DC MACHINES

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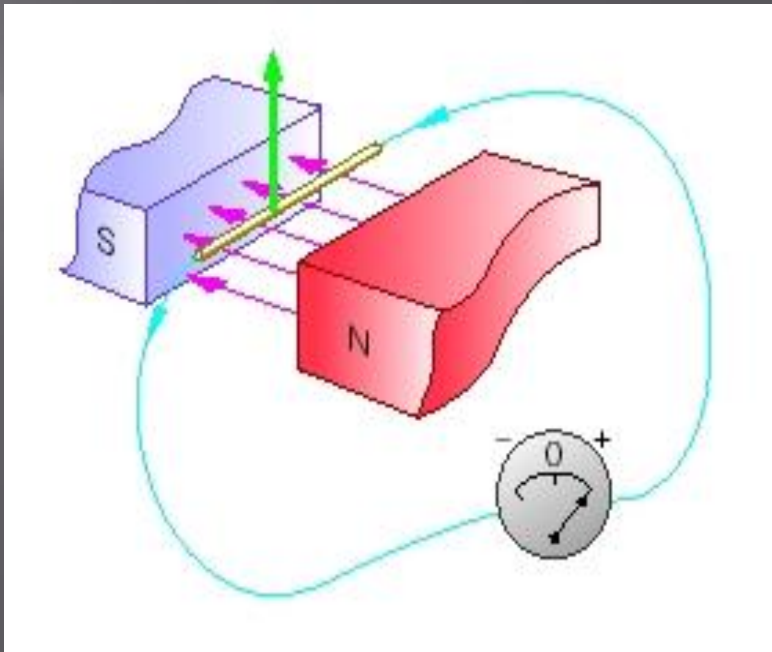
DC Generator

Mechanical energy is converted to electrical energy

Three requirements are essential

1. Conductors
2. Magnetic field
3. Mechanical energy



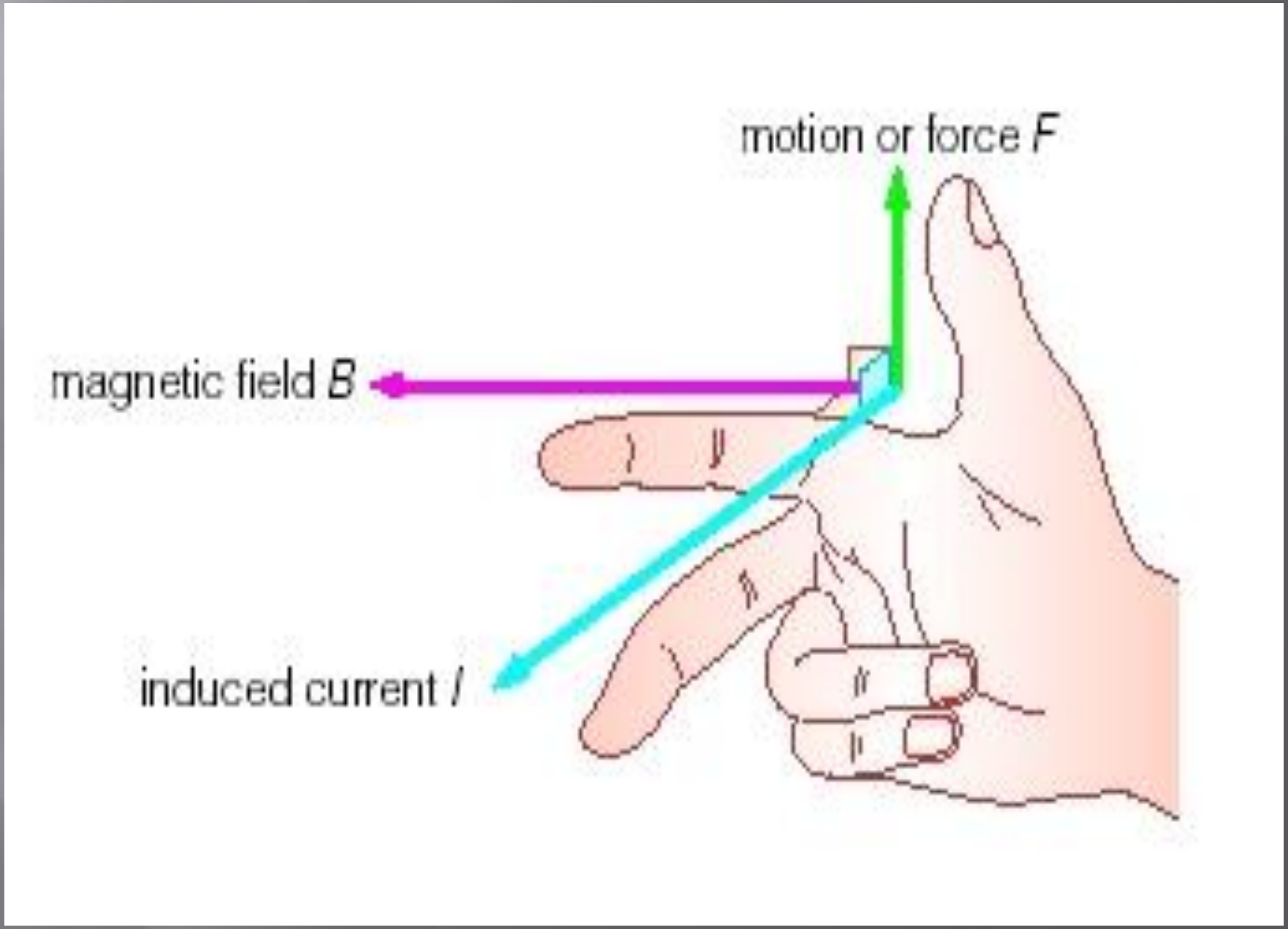
Working principle

- A generator works on the principles of Faraday's law of electromagnetic induction

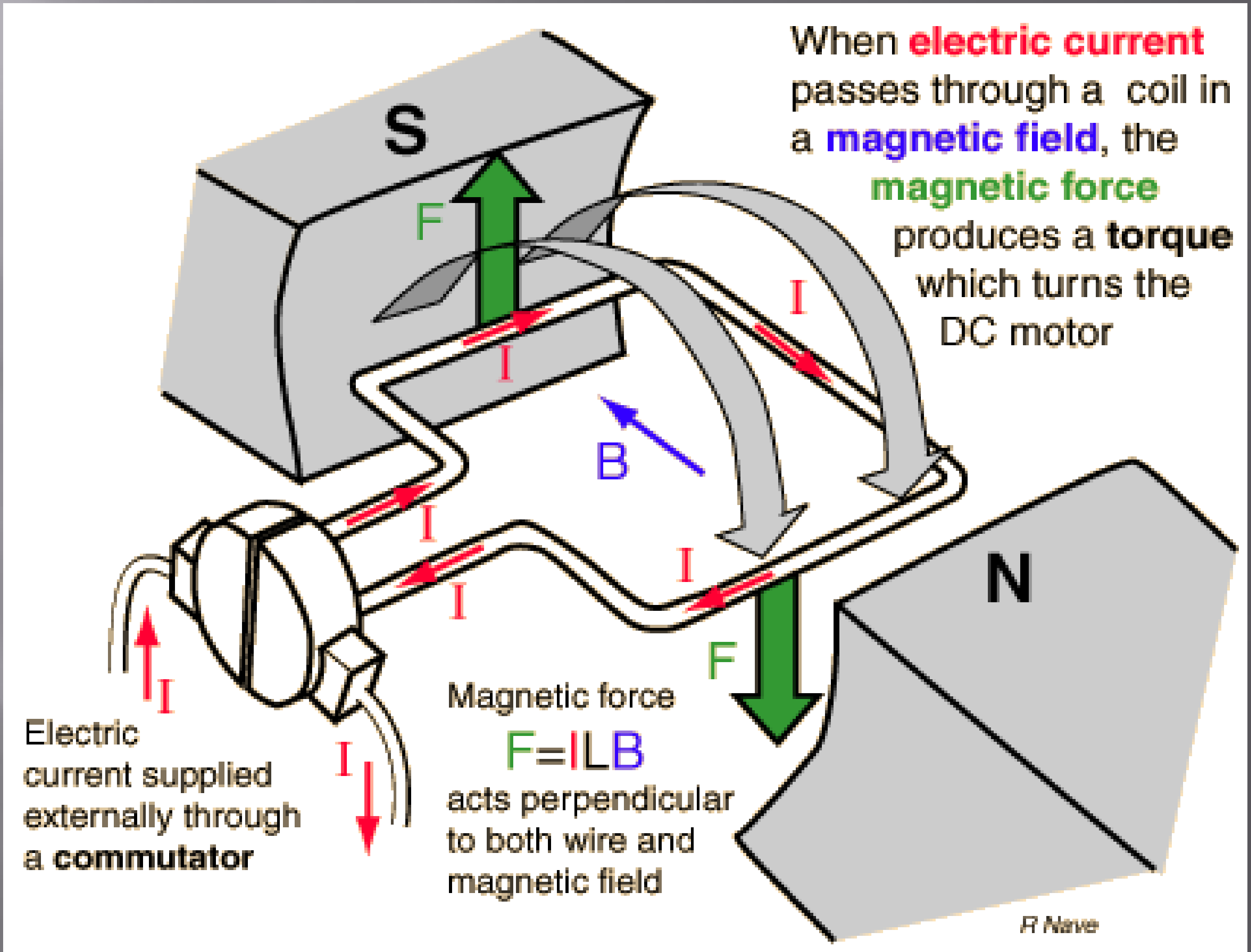
- Whenever a conductor is moved in the magnetic field, an emf is induced and the magnitude of the induced emf is directly proportional to the rate of change of flux linkage.

- This emf causes a current flow if the conductor circuit is closed .

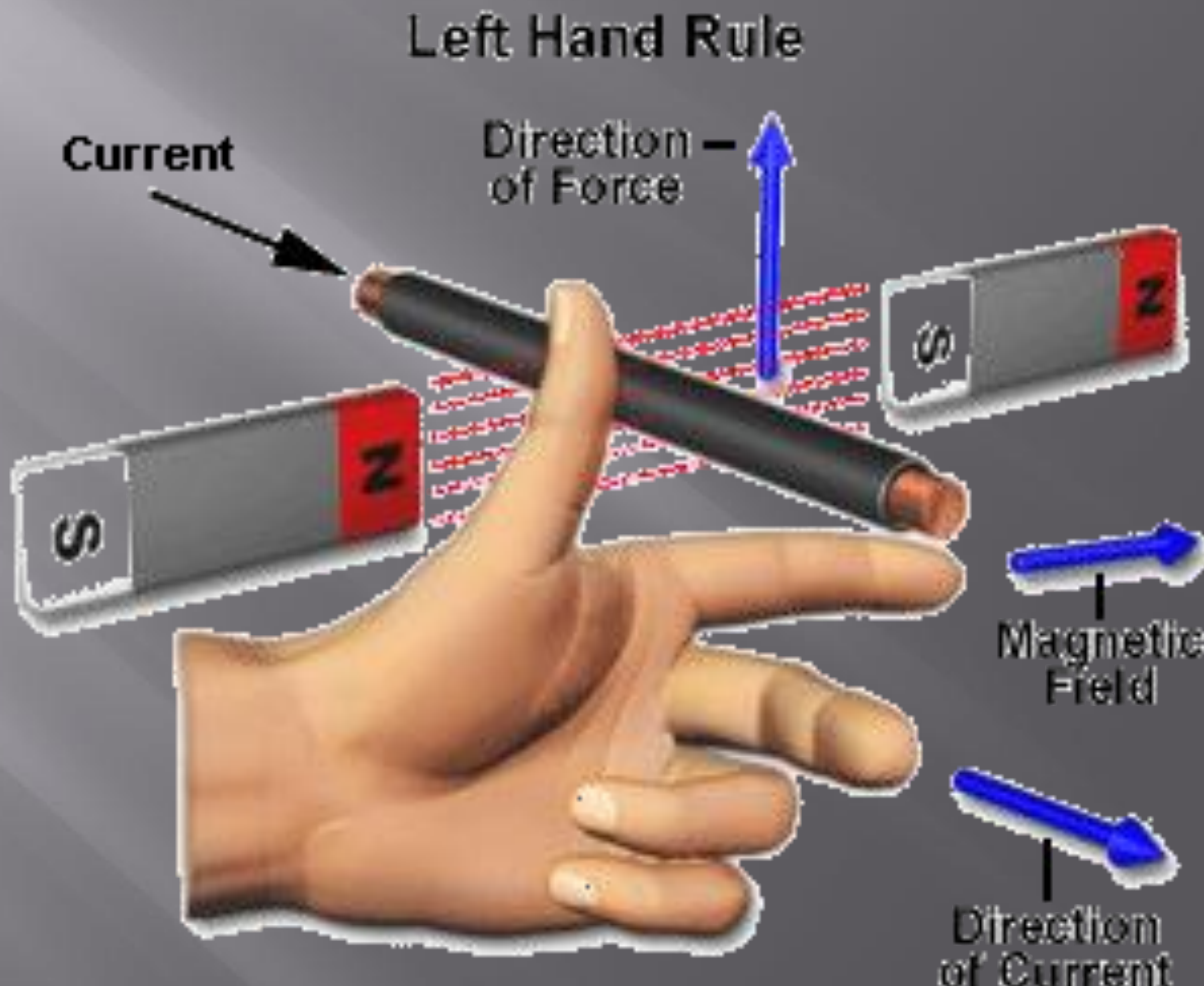
Fleming’s Right hand rule



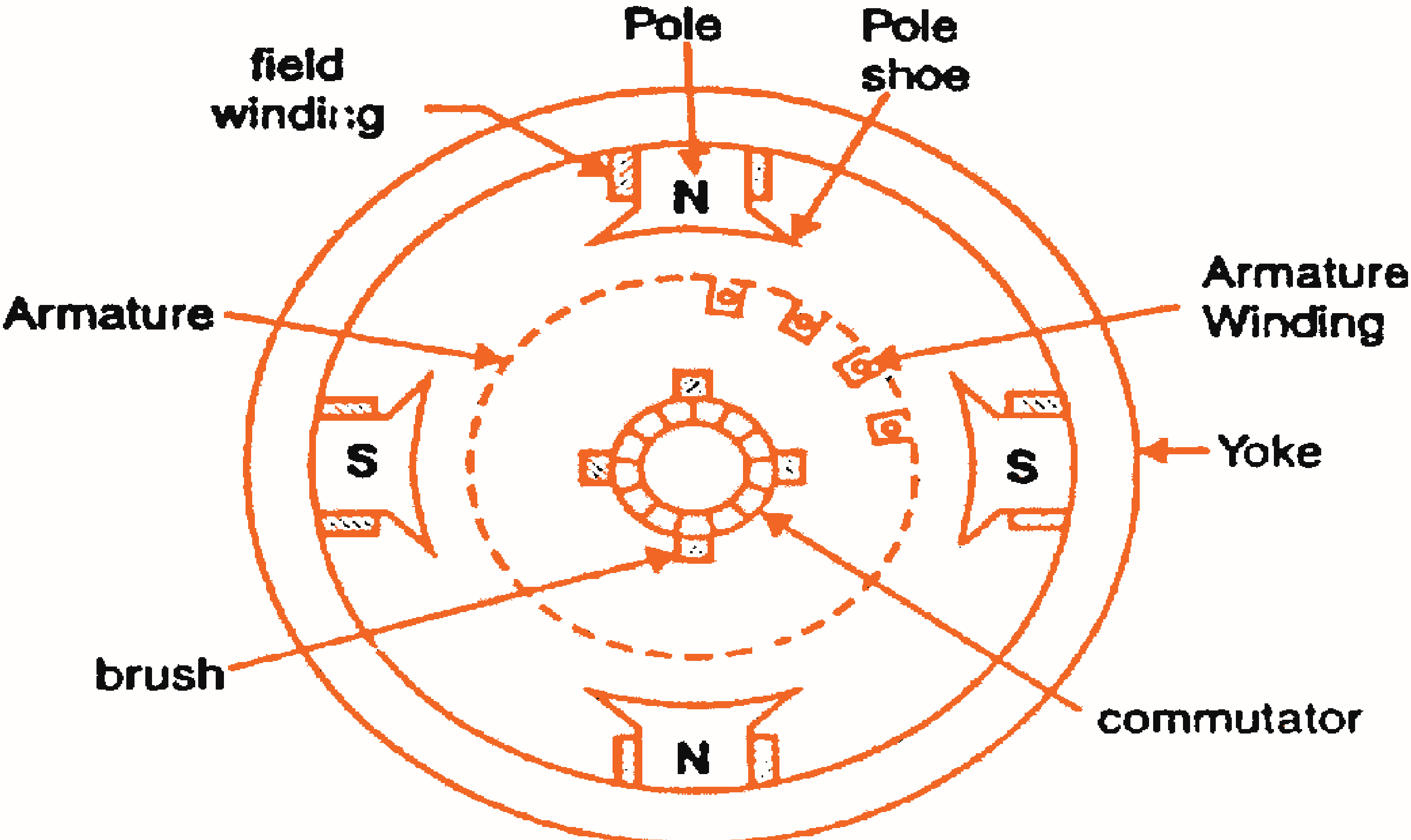
Working principle of DC motor



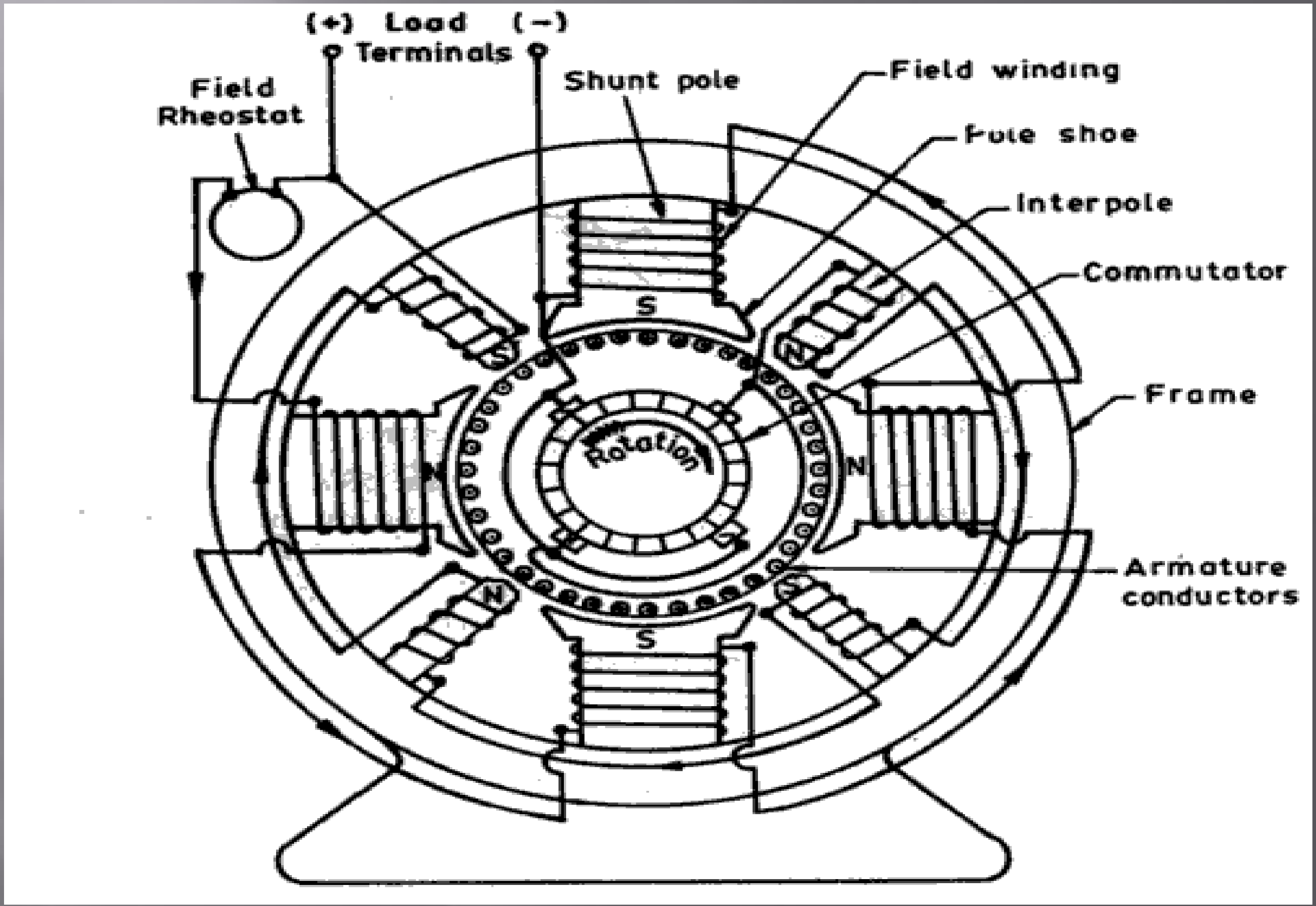
Fleming’s left hand rule



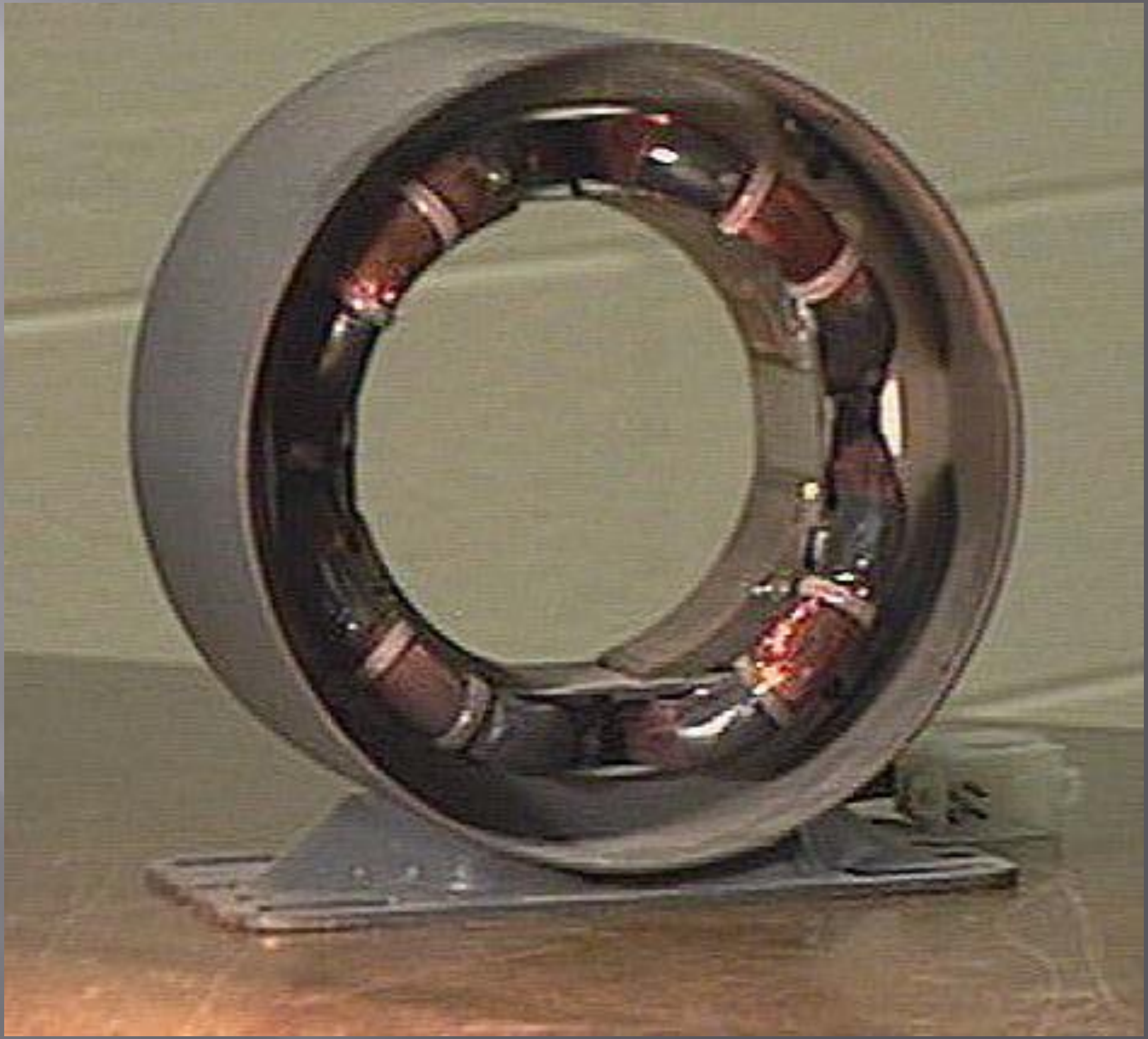
DC Machine Construction:



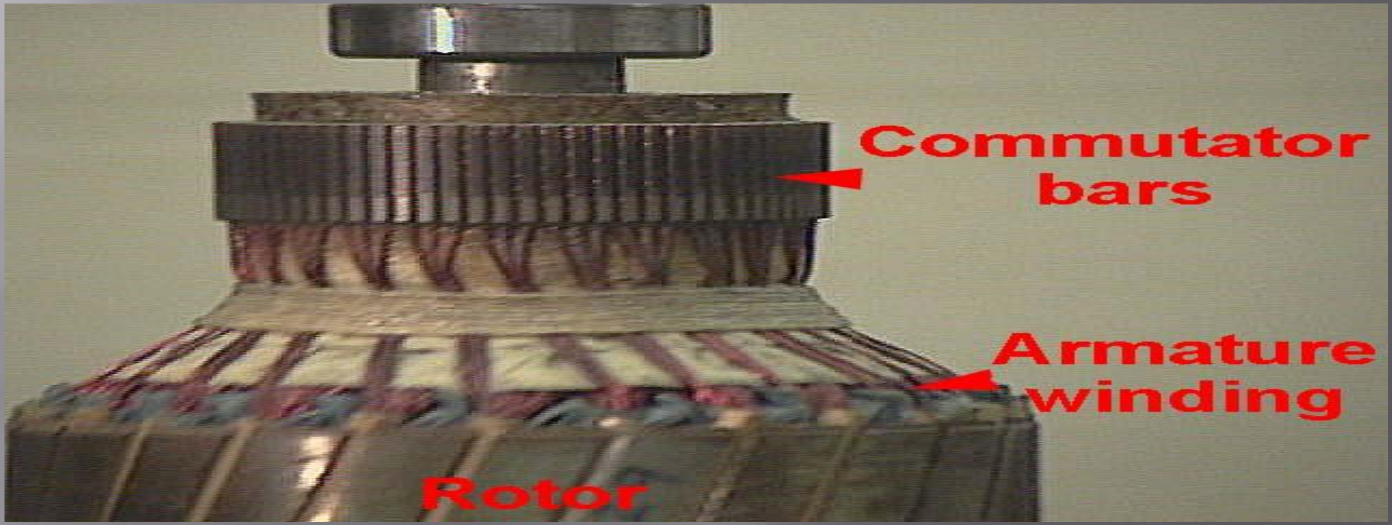
Sectional view of a DC machine



Field winding



Rotor and rotor winding



Armature winding

There are 2 types of winding

Lap and Wave winding

Lap winding

- **A = P**
- The armature windings are divided into no. of sections equal to the no of poles

Wave winding

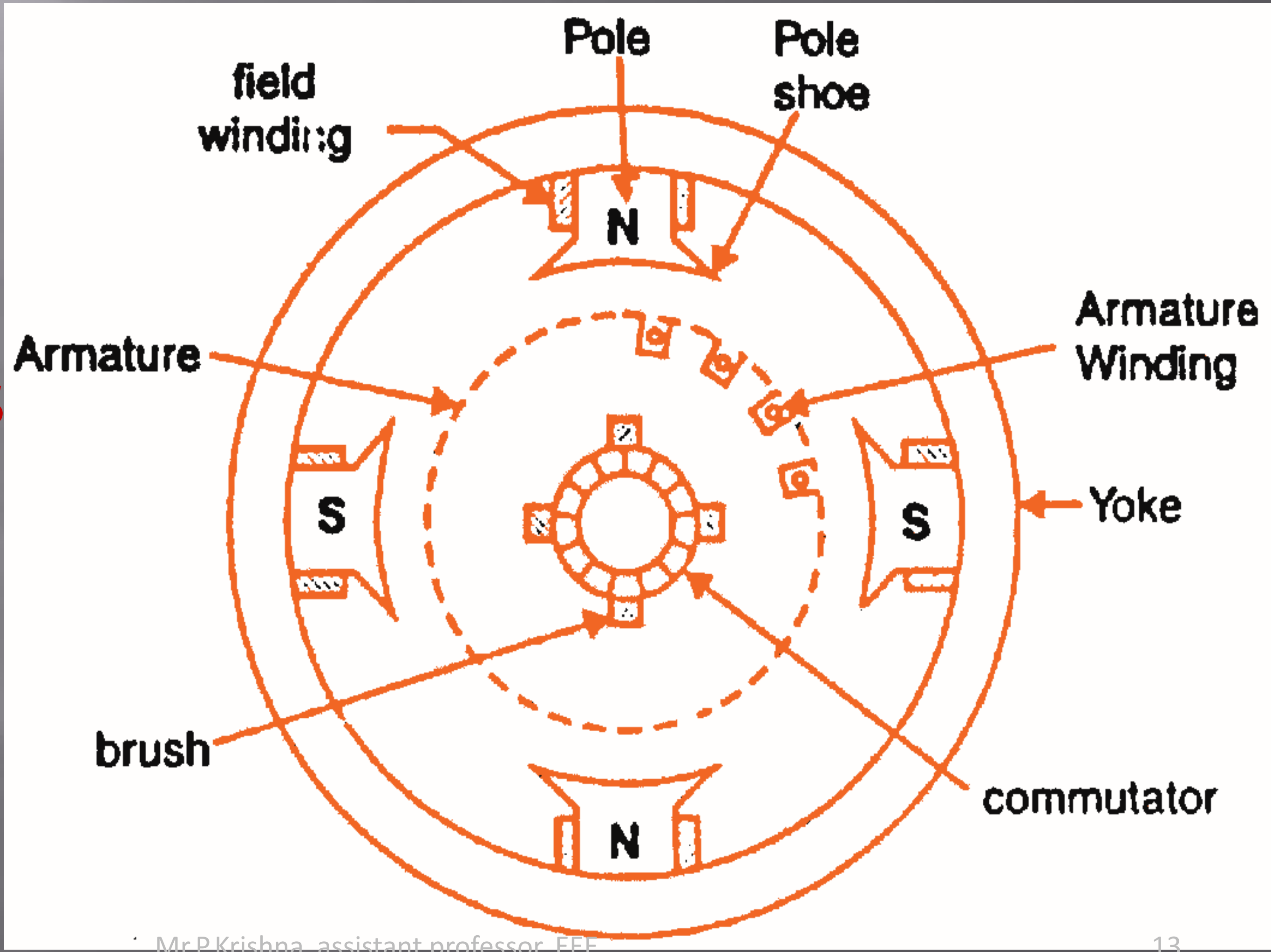
- **A = 2**
- It is used in low current output and high voltage.
- 2 brushes

Field system

- It is for uniform magnetic field within which the armature rotates.
- Electromagnets are preferred in comparison with permanent magnets
- They are cheap , smaller in size , produce greater magnetic effect.
- Field strength can be varied

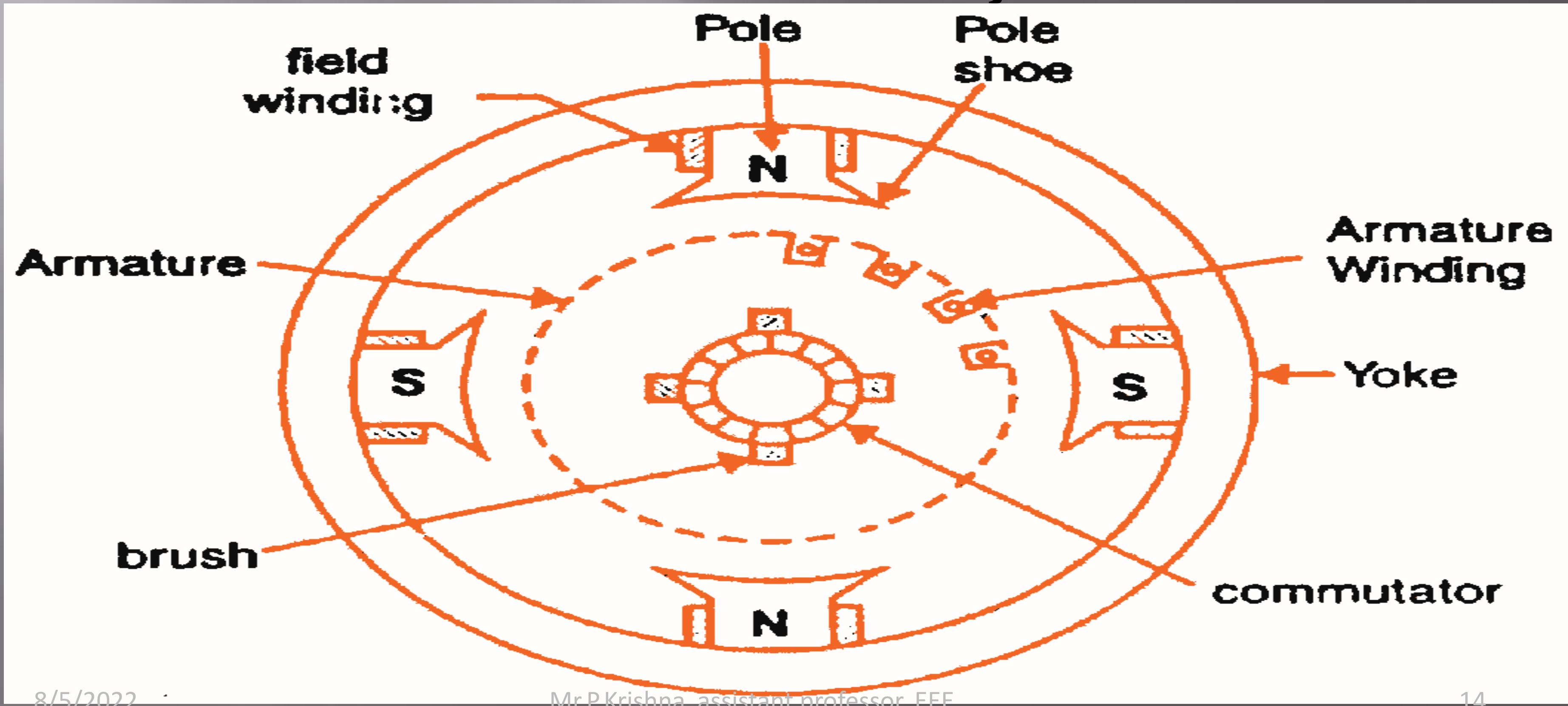
Field system consists of the following parts

- Yoke
- Pole cores
- Pole shoes
- Field coils



Armature core

- The armature core is cylindrical
- High permeability silicon steel stampings
- Lamination is to reduce the eddy current loss



Commutator

- ✓Connect with external circuit
- ✓Converts ac into unidirectional current
- ✓Segments are insulated from each other
- ✓Each commutator segment is connected to armature conductors by means of a cu strip called riser.
- ✓No of segments equal to no of coils

Carbon brush

- Carbon brushes are used in DC machines because they are soft materials
- It does not generate spikes when they contact commutator.
- To deliver the current
- Carbon is used for brushes because it has negative temperature coefficient of resistance

Brush rock and holder

EMF equation

Let,

- Ø= flux per pole in Weber
- Z = Total number of conductor
- P = Number of poles
- A = Number of parallel paths
- N =armature speed in rpm
- Eg = emf generated in any one of the parallel path

EMF equation

Flux cut by 1 conductor in 1 revolution = $P * \phi$

Flux cut by 1 conductor in 60 sec = $P \phi N /60$

Avg emf generated in 1 conductor = $P\phi N/60$

Number of conductors in each parallel path = Z /A

$E_g = P\phi NZ/60A$

Types of DC Generator

DC generators are generally classified according to their method of excitation .

- Separately excited DC generator
- Self excited D C generator

Further classification of DC Generator

- Series wound generator
- Shunt wound generator
- Compound wound generator
  - Short shunt & Long shunt
  - Cumulatively compound

    &

    Differentially compound

Applications

Shunt Generators:

a. in electro plating

b. for battery recharging

c. as exciters for AC generators.

Series Generators :

A. As boosters

B. As lighting arc lamps

DC Motors

- Converts Electrical energy into Mechanical energy
- Construction : Same for Generator and motor
- Working principle : Whenever a current carrying conductor is placed in the magnetic field , a force is set up on the conductor.

Back emf

The induced emf in the rotating armature conductors always acts in the opposite direction of the supply voltage .

According to the Lenz's law, the direction of the induced emf is always so as to oppose the cause producing it .

In a DC motor , the supply voltage is the cause and hence this induced emf opposes the supply voltage.

Classification of DC motors

DC motors are mainly classified into three types as listed below:

- Shunt motor
- Series motor
- Compound motor
  - Differential compound
  - Cumulative compound

Torque

The turning or twisting force about an axis is called torque .

- $P = T * 2 \pi N / 60$
- $E_b I_a = T * 2 \pi N / 60$
- $T \propto \phi I_a$

Applications:

Shunt Motor:

- Blowers and fans
- Centrifugal and reciprocating pumps
- Lathe machines
- Machine tools
- Milling machines
- Drilling machines

Applications:

<u>Series Motor:</u>

- Cranes
- Hoists , Elevators
- Trolleys
- Conveyors
- Electric locomotives

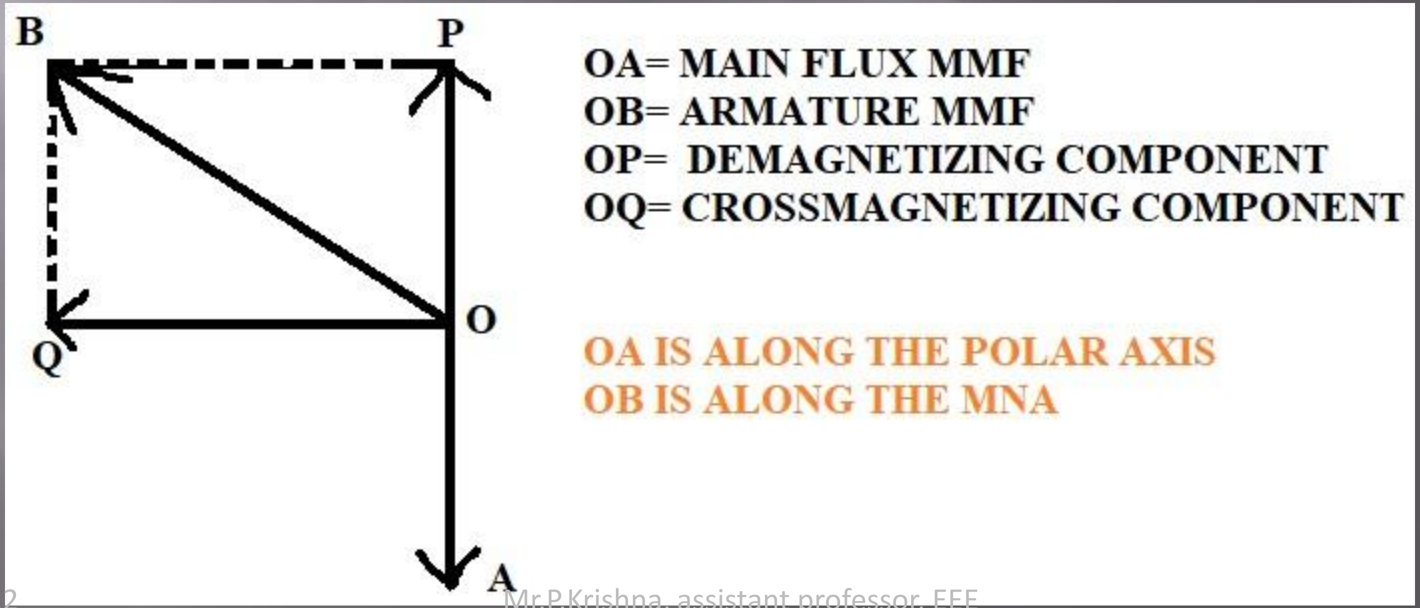
Applications:

<u>Cumulative compound Motor:</u>

- Rolling mills
- Punches
- Shears
- Heavy planers
- Elevators

Armature reaction:

- When a DC generator is loaded, a current flows through the armature conductor in the same direction as that of the induced. The armature conductors carrying current, produce their own magnetic field called magnetic field.
- The effect of armature field on the main field is called armature reaction.
- The major effects are
    1. Demagnetizing effect
    2. Cross-magnetizing effect
- Under no-load condition, the armature current is small and hence the effects of armature are not predominant. They are usually ignored.



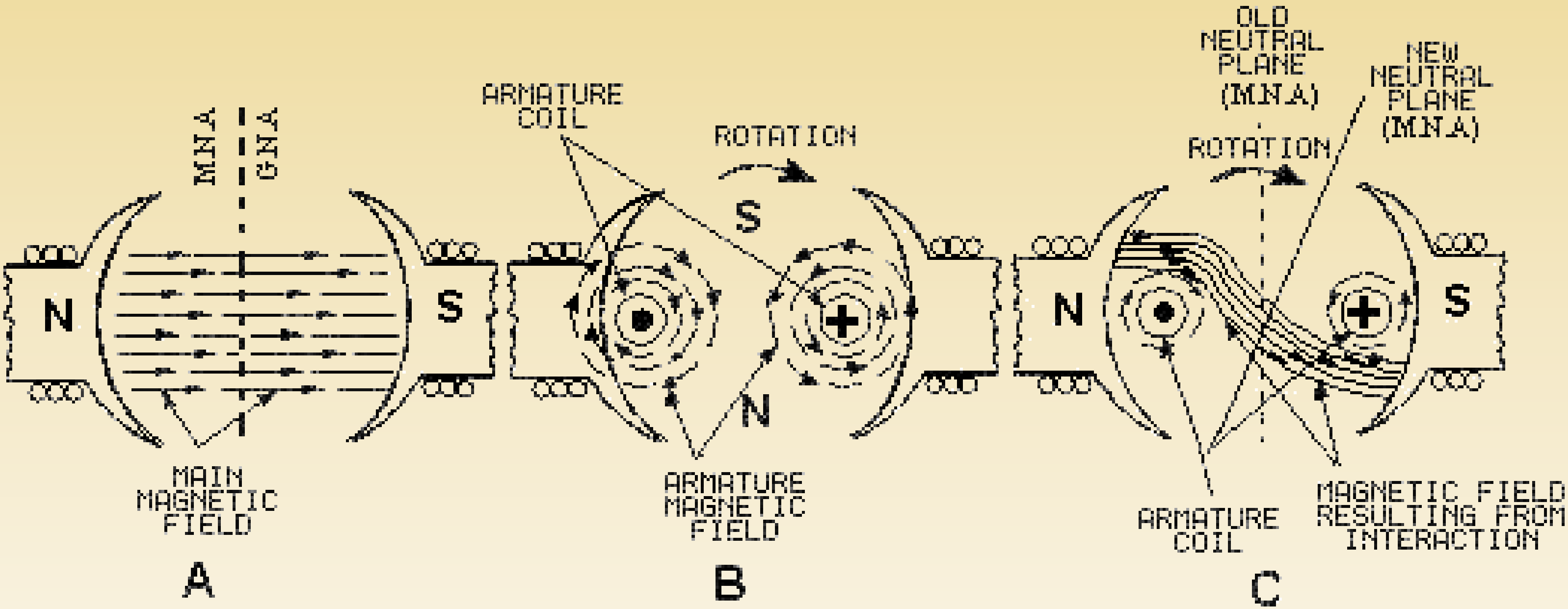
General terms used in Armature Reaction:

Geometrical Neutral Axis(GNA): The line passing through the geometrically central point between the two adjacent opposite magnetic poles.

Magnetic Neutral Axis(MNA): The line passing through the geometrically central point between the two adjacent opposite magnetic poles.

Leading pole Tip: It is the end of the pole which first comes in contact with the armature.

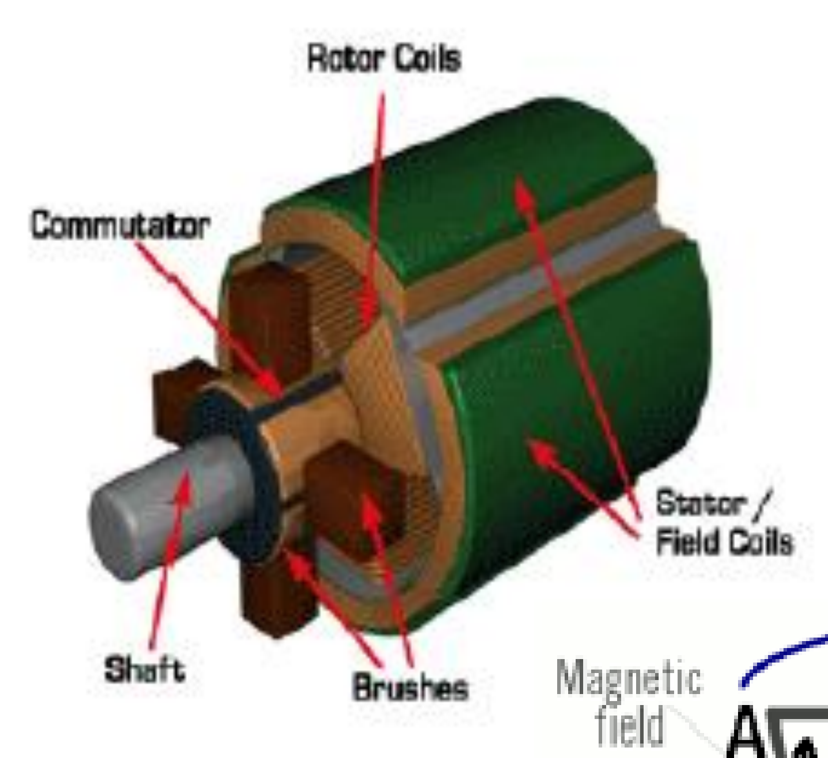
Trailing pole tip: It is the end of the pole which comes in contact later with the armature.

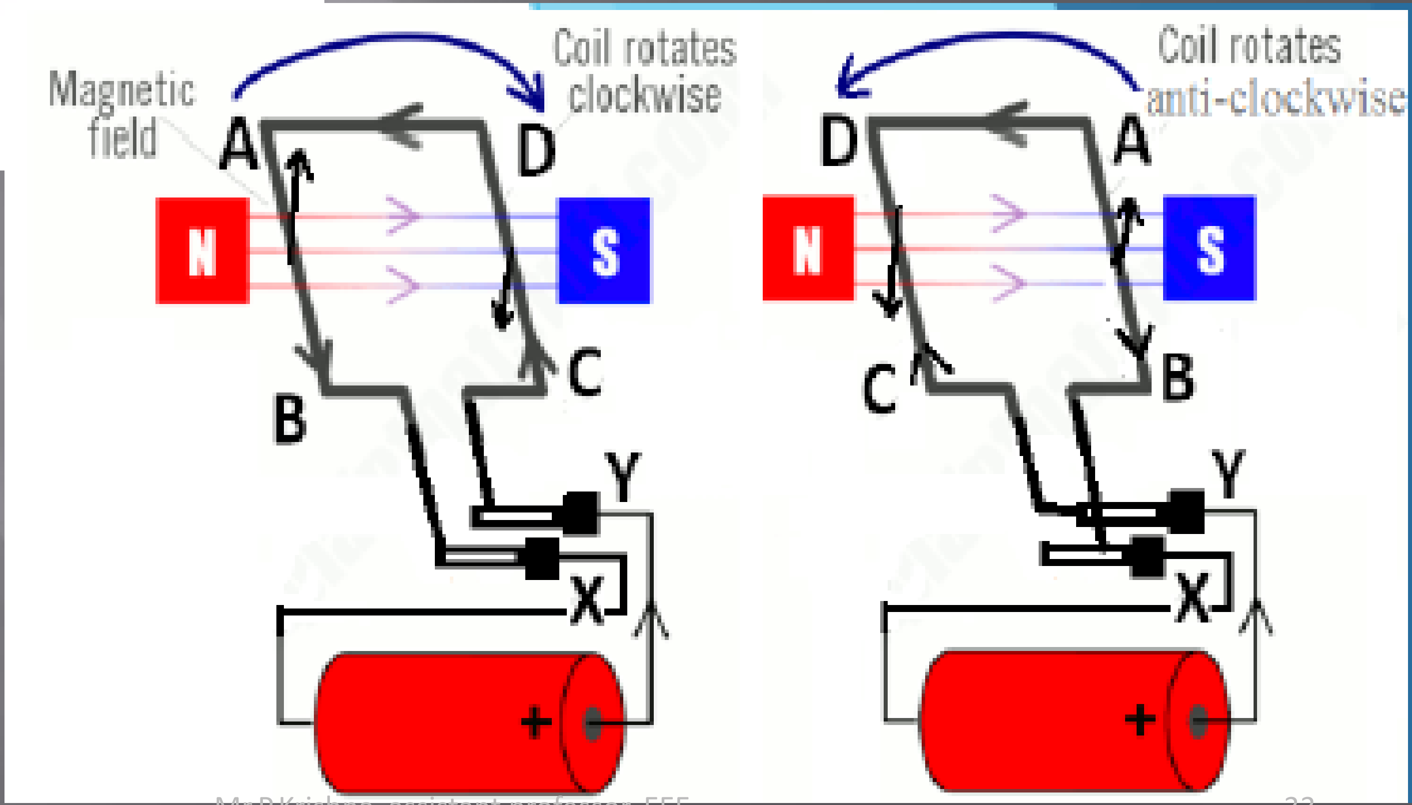


Effects of armature reaction:

1. **It reduces the emf induced** . This can be overcome by either increasing the field current or adding a few extra turns to the field winding.
2. **Causes distortion of the main field flux i.e it alters the pattern of the field flux(high flux density at trailing pole tips and low flux density at leading pole tips).** This can be overcome by providing interpoles (small auxiliary poled fitted between the main poles) and compensating winding(are housed in slots cut in the main pole faces). Both compensating winding and interpole winding are connected in series with the armature winding so that they carry the full armature current.
3. **It produces sparking at the brushes**. The brushes are usually placed along the interpolar axis where flux cut by the coil is zero and no emf induced in it. As MNA is shifted the coil which undergoes commutation induces some emf causing sparking at the brushes.
4. **It decreases the efficiency of the machine** . The change in flux density in the leading and trailing pole tips causes more iron losses.

Commutation:





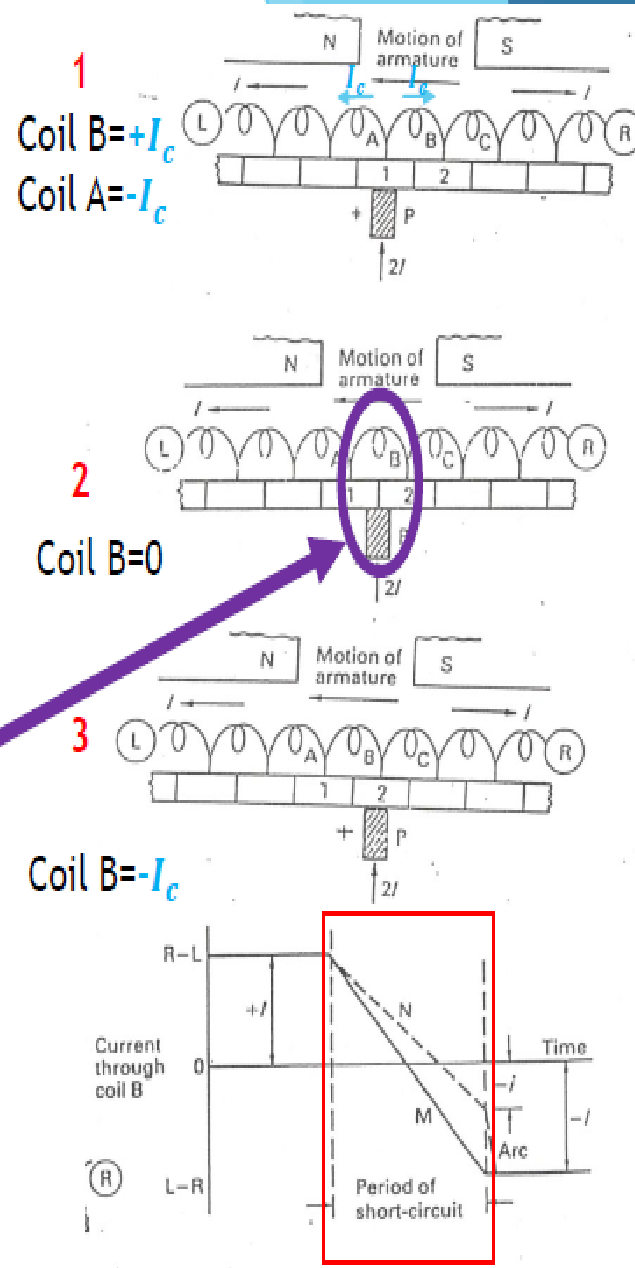
Commutation:

- During the collection of current from the armature(rotating part) to the external circuit (stationary part), one of the armature coil moves from the influence of one pole to the other and consequently the current in this coil is reversed. While moving the coil is short circuited by the brushes through commutator segments for a fraction of a second.
- The process in which a coil is short circuited by the brushes through commutator segments while it passes from the influence of one pole to the other is called commutation.
- The duration for which a coil remains short circuited is called commutation period.

Theory of Commutation

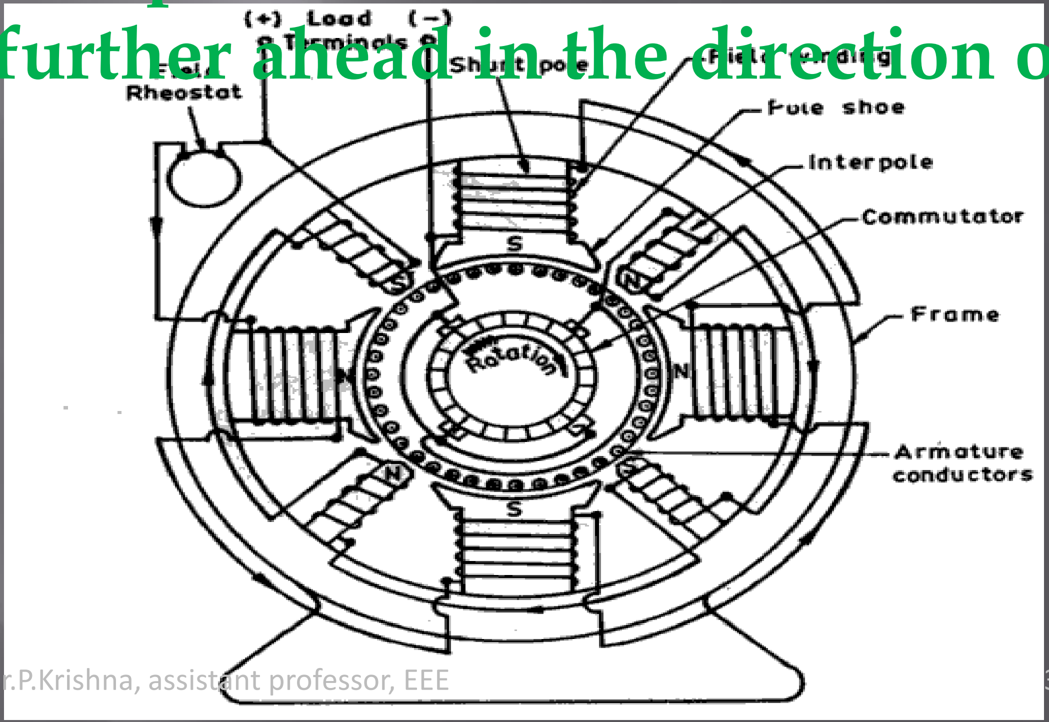
- Ideally, the process of commutation should be instantaneous, as indicated, This can, however, be achieved only if the brush width and the commutator segments are infinitesimally small.
- In practice, not only do the brush and the commutator have finite width but the coil also has a finite inductance. Therefore, it takes some time for the current reversal to take place

At position 2, coil B is undergoing commutation and the current through each brush is still $2I_c$. The induced emf in that coil is **NOT** equal to zero due to the armature reaction flux.



Methods to minimize sparking:

1) Employing high resistance carbon brushes for collection of current (resistance commutation method).
2) Providing interpoles or commutating poles (emf commutation method). **For a generator, the polarity of an interpole is the same as that of the main pole further ahead in the direction of rotation.**



Losses in DC machine:

1. Copper losses or variable losses
2. Stray losses or constant losses

- Stray losses : consist of
  (a) iron losses or core losses
  (b) windage and friction losses .
- Iron losses : occurs in the core of the machine due to change of magnetic flux in the core . Consist of hysteresis loss and eddy current loss.
- Hysteresis loss depends upon the frequency , Flux density , volume and type of the core .
- Eddy current losses : directly proportional to the flux density , frequency , thickness of the lamination .
- Windage and friction losses are constant due to the opposition of wind and friction .

Characteristics of DC Generators:

- There are three important characteristics

1) **Open circuit characteristics or OCC**

   ✓Graph of no load induced emf plotted against field current at constant speed.

2) **External characteristics**

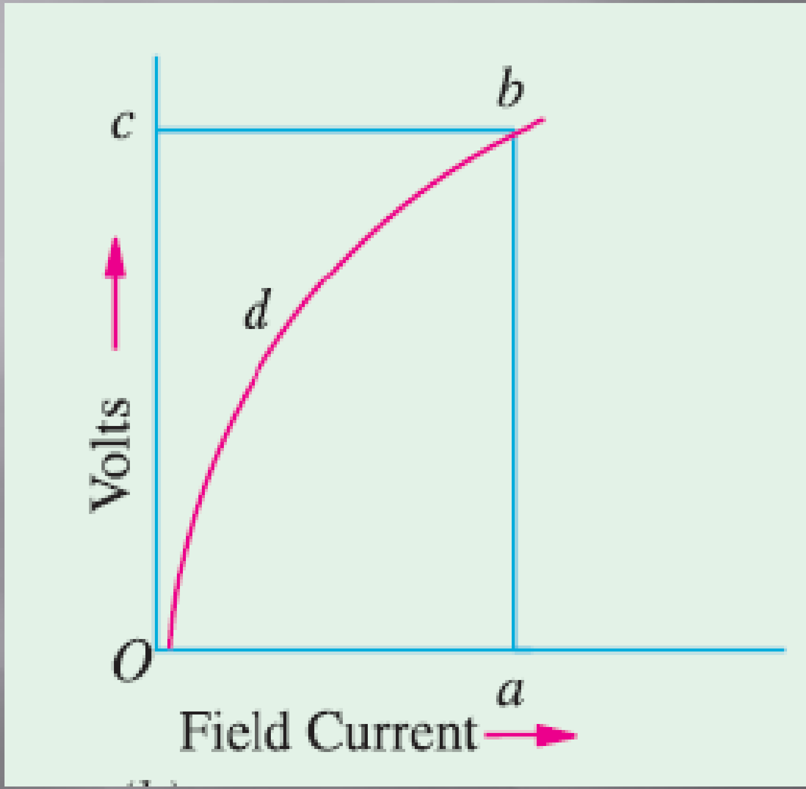
   ✓Graph of terminal voltage plotted against load current.

3) **Internal characteristics**

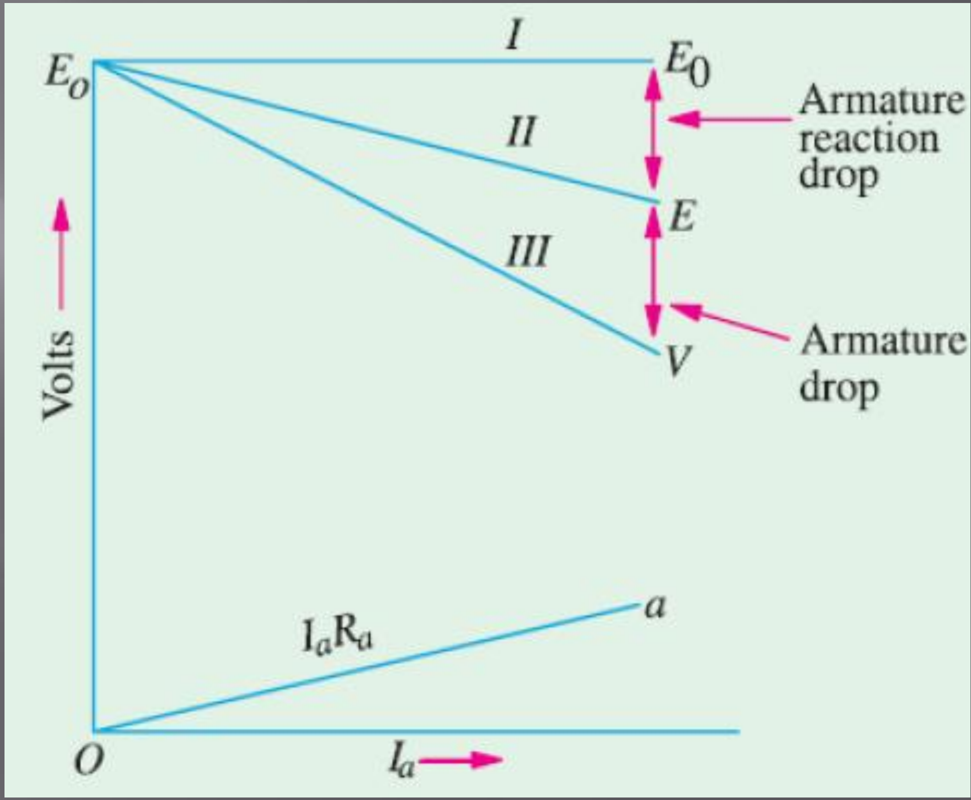
   ✓Graph of induced emf plotted against armature current.

Separately excited generator:

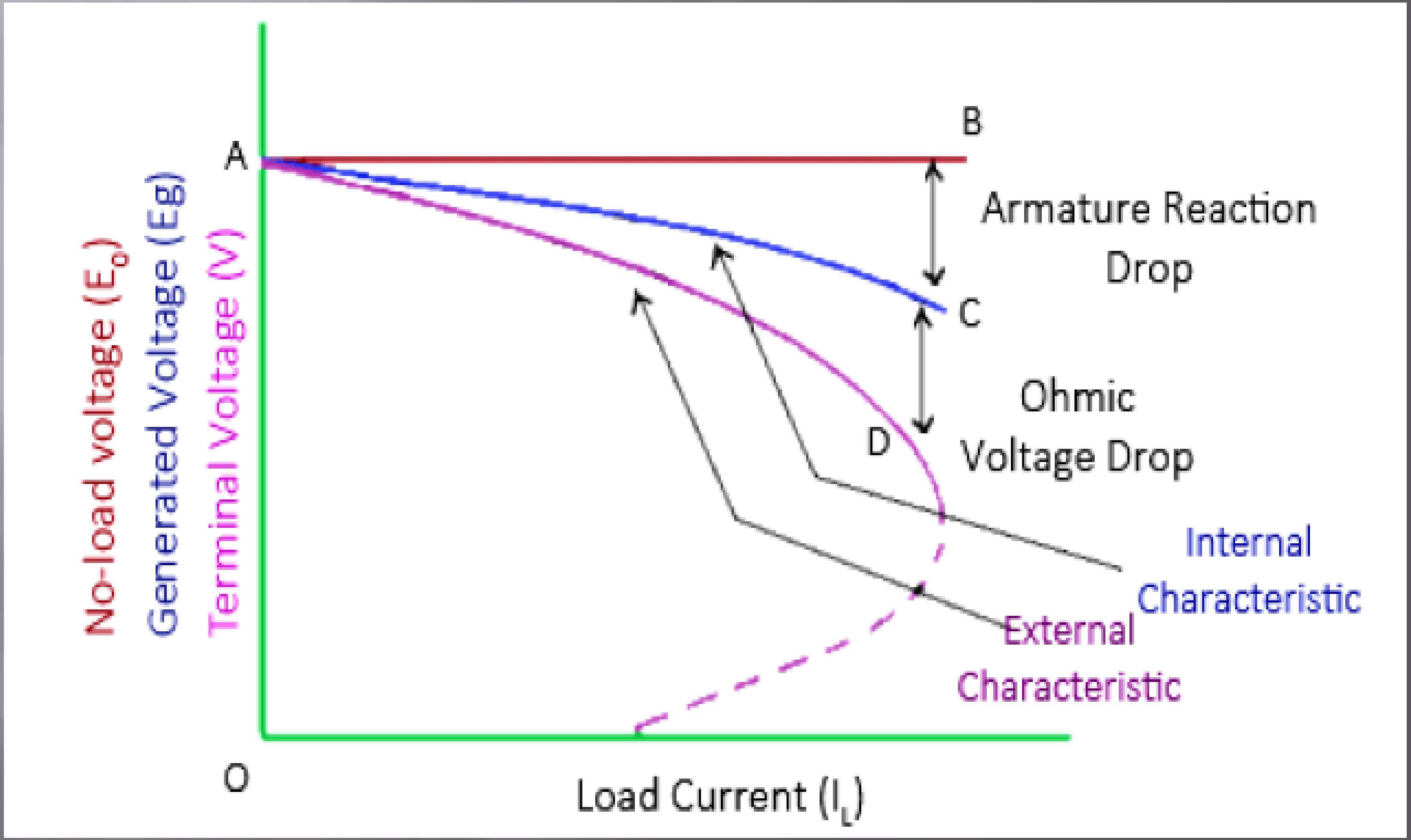
OCC



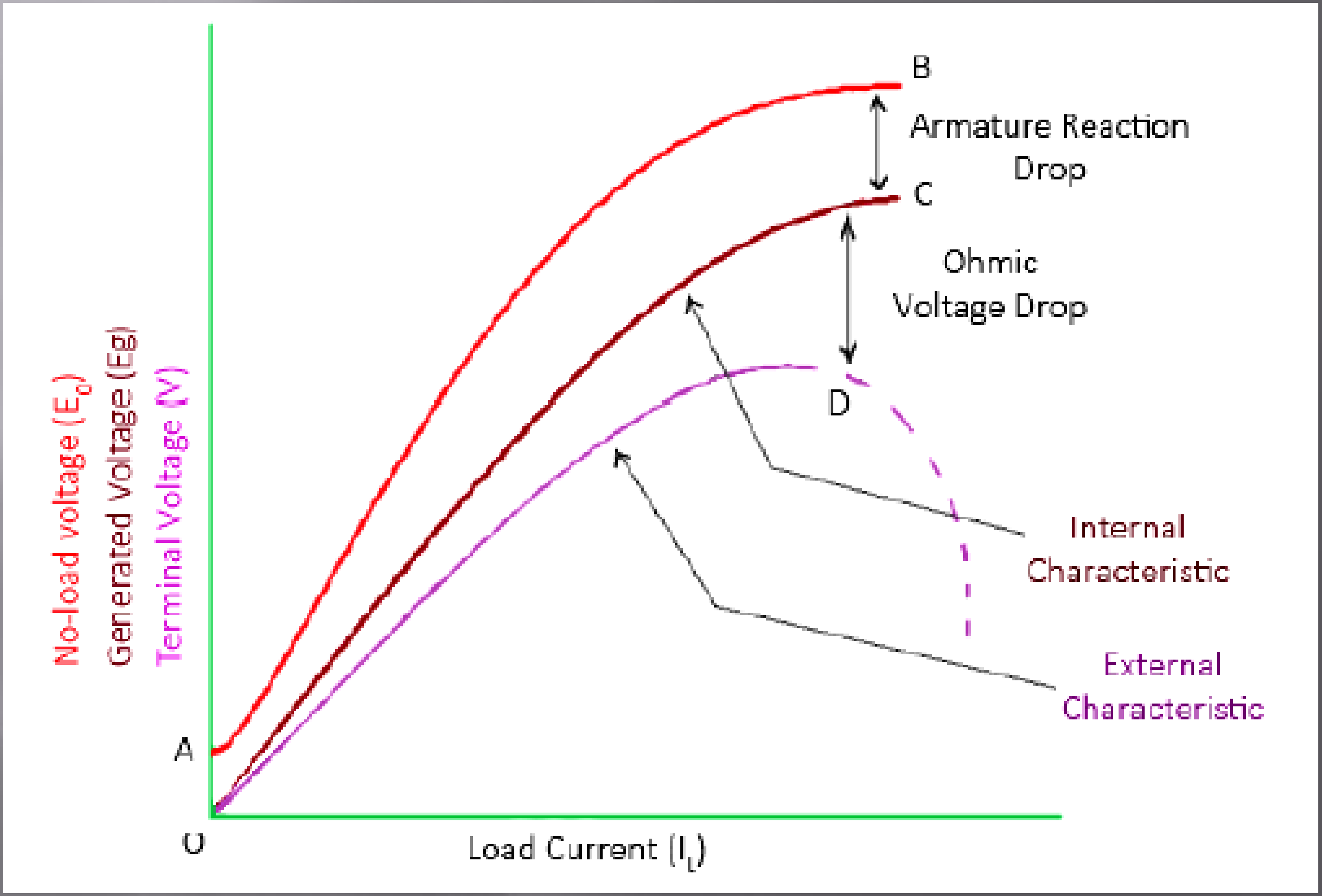
INTERNAL AND EXTERNAL



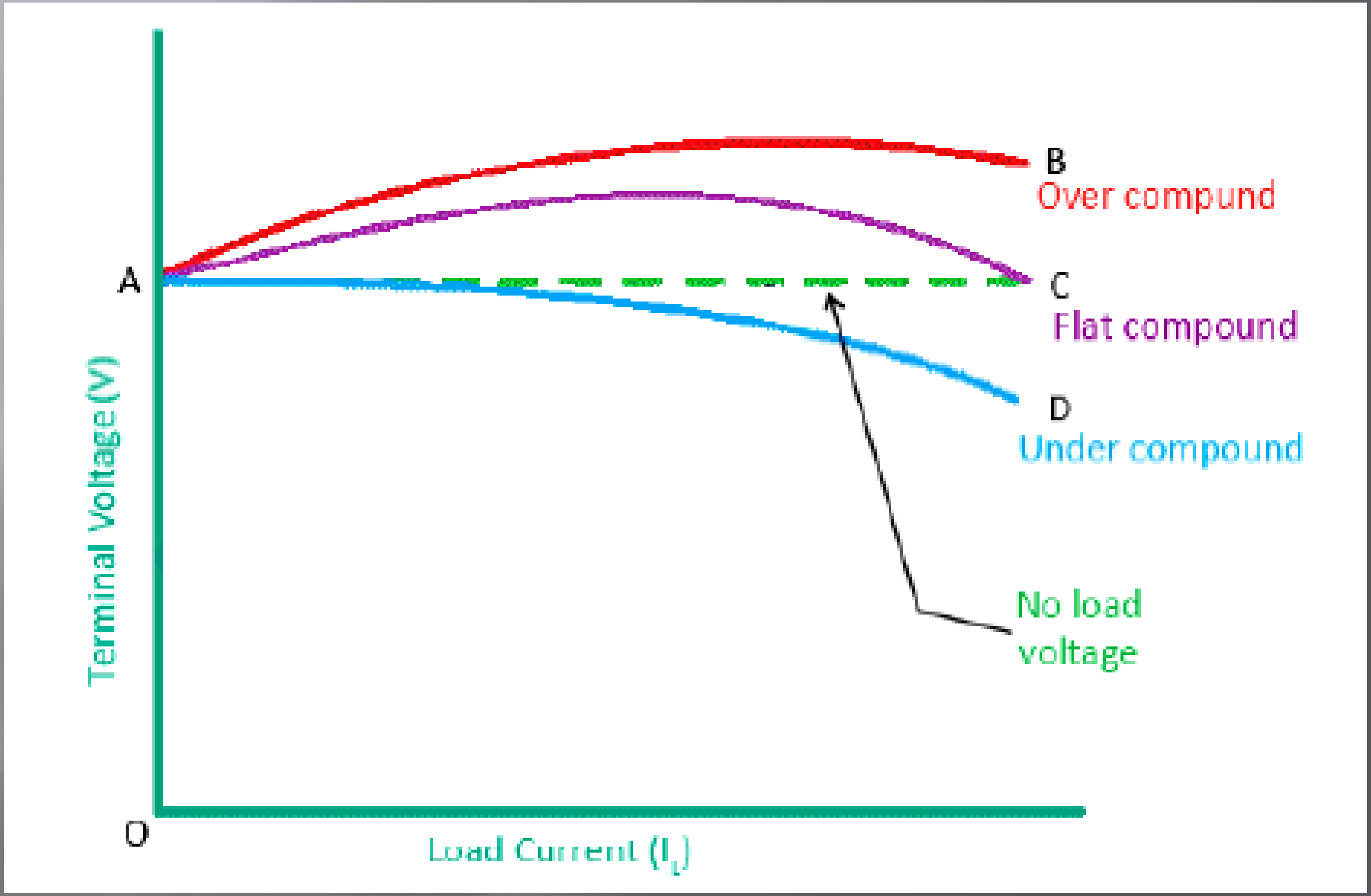
Shunt Generator:



Series Generator:



Compound Generator:

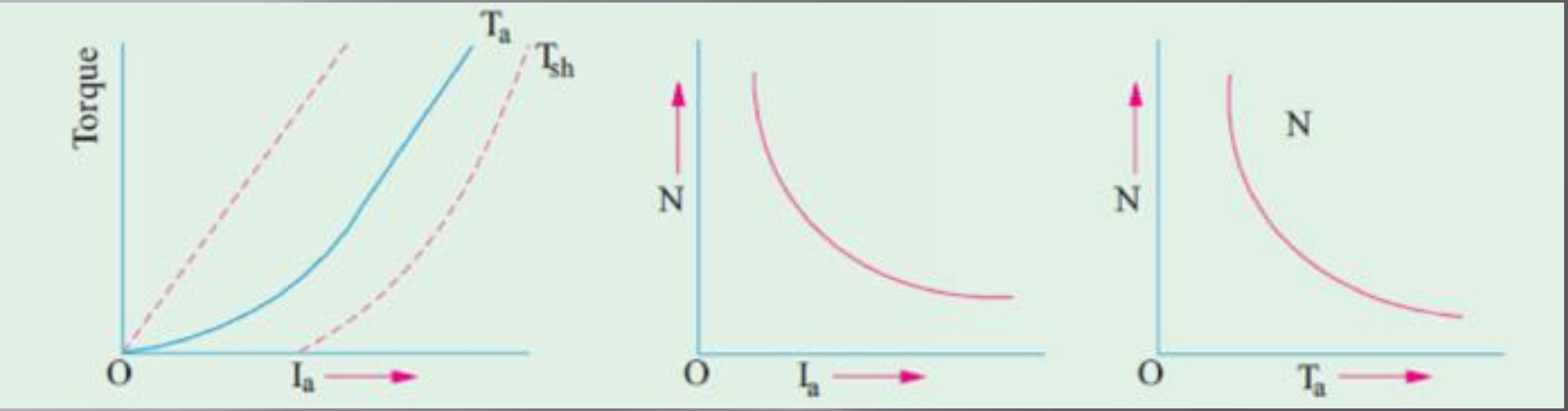


Characteristics of DC Motors:

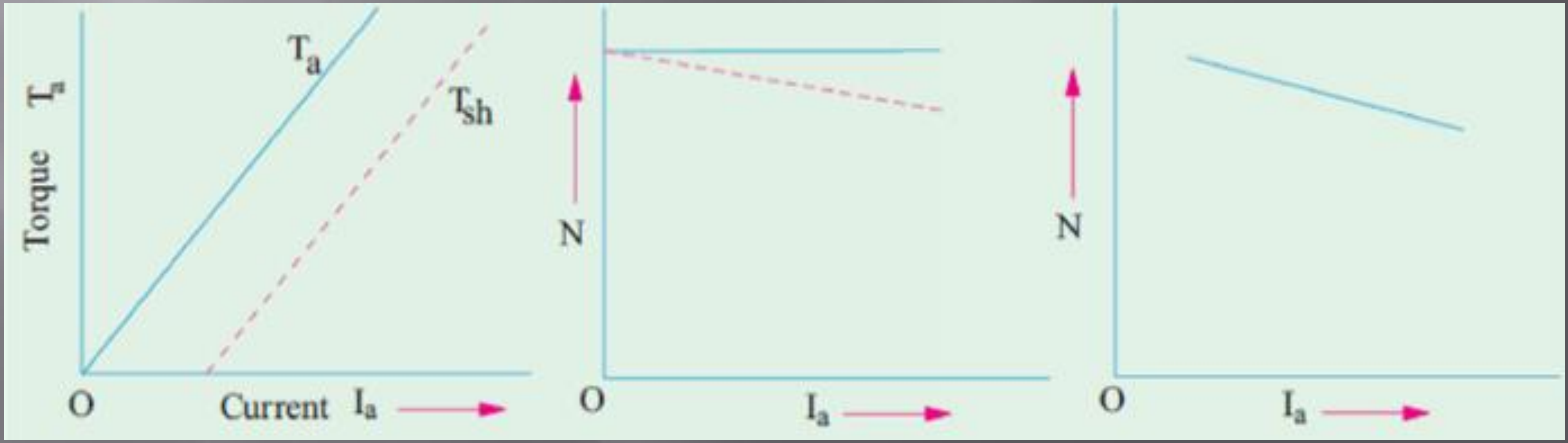
- There are three major characteristics

1) Speed Vs Armature current
2) Torque Vs Armature current
3) Speed Vs Torque

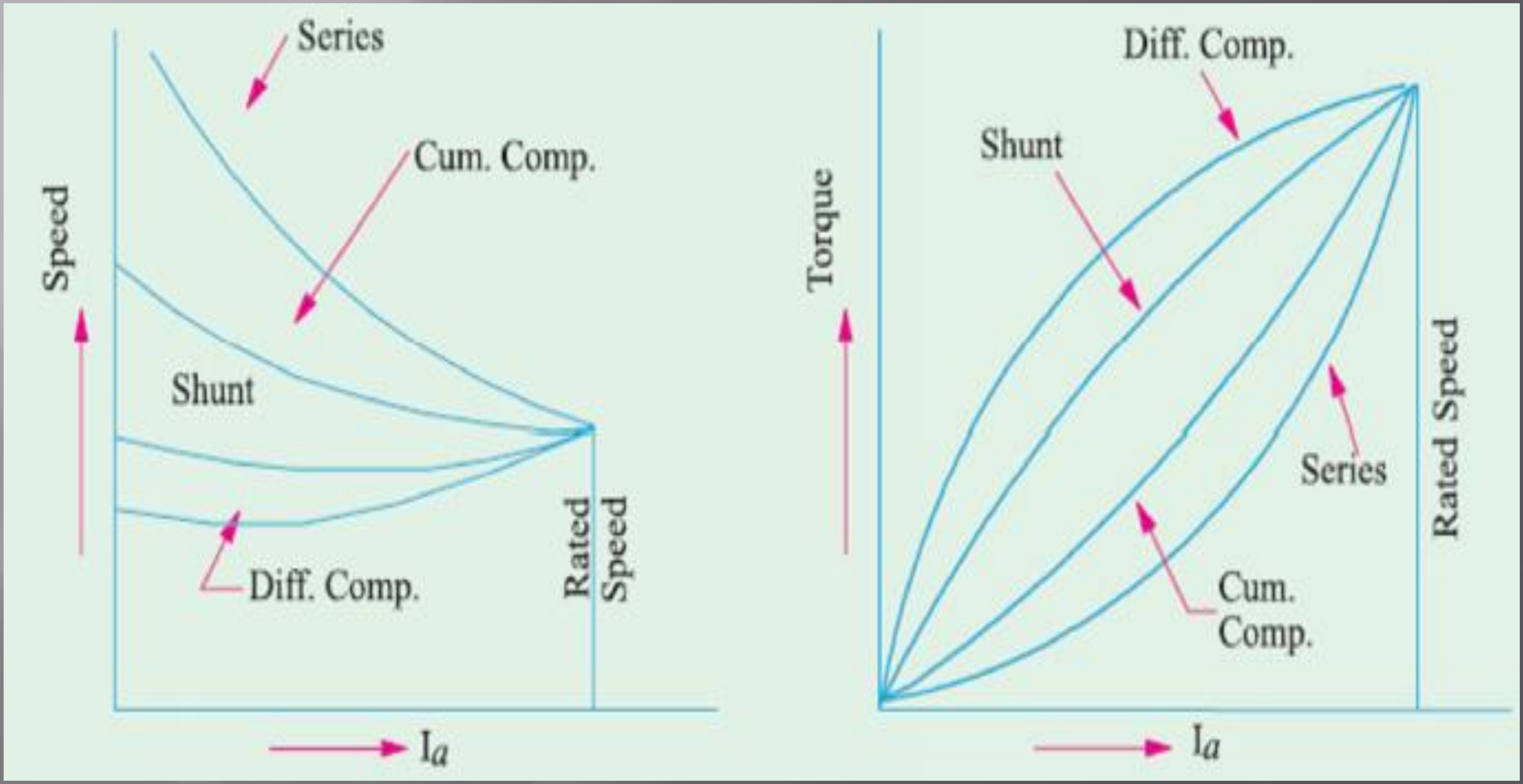
SERIES MOTOR



SHUNT MOTOR



Compound Motor:



Speed control of DC Motors:

- The factors which influence the speed of the motor are

1. V, the applied voltage
2. Ra, the resistance of the armature circuit
3. Φ, the flux/pole

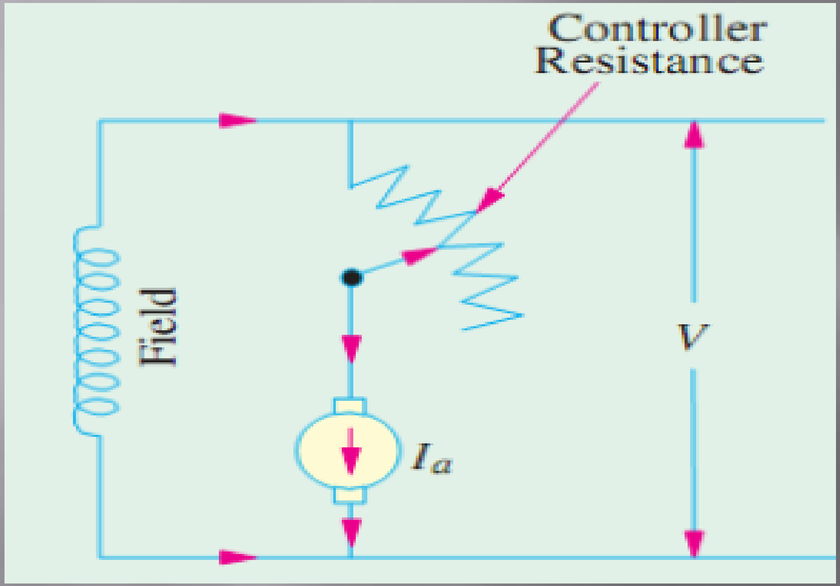
- ✓ By controlling one or more of the influencing factors, the speed can be controlled over a wide range.

Speed control methods:

1) Voltage control method
2) Armature control method
3) Flux control or field control method

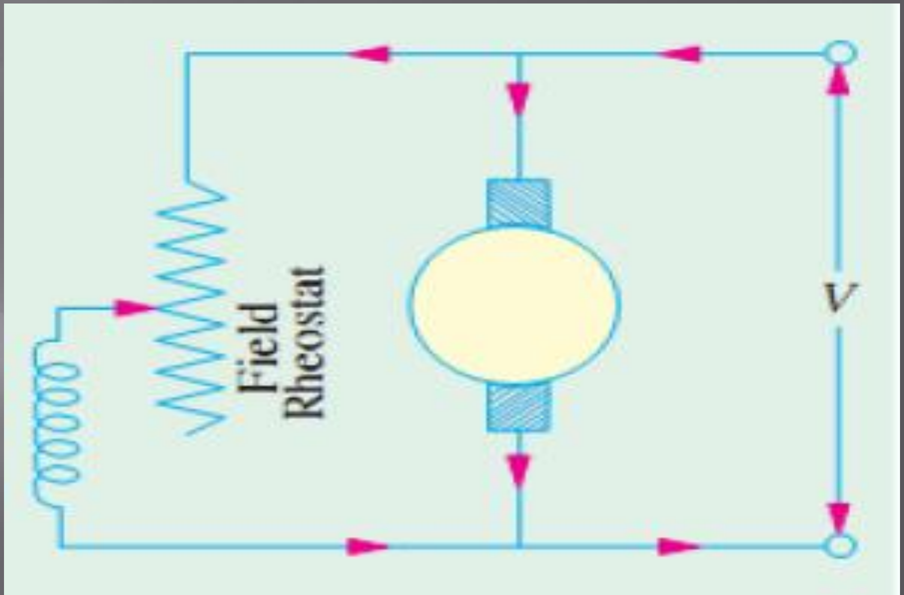
Speed control of DC Shunt Motor:

ARMATURE CONTROL



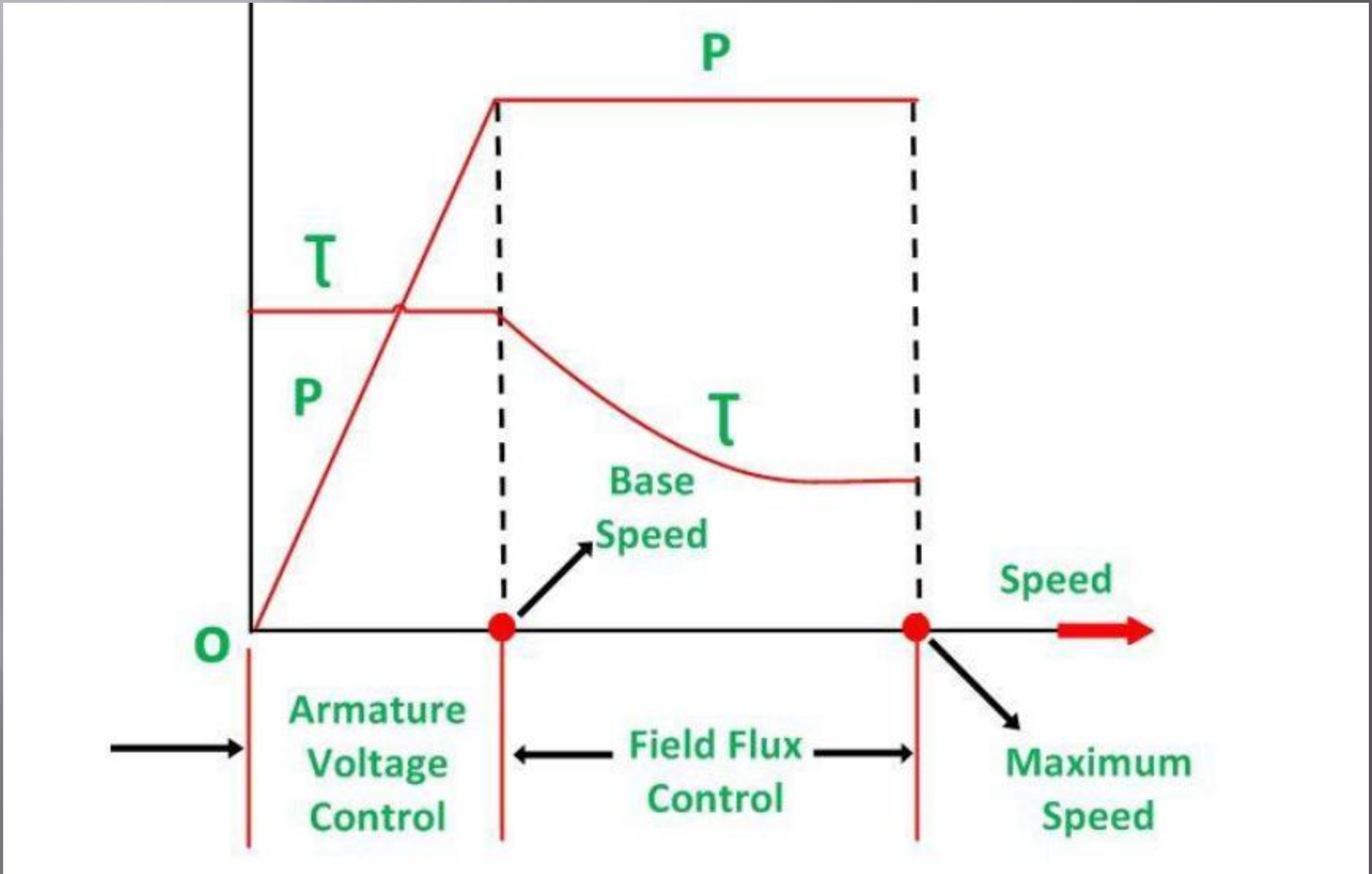
- Only speeds below rated can be obtained
- Power loss in the resistance

FIELD CONTROL



- Only speeds above rated can be obtained
- Power loss in field rheostat but quite small as filed current is generally small

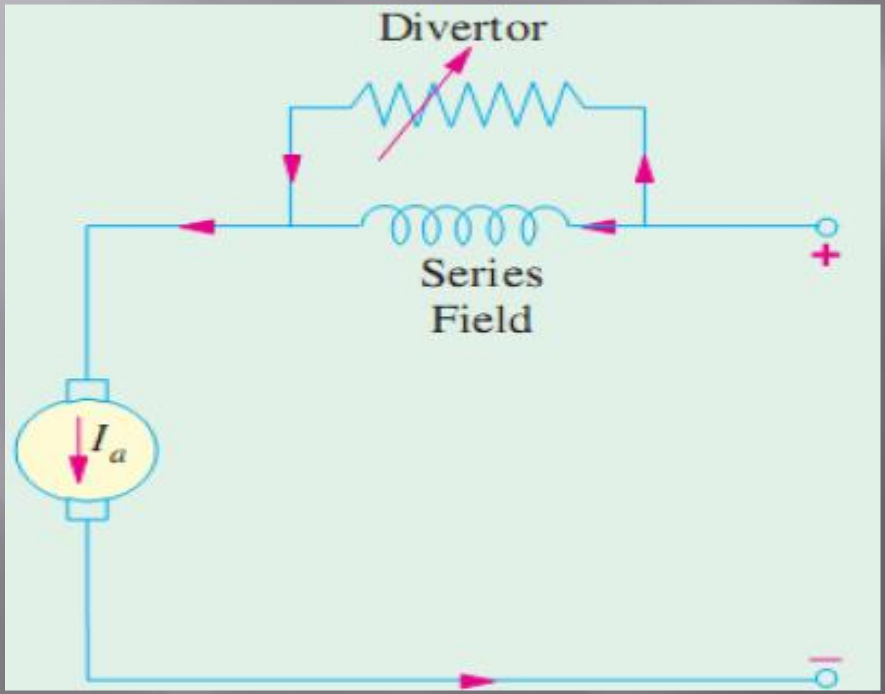
Torque power characteristics:

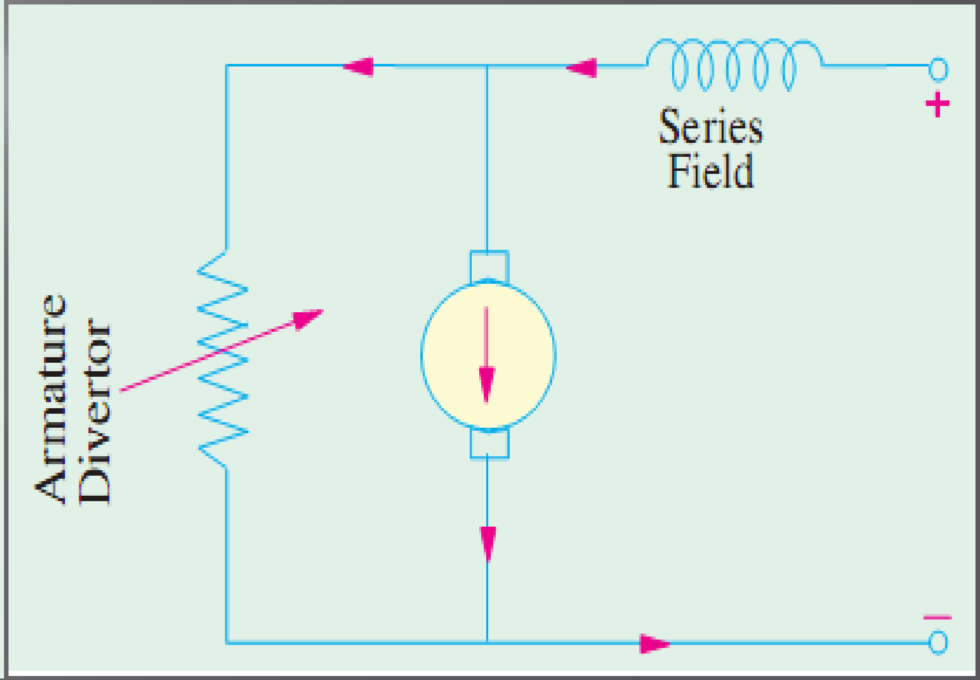


Speed control of DC Series Motor: A) Flux control method

1) FIELD DIVERTER

2) ARMATURE DIVERTER

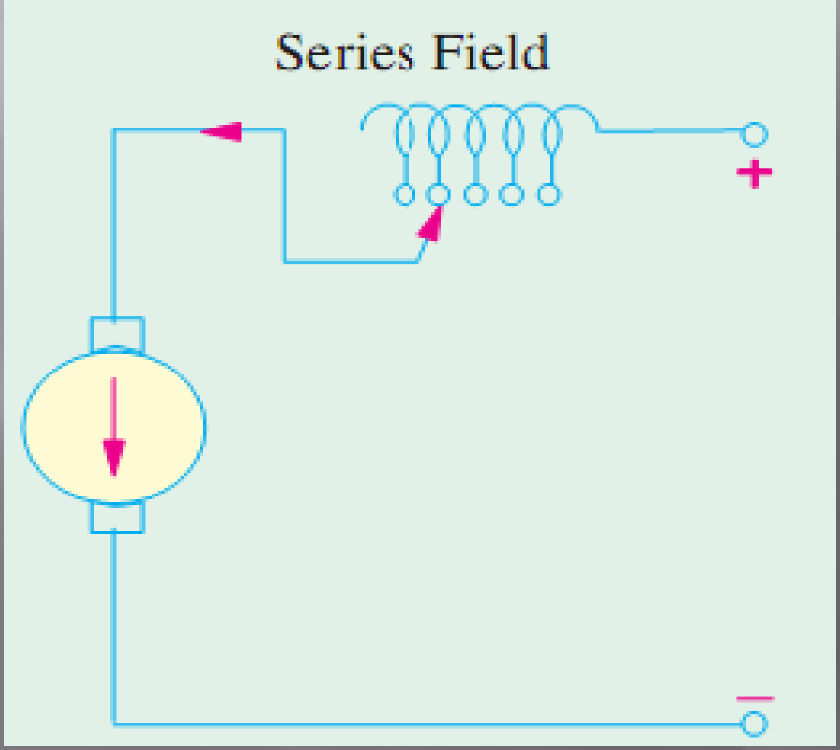




Speed control of DC Series Motor: A) Flux control method

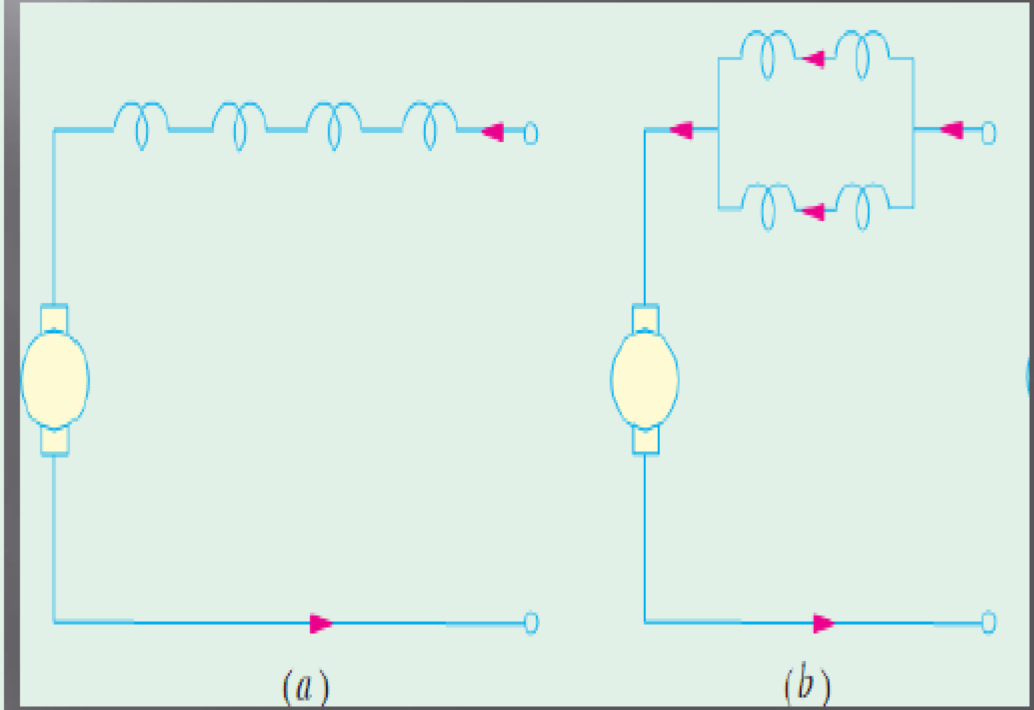
3) TRAPPED FIELD CONTROL

- Often used in electric traction

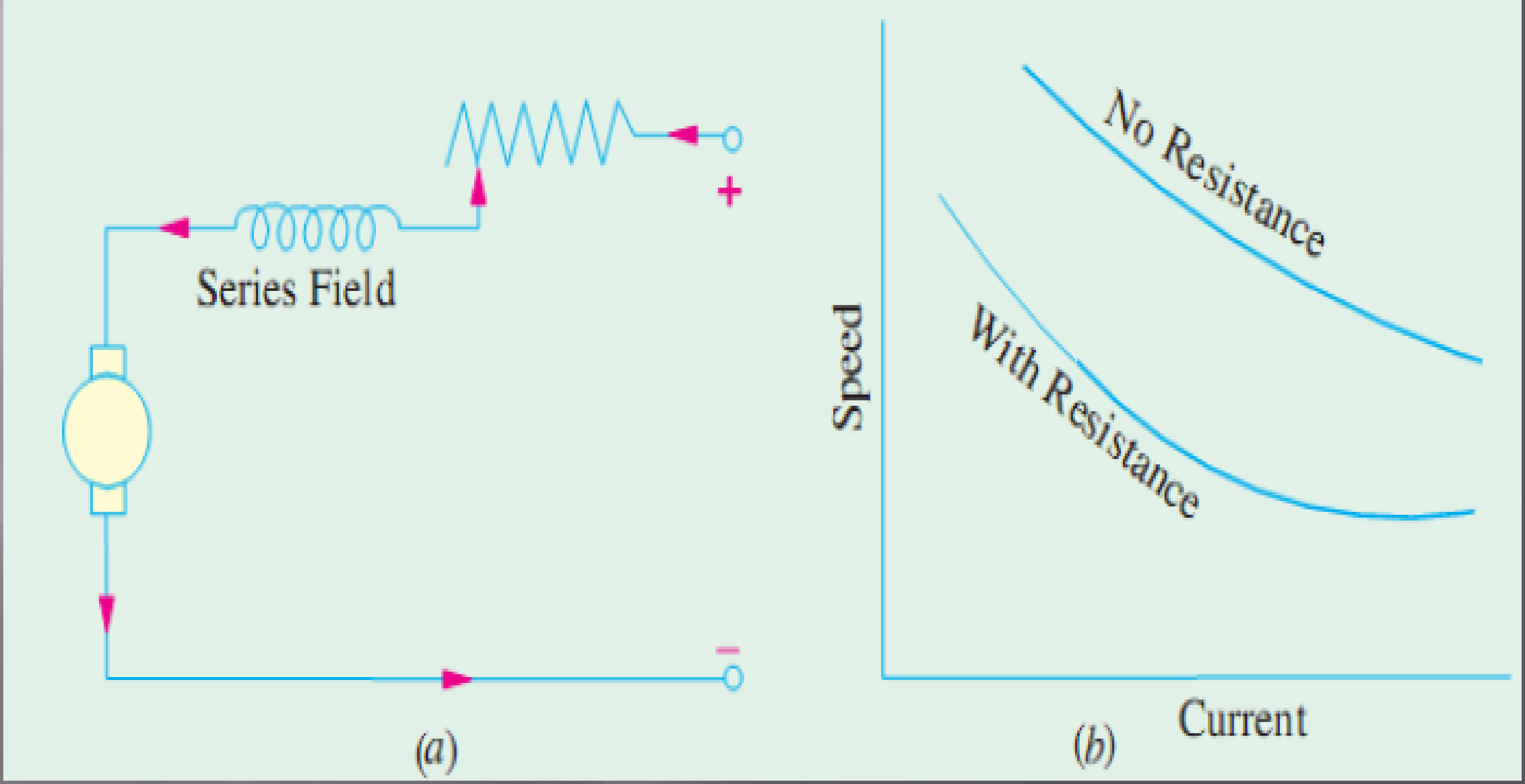


4) PARALLELING FIELD COILS

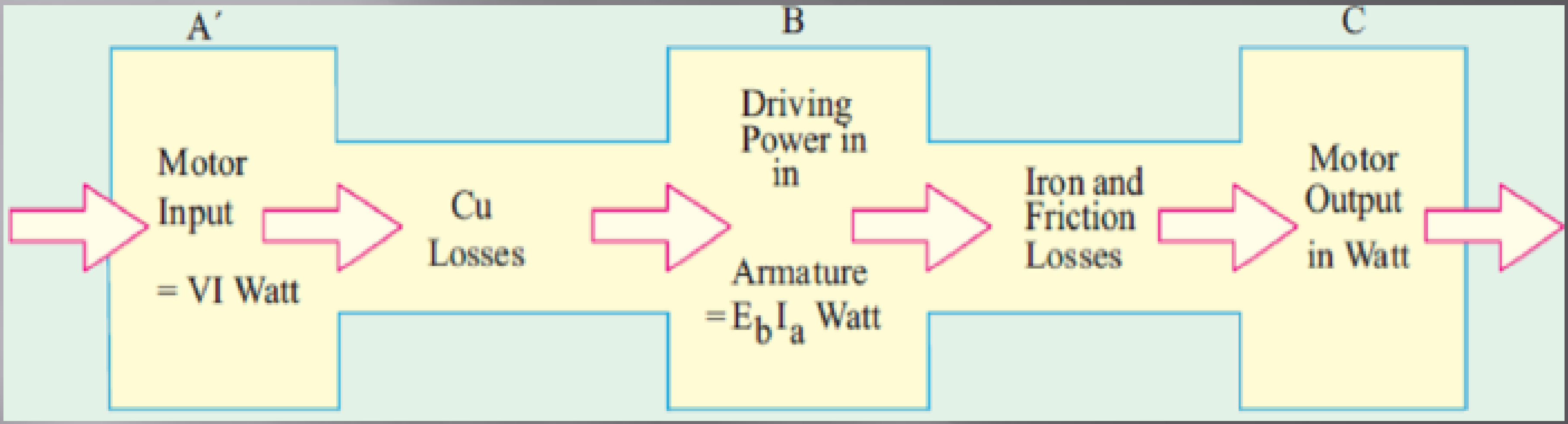
- Used in fan motors
- Regrouping the filed coils



Speed control of DC Series Motor: B) Variable resistance in series with the motor



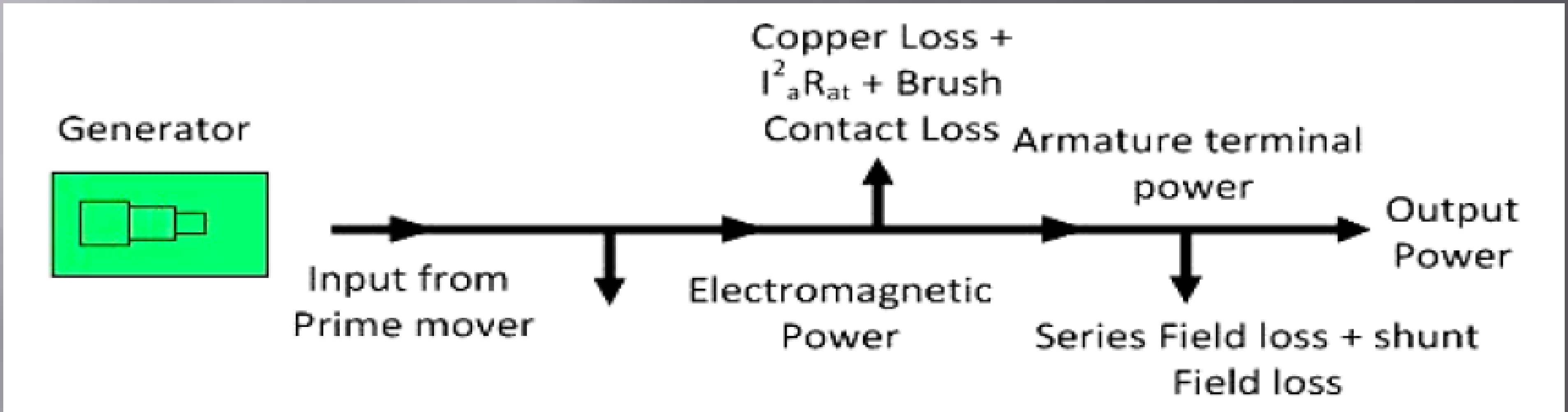
Power flow diagram of DC Motor:



$$\text{Efficiency, } \eta = \frac{\text{output}}{\text{input}} \times 100 = \frac{\text{output}}{\text{output} + \text{losses}} \times 100$$

Overall efficiency, ηc = C/A
Electrical efficiency, ηe = B/A
Mechanical efficiency, ηm = C/B

Power flow diagram of DC generator



DC Motor Starters:

- At the starting(standstill condition) of motor, the motor has no back emf.
- As the resistance of the armature is low, the armature current is very high which damage the motor.
- Heavy current can be prevented by inserting a resistance in series with the armature before switching on power supply.

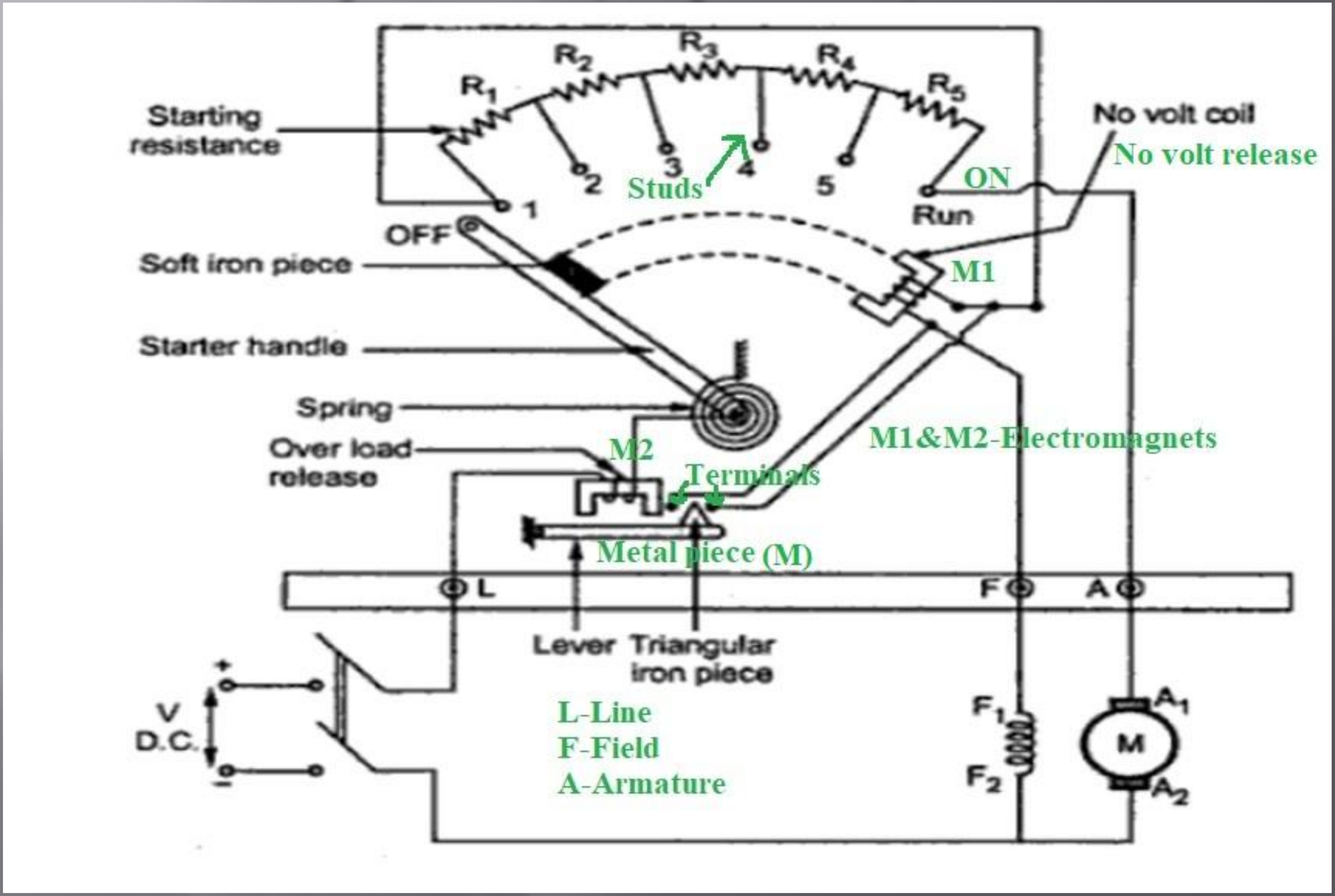
$$I_a = \frac{V - E}{R_a} \quad \dots\dots\dots \quad (1)$$

$$I_{as} = \frac{V - 0}{R_a} = \frac{V}{R_a} \quad \dots\dots\dots\dots \quad (2)$$

- **Example:** If a motor with the armature resistance of 0.5Ω is connected to a 230V supply

$$I_{as} = \frac{V}{R_a} = \frac{230}{0.5} = 460 \quad \text{Ampere}$$

Three point (3 point) starter:



Three point (3 point) starter:

Functions

1) Starting resistance
2) No-volt release
3) Over-load release

Construction of 3-point starter:

- Starting resistance is split into several sections, whose ends are joined to live studs marked as 1,2,3 etc. These studs are so positioned that the starter handle can slide over them.
- In the ON position of the handle, the soft iron piece is rigidly held in position due to the powerful attraction of the electromagnet M1.
- The metal piece gets lifted up due to the attraction of M2 and the arrangement is such that when it lifts up, it bridges terminals, thereby short circuiting the coil of M1. The distance of M from M2 is such that during normal working of the motor, the mmf developed by M2 is not adequate to attract M towards it. But when motor is overloaded M is attracted towards M2.
- A powerful spring is so wound around the starter handle that it always pulls the handle into the initial OFF position.

The no volt release protects the motor in two ways

1.POWER FAILURE

- If there is power failure, M1 gets reenergized and handle is pulled back to the OFF position by the spring .
- If there is no protection handle would remain in ON position and if there is sudden resumption of power supply, heavy current flows.

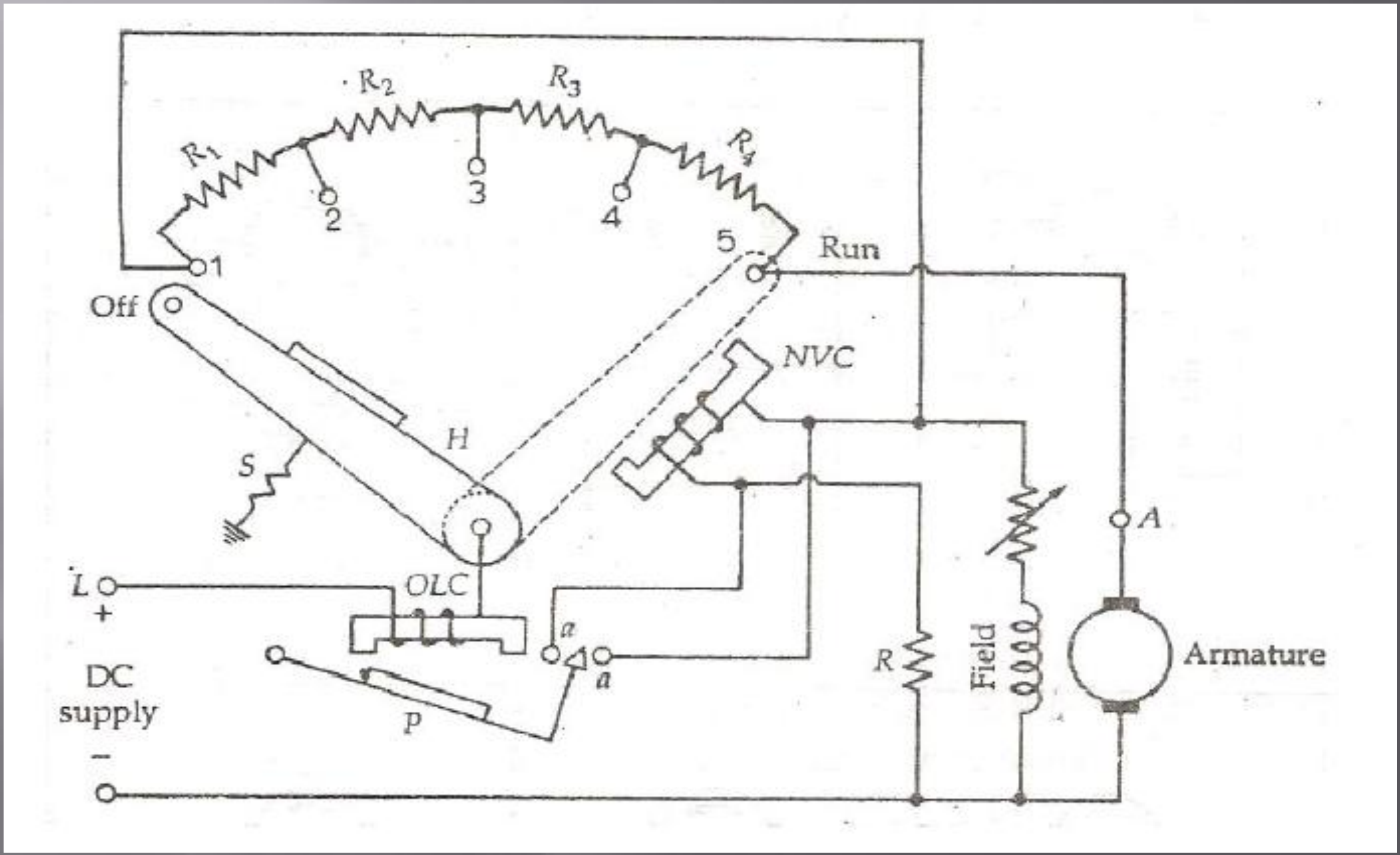
2.BREAK IN FIELD CIRCUIT

- If there is a break in the field circuit, the flux becomes zero, and the motor would attain an excessively high speed.
- As M1 gets demagnetized, the handle is pulled back to the OFF position.

Drawback of 3-point starter:

- In the field control method (speed control of DC motor i.e. above rated speed), to increase the speed, the field resistance should be increased.
- The field current may become very low because of the addition of the high resistance to obtain high speed.
- A very low field current will make the holding magnet too weak to overcome the force exerted by the spring. The holding magnet may release the arm of the starter during the normal operation of the motor and thus, disconnect the motor from the line.
- To overcome this difficulty, the 4-point starter is used.

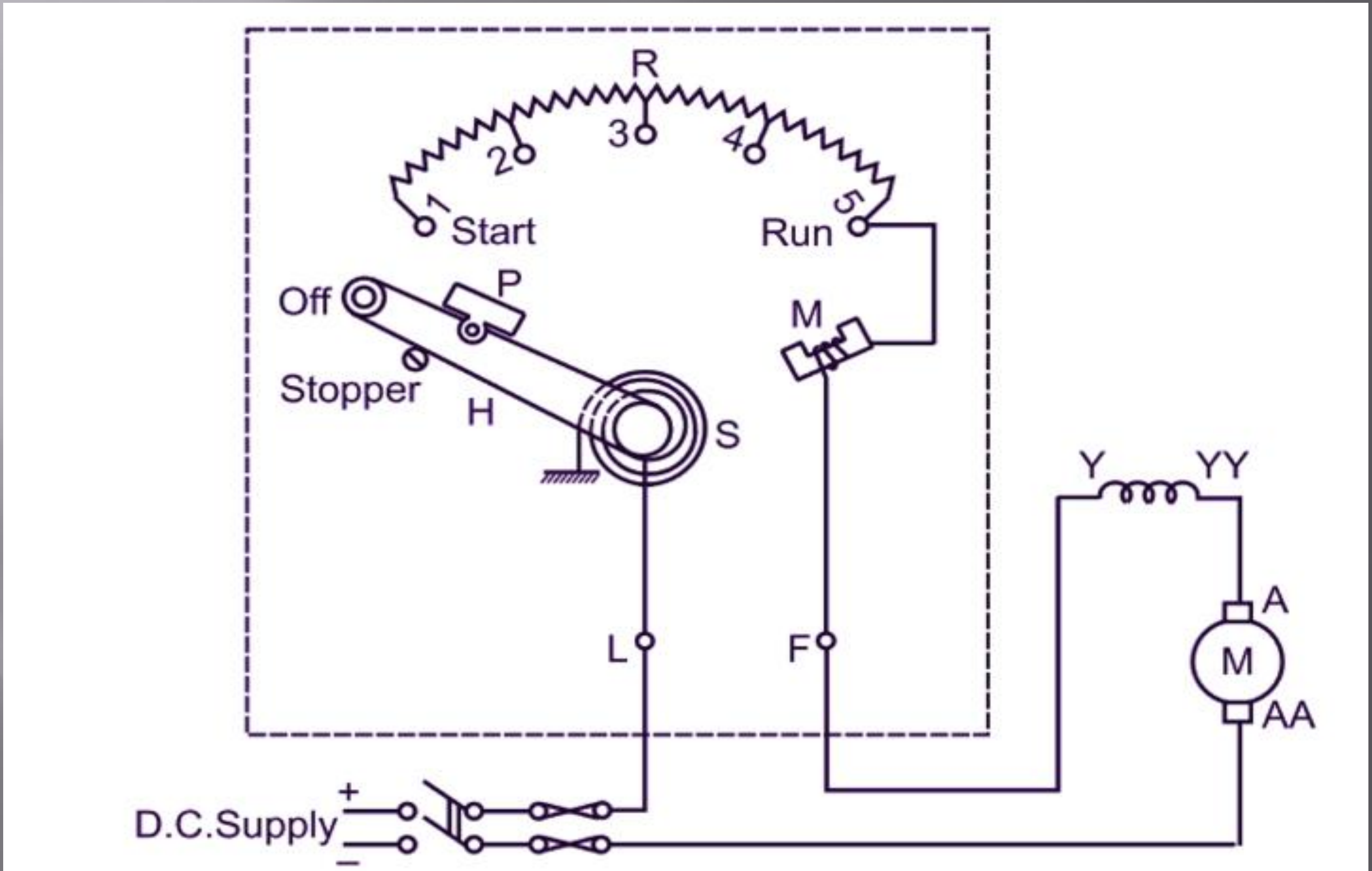
4 point starter:



4 point starter:

- Almost similar in functional characteristics like 3 point starter.
- No volt coil is connected across the line in series with a current limiting resistance.

Two point starter: (for series motor)



Testing of DC machines:

- Tests are to be conducted to estimate the efficiency.
- Classified into two types

1. Direct load test
2. Indirect load test

Direct load test

- Load is physically placed on the machine.
- Input and output power are measured separately.
- Losses are not estimated.
- ✓ Most accurate method of measuring efficiency.
- ✓ Applicable only for small size machine due to wastage of power.

Indirect load test:

- Adopted to large size machines.
- Load is not physically placed on machine.
- Losses of the machine are estimated by performing some experiment. Using this data efficiency is predicted theoretically.
  1) Swinburne's test (no load test)
  2) Hopkinson's test (regenerative or back to back test)
  3) Retardation test
  4) Field's test

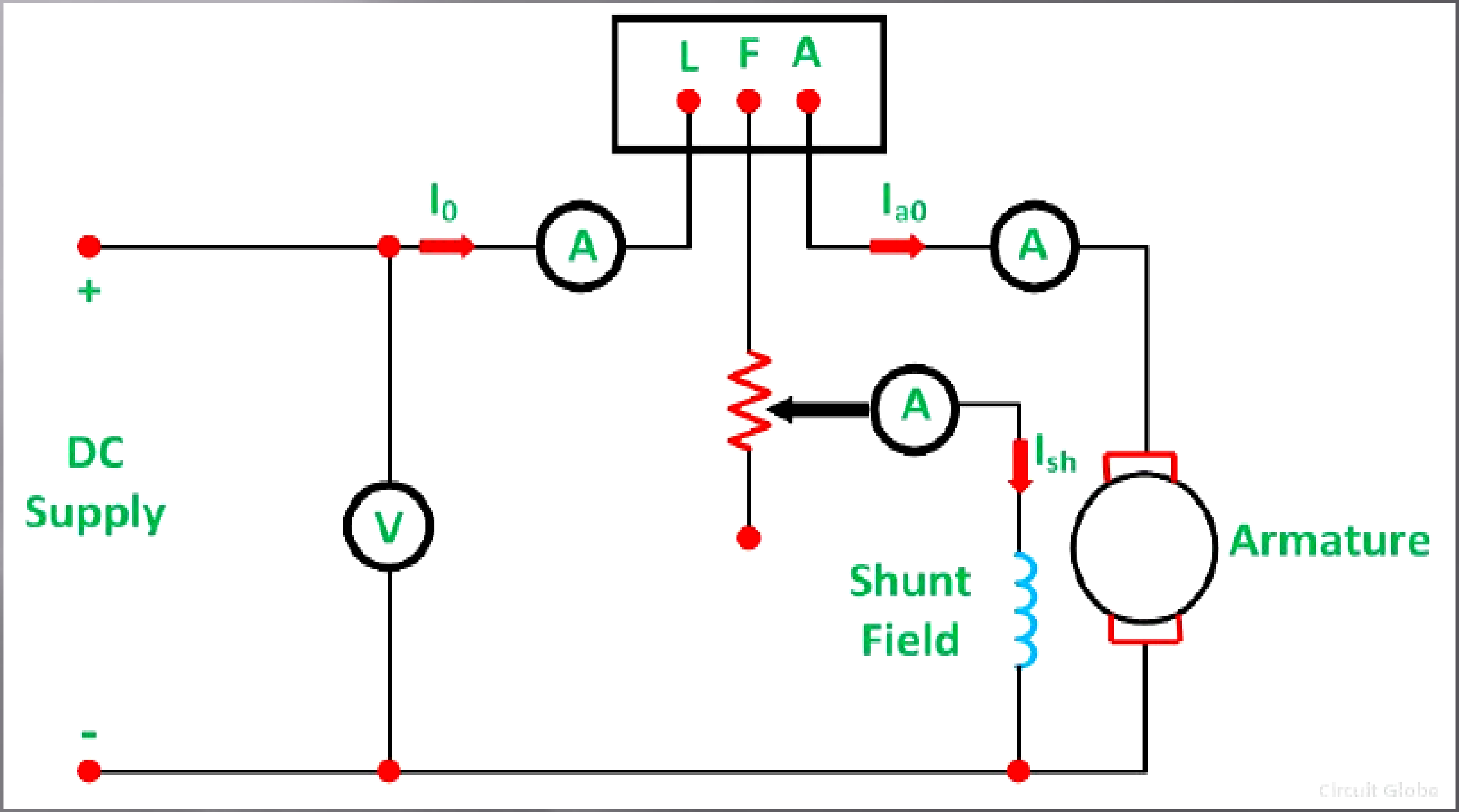
Indirect load test contd…

- Swinburne’s test and Hopkinson's test are the most important and actually conducted in practice on shunt motors.
- For obvious reasons the non-loading test can not be conducted on a series test.
- As Swinburne's test is a no-load test, it can’t be performed on series motor.

Swinburne's test:

- Will be performed only on shunt and compound motors not on series.
- Apply rated voltage to the motor without applying any load to the shaft.
- The motor speed is adjusted to rated value by inserting a rheostat.
- Losses are measured and the efficiency at any desired load is determined.
- Ultimately constant losses are measured.
- Variable losses are predicted by estimating Ia.

Swinburne's test contd…



Swinburne's test contd…

- V= supply voltage
- I_o=No load current
- I_{ao}=No load armature current
- I_{sh}=Shunt field current
- VI_o=No load input power
- VI_{sh}= Shunt field loss
- $I_{ao}^2R_a$=Armature loss (variable)
- Constant loss(stray loss), W_{st} or P_k= VI_{ao}- $I_{ao}^2R_a$+VI_{sh}
- Armature resistance is measured by a dc test.
- Variable loss (copper loss), W_{cu} or P_v=$I_a^2R_a$
- Total loss, PL = Pk+Pv

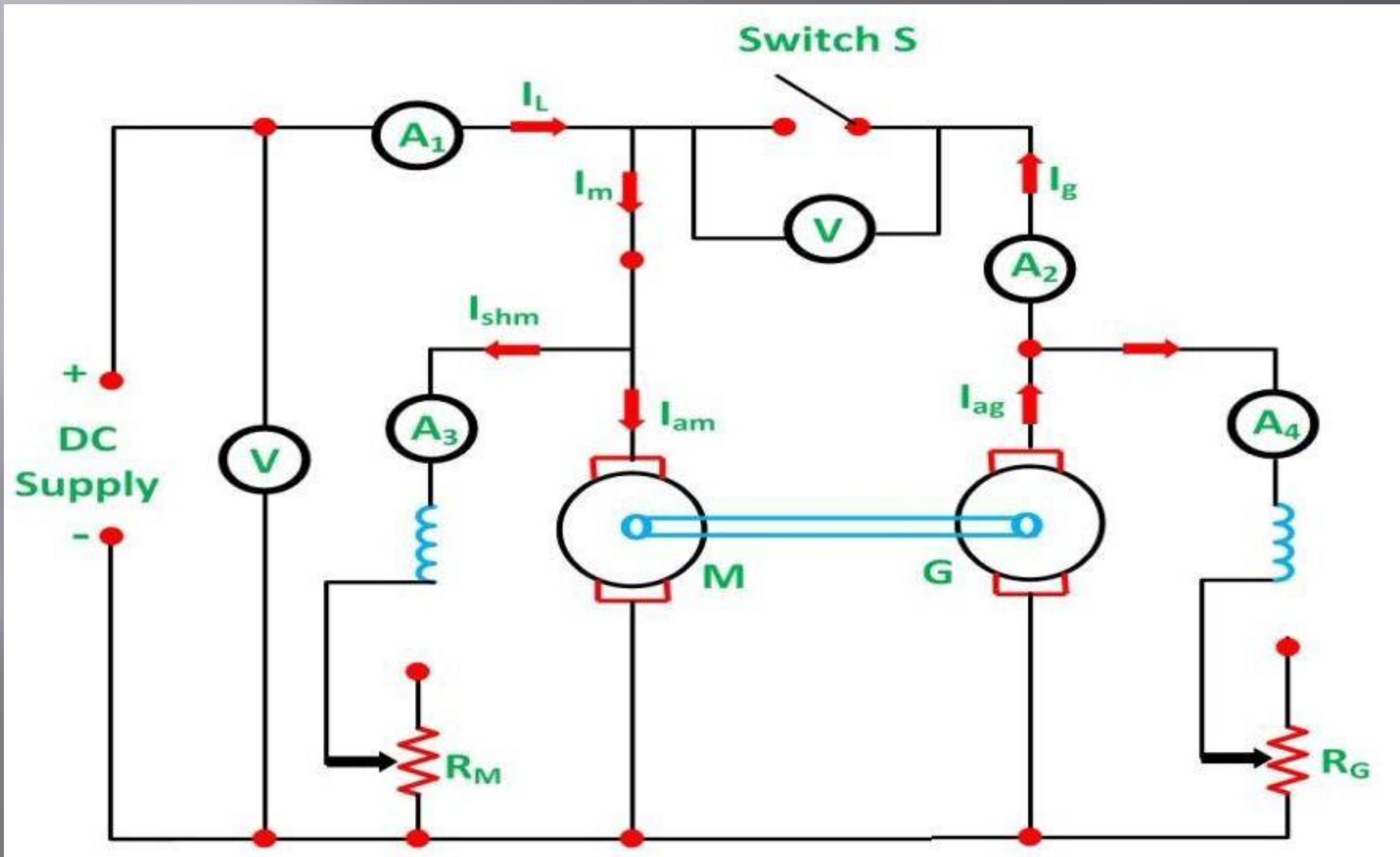
Swinburne's test contd…

- Simple and most economical method.
- The variation of temperature due to variation of load is not considered.
- While physically placing the load the speed of motor is going to be reduced. The change in speed is not considered in the estimation of mechanical and iron losses.
- Due to armature reaction iron losses increases, which is not considered in this test.
- Stray load loss can not be determined and hence efficiency is over estimated.
- Accuracy is less.

Hopkinson's test:

- It is regenerative test.
- For conducting this test two identical dc machines are required.
- One is operated as generator by increasing its field strength and one is acting as motor by reducing its field strength.
- The set draws only loss power from the mains.
- Conduct only on shunt or compound machine.

Hopkinson's test contd…



Hopkinson's test contd…

- Initially switch kept in open position.
- One of the machine s of the set started as motor and brought to speed.
- The two machines are paralleled by means of switch "s", after checking that similar polarities of the machine are connected across the switch(voltage across the switch is zero i.e. motor armature and generator armature are at the same potential, which is achieved by adjusting field currents).
- Now close the switch (machines are electrically coupled)
- Adjust the field of generator such that its armature voltage is slightly greater than motor armature voltage. Generator delivers power to motor under this condition.
- The field of the motor is adjusted to maintain the speed at its rated value.

Hopkinson's test contd…

Power input from the supply = VI_L = total losses of both the machines

Armature copper loss of the motor = $I^2_{am} R_a$

Field copper loss of the motor = $I^2_{shm} R_{shm}$

Armature copper loss of the generator = $I^2_{ag} R_a$

Field copper loss of the generator = = $I^2_{shg} R_{shg}$

Constant losses of both the machines = Power drawn from the supply – Armature and shunt copper losses of both the machines.

$$P_C = VI_L - \left(I^2_{am} R_a + I^2_{shm} R_{shm} + I^2_{ag} R_a + I^2_{shg} R_{shg}\right)$$

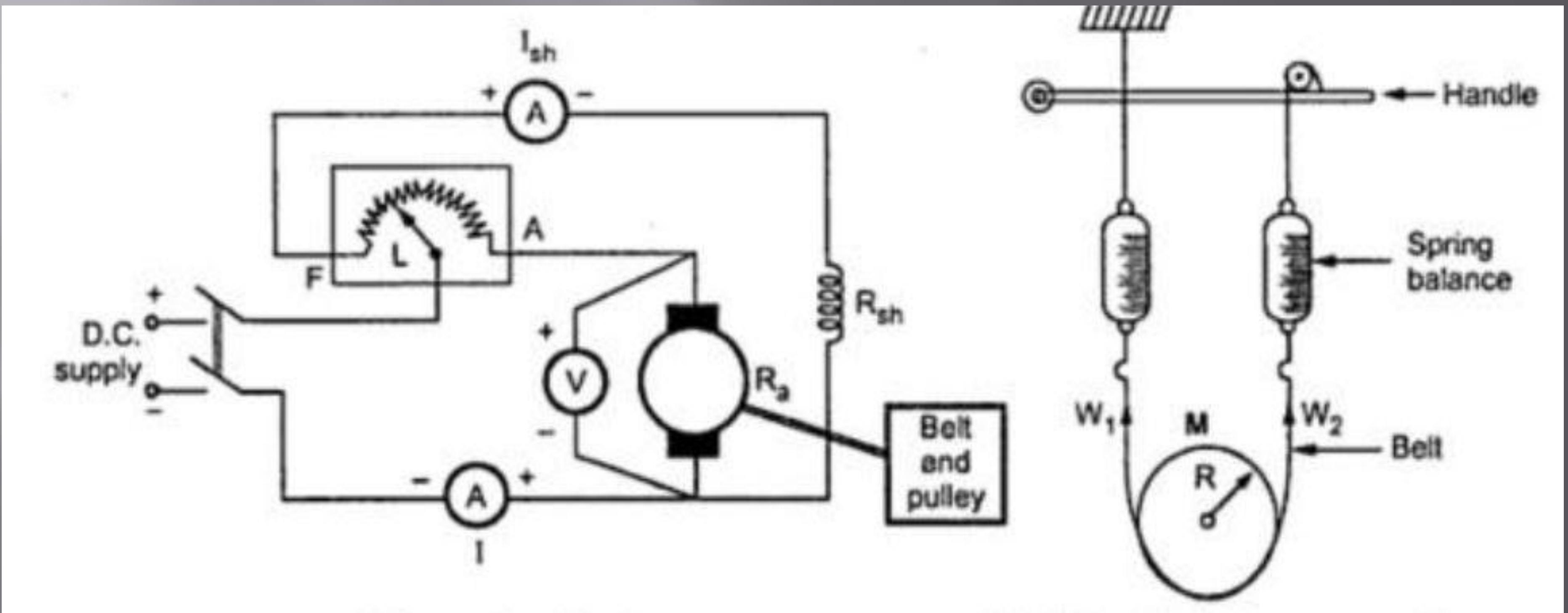
Total stray loss per machine = ½ P_C

Hopkinson's test contd…

- Indirect loading is considered i.e. motor acts as a load on generator and generator acts as a load on motor. But power drawn from the mains is to compensate losses i.e. the effect of temperature is considered.
- The variation of stray losses with the load is also considered.
- Better suited for large machines.

Brake test:

- Also called as direct loading test as loading will be applied on shaft of the motor by means of a belt and pulley arrangement.



(a) Experimental setup (b) Belt and pulley arrangement

Brake test:

Let, spring balance reading on tight side = W_1 kg
spring balance reading on loose side = W_2 kg
Motor speed = N rpm (reading taken by tachometer)
Radius of pulley = r metre
Thockness of belt = t metre

Motor output = T (2 pi N)/60 = (W1-W2)(r+t/2)(2 pi N)/60
(T= effective pull x effective radius)
= (W1-W2)(r)(2 pi N)/60 kg m/sec (neglect t being small)
= (W1-W2)(r)(2 pi N)/60 x 9.81 Nm/s or watt

If voltmeter reading = V volt
ammeter reading = I ampere
motor input = VI watt

efficiency of motor = output/input = (W1-W2)(r)(2 pi N)/60 x 9.81/VI

Brake test:

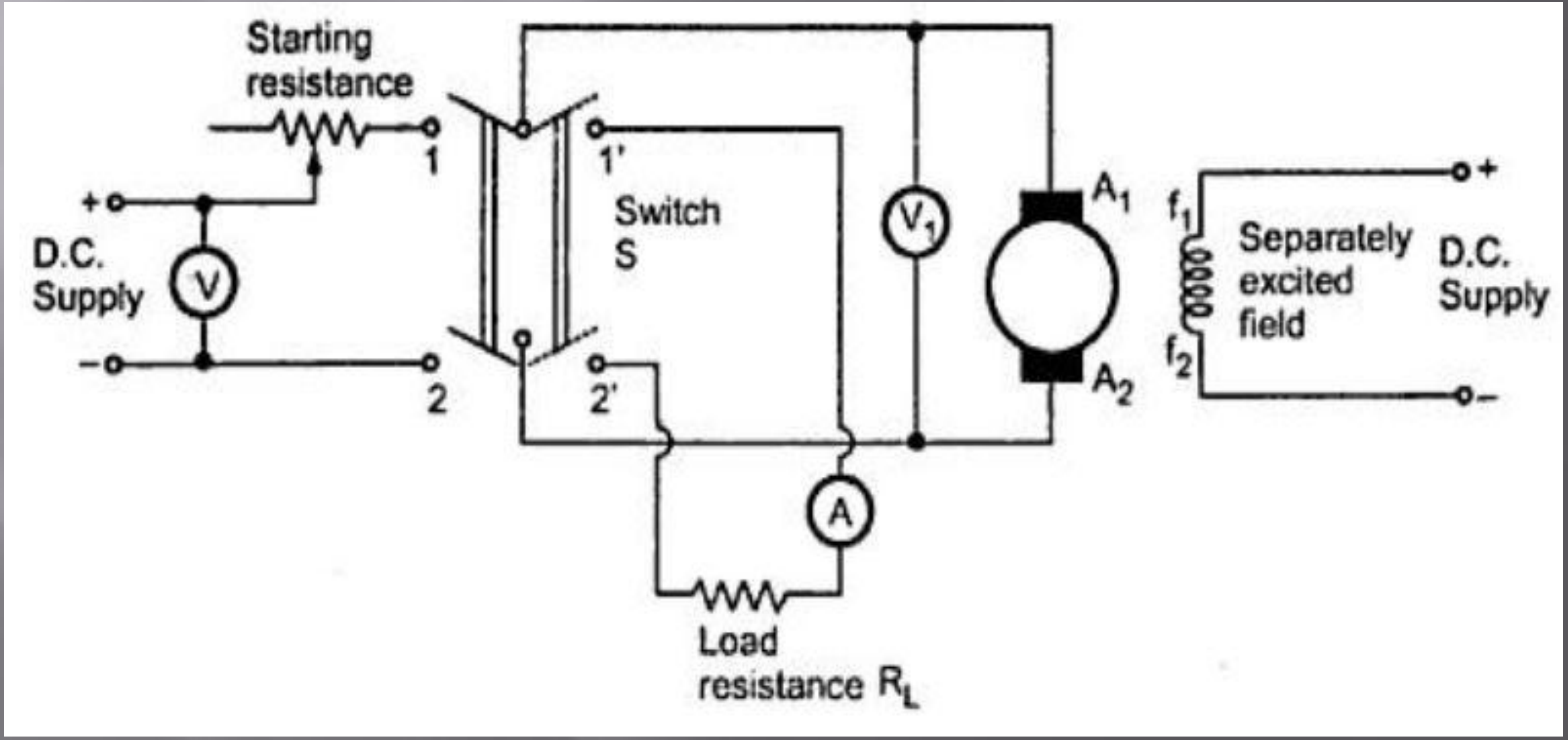
Disadvantages:

1. Can not determine the efficiency of large machines because such facilities of loading are not available.
2. Output measured is not accurate because belt is not offering a constant load (usually belt slips over the pulley)

- ✓ Can be performed on any type of dc motor but a special precaution is to be observed while performing this test on a series motor. If the brakes applied fails, the motor may obtain a dangerously high speed. Therefore this test is usually applied only on shunt and compound machines.

Retardation test:

- Generally employed to shunt machines to estimate i) stray losses ii) moment of inertia.



Retardation test:

If **I** is the amount of inertia of the armature ans is the angular velocity.

Kinetic energy of armature = $0.5\ I\omega^2$

Rotational losses, W = Rate of change of kinetic energy

$$= \frac{d}{dt}\left(\frac{1}{2} I \omega^2\right) = I\omega \frac{d\omega}{dt}$$

Angular velocity, $\omega = (2\pi N)/60$

$$W = I\left(\frac{2\pi N}{60}\right)\frac{d}{dt}\left(\frac{2\pi N}{60}\right) = I\left(\frac{2\pi N}{60}\right)\left(\frac{2\pi}{60}\right)\frac{dN}{dt}$$

$$\boxed{W = \left(\frac{2\pi}{60}\right)^2 I N \frac{dN}{dt}}$$

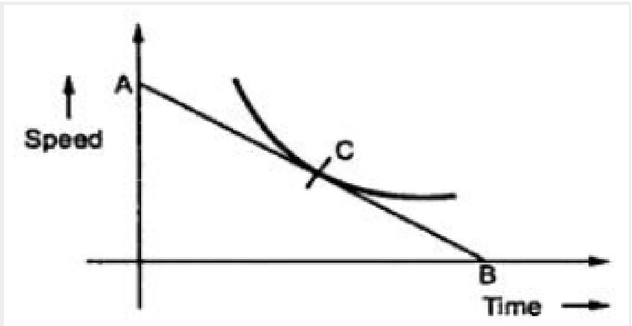
Thus, to find the rotational losses, the moment of inertia I and dN/dt must be known.

Retardation test:

1.1 Determination of dN/dt

The voltmeter V_1 which is connected across the armature will read the back e.m.f. of the motor. We know that back e.m.f. is proportional to speed so that voltmeter is calibrated to read the speed directly.

When motor is cut off from the supply, the speed decrease in speed is noted with the help of stop watch. A curve showing variation between time and speed which is obtained from voltmeter which is suitably calibrated is shown in the Fig. 3.



At any point C corresponding to normal speed, a tangent AB is drawn. Then

$$\boxed{\frac{dN}{dt} = \frac{\text{OA (in r.p.m.)}}{\text{OB (in seconds)}}}$$

The value obtained from above can be substituted in the expression for W which can give the rotational looses.

Retardation test:

1.2 Determination of moment of inertia (I):

Method 1: Using Flywheel

The armature supply is cut off and time required for definite change in speed is noted to draw the corresponding curve as we have drawn in previous case. This curve is drawn considering only armature of the machine. Now a flywheel with known moment of the inertia say is I_1 keyed onto the shaft and the same curve is drawn again. The slowing down time will be extended as combined moment of inertia of the two is increased.

For any given speed (dN/dt_1) and (dN/dt_2) are determined same as previous case. It can be seen that the losses in both the cases are almost same as addition of flywheel will not make much difference to the losses.

In the first case where flywheel is not there then,

$$W = \left(\frac{2\pi}{60}\right)^2 I N \frac{dN}{dt_1}$$

Adding the flywheel to the motor armature in second case we get,

Retardation test:

$$W = \left(\frac{2\pi}{60}\right)^2 (I + I_1)\ N \frac{dN}{dt_2}$$

$$\therefore \qquad I N \frac{dN}{dt_1} = (I + I_1) N \frac{dN}{dt_2}$$

$$\therefore \qquad \frac{I+I_1}{I} = \frac{(dN / dt_1)}{(dN / dt_2)}$$

$$\therefore \qquad I = \left[(I+I_1) \frac{dN}{dt_2}\right] \Big/ \left(\frac{dN}{dt_1}\right)$$

$$\therefore \qquad I = I_1 \times \frac{dN / dt_2}{(dN / dt_1)-(dN / dt_2)} = I_1 \times \frac{dt_1}{dt_2 - dt_1}$$

$$\therefore \qquad \boxed{I = I_1 \cdot \frac{t_1}{t_2 - t_1}}$$

Method 2: without using Flywheel

In this method time is noted for the machine to slow down by say 5 % considering the armature alone. The a retarding torque either mechanical or electrical is applied. Preferably electrical retarding torque is applied and time required to slow down by 5% is noted again. The method by which electrical

Retardation test:

torque can be provided is shown in the Fig. 1 in which the switch S after disconnecting from the supply is thrown to terminals 1'2'. The machine then gets connected to a non-inductive load resistance R_L. The power drawn by this resistance will acts as a retarding torque on the armature which will make it slow more quickly.

The additional loss in the resistance will be equal to product of ammeter reading and the average reading of the voltmeter (for a fall of 5% of voltmeter reading, the time is noted.) The ammeter reading is also changing so its average reading is taken. Thus the additional losses is $I_a^2 (R_a + R)$. Let t_1 be the time when armature is considered alone and t_2 be the time when armature is connected across a load resistance, V be average voltage across R and I_a be the average current and W' is additional retarding electrical torque supplied by motor.

$$W = \left(\frac{2\pi}{60}\right)^2 I N \frac{dN}{dt_1}$$

$$W + W' = \left(\frac{2\pi}{60}\right)^2 I N \frac{dN}{dt_2}$$

If dN i.e. change in speed is same in two cases then

$$\frac{W + W'}{W} = \frac{1/dt_2}{1/dt_1} = \frac{dt_1}{dt_2} = \frac{t_1}{t_2}$$

$$\therefore \quad (W + W')\, t_2 = W\, t_1$$

$$\therefore \quad W (t_1 - t_2) = W' t_2$$

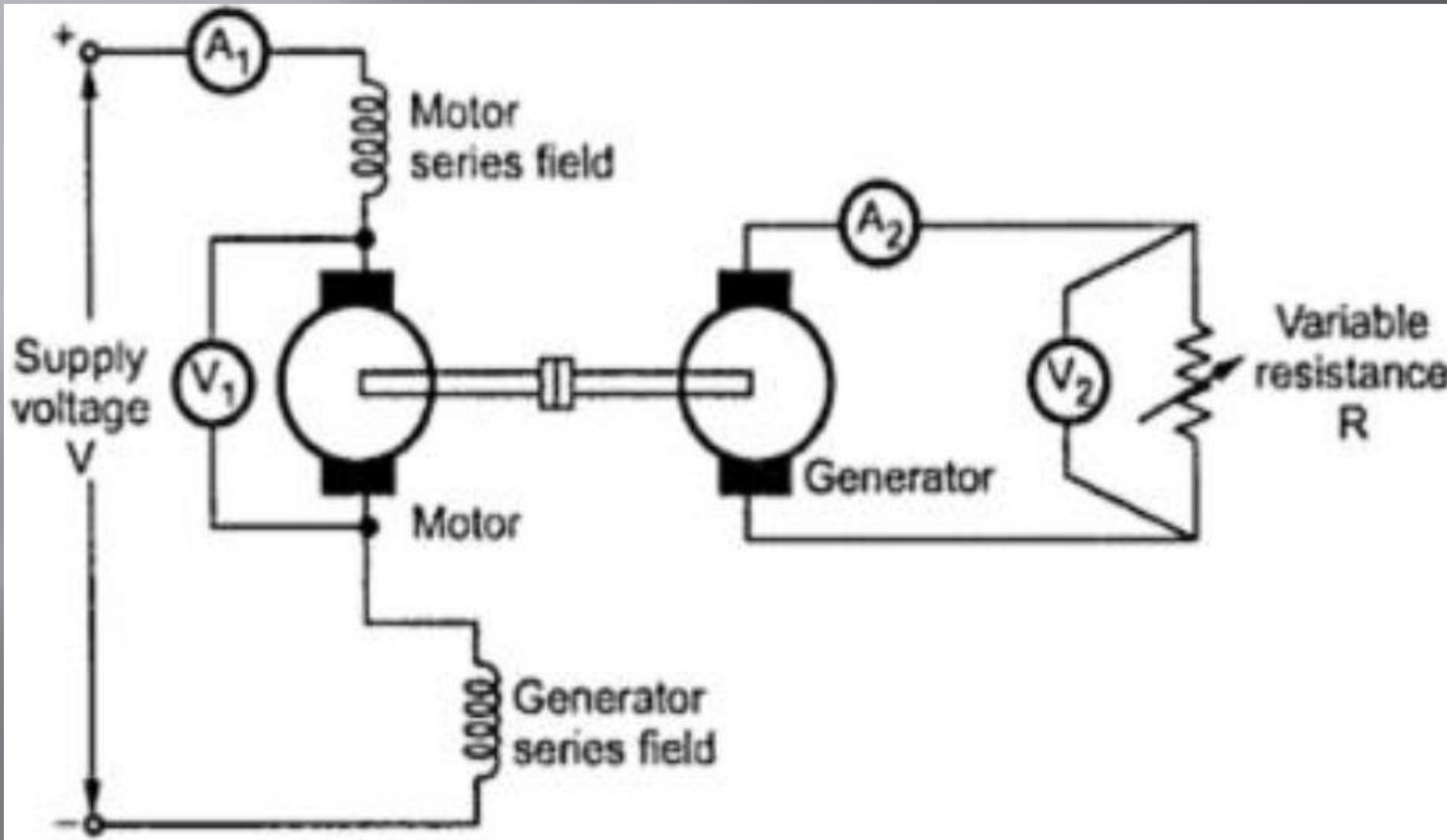
$$\therefore \quad \boxed{W = W' \frac{t_2}{t_1 - t_2}}$$

Here dN/dt_1 is rate of change in speed without extra load whereas dN/dt_2 is rate change in speed with extra electrical load which provides retarding torque.

Field's test:

- Small DC series machines can be tested by brake test but large DC series machines cannot be tested by brake test because neither it is convenient nor possible to develop a mechanism to apply load on such large machines directly.
- DC series machines cannot be tested by Swinburne's test, because at no load these machines obtain dangerously high speeds.
- So field test is considered to be most suitable for determining efficiency of these machines.
- Two identical DC series machines are coupled mechanically and their fields are connected in series so that the iron losses of both the machines be made small.
- This is not a regenerative test, even though one machine acts as a motor and the other as a generator, because generator output is not fed back to motor but wasted in load resistor.

Field's test:



+
A1
Motor
series field
A2
Supply
voltage
V
V1
V2
Variable
resistance
R
Generator
Motor
Generator
series field
−

Field's test:

Disadvantages

1. Even for a small error in the measurement of the input to motor or output of generator may cause a relatively large error in efficiency.
2. Whole of the power supplied to the set is wasted.

THANK YOU

Any Queries??????????