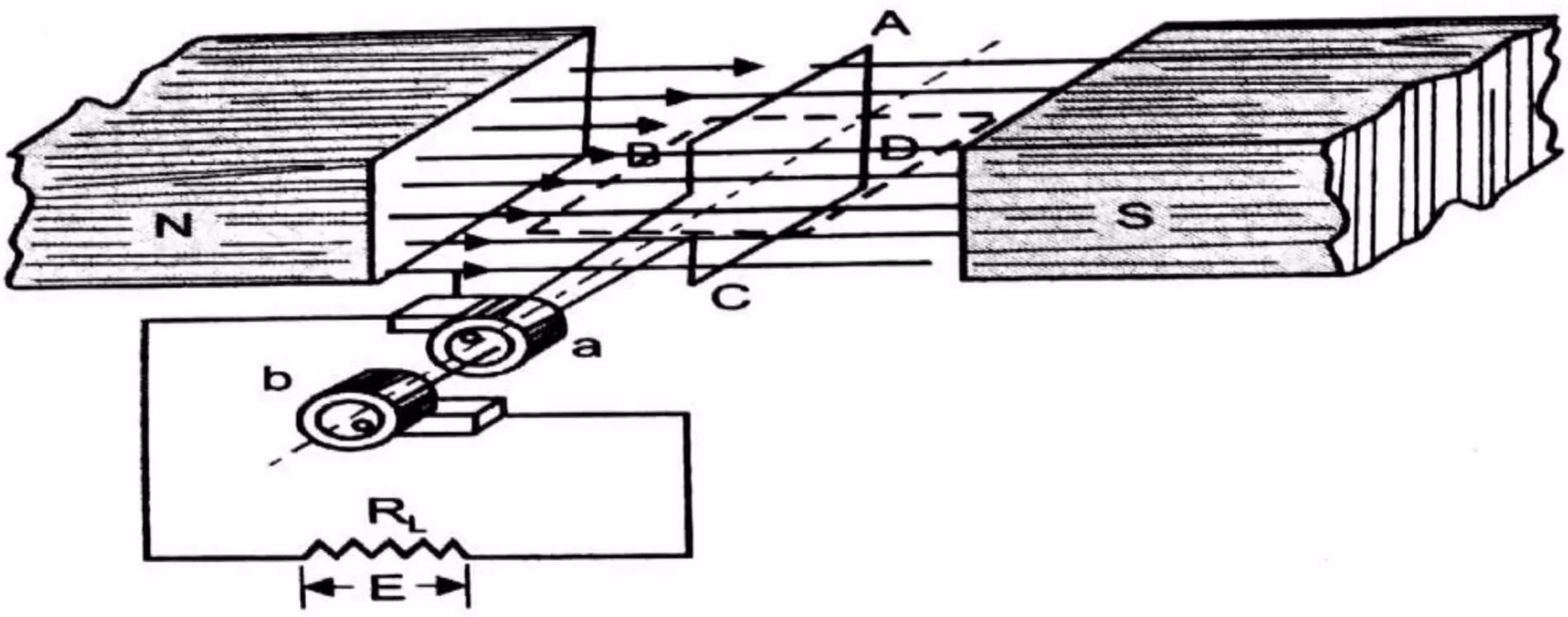
Commutator

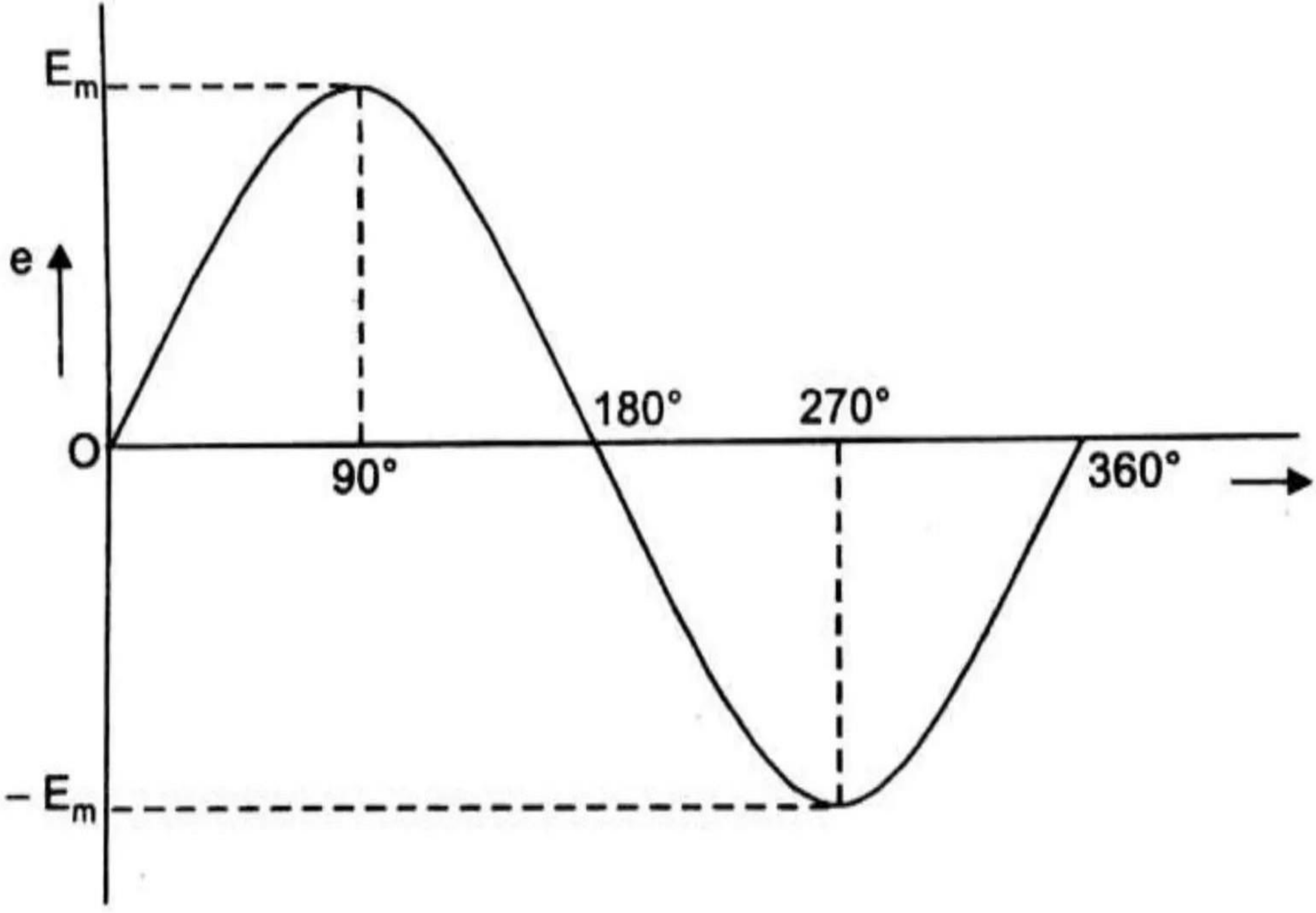
Converts alternating emf to unidirectional emf

Brushes and Bearing

Collect the current from the commutator and convey to external load

Principle of operation





Dynamically induced emf

Split ring arrangement for unidirectional emf

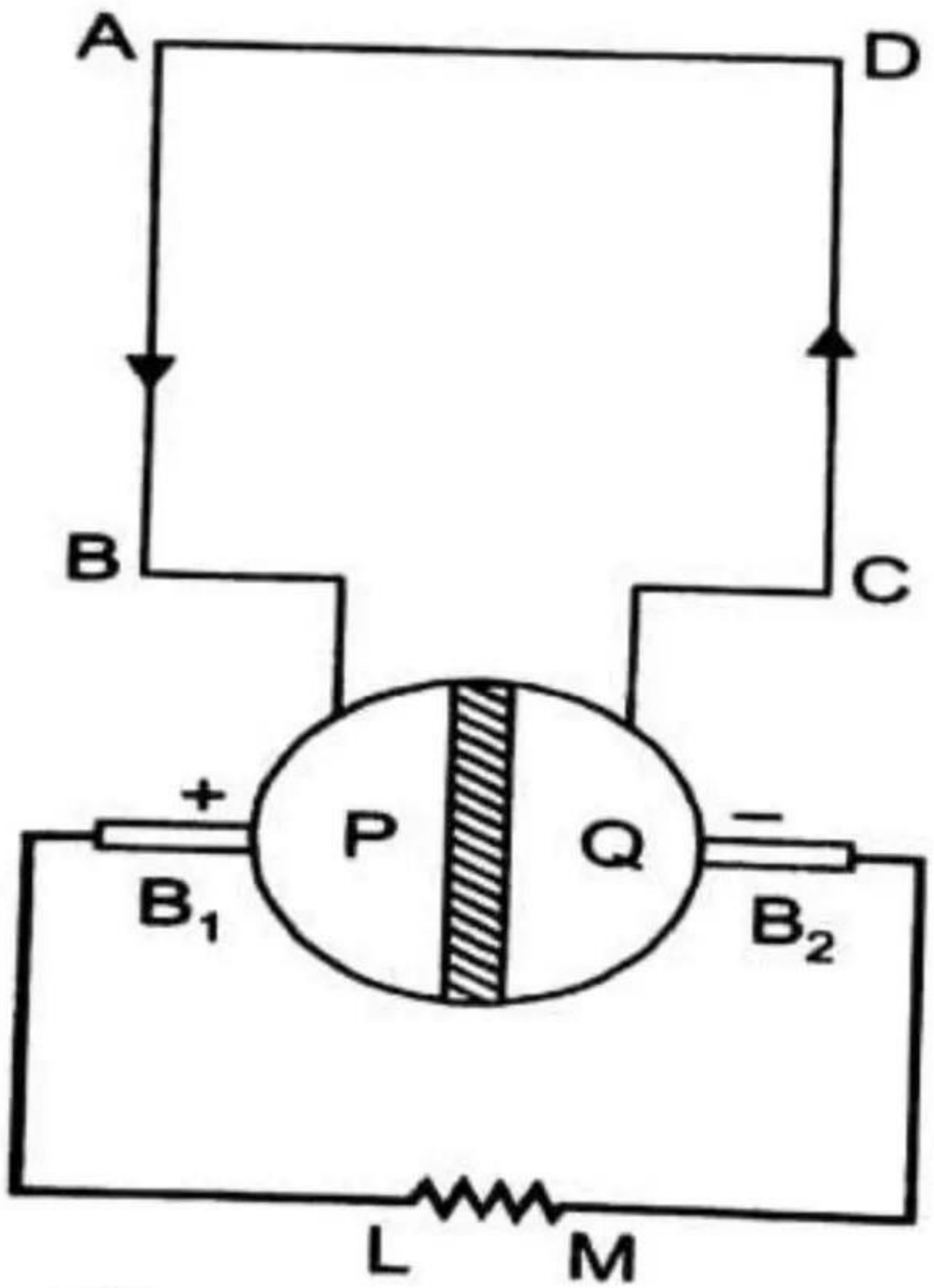


Figure 2.9 (b)

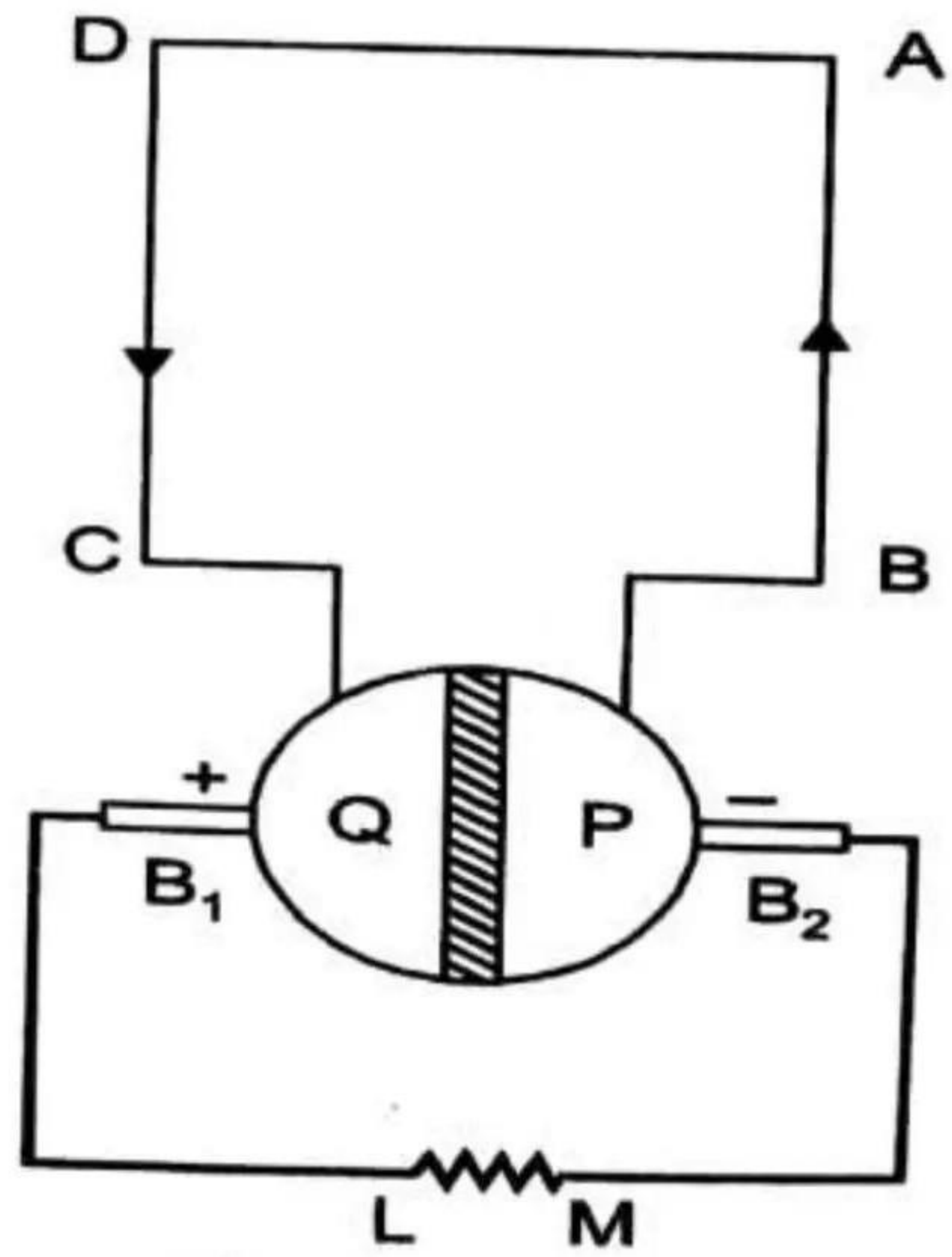
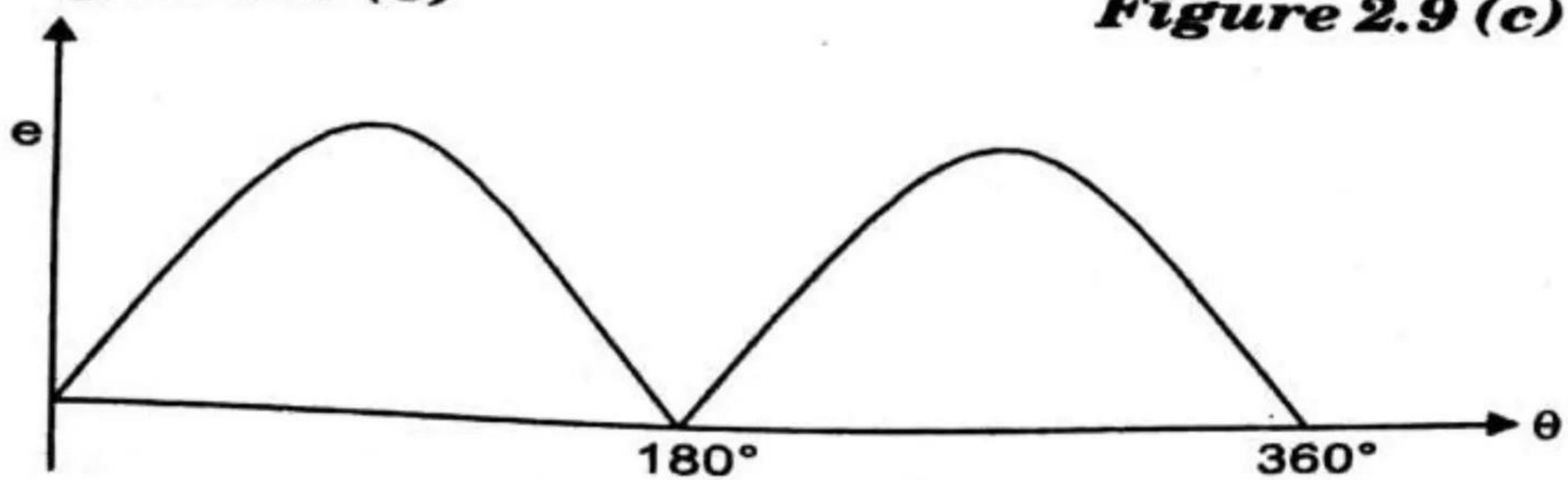


Figure 2.9 (c)



E M F induced in a DC Generator

- let Ø be the flux per pole in webers
- let P be the number of poles
- let Z be the total number of conductors in the armature
- All the Z conductors are not connected in series. They are divided into groups and let A be the number of parallel paths into which these conductors are grouped.

- Each parallel path will have Z/A conductors in series
- Let N be the speed of rotation in revolution per minute (rpm)
- Consider one conductor on the periphery of the armature. As this conductor makes one complete revolution, it cuts PØ webers.
- As the speed is N rpm, the time taken for one revolution is 60/N sec.
- Since the emf induced in the conductor is equal to rate of change of flux cut.

- $e \alpha d\text{Ø}/dt$

  $= (P\text{Ø})/60/N$

  $e = PN\text{Ø}/60$ volts

Since there are Z/A conductors in series in each parallel path the emf induced

$E_g = (NP\text{Ø}/60)(Z/A)$ volts

$E_g = (\text{Ø}ZN/60)(P/A)$ volts

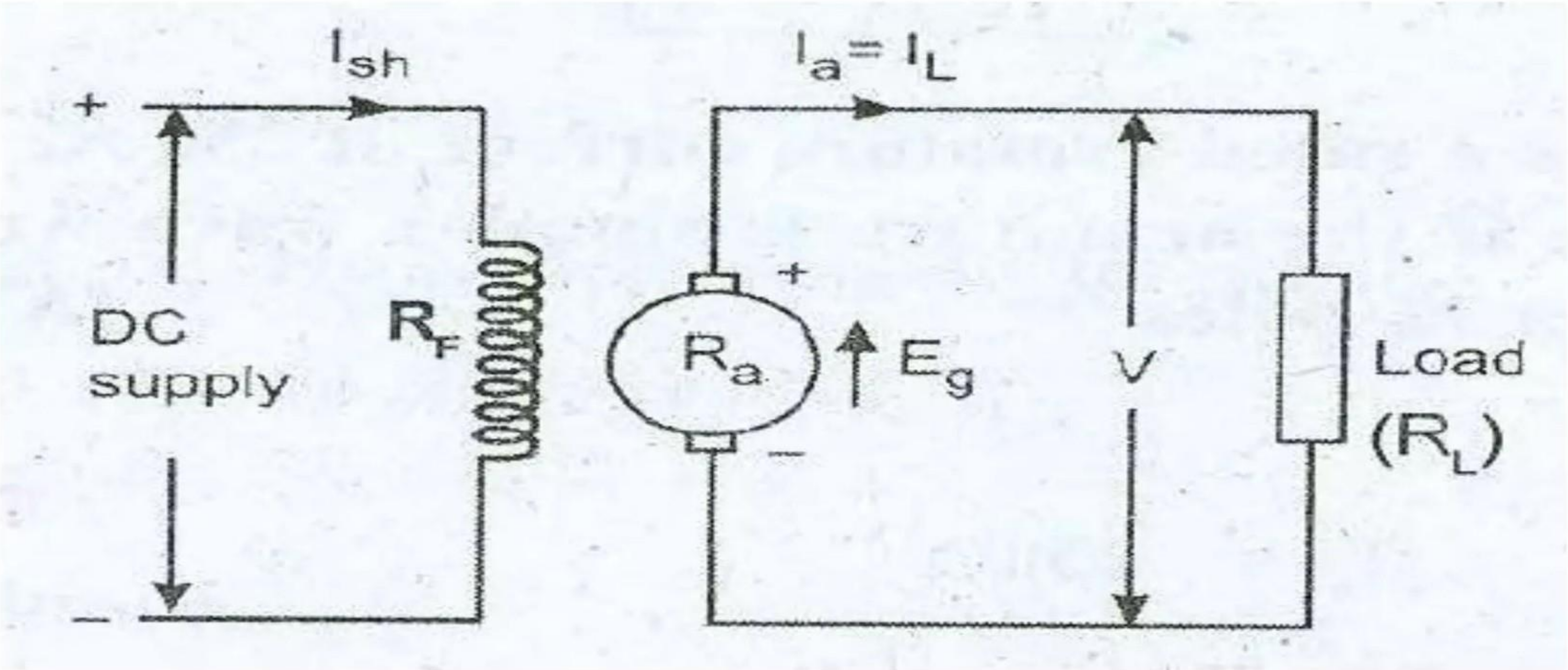
- The armature conductors are generally connected in two different ways, viz, lap winding and wave winding. For lap wound armature A=P. In wave wound machine, A = 2,always

Types of DC Generators

According to their methods of field excitation, DC Generators are classified into two types.

- Separately excited DC generator
- Self-excited DC generator

Separately excited DC generator

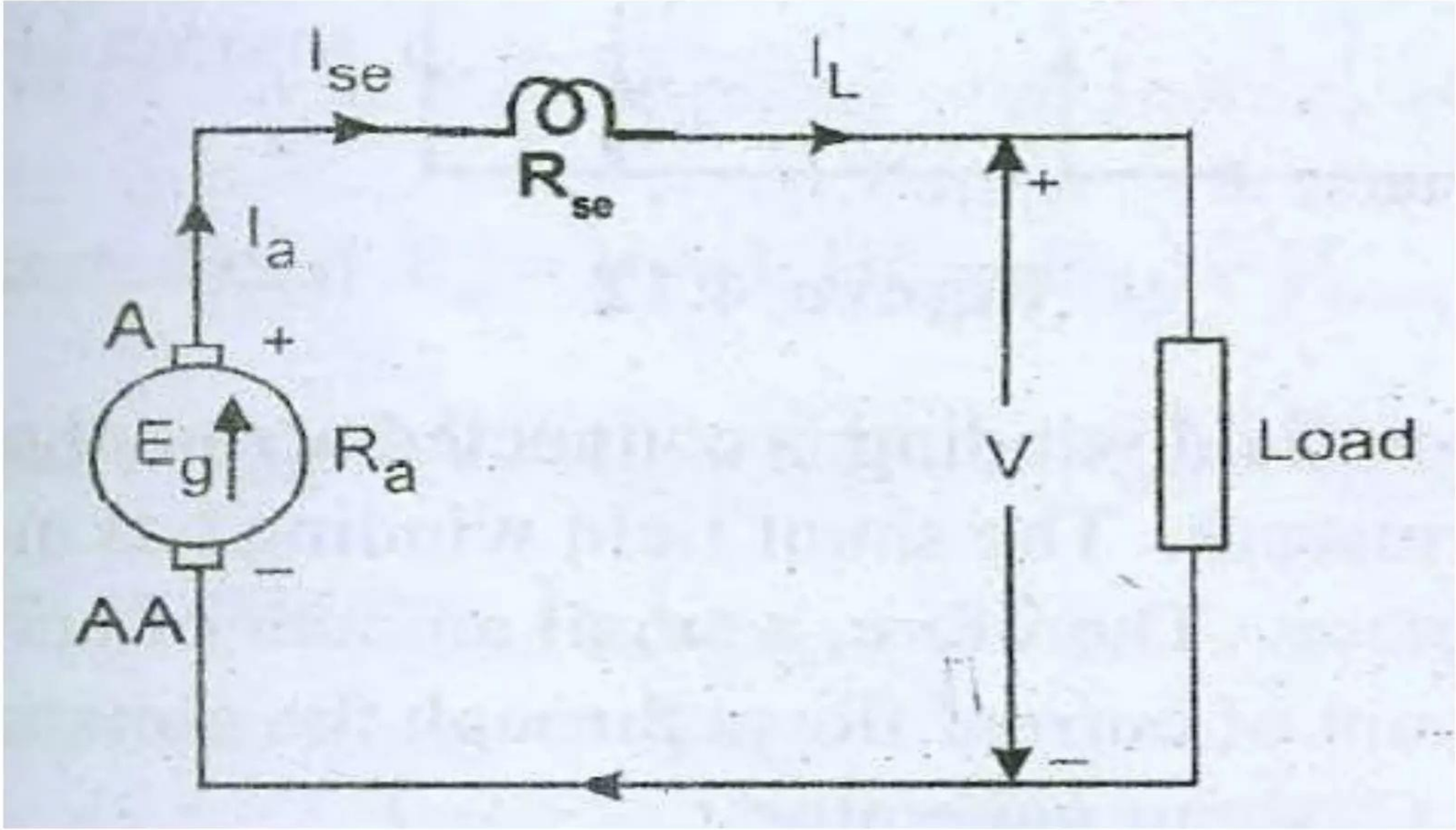


- $I_a = I_L$
- R_a = Resistance of the armature winding
- Terminal Voltage $V = E_g - I_a R_a - V_{brush}$
- V_{brush} = voltage drop at the contact of the brush
- Generally V_{brush} is negelected because of very low value
- Generally emf $E_g = V + I_a R_a + V_{brush}$
- Electric power developed = $E_g I_a$
- Power delivered to load = $V I_a$

Self-excited DC Generators

- Series generator
- Shunt generator
- Compound generator

Series Generator



- $I_a = I_L = I_{se}$
- Generated emf $E_g = V + I_a R_a + I_{se} R_{se} + V_{brush}$

Where,

V = terminal voltage in volts

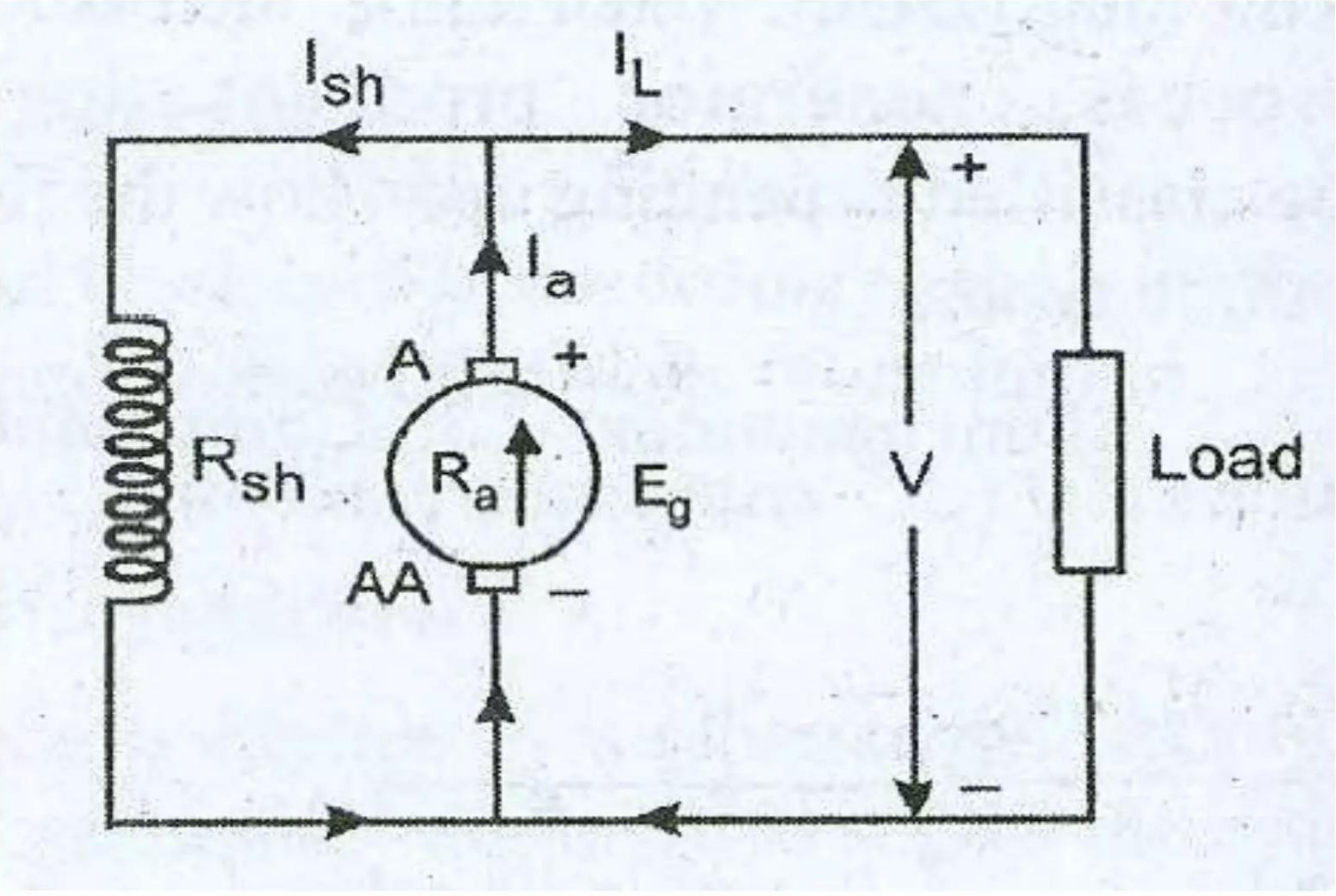
$I_a R_a$ = voltage drop in the armature

$I_a R_{se}$ = voltage drop in the series field winding resistance

V_{brush} = brush drop

- Terminal voltage $V = E_g - I_a R_a - I_a R_{se} – V_{brush}$
- Power developed in the armature = $E_g I_a$
- Power delivered to load = $V I_a$ or $V I_L$

Shunt Generator

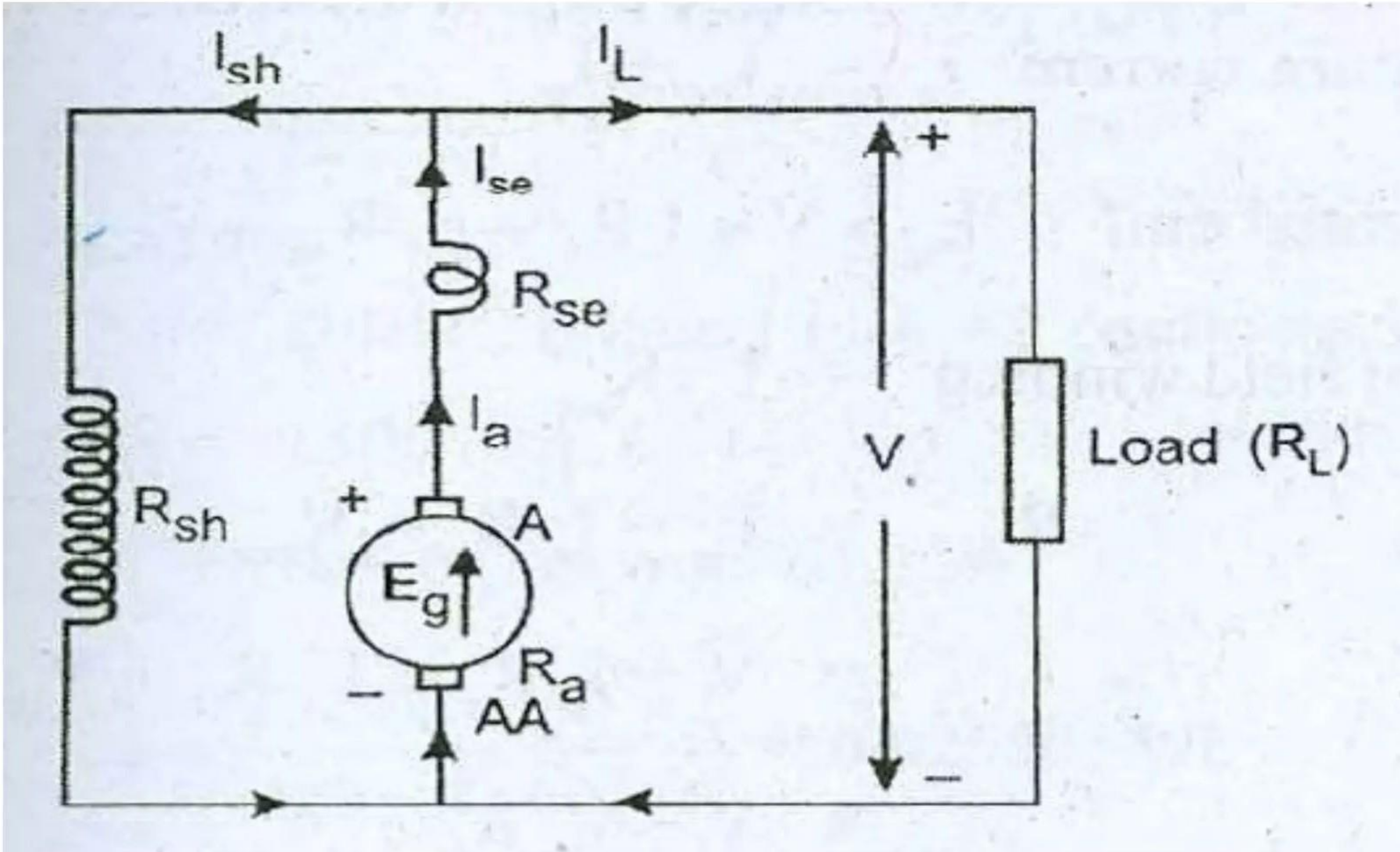


- Terminal voltage $V = E_g - I_a R_a$
- Shunt field current $I_{sh} = V/R_{sh}$
- Armature current $I_a = I_L + I_{sh}$
- Power developed by armature $= E_g I_a$
- Power delivered to load $= V I_L$

Compound Generator

- Long shunt compound generator
- Short shunt compound generator

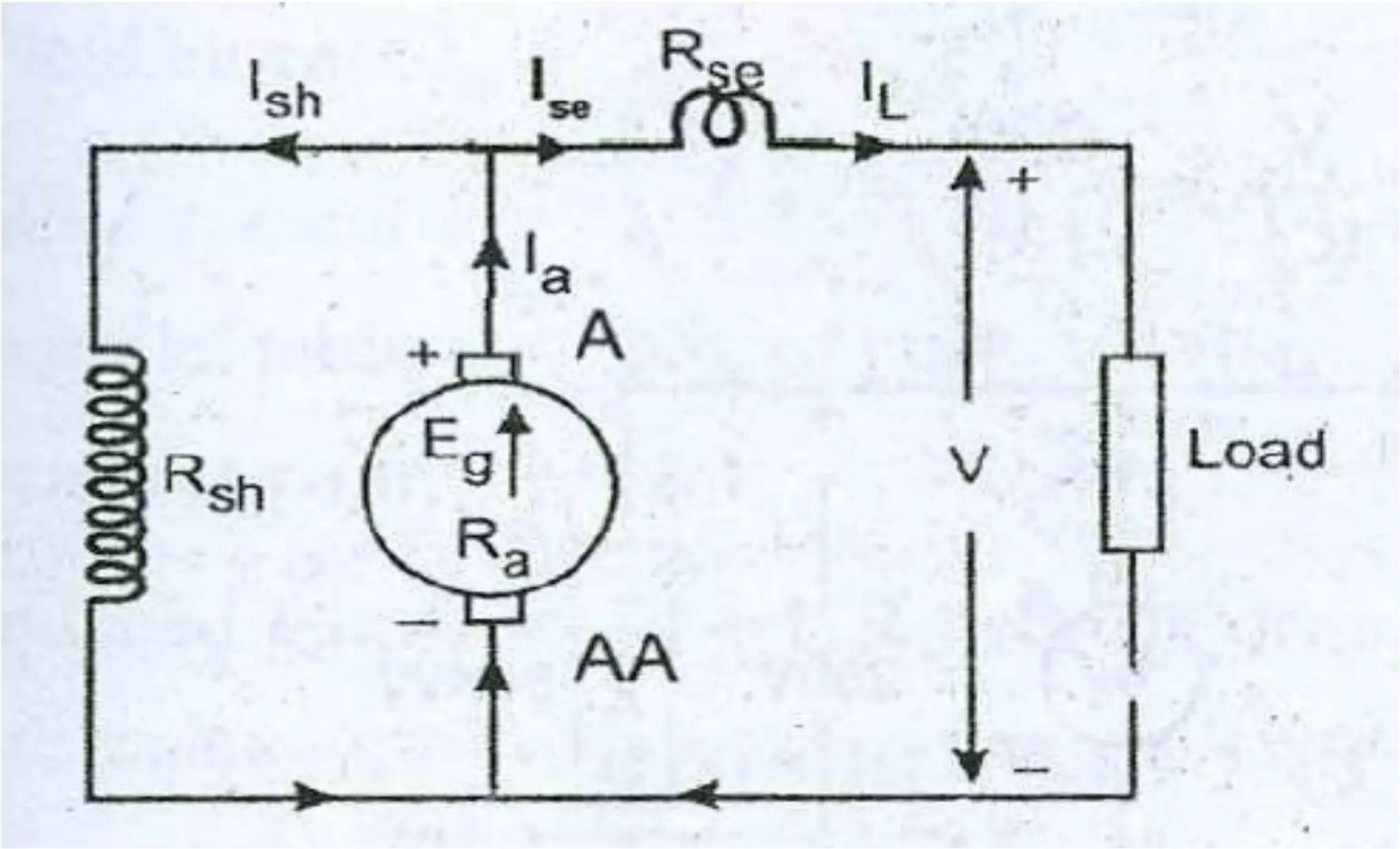
Long shunt compound generator



Long shunt compound generator

- Series field current $I_{se} = I_a = I_L + I_{sh}$
- Shunt field current $I_{sh} = V / R_{sh}$
- Generated emf $E_g = V + I_a (R_a + R_{sh}) + V_{brush}$
- Terminal voltage $V = E_g - I_a(R_a + R_{sh}) - V_{brush}$
- Power developed in armature $= E_g I_a$
- Power delivered to load $= V I_L$

Short shunt compound generator



Short shunt compound generator

- Series field current = $I_{se} = I_L$
- Load current = I_L
- Armature current $I_a = I_{sh} + I_{se}$
- Generated emf $E_g = V + I_a R_a + I_{se} R_{se} + V_{brush}$
- Voltage across shunt field winding = $I_{sh} R_{sh}$
- $I_{sh} R_{sh} = E_g - I_a R_a - V_{brush}$

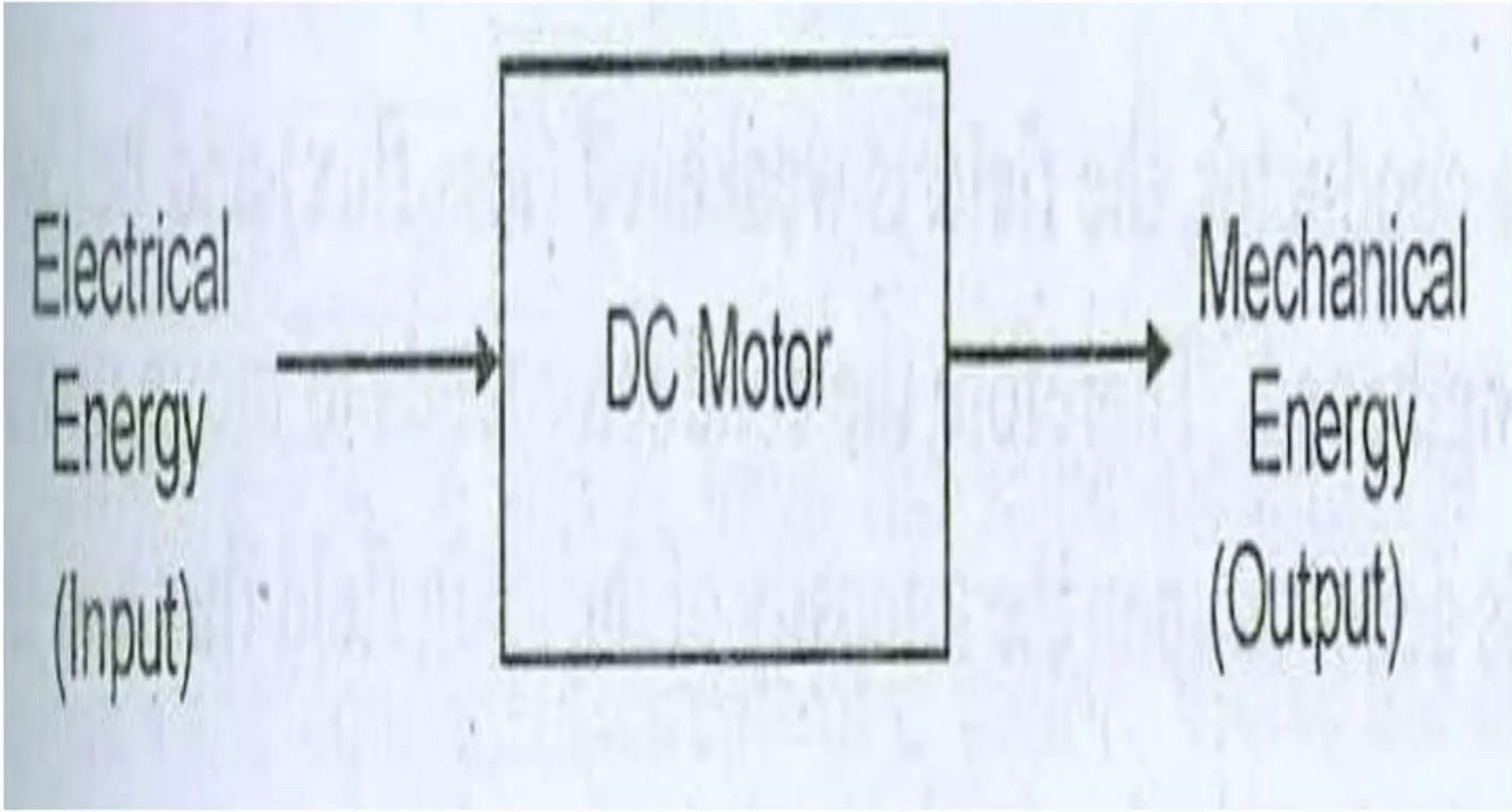
$$= V + I_a R_a + I_{se} R_{se} + V_{brush} - I_a R_a - V_{brush}$$

$$= V + I_{se} R_{se}$$

Applications of DC Generators

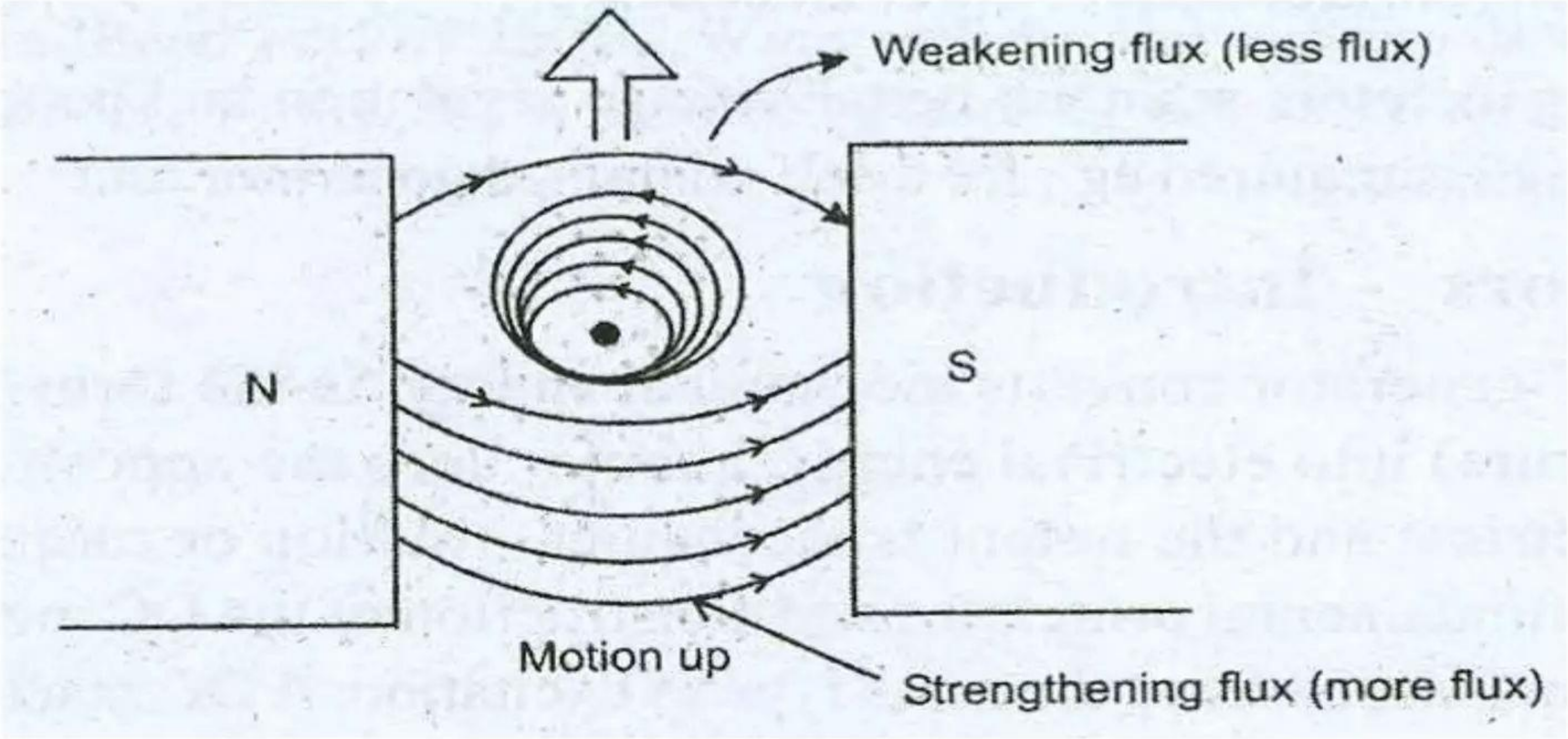
- Shunt generators are used for supplying nearly constant loads. They are used for battery charging, for supplying the fields of synchronous machines and separately excited DC machines
- Since the output voltage of a series generator increases with load, series generators are ideal for use as boosters for adding voltage to the transmission line and to compensate for the line drop.
- Compound generators maintain better voltage regulation and hence find use where constancy of voltage is required.

DC Motors


Electrical
Energy
(Input)
DC Motor
Mechanical
Energy
(Output)

Principle of operation of DC Motor

- Whenever a current carrying conductor is placed in magnetic field, the conductor experiences a force tending to move it. (Lorentz force)



The direction of motion of conductor is given by Fleming's Left hand rule.

The magnitude of the force experienced by the conductor is given by

$$F = BIL \text{ Newtons}$$

Where,

B = magnitude of flux density in Wb/m^2

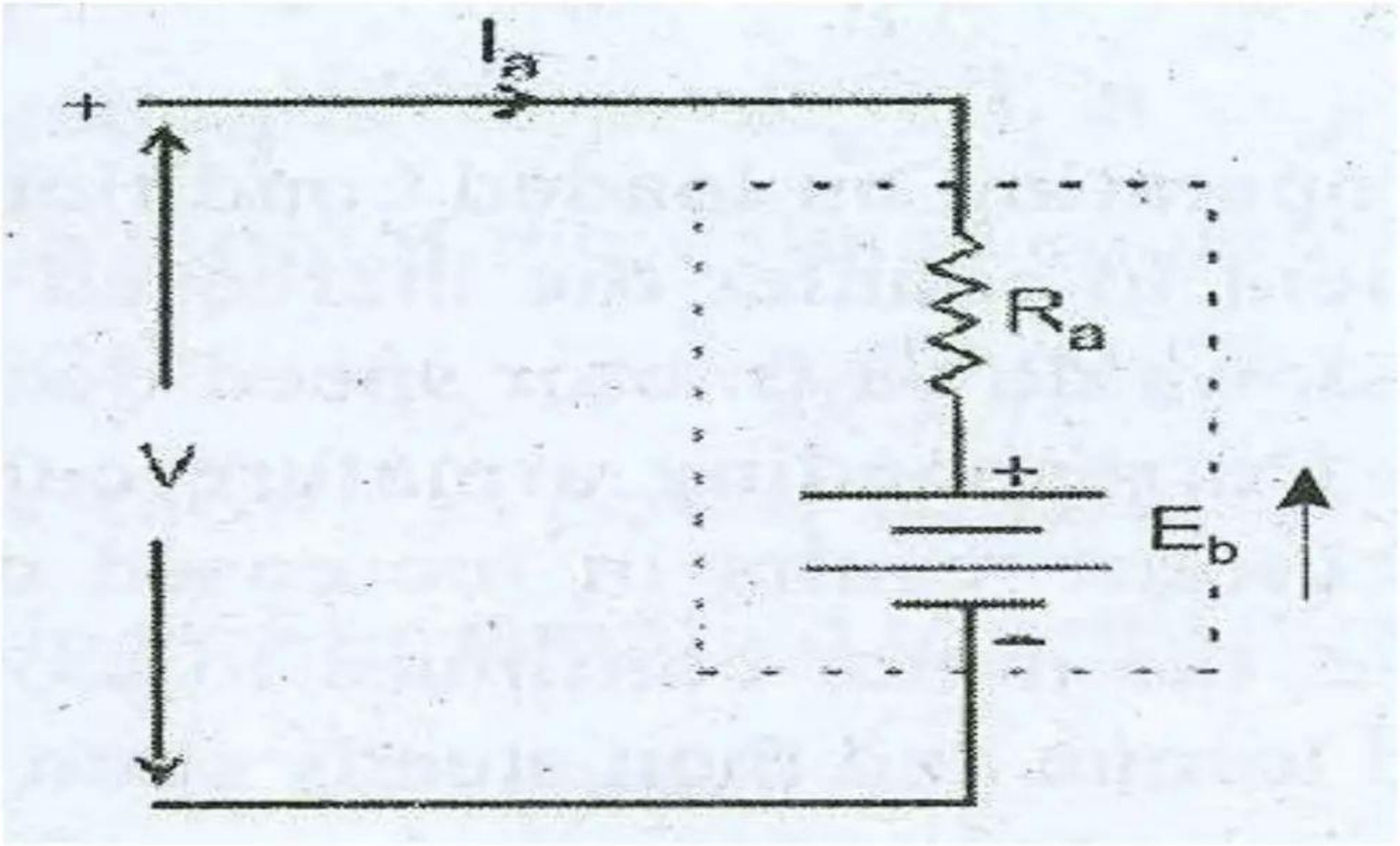
I = current in amperes

L = length of the conductor in meters

Back EMF (or) Counter EMF

- The conductors are cutting flux and that is exactly what is required for generator action to take place.
- This means that even when machine is working as a motor, voltage are induced in the conductors. This emf is called as back emf or counter emf(Lenz law)
- $E_b = (\text{Ø}ZN/60)(P/A)$ volts

Equivalent circuit of motor



- The voltage equation of this motor is

$$V = E_b + I_a R_a$$

- Form this equation, armature current

$$I_a = (V - E_b) / R_a$$

Where,

V – applied voltage

E_b = back emf

I_a = armature current

R_a = armature current

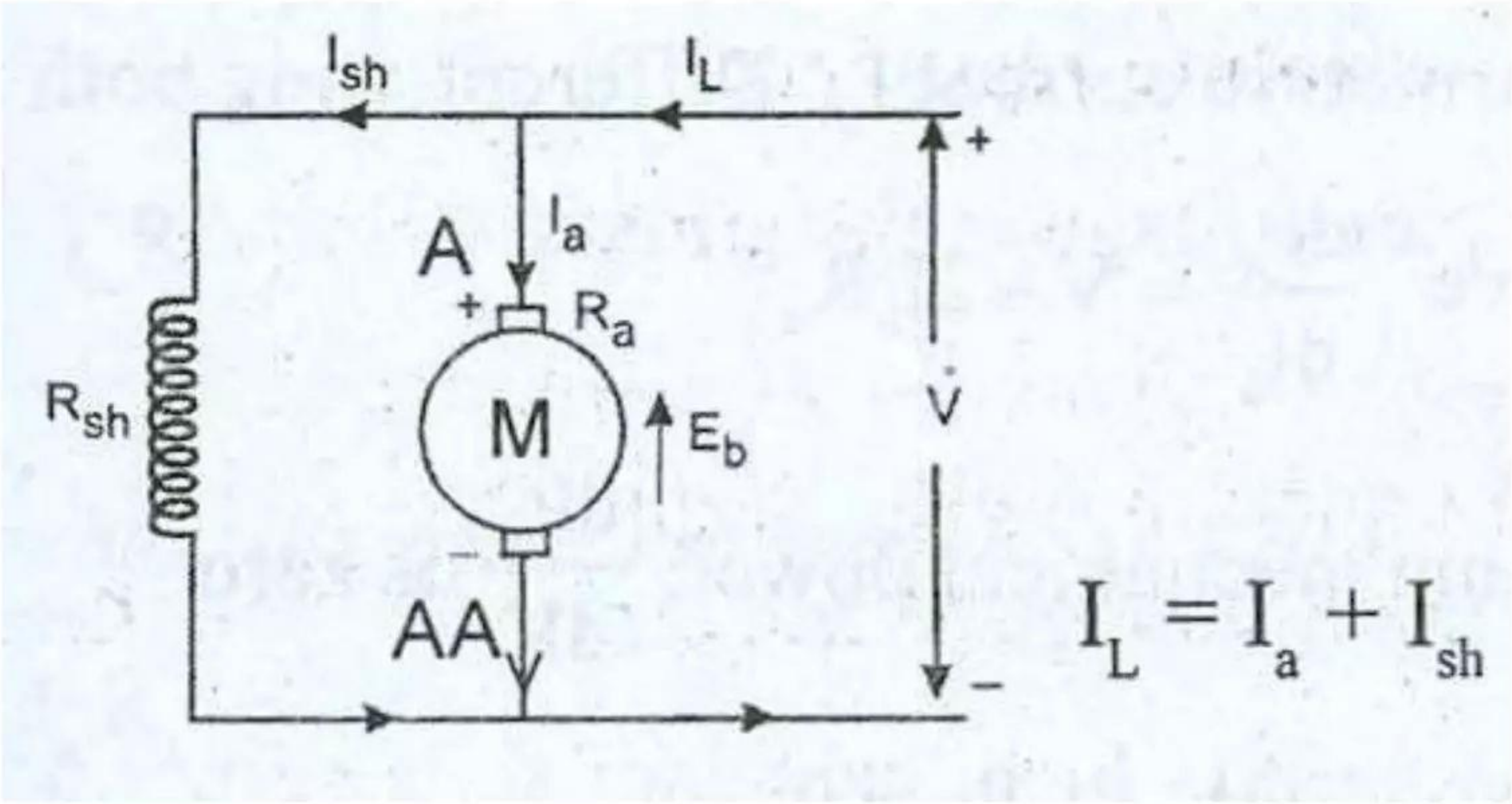
$V - E_b$ = net voltage in the armature circuit

Importance of Back EMF

- When DC motor is operating on no load condition, Therefore the back emf is equal to input voltage and armature current is small/decreseas.
- When the DC motor is operating on loaded condition, speed decreases and motor back emf also decreases. Corresponding armature current increases.
- When load on the motor decreased, the speed increases, the back emf also increases causing armature current to decreases.

Regulates armature current

Voltage equation of DC motor



V – input voltage E_b – back emf

R_a – armature resistance; I_a – armature current

I_{sh} – shunt field current; R_{sh} – shut field resistance

Voltage equation of DC motor

Here, the current flowing in the armature is given by

$$I_a = (V - E_b)/R_a$$

Or

$$V = E_b + I_a R_a$$

This equation is known as voltage equation of a DC motor.

Types of DC motors

According to their methods of field excitation, DC motors are classified into two types.

- Separately excited DC motors
- Self-excited DC motors

  . Series motor

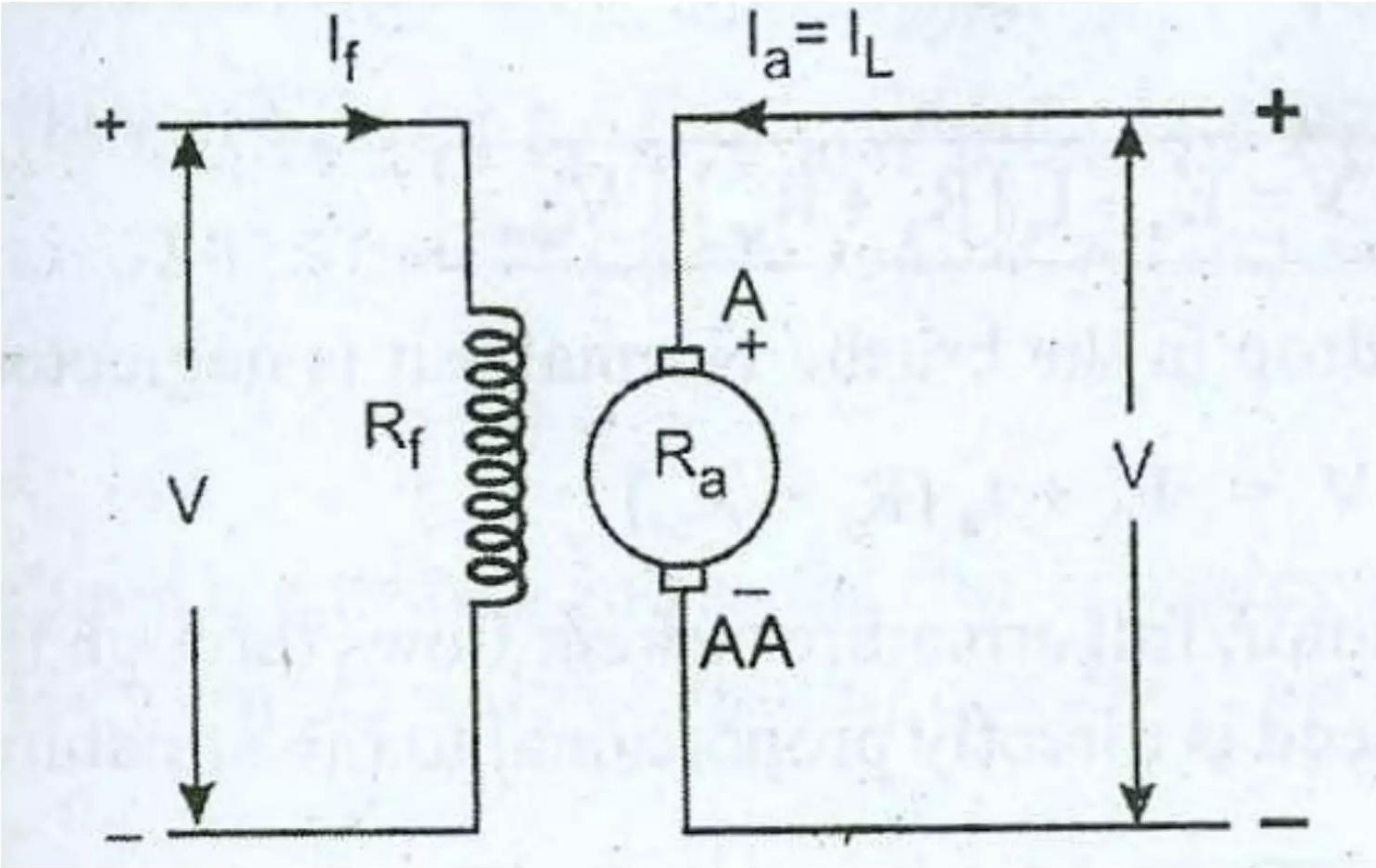
  . Shunt motor

  . Compound motor

    * long shunt compound motor

    * short shunt compound motor

Separately excited DC motor



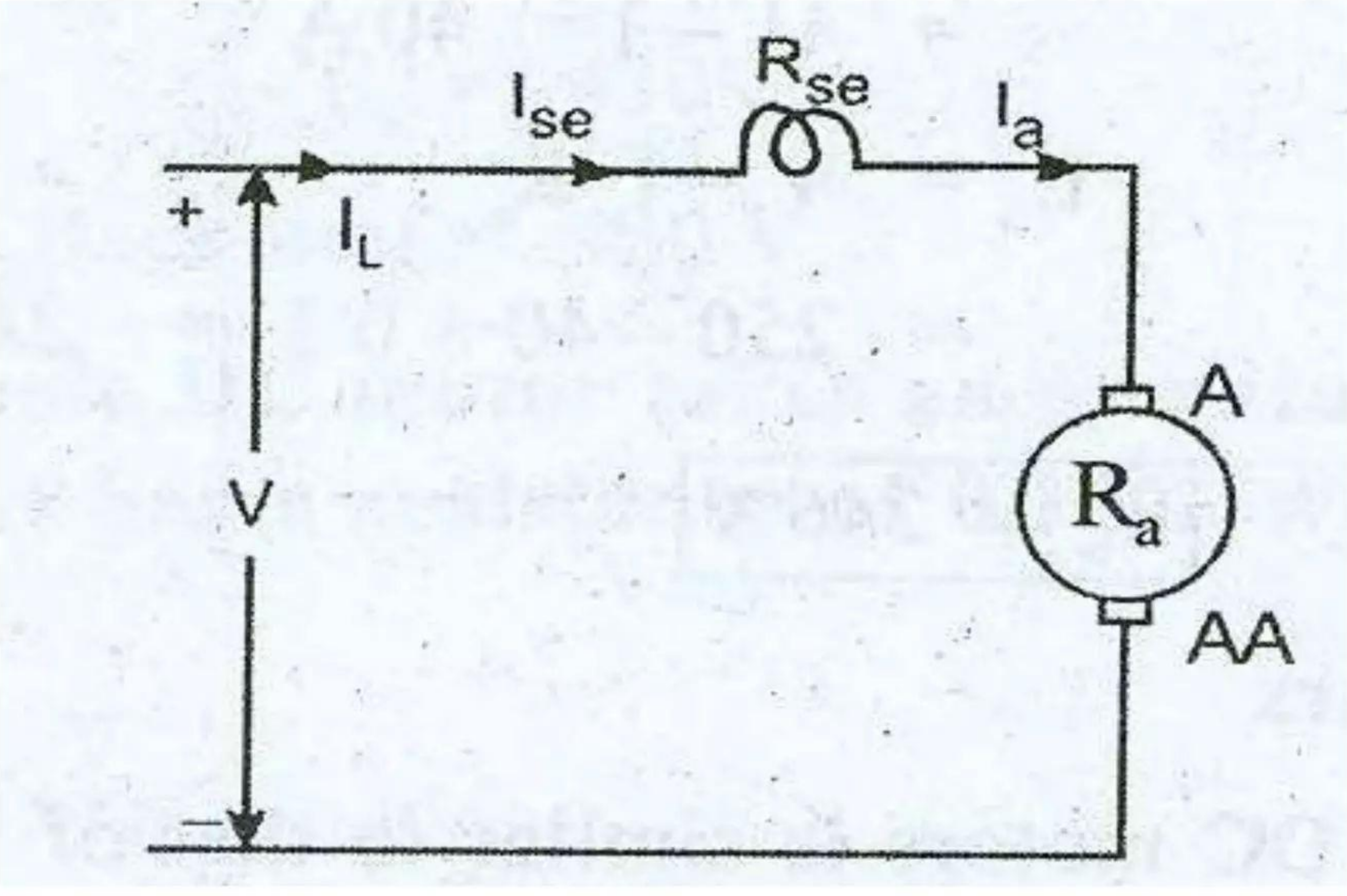
Separately excited DC motor

Armature current I_a = line current I_L

Back emf $E_b = V - I_a R_a – V_{brush}$

V_{brush} is very small and therefore it is neglected

DC Series Motor



DC Series Motor

- $I_a = I_L = I_{se}$
- The voltage equation is given by

$$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$$

$$I_a = I_{se}$$

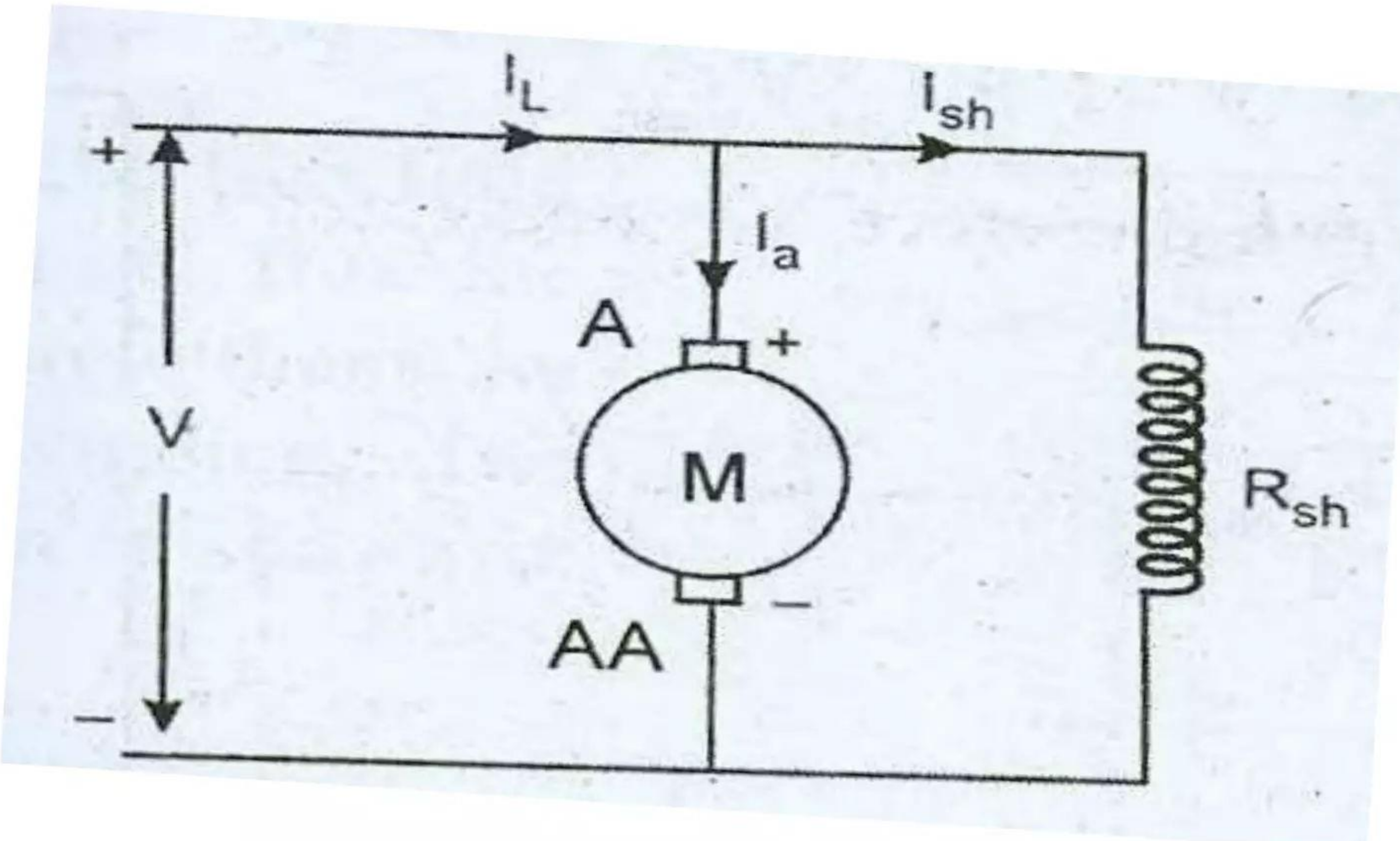
$$V = E_b + I_a (R_a + R_{se}) + V_{brush}$$

V_{brush} is neglected and hence

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

- $\emptyset \propto I_a \propto I_a$

DC Shunt Motor



DC Shunt Motor

- $I_L = I_a + I_{sh}$
- $I_{sh} = V/ R_{sh}$

Voltage equation of a DC shunt motor is given by

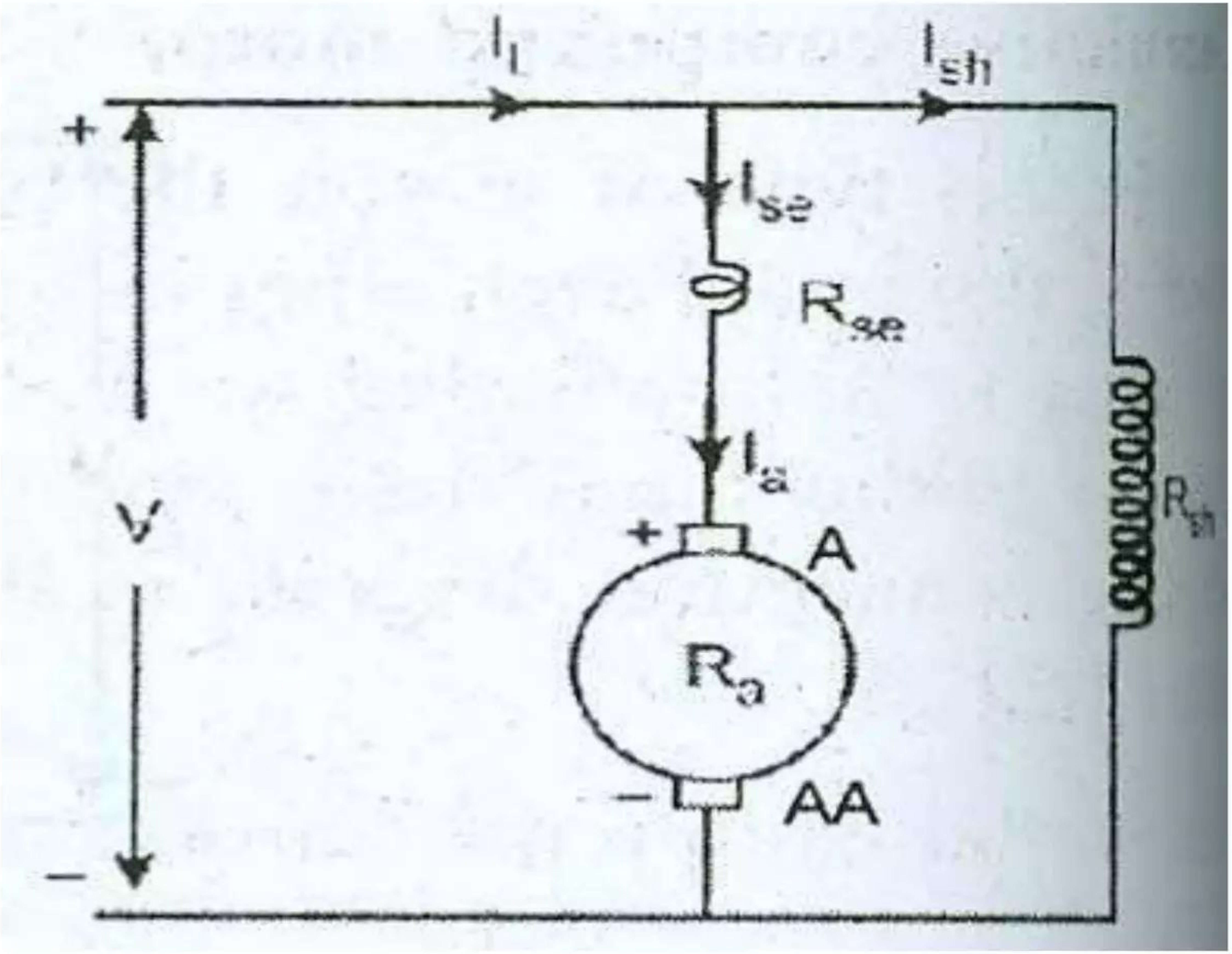
$$V = E_b + I_a R_a + V_{brush}$$

- $\Phi \ \alpha \ I_{sh}$

DC Compound Motor

- Long shunt compound motor
- Short shunt compound motor

Long shunt Compound Motor



Long shunt Compound Motor

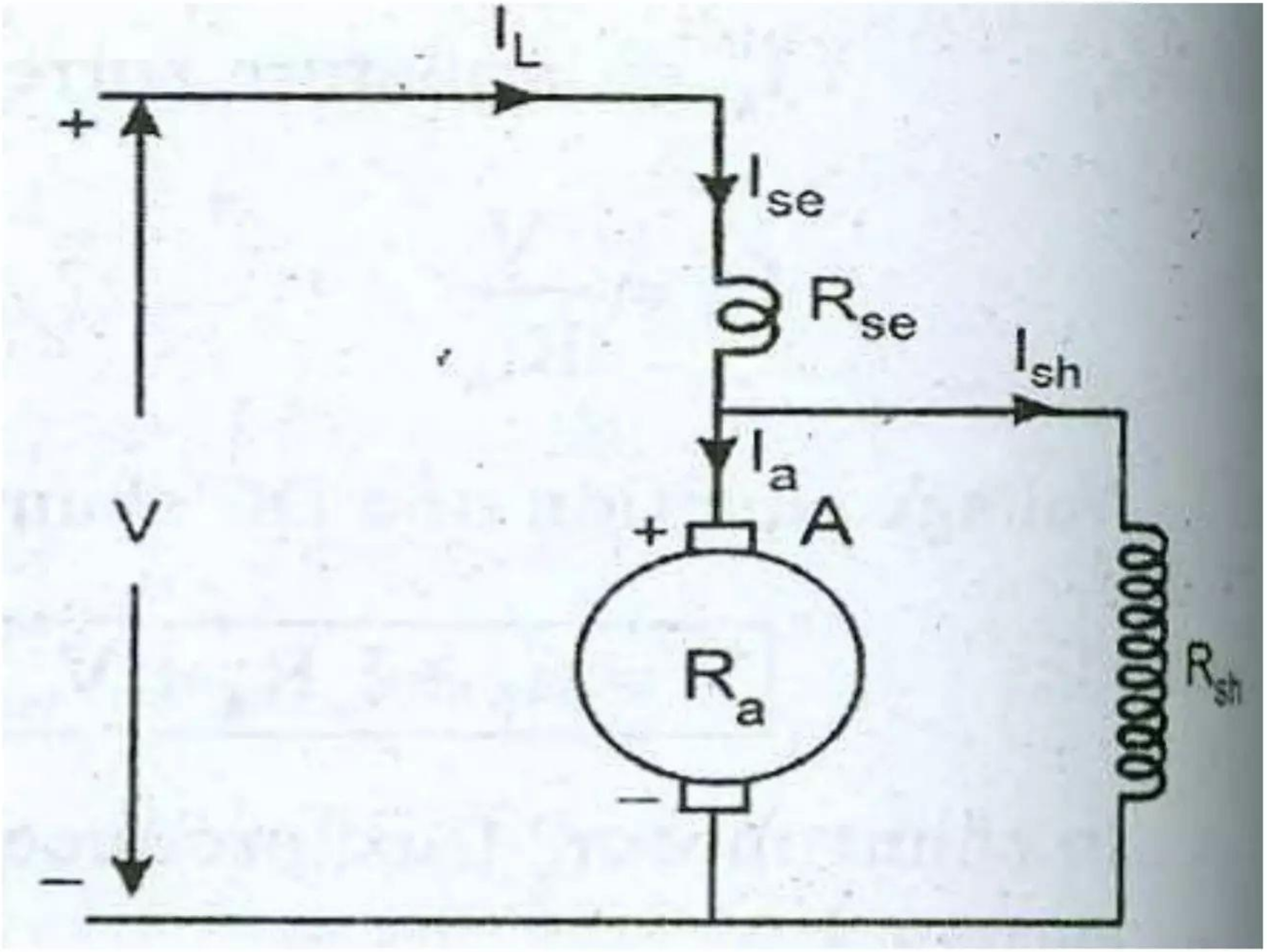
- $I_L = I_{se} + I_{sh}$
- $I_{se} = I_a$
- $I_L = I_a + I_{sh}$
- $I_{sh} = V / R_{sh}$
- Voltage equation is given by

$$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$$

Where $I_a = I_{se}$

$$V = E_b + I_a (R_a + R_{se}) + V_{brush}$$

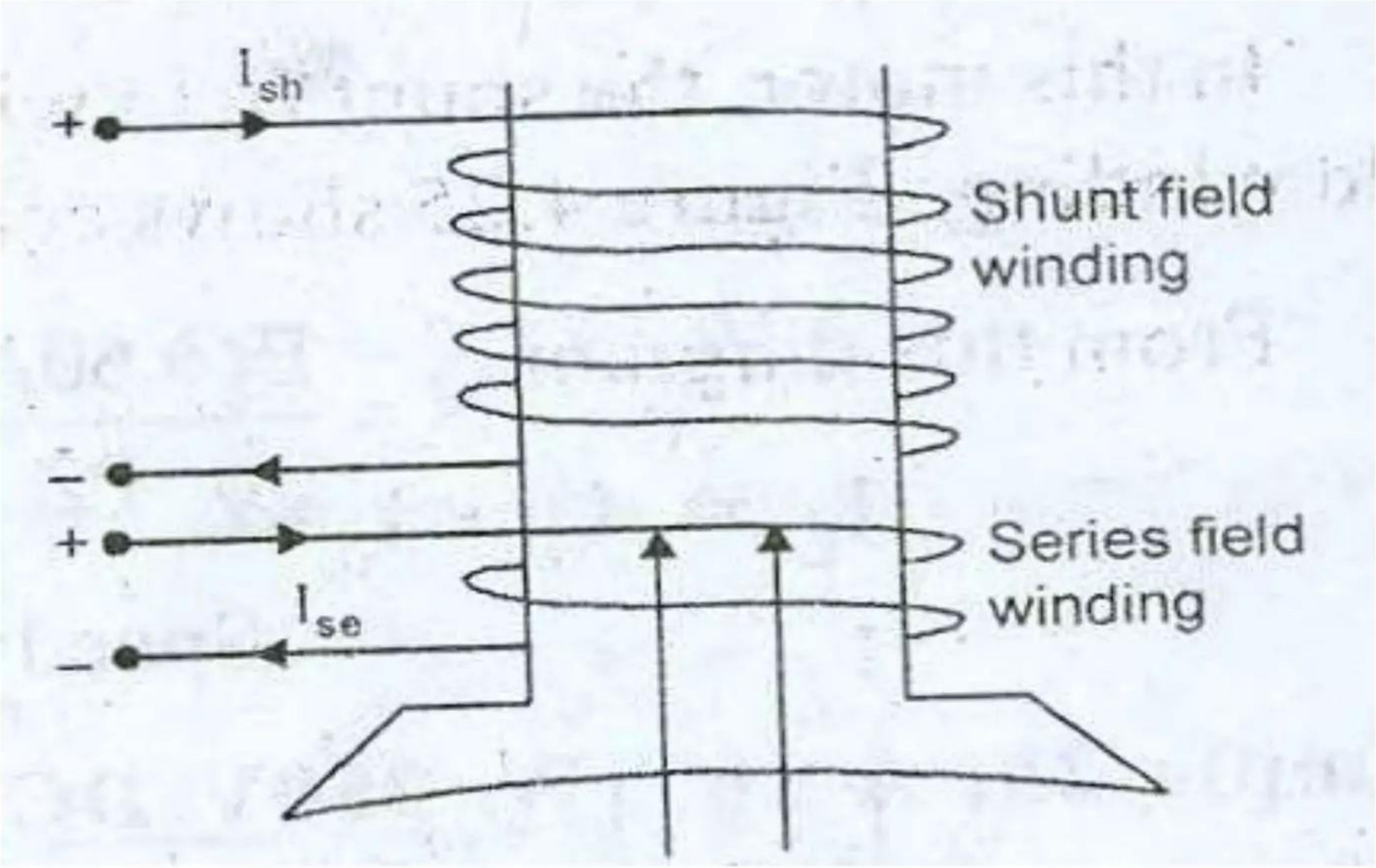
Short Shunt Compound Motor



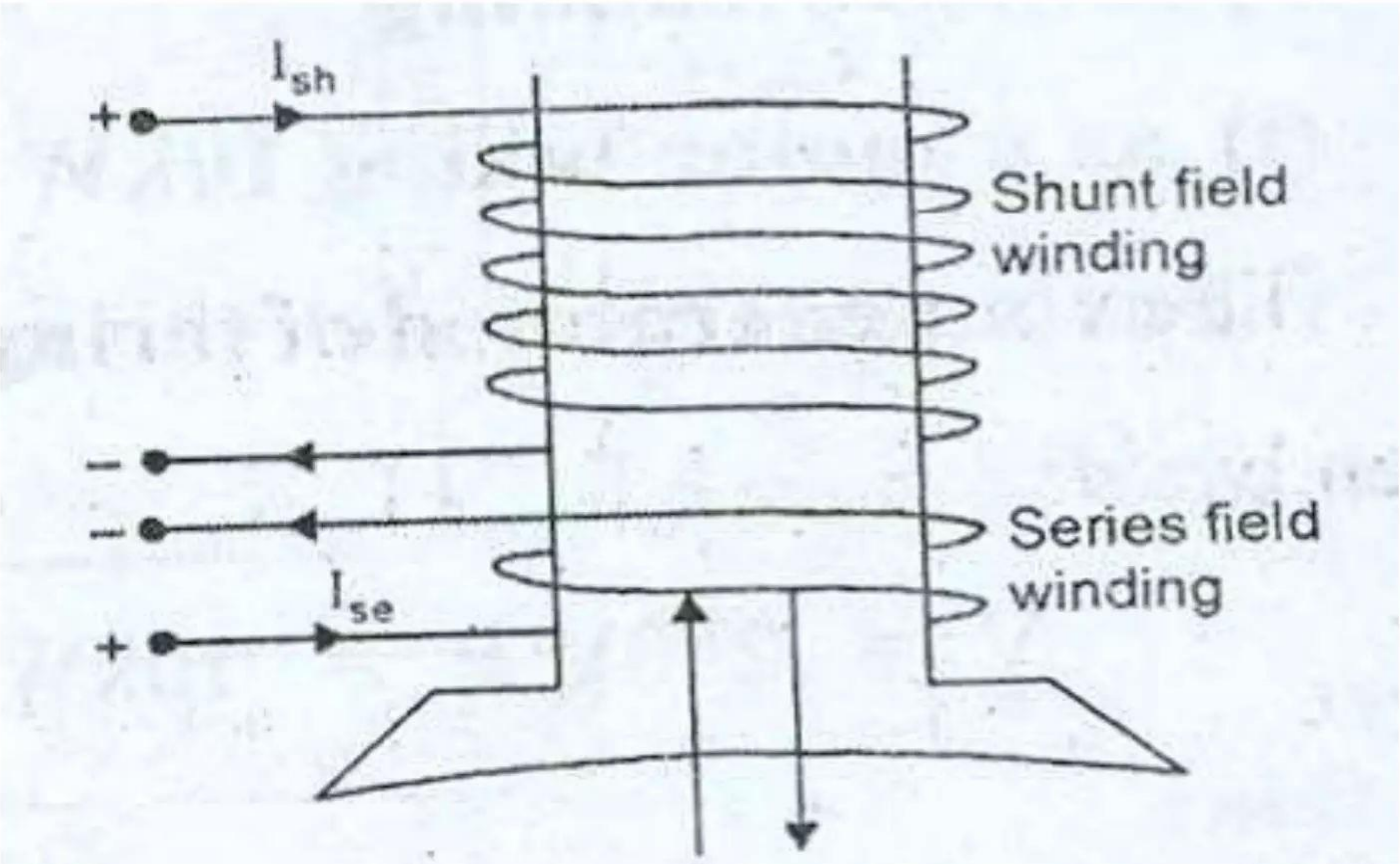
Short Shunt Compound Motor

- $I_L = I_{se}$
- $I_L = I_a + I_{sh}$
- $I_L = I_{se} = I_a + I_{sh}$
- $V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$
- $I_{se} = I_L$
- $V = E_b + I_a R_a + I_L R_{se} + V_{brush}$
- Voltage drop across the shunt field winding is = V - $I_L = I_{se}$
- $V_{sh} = E_b + I_a R_a + V_{brush}$
- $I_{sh} = V - I_L R_{se} / R_{sh}$

Cumulative Compound Motor

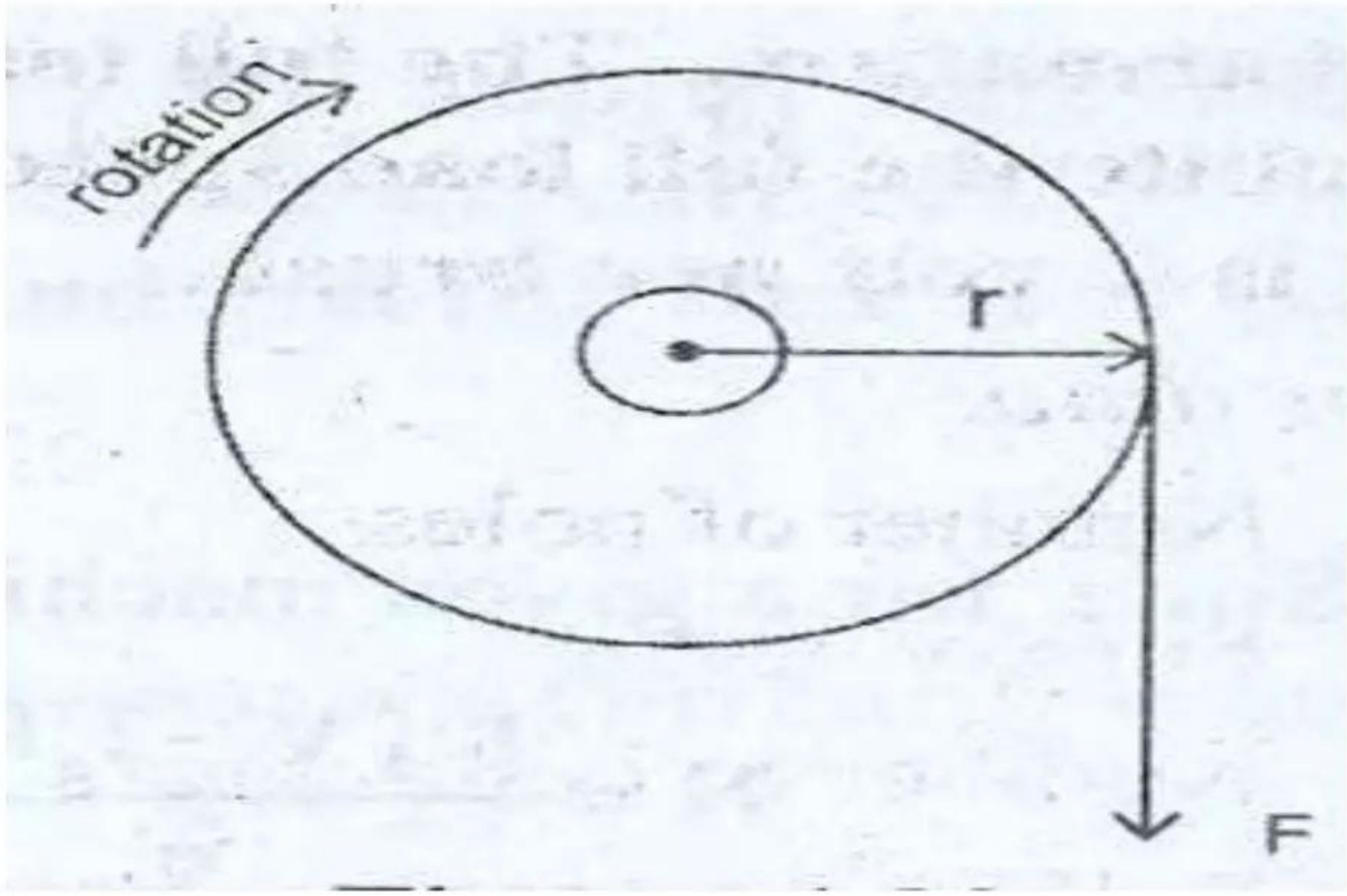


Differential Compound Motor



Torque Equation of a DC Motor

- Torque is nothing but turning or twisting force about an axis
- Torque is measured by the product of force and radius at which the force acts.



- The angular velocity of the wheel is

$$\omega = (2\Pi N)/60 \text{ rad/sec}$$

$$\text{Torque } T = F \times r \text{ (N-m)}$$

$$\text{Workdone per revolution} = F \times \text{distance moved}$$

$$= F \times 2\ \Pi\ r \text{ joules}$$

$$\text{Power developed } P = \text{workdone / time}$$

$$= (F \times 2\ \Pi\ r)/\text{time for 1 rev}$$

$$= (F \times 2\ \Pi\ r)/(60/N)$$

(rpm = 60 ; rps = 60/N ; time for 1 rev = 60/N

$$P = (F \times r)\ (2\Pi N)/60$$

$$P = T\ \omega \text{ watts}$$

Where T = torque in N-m , ω = angular speed in rad/sec

- The gross mechanical power developed in the armature is $E_b I_a$
- Then power in armature = armature torque × ω

$$E_b I_a = T_a \times (2\Pi N)60$$

$$E_b = P\O ZN/60A$$

$$P\O ZN/(60A)\ I_a = T_a \times (2\Pi N)60$$

$$T_a = (\O\ I_a\ PZ)/\ 2\Pi A$$

$$\mathbf{T_a = (0.159\O\ I_a)(PZ/A)\ N\text{-}M}$$

The above equation is torque equation of a DC motor.

Torque is proportional to the product of the armature current and the flux

Speed control of DC shunt motor

For a Dc motor, the speed equation is obtained as follows

$$E_b = V - I_a R_a$$

$$E_b = P\text{Ø}ZN/60A$$

$$V - I_a R_a = P\text{Ø}ZN/60A$$

$$N = (V - I_a R_a)60A/ P\text{Ø}Z$$

Since for a given machine , Z,A and P are constants

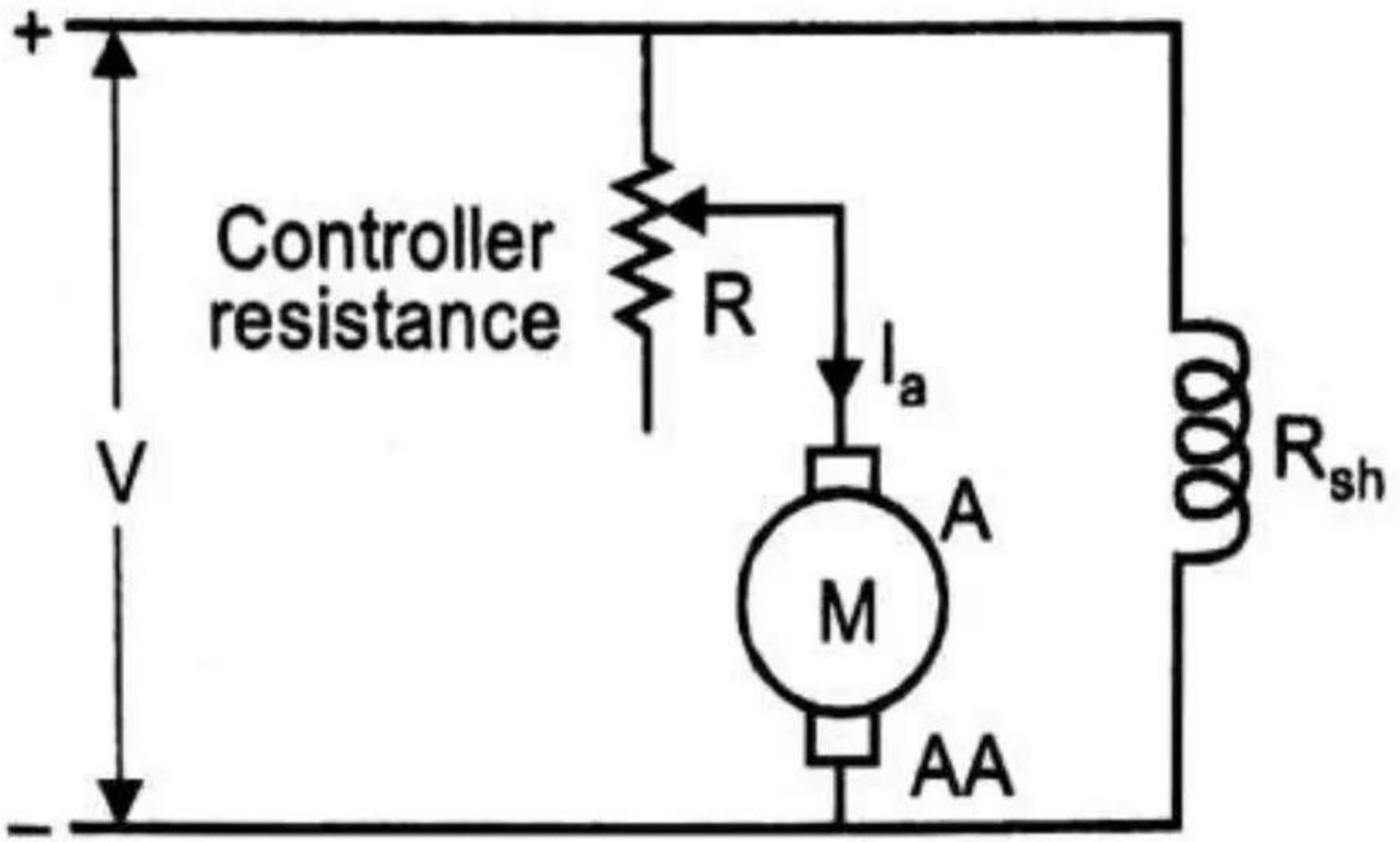
$$N = K(V - I_a R_a)/\text{Ø}$$

Where K is a constant.

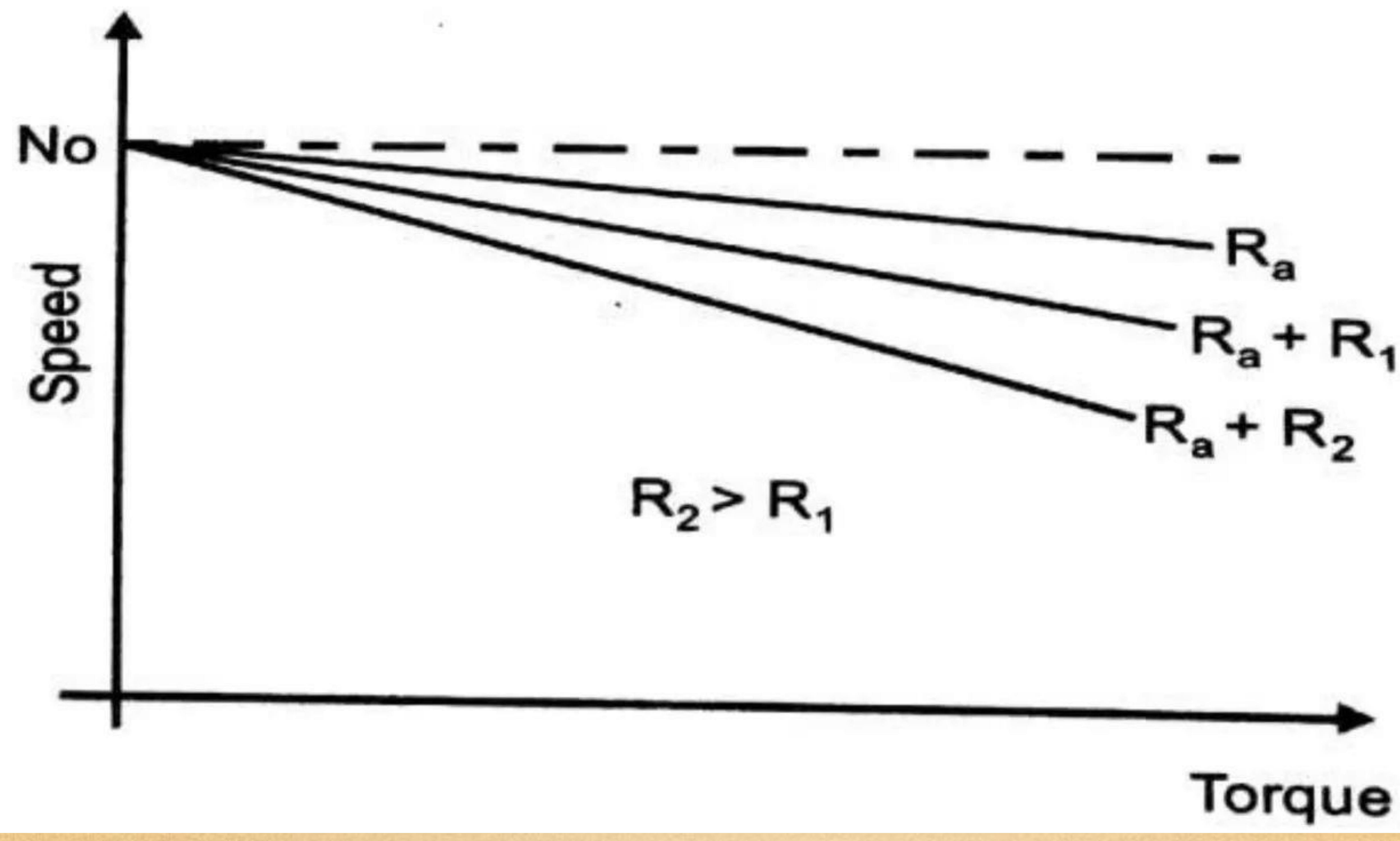
Speed equation becomes $N \alpha E_b /\text{Ø}$

Hence speed of the motor is directly proportional to back emf and inversely proportional to flux. By varying flux and voltage, the motor speed can be changed.

By varying resistance in armature circuit

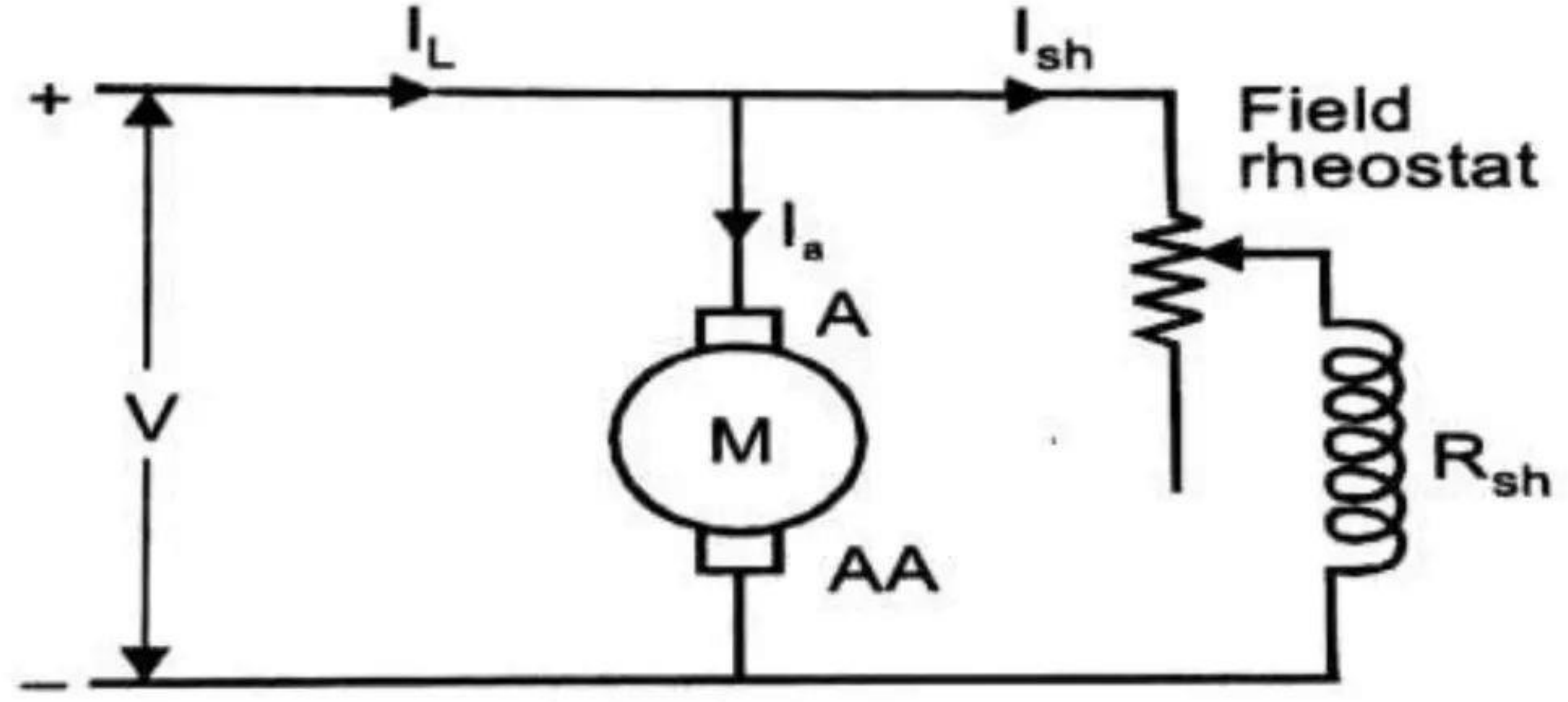


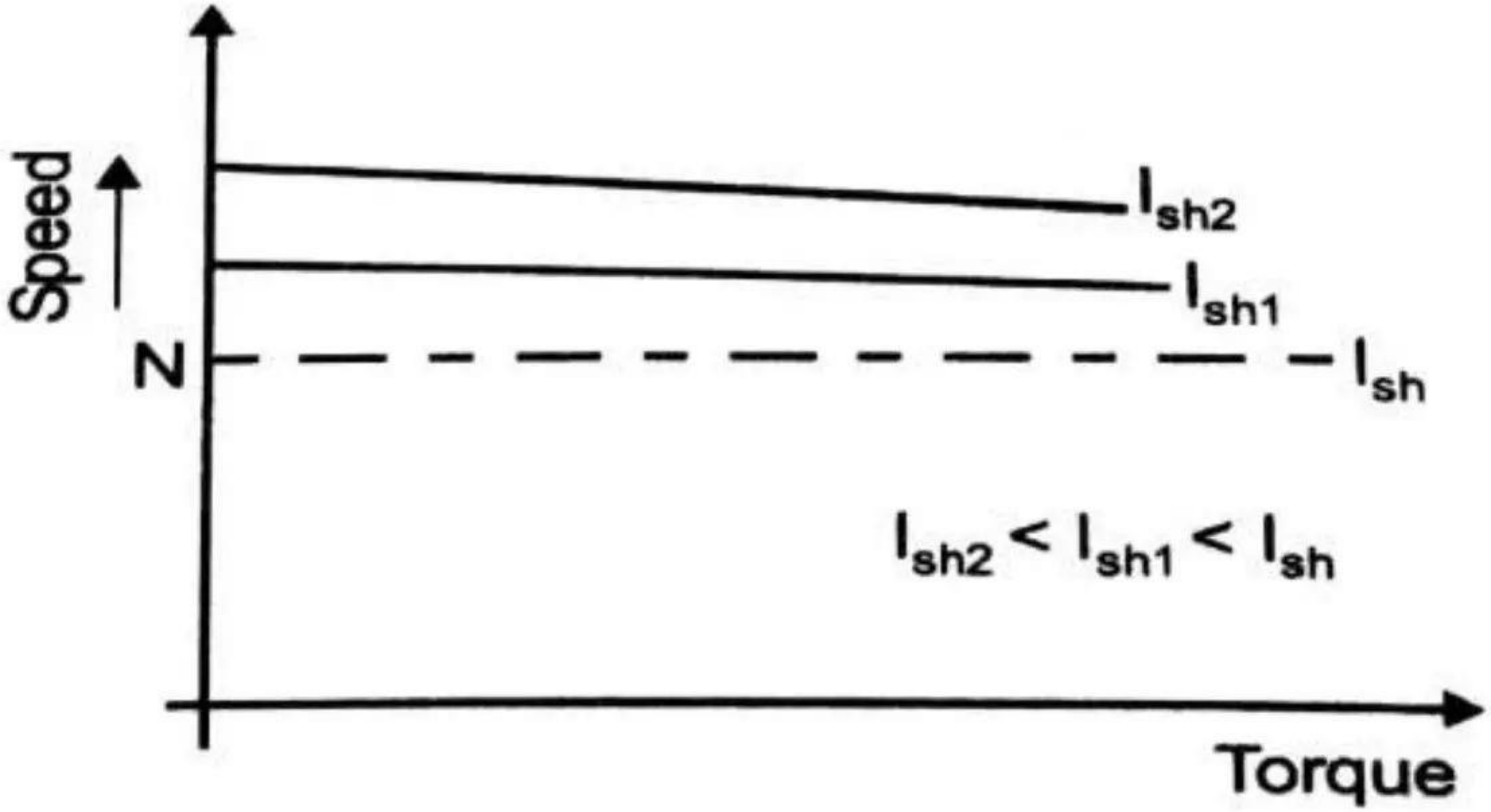
$$N = \frac{K[V - I_a(R_a + R)]}{\phi}$$



By varying flux

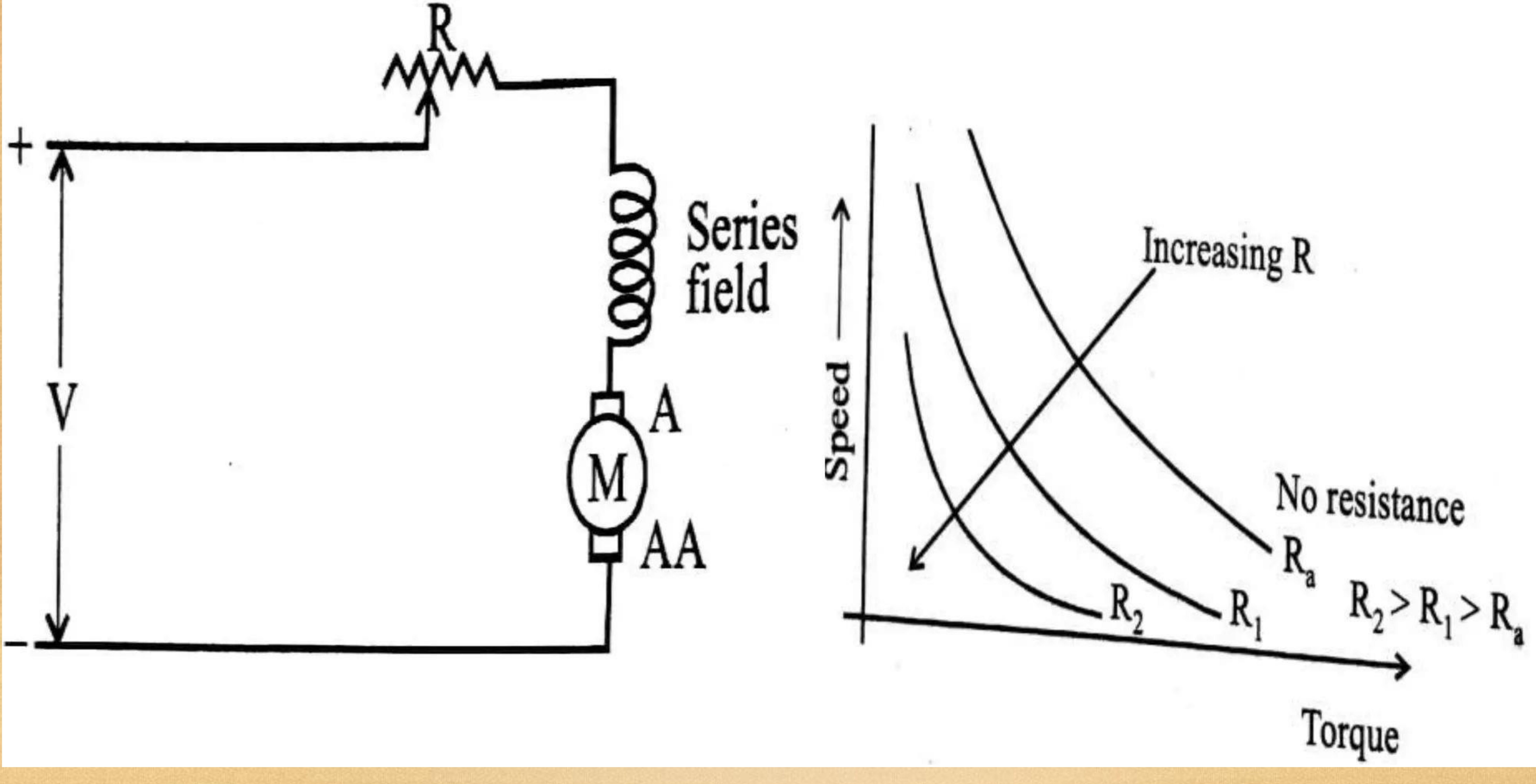
$$N \propto \frac{1}{\phi}$$





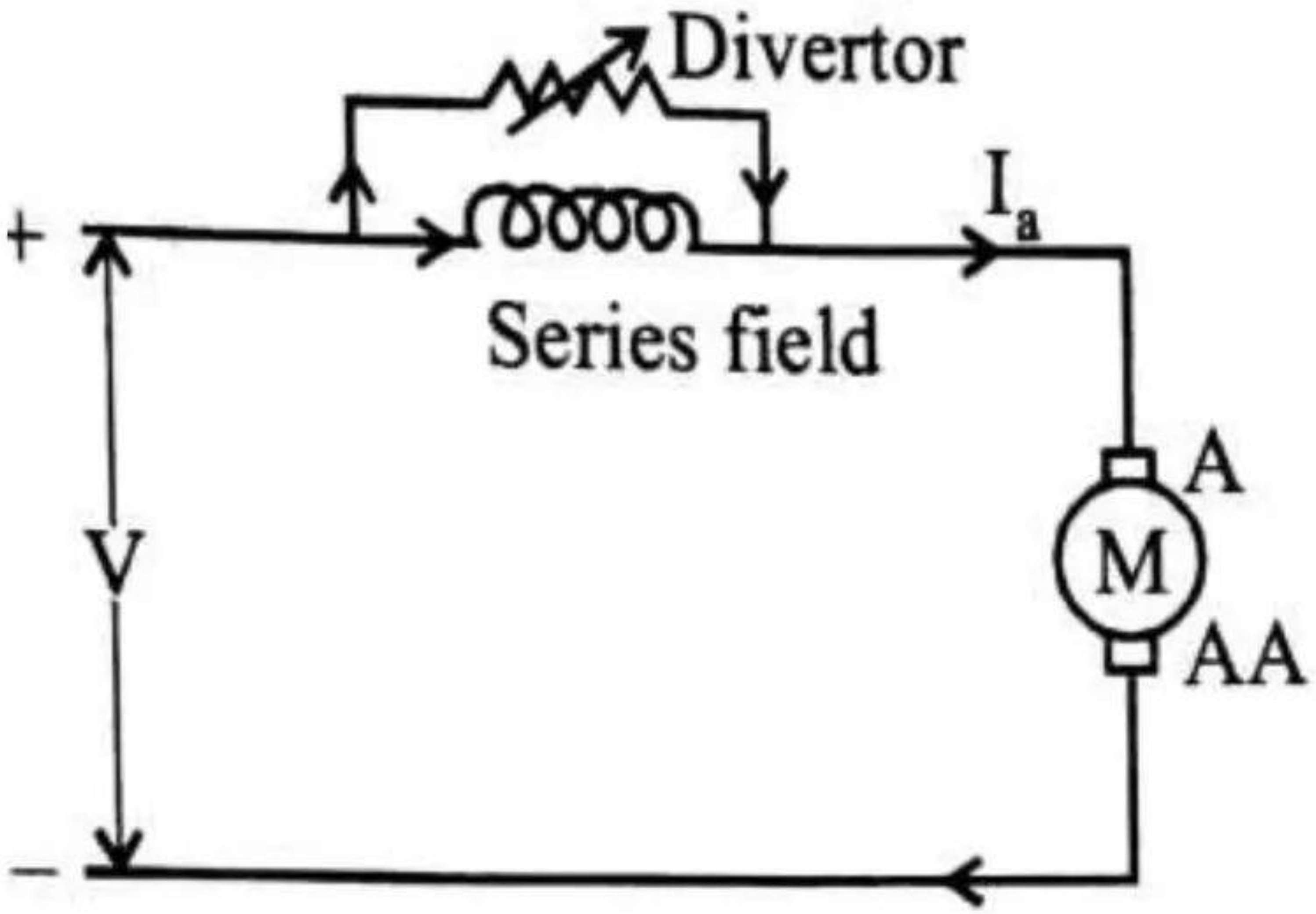
Speed control of DC series motor

1. Variable resistance in series with motor

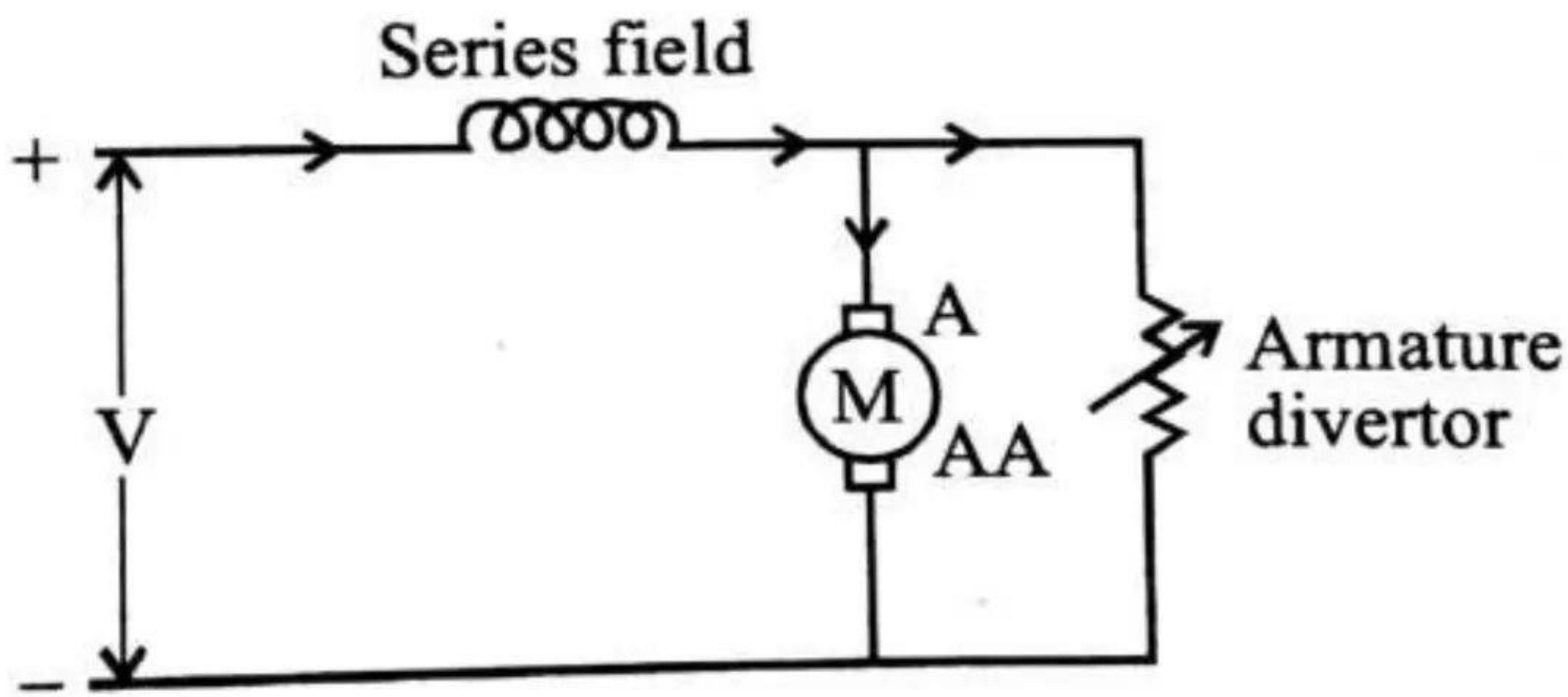


2. Flux control method

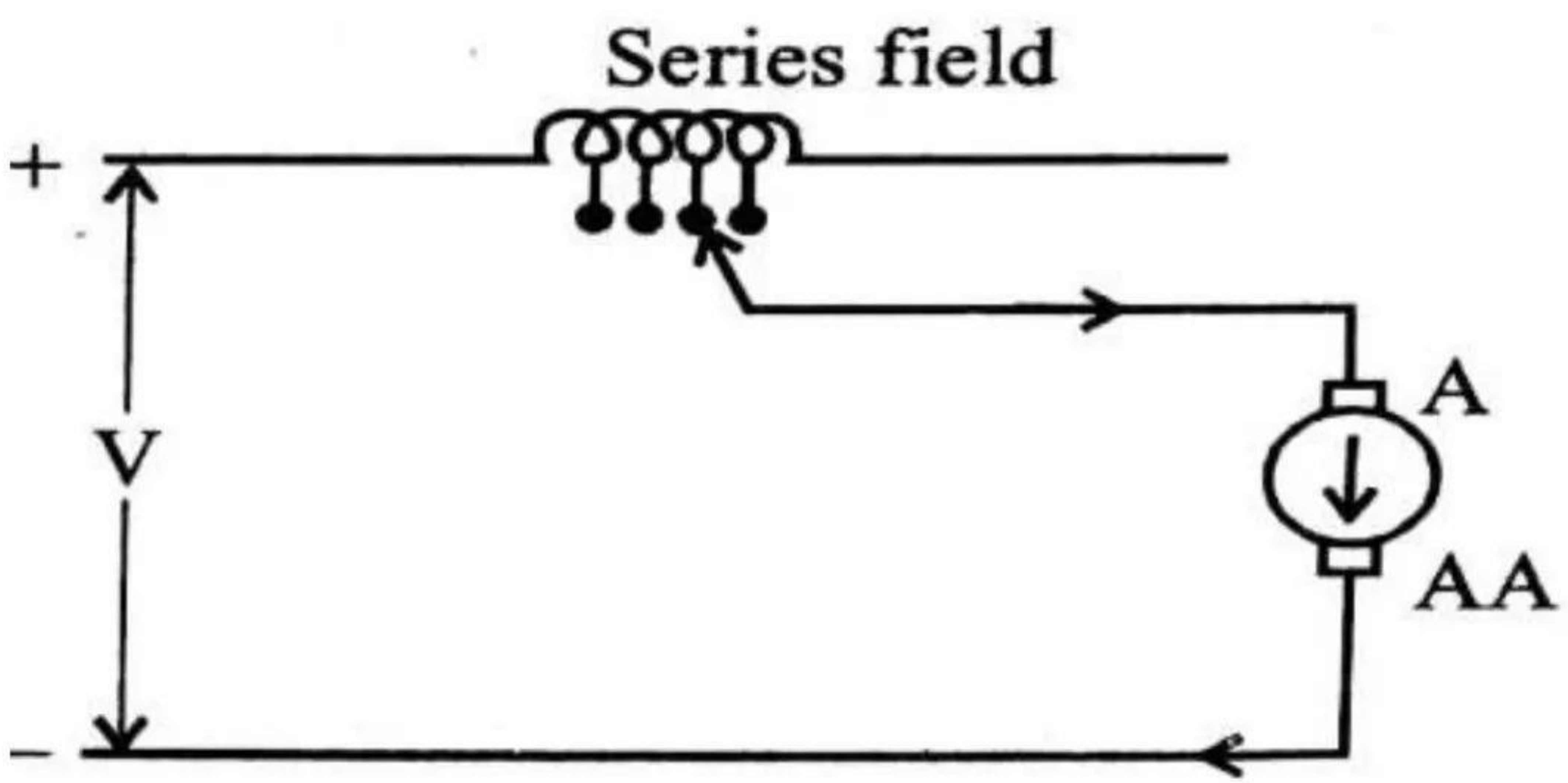
Field diverter



Armature diverter



Tapped field control



For DC Shunt motor torque is directly proportional to the armature current. For Dc series motor, the series field current is equal to the armature current I_a

$$\phi \ \alpha \ I_a$$

$$\text{Hence} T \ \alpha \ I_a \ \alpha \ I^2_a$$

For DC series motor, the torque is directly proportional to the square of the armature current. The speed and torque equations are mainly used for analyzing the various characteristics of DC motors.

Applications of DC Motors

- DC shunt motor are used where speed has to maintain nearly constant with load and where a high starting torque is not required. Thus shunt motors may be used for driving centrifugal pumps and light machine tools, wood working machines, lathe etc.,
- Series motors are used where the load is directly attached to the shaft or through a gear arrangements and where there is no danger of load being "thrown off". Series motors are ideal for use in electric trains, where the self-weight of the train acts as load and for cranes, hoists, fans, blowers,converyers,lifts etc. where starting torque requirement is high.