BE 3254 Electrical and Instrumentation Engineering

UNIT-I Transformer

Introduction - Ideal and Practical Transformer - Phasor diagram - Per Unit System - Equivalent circuit - Testing - Efficiency and voltage Regulation - Three Phase Transformers - Applications - Auto Transformers, Advantages - Harmonics.

Introduction.

* A transformer is a device that changes ac electric power at one voltage level to ac electric power at another voltage level through the action of a magnetic field.
* Transformer works on the Principle of electromagnetic induction.

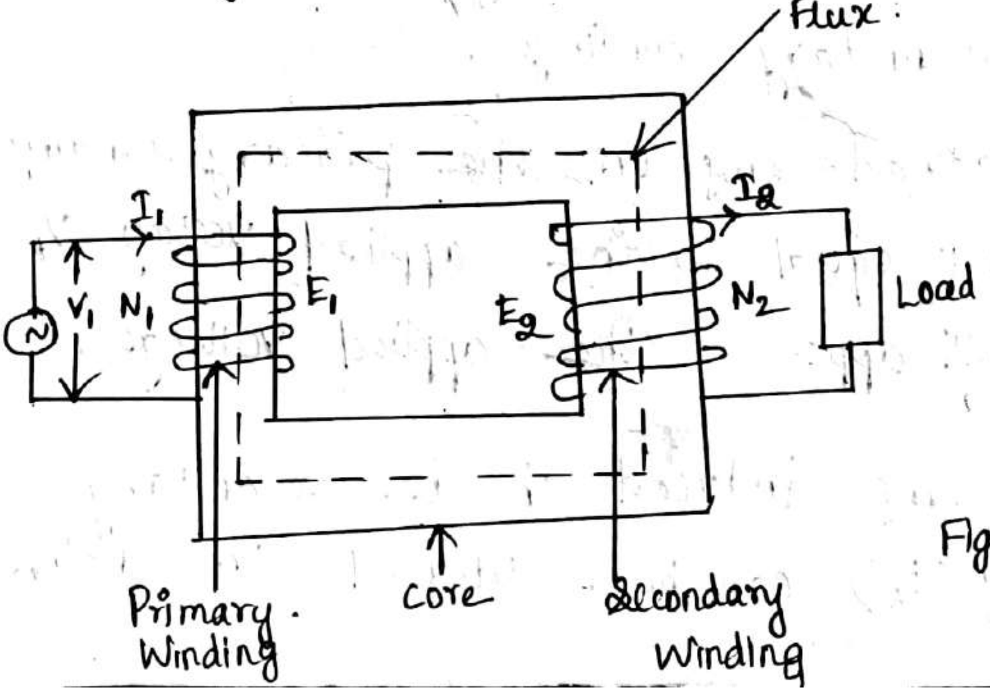

Figure 1.1

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Working Principle of a Transformer.

* From the Figure 1.1, Transformer consists of two windings insulated from eachother and wound on a common core made up of magnetic material.

* Alternating voltage is connected across one of the windings called the primary winding. In both the windings emf is induced by the electromagnetic induction. The second winding is called secondary winding.

* When the primary winding is connected to an ac source an exciting current flows through the winding. As the current is alternating, it will produce an alternating flux in the core which will be linked by both the primary and secondary windings.

* The induced emf in the primary winding (E_1) is almost equal to the applied voltage V_1 and will appose the applied voltage.

* The emf induced in the secondary winding (E_2) can be utilised to deliver

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Power to any load connected across the secondary.

* Thus power is transferred from the primary to the secondary circuit by the electromagnetic Induction.

* The flux in the core will alternate at the same frequency as the frequency of the supply voltage.

* The Frequency of induced emf in the secondary is same as that of the supply voltage.

* The magnitude of the emf induced in the secondary winding will depend upon its number of turns.

* In a Transformer, if the number of turns in the secondary winding is less than that in the Primary winding, it is called a step-down Transformer. fig 1.3

* when the number of turns in the secondary winding is higher than the primary winding, it is called a step-up transformer. Fig 1.2

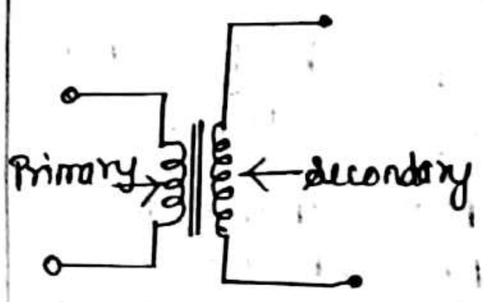

Fig 1.2 Step up Transformer

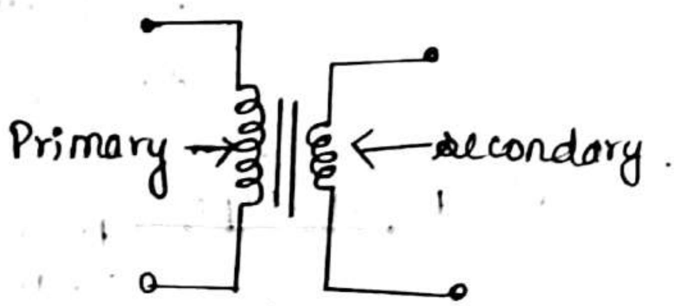

Fig 1.3: Step down Transformer

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Classification of Transformers

(i) Duty they perform.

1. Power Transformer - for transmission and distribution purposes.

2. Current Transformer - instrument transformers.

3. Potential Transformer - instrument transformers.

(ii) Construction.

1. Core Type Transformer
2. Shell Type Transformer
3. Berry Type Transformer

(iii) Voltage output.

1. Step down Transformer (Higher to Lower)
2. Step up transformer (lower to Higher)
3. Auto Transformer (variable from '0' to rated value)

(iv) Application

1. Welding Transformer
2. Furnace Transformer.

(v) Cooling
1. Duct type Transformer (Air natural (or) Air blast)
2. Oil Immersed.
a. Self cooled
b. Forced air cooled
c. Water cooled
d. Forced oil cooled.

(vi) Input supply
1. Single phase Transformer
2. Three phase Transformer
a). Star - star
b) Star Delta
c) Delta - Delta
d) delta - star
e) open - Delta
f) Scott connection.

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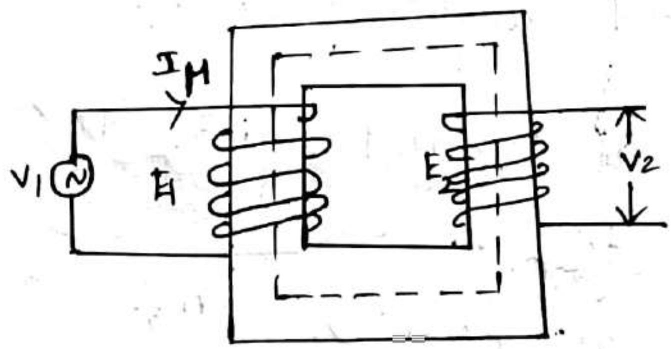
Ideal Transformer

The Ideal Transformer has the following Properties

1. NO winding Resistance i.e, purely inductive
2. NO magnetic Leakage flux.
3. NO I^2R loss i.e, no copper loss.
4. NO core loss.

* The ideal Transformer consists of purely inductive coil (windings) and loss free core.
* Windings are wound on a core.
* It is shown in Figure.



* Here, the ideal transformer secondary is open.
* the AC supply is connected to the primary winding.
* A current flows through the primary winding.
* This current is called magnetising current
* It is denoted by I_μ.

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* This current is mainly used to magnetise the core.

* The value of magnetising current is small.

* It is lagging V_1 by 90°.

* The current I_μ produces an alternating flux ϕ.

* I_μ and ϕ are inphase.

* This changing flux is linking with Primary and secondary windings.

* Due to the alternating flux, a self-induced emf is produced in the primary winding.

* It is denoted as E_1 and equal to and in opposition to V_1.

* It is known as counter emf or back emf of the primary winding.

* Similarly, an induced emf E_2 is produced in the secondary winding, because the alternating flux is linking with secondary winding. This emf is known as mutually induced emf.

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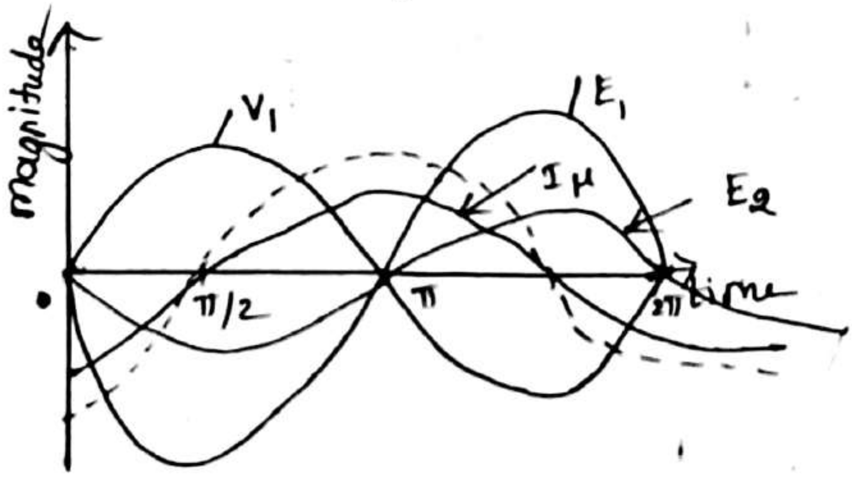
* This emf E_2 is in opposition to V_1 and its magnitude is propotional to the rate of change of flux and number of secondary ~~turns~~. turns.

* Figure shows input voltage (V_1), induced emf (E_1, E_2), flux (ϕ) and magnetising current (I_μ) waveforms.



Vector diagram on no load.

The following steps are adopted to draw the vector diagram for ideal Transformer under no-load.

Step 1: First draw the input voltage line V_1 (OA)

Step 2: Draw the flux line ϕ(OB). The angle between V_1 and ϕ is 90°

Step 3: Draw the magnetising current I_μ (OC). It is inphase with flux

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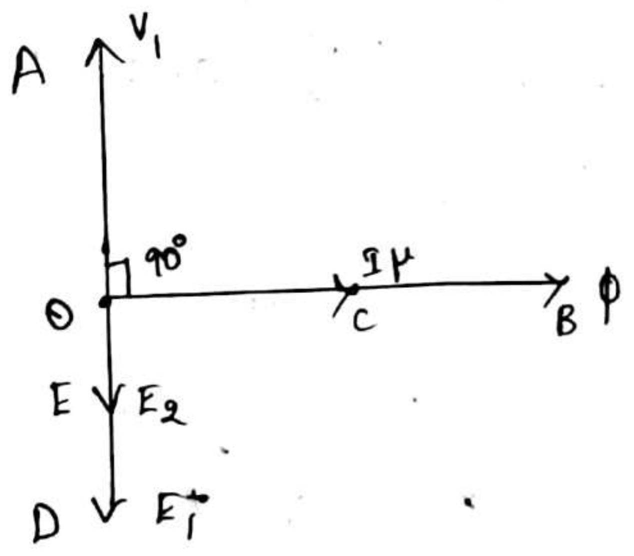
Step 4: Draw the induced emf E_1 and E_2.

The angle between E_1 and V_1 is $180°$..

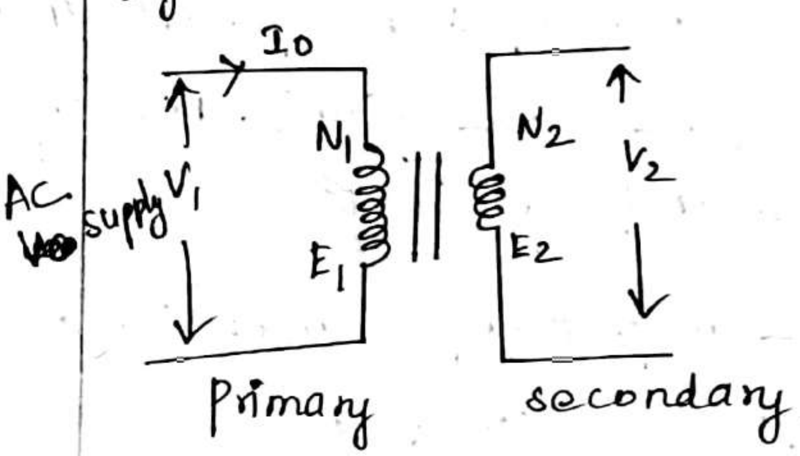
i.e, E_1 and V_1 are in opposite directions (OD and OA)

Then draw E_2 Line. It is inphase with E_1 (OE)



Practical Transformer on No-Load.

* If the primary winding is connected to an alternating voltage and secondary winding is left open, then the transformer is said to be on no load as shown in figure.



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* Let the supply voltage be 'V_1' volts.
* This causes an alternating current to flow through the primary.
* Since secondary is open, this current is called no load primary current (I_0).
* This 'I_0' establishes a flux 'ϕ' weber in the core.
* Thus I_0 is not at $90°$ behind V_1, but lags it by an angle $\phi_0 < 90°$.
* No load input power $P_0 = V_1 I_0 \cos\phi_0$.
* 'I_0' has two components.
    - Active or working or iron loss or wattfull component (I_W), which is in phase with 'V_1' and supplies the iron loss and negligible amount of primary copper loss.

$$I_W = I_0 \cos\phi_0 \quad \text{--- (1)}$$

Where $\cos\phi_0$ = No load power factor

    - Reactive (or) magnetizing (or) wattless component (I_μ) which is in quadrature with V_1 and its function is to sustain the flux in the core.

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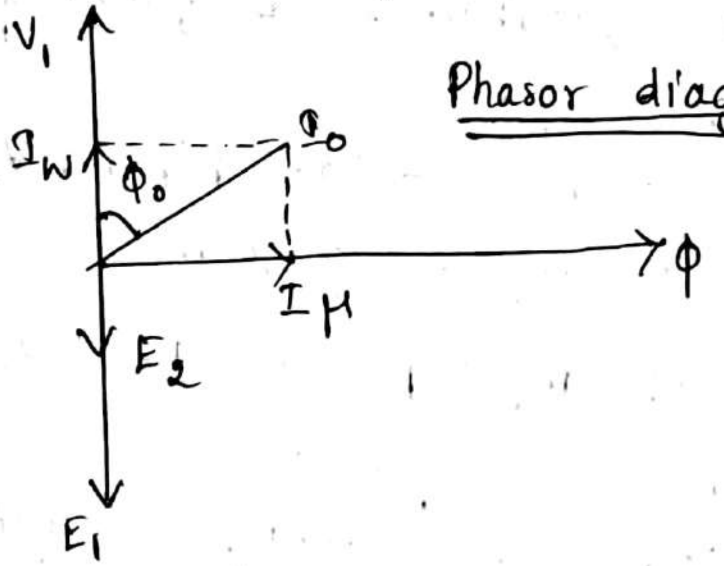
$$I_\mu = I_0 \sin\phi_0 \quad \text{--- (2)}$$

from (1) & (2) we have

$$I_0 = \sqrt{I_W^2 + I_\mu^2} \quad \text{--- (3)}$$

* No load vector diagram is shown in figure (2)



Phasor diagram - Per unit system

* From the above discussion, the following points are noted.

⇒ The no-load primary current I_0 is very small as compared to the full load primary current.

→ As I_0 is very small, the no-load primary copper loss is negligible. This no-load input power is practically equal to the iron or core loss of the transformer.

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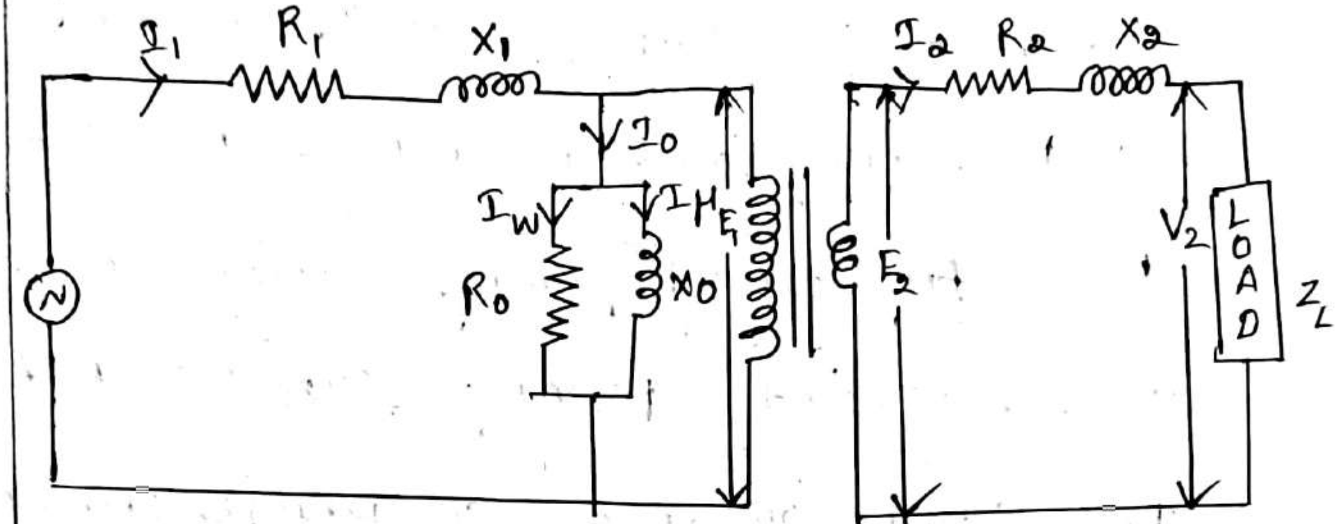
Equivalent circuit of a Transformer

* An equivalent circuit is merely a circuit interpretation of the equations which describe the behaviour of the system.

* Figure shows the equivalent circuit of a transformer.



* Under no load condition, the primary of a transformer draws no load current I_0.

* It is mainly used to supply the iron loss and to produce the flux in the core.

* The effect of iron loss is represented by a non-inductive resistance R_0 and the magnetising current is represented by X_0.

* Both of them are connected in parallel with primary winding.

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* This circuit is known as exciting branch or no-load branch (R_0 and X_0) . It is shown in figure. In this equivalent circuit

R_1, X_1 - Primary winding resistance and resistance in Ω

R_0 - No-load resistance in Ω

X_0 - No-load reactance in Ω

I_1 - Full load primary current in A

I_0 - No load primary current in A

I_2 - Load component of primary current in A.

I_W - Working component

I_μ - Magnetising component

E_1 - Induced emf in primary winding in V

E_2 - Induced emf in secondary winding in V.

R_2, X_2 - Secondary winding resistance and reactance in Ω

Z_L - Load impedance in Ω

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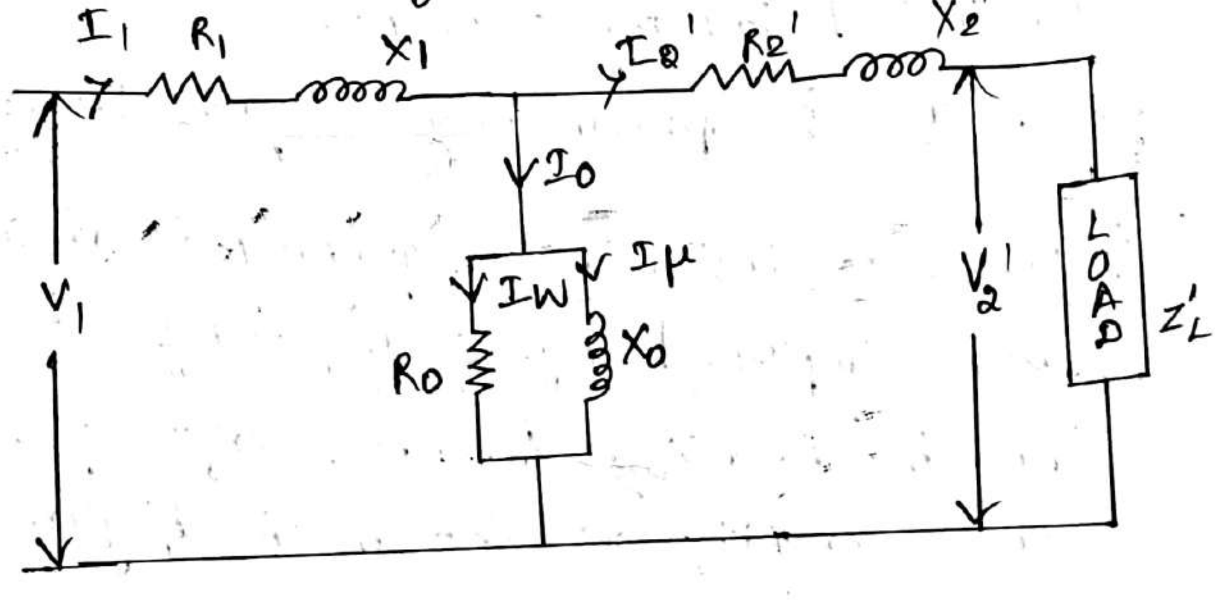
I_2 — Full load secondary current in A

K — Transformation ratio.

Equivalent circuit of a transformer referred to primary

* If all the secondary parameters are transferred to the primary side, we get the equivalent circuit of transformer referred to primary as shown in figure.



$$R_2' = \frac{R_2}{K^2}$$

$$X_2' = \frac{X_2}{K^2}$$

$$I_2' = K I_2$$

$$Z_L' = \frac{Z_L}{K^2}$$

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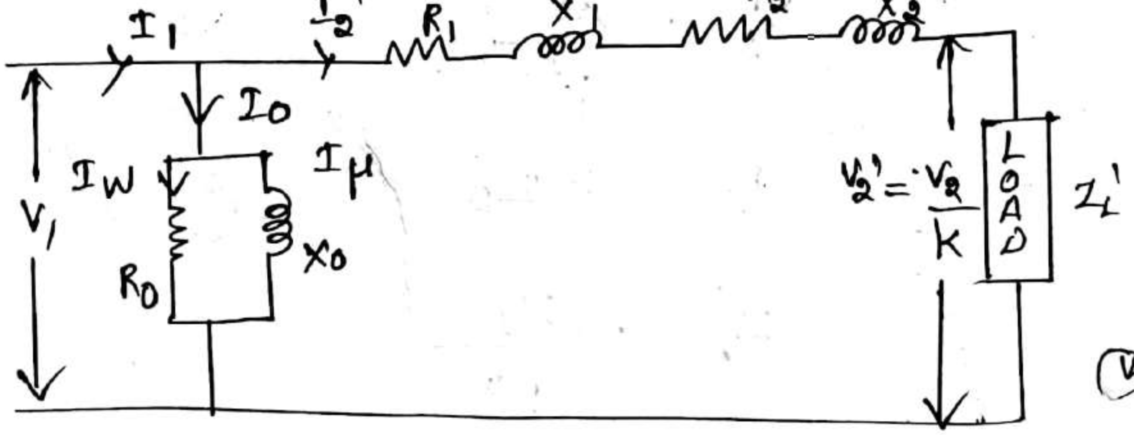
$$V_2' = \frac{V_2}{k}$$

$$R_0 = \frac{V_1}{I_W}$$

$$X_0 = \frac{V_1}{I_\mu}$$

Approximate equivalent circuit

* The no-load current I_0 is only 1-3% of rated primary current.
* So I_2' is practically equal to I_1.
* Due to this, the equivalent circuit can be simplified by transferring the exciting branch (R_0 & X_0) to the left position of the circuit as shown in figure.
* This circuit is known as approximate equivalent circuit of the tranformer.



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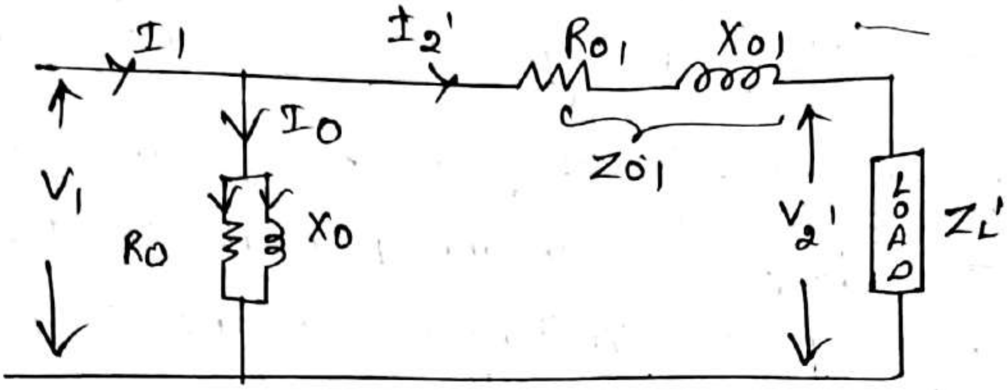
2, 19, 46, 51 (43, 53) OD to - OD 148

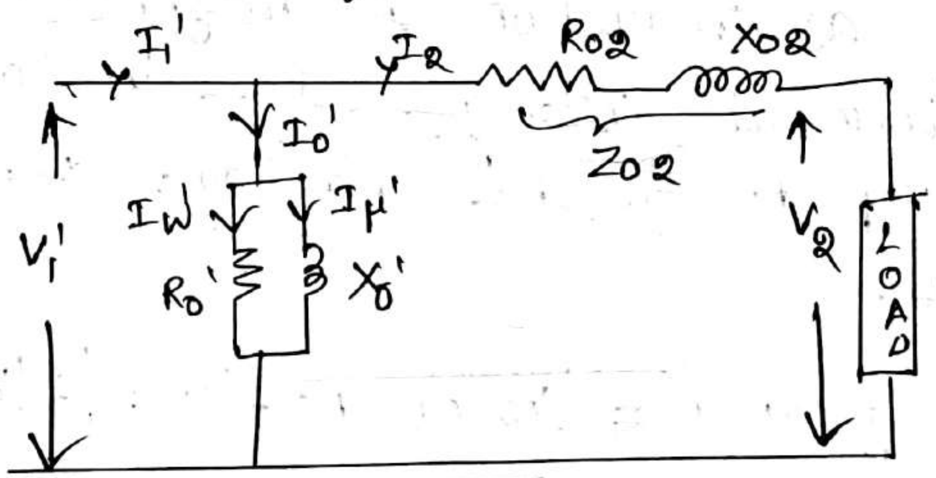
* Figure shows combined R_1 and R_2' and X_1 and X_2'. i.e, $R_{01} = R_1 + R_2'$ and $X_{01} = X_1 + X_2'$



$$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$$

* The above figure shows all parameters referred to primary.

* Similarly the figure below shows all parameters referred to secondary.



$$R_{02} = R_1' + R_2 = R_1 k^2 + R_2$$

$$X_{02} = X_1' + X_2 = X_1 k^2 + X_2$$

$$Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}$$

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9.29.15 <u>Voltage Regulation of a Transformer</u>

* All electrical appliances are designed to operate satisfactorily at constant voltage.
* Therefore, the transformers from which electric supply is obtained must maintain their output voltages without variations.
* The voltage in a transformer on load varies however and it is mainly due to its leakage reactance.

<u>Definition</u>

The regulation of a transformer is defined as reduction in magnitude of the terminal voltage due to load, with respect to the no-load terminal voltage.

$$\% \text{ regulation} = \frac{|V_2 \text{ on no-load}| - |V_2 \text{ when loaded}|}{|V_2 \text{ on no-load}|} \times 100 \quad \text{(1)}$$

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For an ideal transformer, regulation is 0% since voltage drops due to R_1, X_1, R_2, X_2 are negligible

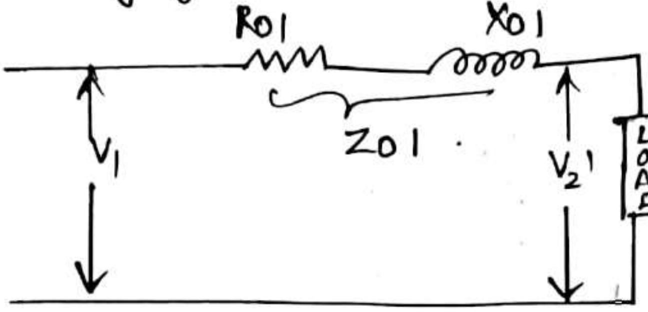
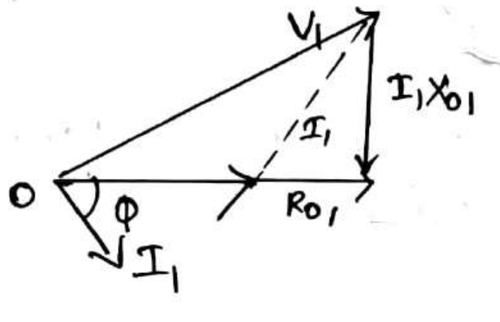


Figure shows the approximate equivalent circuit of a transformer. From this figure, we can draw vector diagram for different power factors.

Lagging power factor

Figure shows vector diagram for lagging power factor



V_2' - secondary terminal voltage referred to primary

I_1 = Primary current.

→ From this vector diagram, voltage regulation

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formula is given by

$$\% \text{ Regulation} = \frac{I_1 R_{01} \cos\phi + I_1 X_{01} \sin\phi}{V_1} \times 100$$

Leading factor.

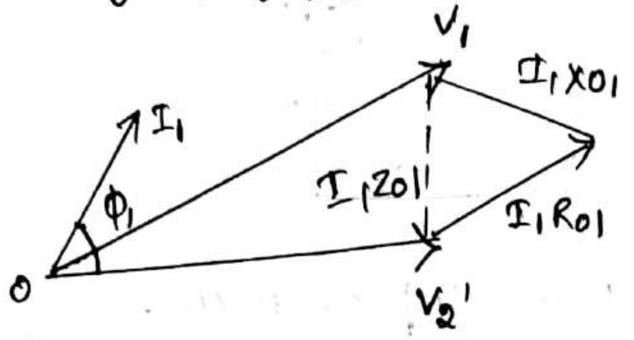


Figure shows vector diagram for leading power factor.

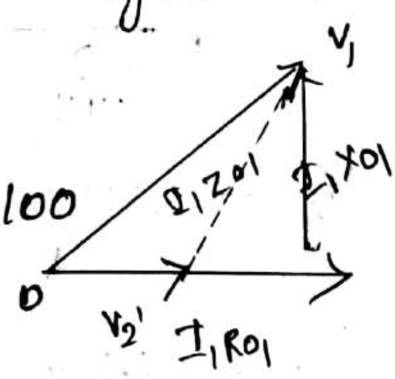
Voltage regulation for leading power factor is given by,

$$\% \text{ Regulation} = \frac{I_1 R_{01} \cos\phi - I_1 X_{01} \sin\phi}{V_1} \times 100$$

Unity power factor

Figure shows vector diagram for unity power factor

$$\% \text{ Regulation} = \frac{I_1 R_{01}}{V_1} \times 100$$



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Efficiency of a Transformer

Transformer efficiency $\eta = \frac{\text{Output power}}{\text{Input power}}$

$$\eta = \frac{\text{Output power}}{\text{Output power} + \text{losses}} = \frac{\text{Output power}}{\text{Output power} + \text{iron losses} + \text{copper losses}}.$$

Output power $= V_2 I_2 \cos\phi$

Where,

V_2 = secondary terminal voltage on load

I_2 = secondary current at load.

$\cos\phi$ = power factor of the load

Iron loss, $P_I = W_0$, determined from O.C Test

Copper loss $P_{cu} = W_s$, determined from S.C Test at full load

Copper loss at a load n times the full load $= n^2 P_{cu}$

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So, transformer efficiency $\eta = \dfrac{n V_2 I_2 \cos\phi}{n V_2 I_2 \cos\phi + P_i + n^2 P_{cu}}$

Note:

At full load $n = 1$

At half load $n = 1/2$

Condition for maximum efficiency

Output power $= V_2 I_2 \cos\phi_2$

If R_{02} is the total resistance of the transformer referred to secondary, then

Total copper loss $P_{cu} = I_2^2 R_{02}$

Total losses $= P_i + P_{cu}$

$\eta = \dfrac{\text{Output power}}{\text{Input power}} = \dfrac{\text{Output power}}{\text{Output power} + \text{losses}}$

$= \dfrac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_{cu}}$

$\eta = \dfrac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{02}}$

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Dividing both numerator and denominator by I_2,

We get = $$\eta = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}} \quad \text{—— (1)}$$

For maximum value of efficiency for given $\cos\phi_2$ (pf) of the denominator must have the least value. The condition for maximum efficiency is obtained by differentiating the denominator and equating it to zero.

$$\frac{d\,(\text{denominator})}{dI_2} = 0$$

$$\frac{d}{dI_2}\left(V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02} \right) = 0$$

$$0 - \frac{P_i}{I_2^2} + R_{02} = 0 \quad (\text{or}) \quad P_i = I_2^2 R_{02}$$

$$= P_{cu} \quad \text{—— (2)}$$

Iron loss = copper loss (or) constant loss = variable loss —— (3)

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Hence efficiency of a transformer will be maximum when copper losses are equal to iron losses.

From (2) the load current corresponding to maximum efficiency is given by,

$$I_2 = \sqrt{\frac{P_i}{R_{02}}}$$

If we are given iron loss and full load copper loss, then the load corresponding to the maximum efficiency is given by

$$= \text{full load KVA} \times \sqrt{\frac{\text{Iron loss}}{\text{Full load copper loss}}}$$

Testing of Transformer

(i) open circuit test (or) No load Test

(ii) Short circuit Test (or) Impedance Test

By using these two tests we can find

1) circuit constants (R_0, X_0, R_{01}, X_{01}, R_{02} & X_{02})

2) core loss and full load copper loss

3) predetermine the efficiency and voltage Regulation at any load.

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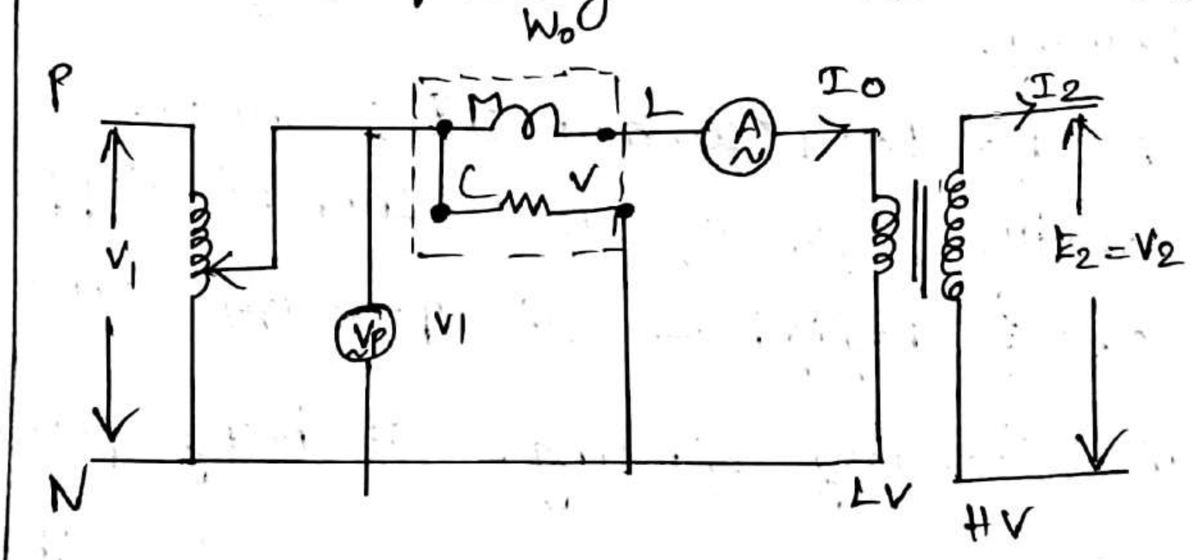
These tests are convenient to perform and very economical because they provide the required information without actually loading the transformer. Other two tests are

(iii) Load Test
(iv) Sumpner's Test

Open circuit Test.

the open circuit test is useful to find

(i) No-Load Loss (or) core loss
(ii) No load current I_0 which is helpful in finding out R_0 and X_0



* The connections are made as shown in the circuit diagram.
* one winding of the transformer, usually high voltage winding is left open & the

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other winding is connected to the supply of normal voltage and frequency.

* the applied voltage V_1 is measured by a voltmeter, the no load current I_0 by an ammeter and no load input power W_0 by a wattmeter as shown in figure.

* As the normal rated voltage is applied to the primary, normal iron loss will occur in the transformer core.

* Hence wattmeter will read the iron losses and small copper loss in the primary.

* As no load current I_0 is small (usually 1-3% of rated current) copper loss is negligible in primary and nil in secondary winding (it being open).

* Hence, wattmeter reading gives the iron losses in the transformer and it is same at all loads.

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Iron losses P_i = Wattmeter reading = W_0

No-load current = Ammeter reading = I_0

Applied voltage = Voltmeter reading = V_1

Input power $W_0 = V_1 I_0 \cos\phi_0$

No-load power factor $\cos\phi_0 = \frac{W_0}{V_1 I_0}$

$$\phi_0 = \cos^{-1}\left(\frac{W_0}{V_1 I_0}\right)$$

No-load wattful component $I_W = I_0 \cos\phi_0$

$$= \frac{W_0}{V_1}$$

No-load magnetising component

$$I_\mu = I_0 \sin\phi_0 = \sqrt{I_0^2 - I_W^2}$$

No-load resistance $R_0 = \frac{V_1}{I_W} = \frac{V_1^2}{W_0}$

No-load reactance $X_0 = \frac{V_1}{I_\mu} = \frac{V_1}{\sqrt{I_0^2 - I_W^2}}$

Thus open circuit test gives no load loss P_i, I_W, I_μ, R_0 and X_0

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Short circuit test

The short-circuit test is useful to find
(i) Full-load copper loss
(ii) Equivalent resistance and reactance referred to metering side.

* In this test, the secondary winding (usually low voltage winding) is short circuited by a thick conductor and variable low voltage is applied to the primary winding as shown in figure.
* The input voltage is gradually raised with the help of a variac till I_{sc} full load current flows in the primary winding.
* There is no output from the transformer under short circuit conditions.
* Therefore input power is all loss and this loss is almost entirely copper loss.
* Since applied voltage is very low, flux linking with the core is very

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small and therefore iron losses are so small that these can be neglected and so the reading of the wattmeter gives total copper loss at full load.

Full-load cu loss P_{cu} = wattmeter reading $= W_S$

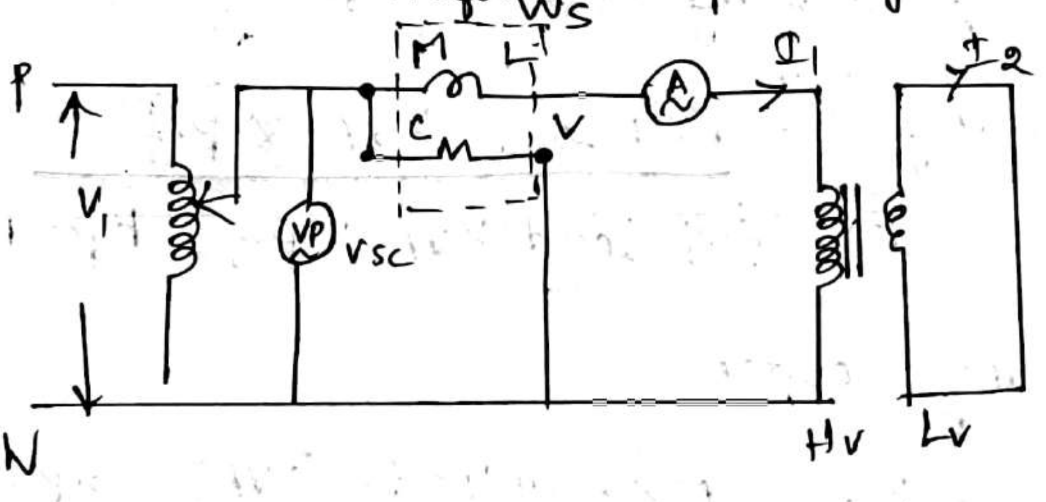
Applied voltage = voltmeter reading $= V_{SC}$

* Full-Load primary current = Ammeter Reading $= I_1$

$$P_{cu} = I_1^2 R_1 + I_1^2 R_2' = I_1^2 R_{01}$$

$$R_{01} = \frac{P_{cu}}{I_1^2}$$

where R_{01} is the total Resistance of transformer referred to primary.



Total Impedance referred to primary

$$Z_{01} = \frac{V_{SC}}{I_1}$$

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Total leakage reactance referred to primary $X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

Short circuit power factor $\cos\phi_s = \frac{P_{cu}}{V_{sc} I_1}$

Thus short circuit test gives full load Cu loss R_{01}, X_{01} and $\cos\phi_s$

Efficiency from OC and SC tests

From the open circuit test, we can get core loss (P_i) of the transformer and from short circuit test, we can get full load copper loss (P_{cu}). Now, we can find the full load efficiency of the transformer at any power factor without actually loading the transformer

$$\text{Efficiency} = \frac{\text{Full Load KVA} \times \text{p.f}}{(\text{full Load KVA} \times \text{p.f}) + P_i + P_{cu}}$$

for any load(n)

$$\eta = \frac{(n \times \text{full load KVA}) \times \text{p.f}}{(n \times \text{full load KVA}) \times \text{p.f} + P_i + n^2 P_{cu}}$$

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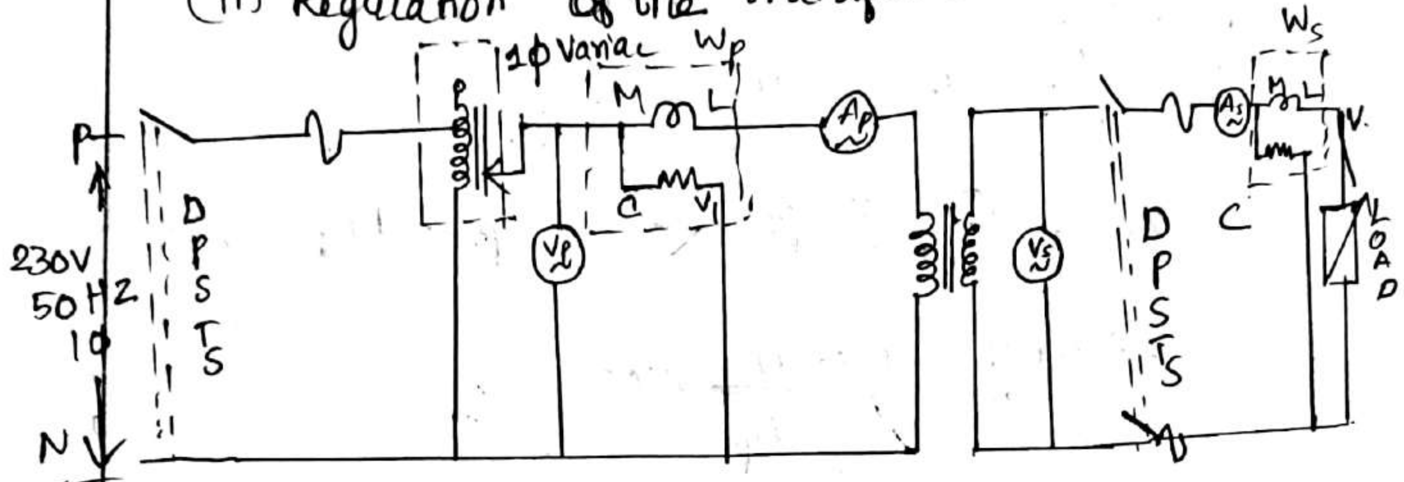
Load Test

Load Test is helpful to determine the following.

(I) Efficiency of the transformer

(II) Regulation of the transformer



The following precautions are necessary

⇒ the Variac should be kept in the minimum position while switching on and off the supply side DPSTS

⇒ At the time of switching on the supply there should not be any load connected.

* The transformer is excited to its rated voltage on no load. the meter readings are observed at no load condition.

* the load is gradually increased and meter readings are noted for each

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loading.

* The Transformer is loaded till it draws rated current from the supply.

* Note that the applied voltage to the primary side should be kept at its rated voltage on loading

W_s = output power W_p = Input power

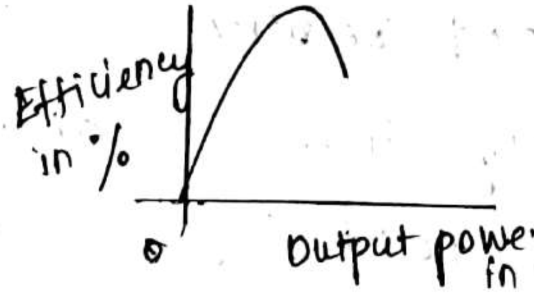
Efficiency $\eta = \frac{W_s}{W_p} \times 100$

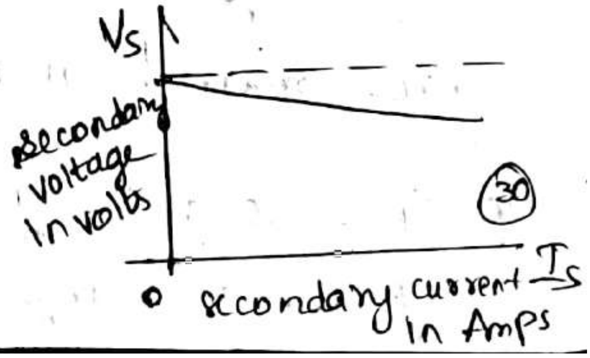
$$\% \text{ Regulation} = \frac{|V_2 \text{ on no-load}| - |V_{20} \text{ when loaded}|}{|V_2 \text{ on no-load}|} \times 100$$

V_2 – no load secondary rated terminal voltage

V_{20} – secondary voltage on load.

* From these data the following characteristic curves shown in figure can be drawn.





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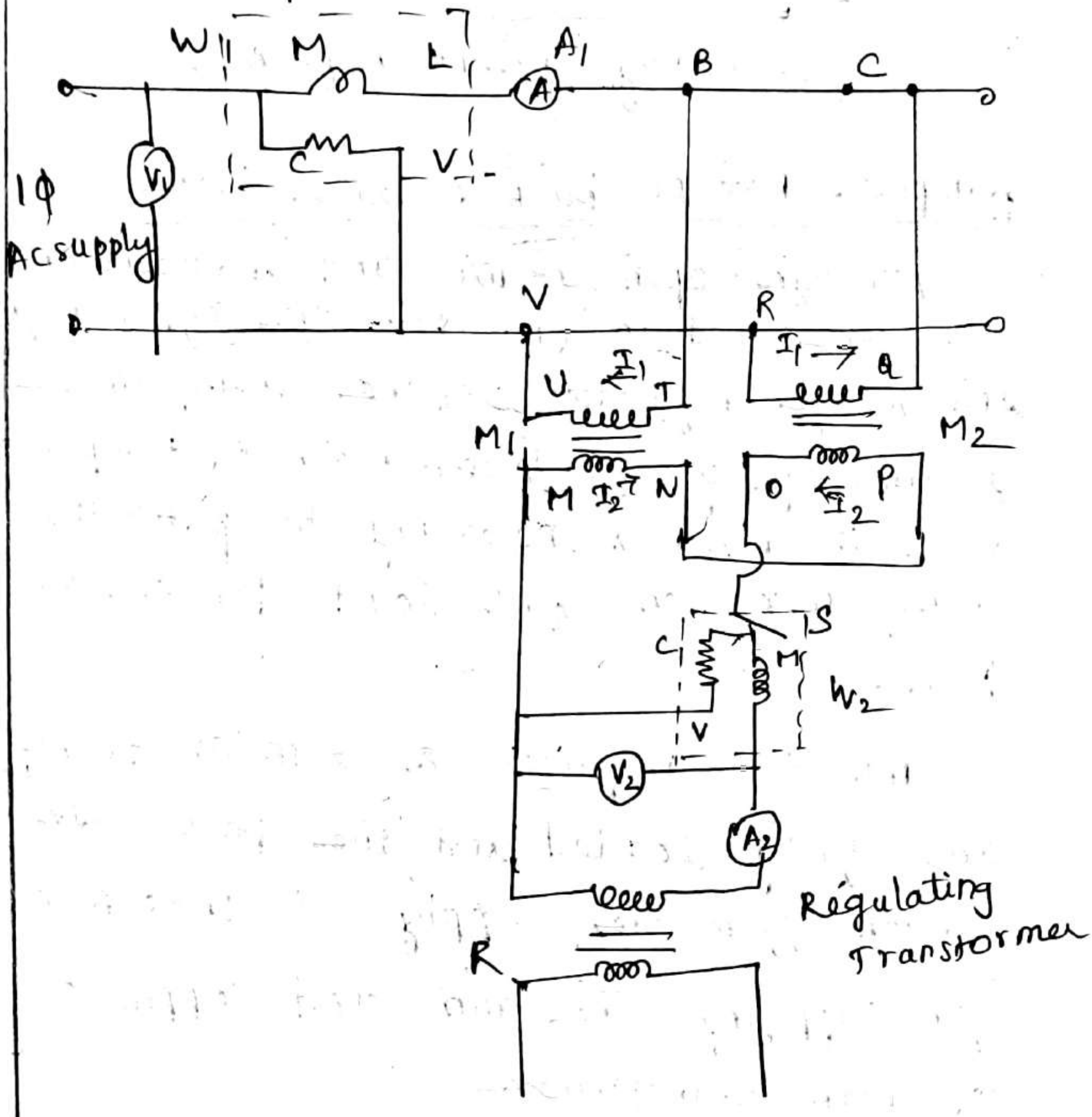
transformers. The primaries of the two transformers M_1, M_2 are connected in parallel across the AC supply, with switch S open.



* With switch S open, the wattmeter W_1 reads only core loss of the two transformers because the transformers are under no load.

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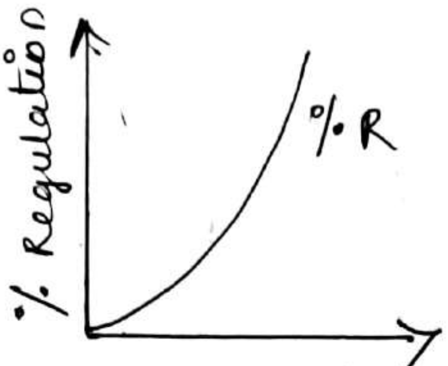

Sumpner's Test (or) back to back test

Although open circuit and short circuit tests are used to find out the efficiency and voltage regulation of the transformer accurately, yet for determination of temperature rise it becomes necessary to put the transformer on full load for several hours.

This test requires 2 similar transformers are fully loaded and the power taken from the supply is that necessary for supplying the iron and copper losses of both transformers.

Figure shows connection diagram for sumpner's test or back to back test.

This circuit consists of two main similar transformers and one regulating

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* The secondaries are so connected that their Potentials are in opposition to each other

* This would be so if $V_{PO} = V_{NM}$ and P is joined to N and O is joined with M.

* In this condition, there would be no secondary current flowing around the loop formed by the two secondaries in series opposition.

* R is the regulating transformer which can be adjusted to give a variable voltage and hence current in the secondary loop circuit.

* By proper variation of R, full-load secondary current can be made to flow.

* In this diagram, secondary current I_2 flows from M to N, and then from P to O.

* Flow of primary current I_1 is confined to RQCBTUVR and it does not pass through wattmeter W_1.

* Hence wattmeter W_2 reads full-load copper loss and wattmeter W_1 continues to read the core losses of two transformers.

* Obviously, the power taken is twice the losses of the single transformer.

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Advantages.

1. The power required to carry out the test is small.
2. The Transformers are tested under full-load conditions.
3. The iron losses and full load copper losses are measured simultaneously.
4. The temperature rise of the transformers can be noted.

Polarity Test

* Figure shows polarity test on two winding transformer. A polarity test is carried out to findout the terminal having the same instantaneous polarity assuming that terminals are not marked.

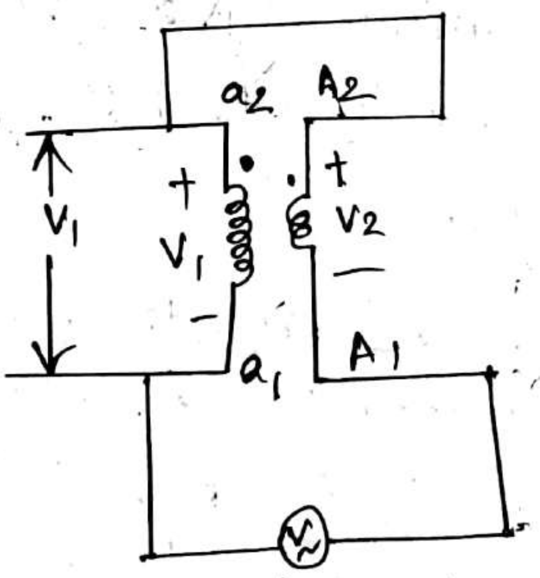

figure: polarity test on two winding Transformer

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* Similar polarity ends of the two windings of a tranformer are those ends that acquire simaltaneously positive or negative polarity of emf's induced in them.

* These are indicated by the dot convention.

* Usually the ends of the LV winding are labelled with small letter of the alphabet with suffix 1 and 2, while the HV winding are labelled by the corresponding capital letter with suffix 1 and 2.

* In determining the relative polarity of the two winding of a transformer the two windings are connected in series across a voltmeter, while one of the windings is excited from a suitable voltage source.

* If the polarities of the windings are as marked on the diagram, the voltmeter should read $V = V_1 \sim V_2$. If it reads $V = V_1 + V_2$ the polarity marking of one of the windings must be interchanged.

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Three phase Transformers

* the generation of electric power is three-phase in nature and the generated voltage is 13.2 KV, 22 KV or higher. Transmission of Power is carried out at high voltages like 132 KV or 400 KV.

* Before Transmission, it is required to step-up the voltage and for this a three phase step-up transformer is required.

* similarly, at the distribution sub station the voltage must be stepped down and it is necessary to reduce the voltage upto 600 V, 400 V, 230 V and so on.

* Here a three phase step-down transformer is required.

* Therefore it is economical to use three phase transformers for transmission and Utilisation purposes.

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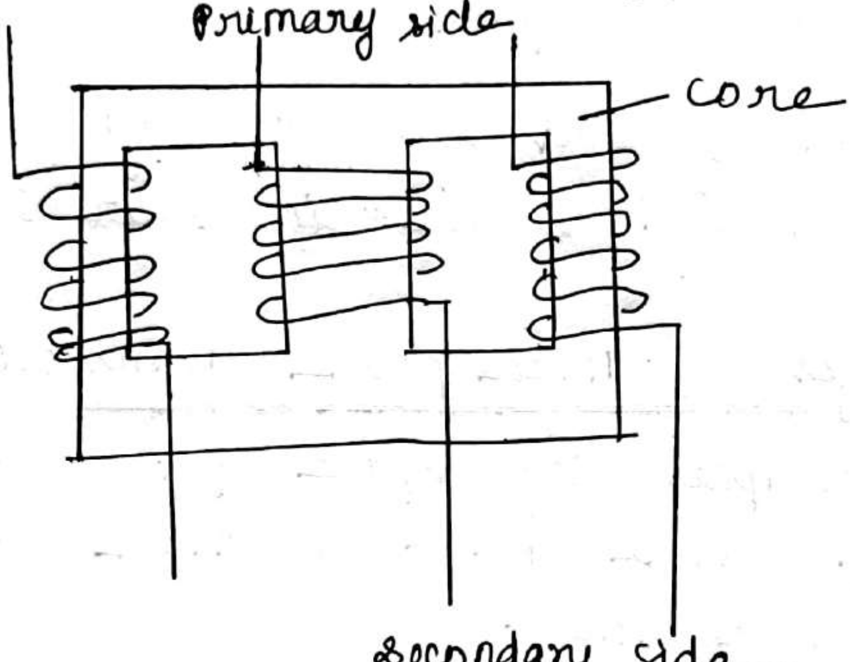
* Three phase Tranformer construction is similar to single phase transformer like shell or core type.

* It is shown in the diagram below



* Three Phase shell type tranformer has three limbs. Here, we use only I core.. Around each limb, the primary and secondary windings are placed.

* The operation of three phase transformer is similar to single phase transformer.
* Three phase supply (input voltage) is given to the primary winding.
* Due to this, three phase flux is

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Produced in the primary winding.

* This flux is linked with secondary winding.
* Depending upon the numbers of turns in the secondary, the secondary voltage will be stepped up or stepped down.
* The primary and secondary windings can be connected either in star or delta.

Advantages of three phase Transformers

1. It occupies less space for same rating, compared to a bank of three single-phase transformers.
2. It has less weight.
3. the cost is also low.
4. Easy to handle.
5. It can be transported very easily.
6. the core is of a smaller size and, hence less material is required.

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Autotransformer

* An autotransformer is a type of electrical transformer with only one winding.

* The "auto" prefix refers to the single coil acting alone (Greek for "self") - not to any automatic mechanism.

* An autotransformer is similar to a two winding transformer but varies in the way the primary and secondary winding of the transformer are interrelated.

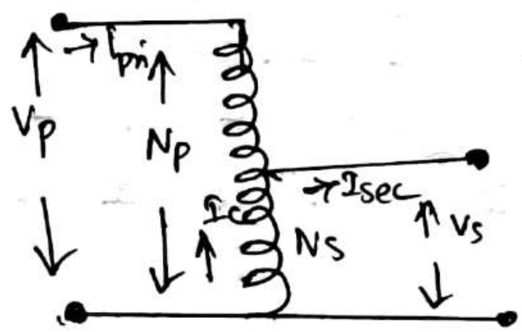

fig: Auto transformer.

* Diagram shows a single phase autotransformer with N_P turns primary and N_S turns tapped from the primary in order to get a lower voltage.

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* The winding section with N_s turns tapped from the is common to both the side of the autotransformer.

If $\frac{V_2}{V_1} = \frac{N_2}{N_1} = a$

$$\frac{\text{conduct power}}{\text{Input power}} = 1 - a \quad \text{——} (1)$$

$$\frac{\text{Transferred power}}{\text{Input power}} = a \quad \text{——} (2)$$

Advantages

* For the same VA rating an auto transformer requires less copper, less iron and hence low exciting current, low ohmic loss and less weight as compared to a two winding transformer.

* For the same material used, an autotransformer as compared to a 2-winding transformer gives higher output, has higher efficiency, lower leakage impedance and hence better voltage regulation.

* The saving of cost is appreciable when the ratio of transformer is low, that is lower than 2

* Thus auto transformer is smaller in size and cheaper.

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Harmonics.

* Harmonics are a distortion of the normal electrical current waveform, generally transmitted by nonlinear loads.

* Switch-mode power supplies (SMPS), variable speed motors and drives, photocopiers, Personal computers, Laser printers, fax machines, battery chargers and UPS are examples of nonlinear loads.

* Harmonics in transformers cause an increase in the iron and copper losses.

* Voltage distortion increase losses due to hysteresis and eddy currents and causes overstressing of the insulation material used.

* The primary effect of power line harmonics in transformer is, thus the additional heat generated.

* Other problems include possible resonance between the transformer inductance and the system capacitance, thermal fatigue due to temperature cycling and possible core vibrations.

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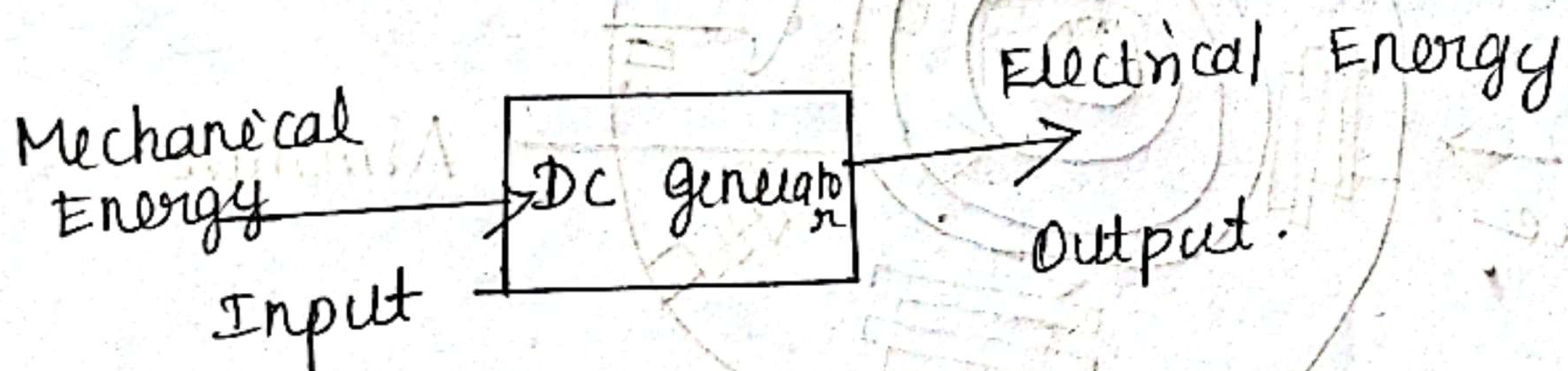
UNIT-II DC Machines

Introduction - constructional Features - Motor and Generator mode - EMF and Torque equation - circuit Model - Methods of Excitation - characteristics - starting and speed control - Universal Motor - Stepper Motors - Brushless DC Motors - Applications.

DC Generator

"An electrical generator is a rotating machine which converts mechanical energy into electrical energy."



The energy conversion is based on the principle of electromagnetic induction.

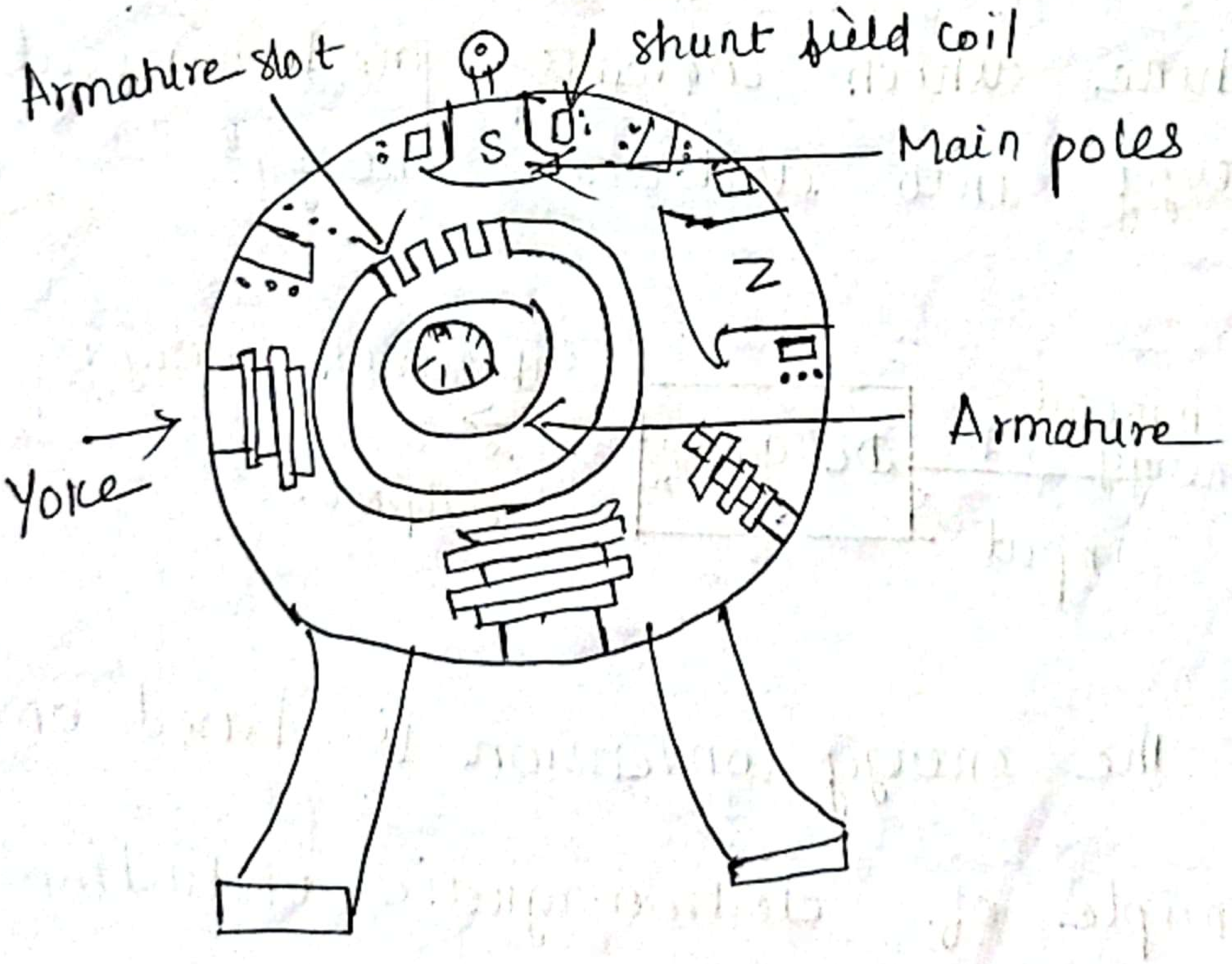
* According to Faraday's Laws of electromagnetic induction, whenever a conductor is moved in a magnetic field,

dynamically induced emf is produced in the conductor.

Parts of DC Generator

The major parts of DC generator are

1. Magnetic frame or yoke
2. Poles, interpoles, windings, pole shoes
3. Armature
4. Commutator
5. Brushes, Bearings and shaft.



Magnetic Frame.

It is used for two purpose.

* It acts as a protecting cover for the

whole machine and provides mechanical support for the poles.

* It carries the magnetic flux produced by the poles.

Poles

The pole consist of

(i) pole cores

(ii) pole shoes.

(iii) pole coils

* It acts as a protecting cover for whole Machine and provides mechanical support for poles.

* It carries the magnetic flux produced by the poles.

Interpoles

* commutating poles (or) interpoles are provided to improve commutation.

* The commutating poles also have exciting coils which are connected in series with Armature

* The coils are made up of fewer turns of thicker conductor to reduce the resistance

Armature

* The armature consists of an armature core and Armature windings.
* the armature core houses the armature conductor or coils.

Commutator

* commutator converts alternating emf into Unidirectional emf or direct emf.

* It is made up of wedge-shaped copper, insulated from each other by thin layers of built up-mica.

Brushes

* The brushes which are madeup of carbon or graphite.

* It collects the current from the commutator and to convey it to the external load resistance.

* They are rectangular in shape.

Bearings

* Ball Bearings are usually employed as they are reliable for light machines.

* For heavy duty machines roller bearings are used.

Principle of operation:

* Let us consider a single turn coil ABCD rotated on a shaft within a uniform magnetic field of flux density.

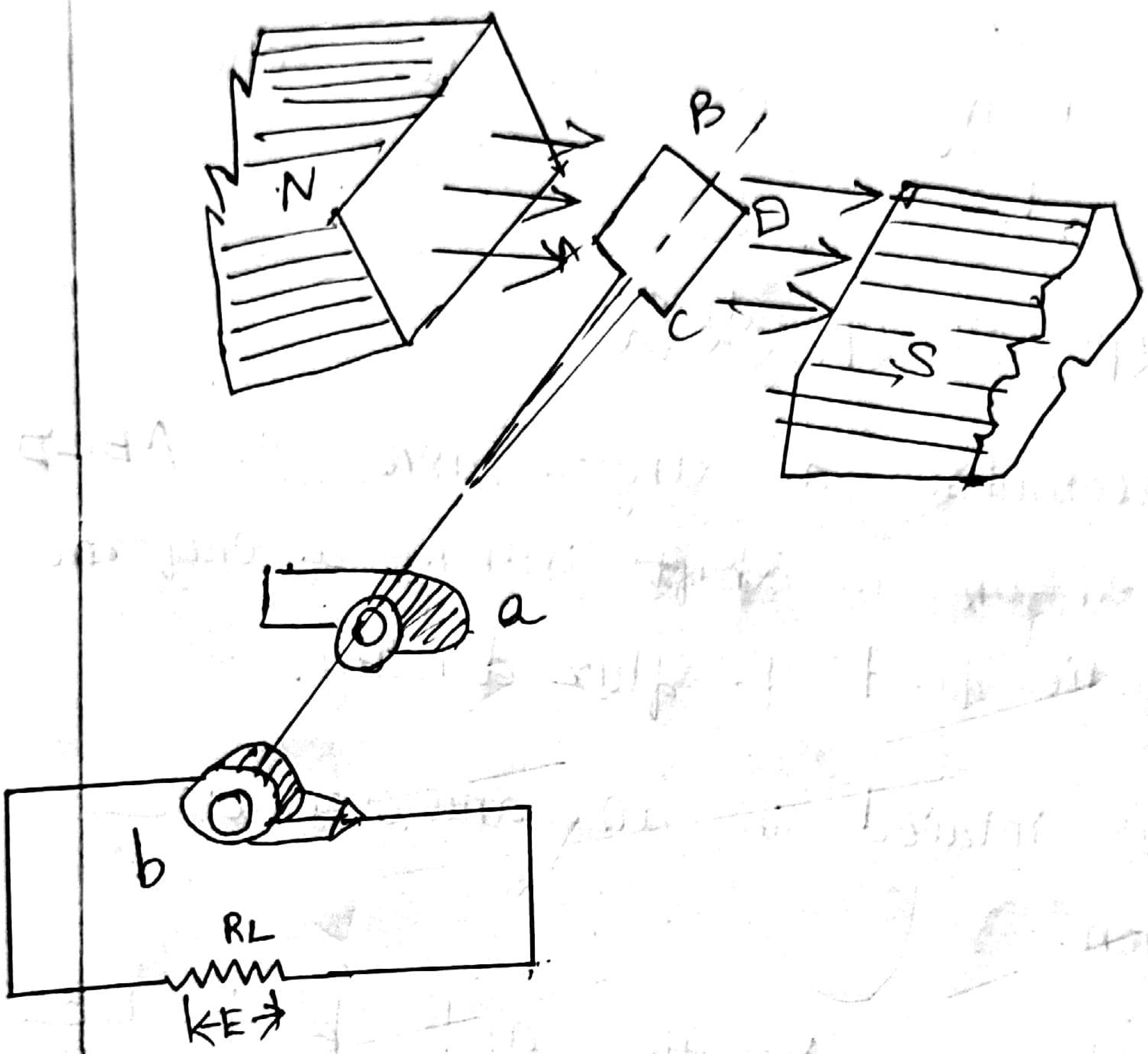
* It is rotated in an anti clockwise direction.

* Let 'L' be the length and 'b' be the breadth of coil in metres.

* When the coil sides AB and CD Moving parallel to the magnetic field no flux linking the coil. hence no emf induced in it. ∴ $\frac{d\phi}{dt} = 0$ & $e = 0$

* When the coil sides AB and CD

be Vertical to the magnetic field, flux linking the coil and an emf is induced in it. i.e $\boxed{\phi = BLb\cos\omega t}$



According to Faraday Law II, the emf induced is Proportional to rate of change of flux linkages.

$$e = -N\frac{d\phi}{dt}$$

where $N \rightarrow$ No. of turns.

$t \rightarrow$ time in sec

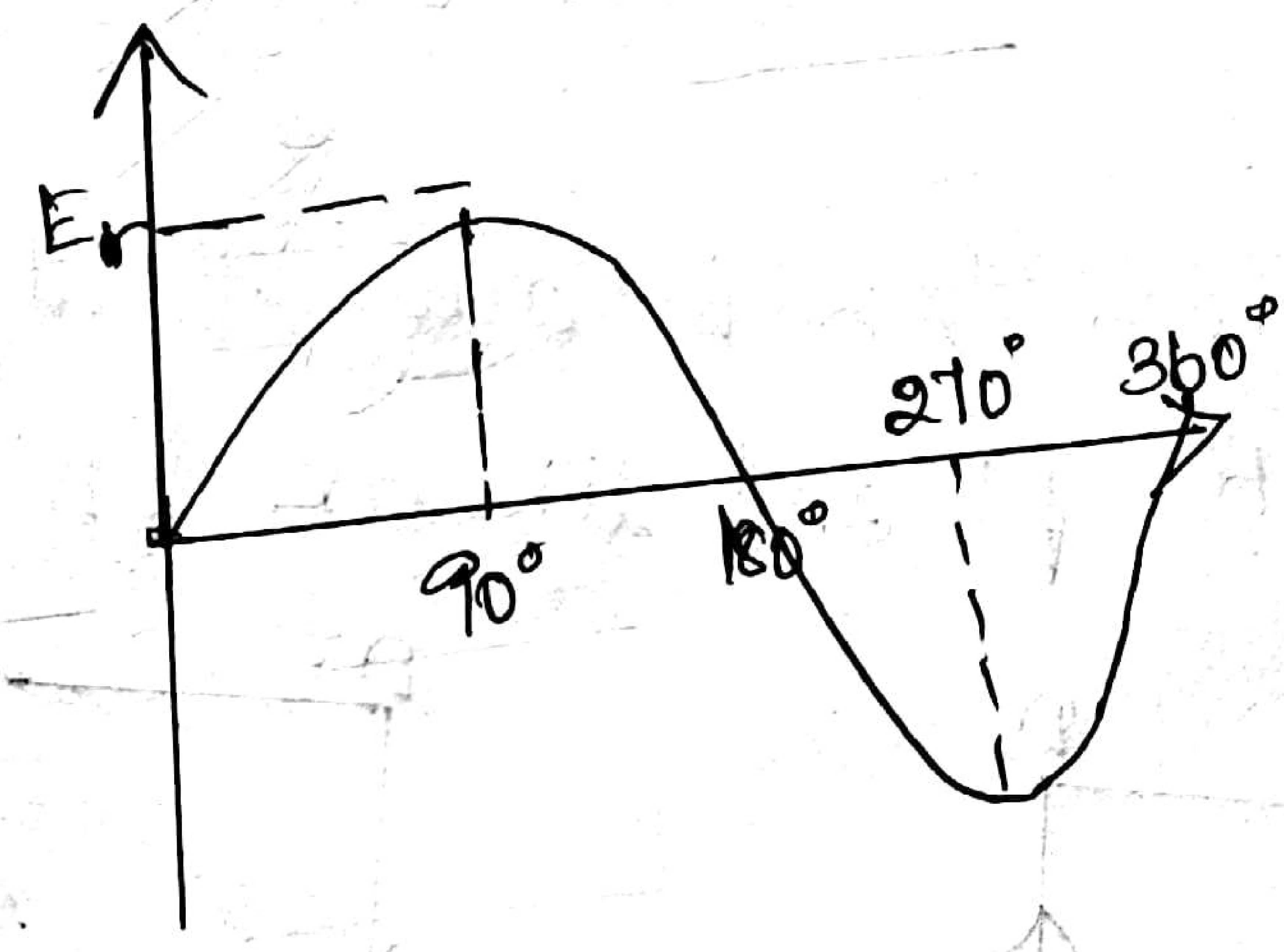
$\phi \rightarrow$ flux in weber

$$e = -\frac{d}{dt}(BLb\cos\omega t) \qquad (\because N = 1,\ \phi = BLb\cos\omega t)$$

$$\boxed{e = E_m \sin\omega t}$$

where $E_m = BLb\omega$ (maximum induced emf)

* When $\omega t = 90^\circ$, $e = E_m \sin 90^\circ$ $\therefore e = E_m$ the emf induced is maximum.



* When $\theta = 180^\circ$, $e = E_m \sin 180^\circ$ $\therefore \boxed{e = 0}$ Now the emf induced is zero.

* When $\theta = 270^\circ$, $e = E_m \sin 270^\circ$ $\boxed{e = -E_m}$

The coil sides again move at right angles to flux lines but with their position reversed. Hence the induced emf is maximum in the opposite direction.

* when $\theta = 360°$ $e = 0$ the coil has now back to the starting point.

* This alternating emf is made directional emf by using the commutator (split ring)

* The ring is split into two equal segments P and Q. They insulated from each other.

* The coil side AB is always attached to segment 'p' and likewise 'CD' to Q.

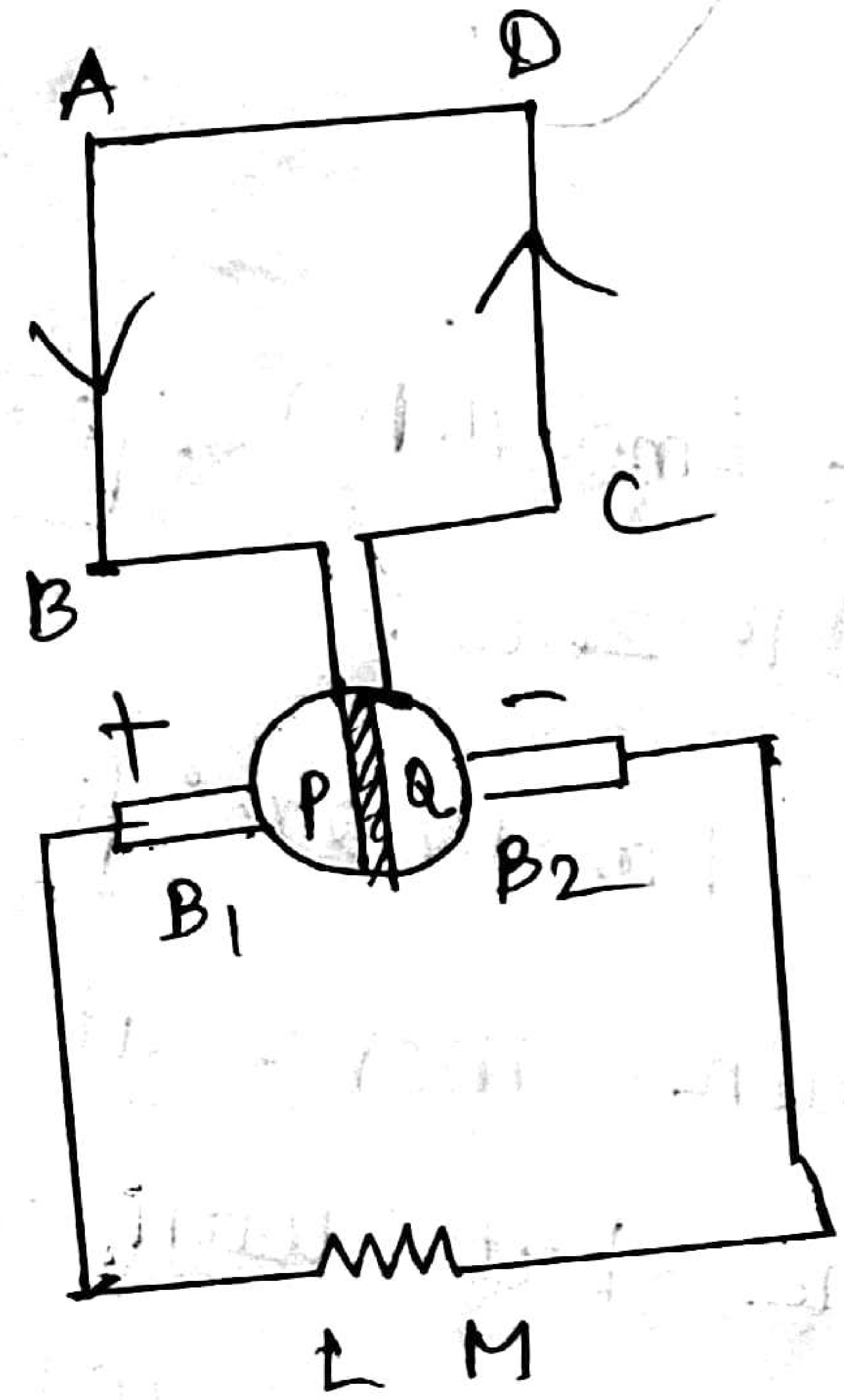


fig (a)

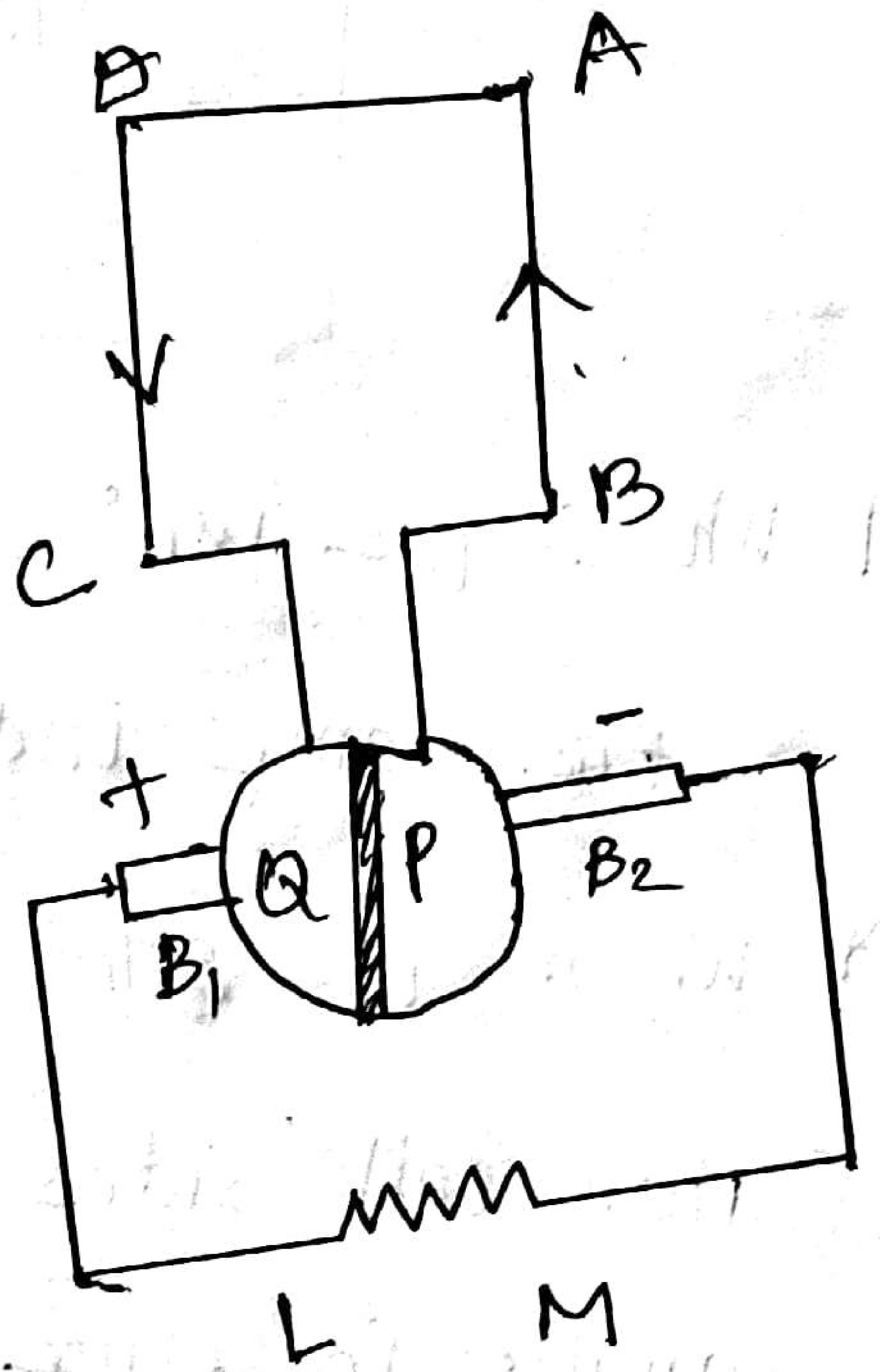


fig (b)

* During the first half revolution current flows along ABLMCD through brush B_1 (positive) and into B_2 C (Negative) (fig a)

* After a half cycle AB and CD exhausted their position along with segments P and Q and now currents flow through DCLMBA. B1 is new contact with Q and B_2 with 'P' (fig b)

* This Process repeat again and again and new unidirectional emf fed to the external load resistance "R".

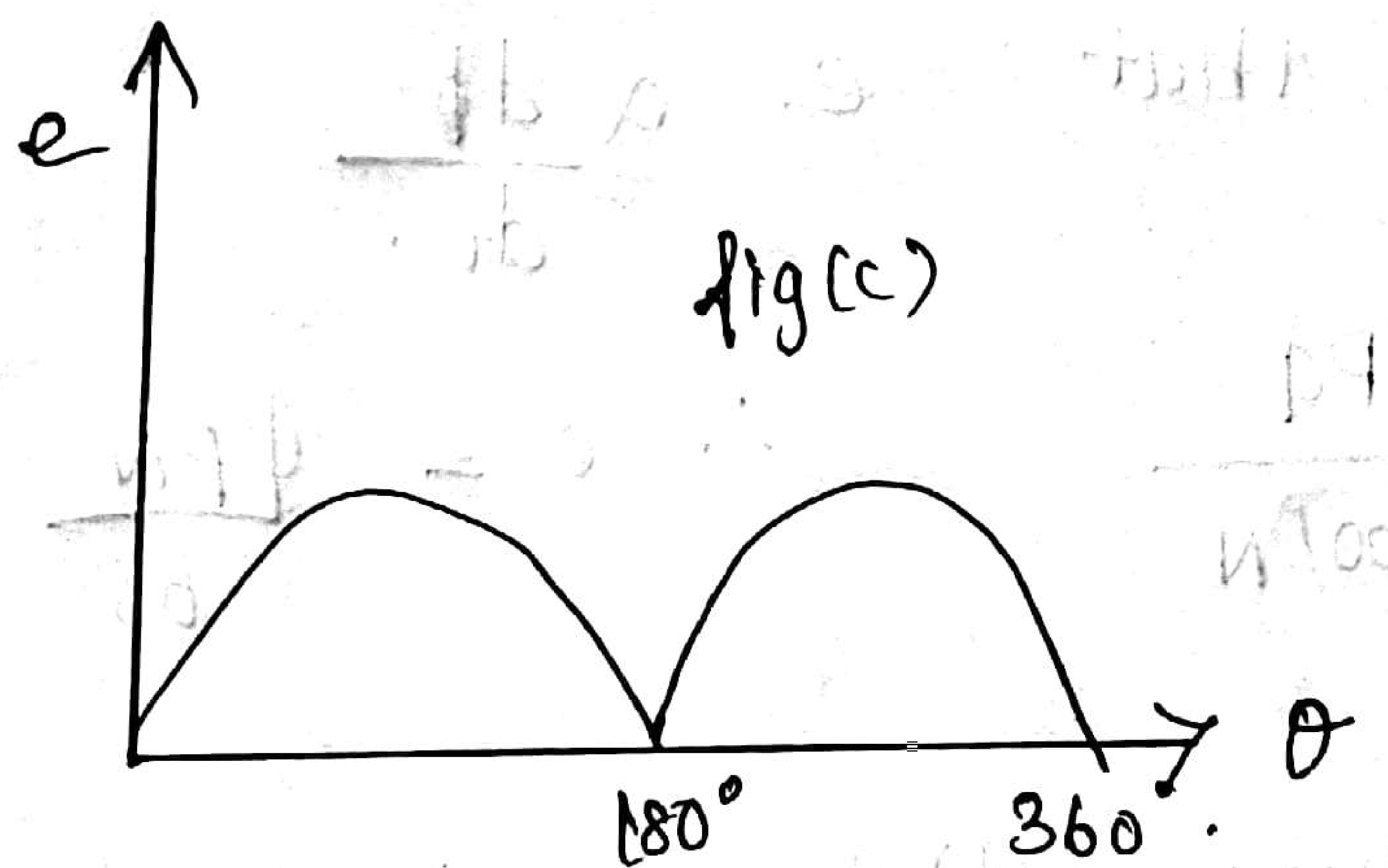


fig (c)

EMF equation of Generator & Motor

Let ϕ → flux in Web

P → No. of Poles

Z → Total no. of conductors.

A → No. of parallel path.

[Note $\boxed{A=2}$ for wave winding
$\boxed{A=P}$ for lap winding]

N → speed of rotation in rpm.

* consider only one conductor on the periphery of the armature.

* As this conductor makes one complete revolution it cuts $P\phi$ (wb)

* As speed is "N" rpm, the time taken for one revolution is "60/N" secs.

* We know that $e \propto \frac{d\phi}{dt}$.

$$e = \frac{P\phi}{60/N} \qquad \therefore e = \frac{\phi P N}{60} \text{ volts}$$

* since there are Z/A conductors in series in each parallel path the emf induced is

$$E_g = \frac{NP\phi}{60}\left(\frac{Z}{A}\right) \text{Volts}$$

where E_g → Generated Emf (for generator) for motor

$$E_b = \frac{\phi Z N}{60}\left(\frac{P}{A}\right) \text{ volts}$$

where E_b = Back emf of motor in volts

Application of DC generator

① Shunt generators are used for supplying nearly constant loads.

② It is used for battery charging, for supplying the fields of synchronous machines.

③ DC series generators are used as booster for adding a voltage to the transmission lines and to compensate for line drop.

④ compound generator as a voltage regulator in self contained generator unit.

Types of DC Generator

There are two types of DC generators.

They are,

(I) seperately excited DC generators

(II) Self excited DC generators

(i) seperately excited DC generator :

If the field winding is excited by a seperate DC supply, then the generator is called separately exeited DC generator.

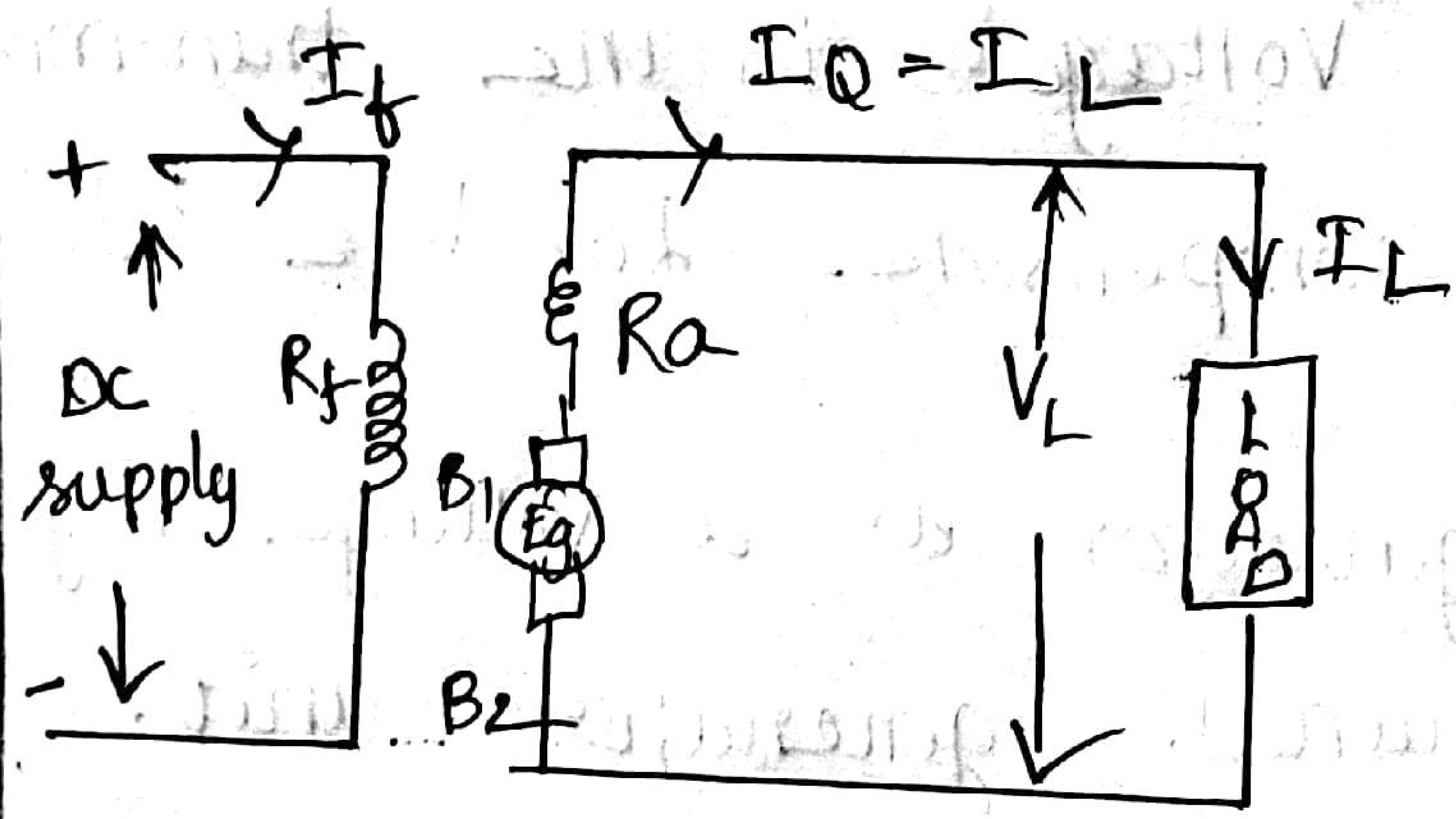


Fig: seperately exited DC generator

From this diagram,

Generated emf $E_g = V + I_a R_a + V_{brush}$ (V)

where

I_a ⇒ Armature current (A)

R_a ⇒ Resistance of armature winding (Ω)

V_{brush} → voltage drop in brush (V)

E_g → Generated Emf.

Here $I_a = I_L$

I_L → Load current (A)

Electric power developed $P_g = E_g I_a$ (W)

Power delivered to load $P_L = V_L I_a$ (W)

where,

V_L = Terminal Voltage.

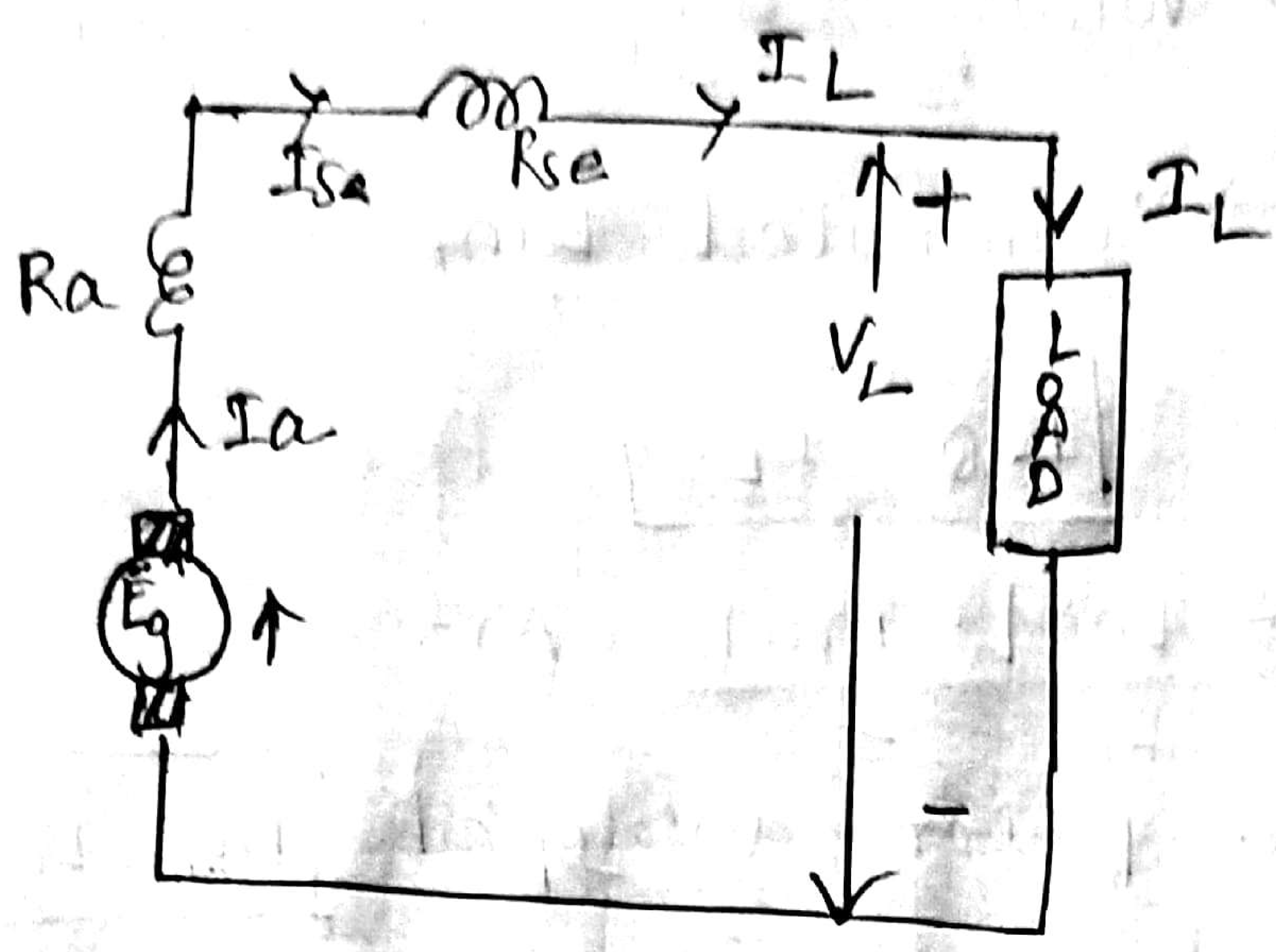
(ii) Self excited DC Generator

If in a DC Generator field winding is supplied from a armature of Generator itself then it is called self excited DC Generator.

The self excited DC generators can be classified depending upon how the field winding is connected to the armature. There are three types

(a) series generator (b) shunt Generator
(c) compound generator

Series Generator



* The field winding is connected in series with the armature.

* This type of DC generator is called DC Series generator.

* Here the armature current flows through the field winding as well as the load.

* The field winding has less no. of turns of thick wire.

* It has low resistance. It is denoted by Rse.

* Here armature, field and load are all in series. So they carry the

same current.

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

Generated Emf $E_g = V_L + I_a R_a + I_a R_{se} + V_{brush}$ (V)

where

V_L = Terminal Voltage (V)

I_a = Armature current.

R_a = Armature Resistance

R_{se} = field winding Resistance

V_{brush} = Brush drop.

* Power developed in Armature $P_g = E_g I_a$

Power delivered to load $P_L = V_L I_a$ (or) $V_L I_L$

$$E_g = V_L + I_a (R_a + R_{se}) + V_{brush}$$

$[\because I_a = I_{se}]$

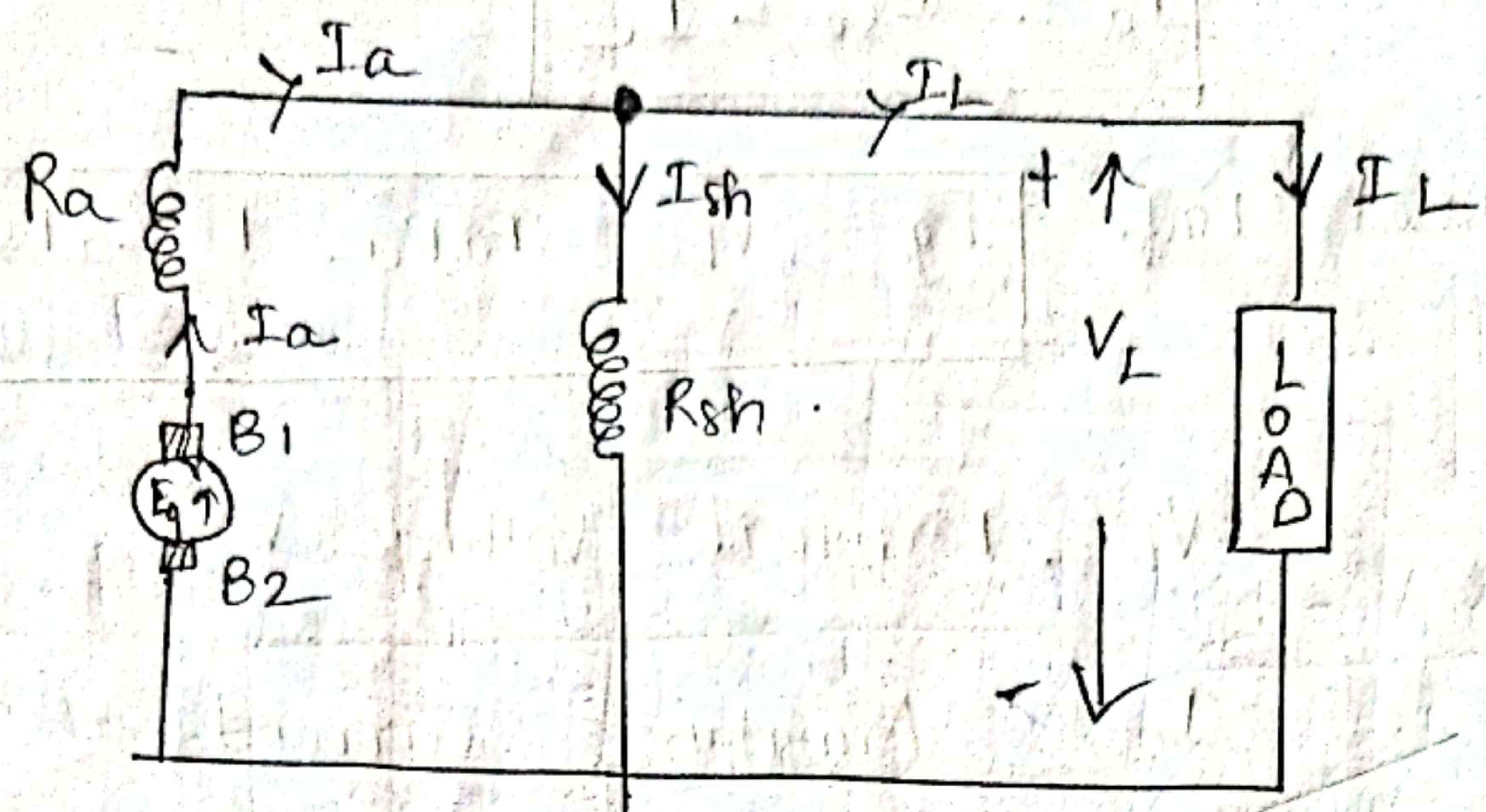
(b) Shunt Generator

* Here the field winding is connected in Parallel with Armature winding.

* The shunt field winding has more no. of

turns of thin wire. It has high resistance.

* The Load is connected across the armature.



Generated Emf $E_g = V_L + I_a R_a + V_{brush}$ (V)

Armature current $I_a = I_{sh} + I_L$ (A)

* shunt field current $I_{sh} = \frac{V_L}{R_{sh}}$ (A)

Power developed by Armature $P_g = E_g I_a$ (W)

Power delivered to load $P_L = V_L I_L$ (W)

$V_L \to$ Terminal voltage.

(iii) Compound Generator

* It consits of both shunt field and series field windings

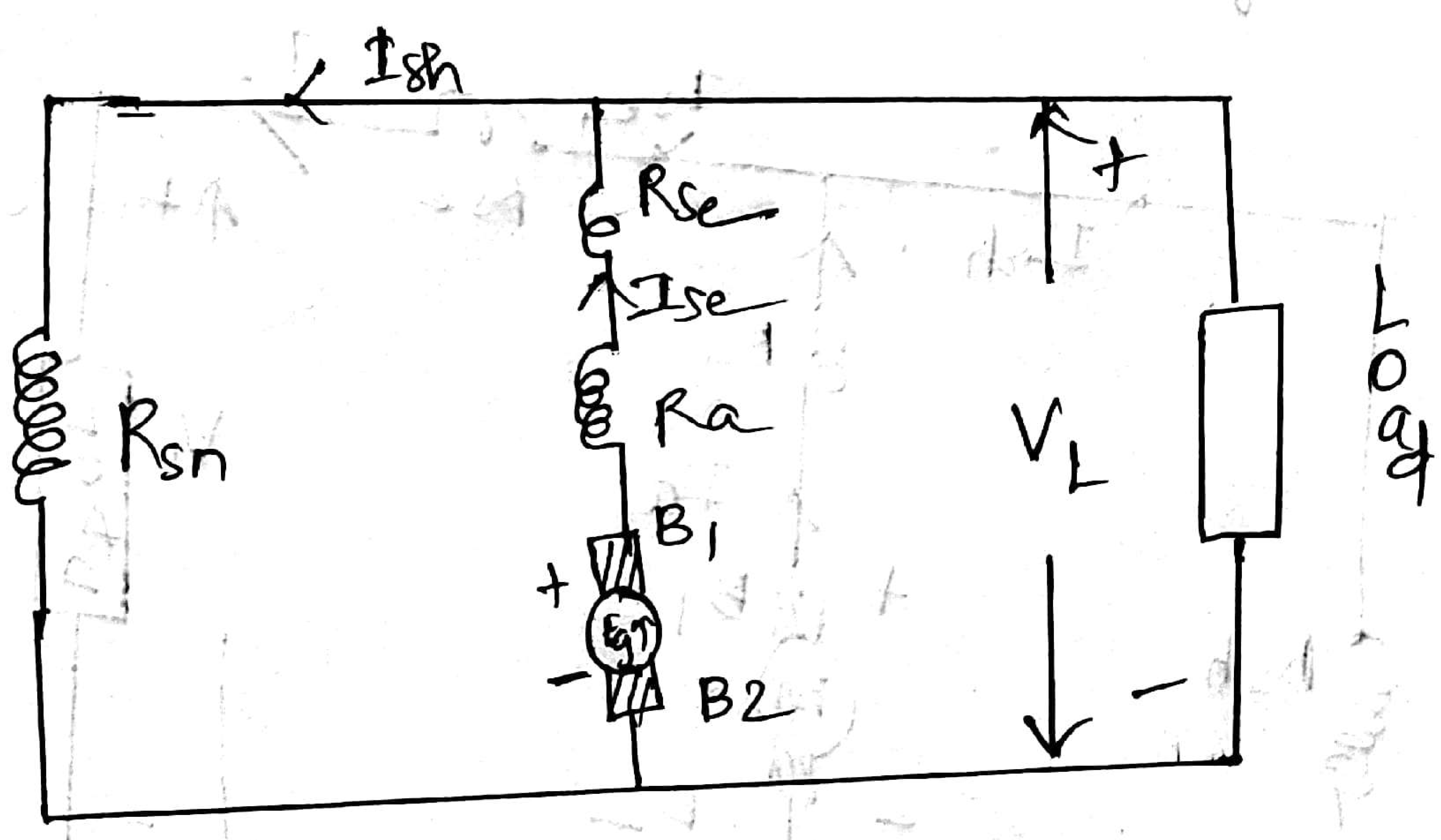
* One winding is in series and another winding is in parallel with armature

* This Generator can be classified as,

(a) Long Shunt compound Generator
(b) short shunt compound Generator

(a) Long Shunt compound Generator

* Here shunt field winding is connected across both series field and armature windings



From the figure

$$I_a = I_{se} = I_L + I_{sh} \text{ (A)}$$

Shunt field current $I_{sh} = \frac{V_L}{R_{sh}}$

Generated Emf $E_g = V + I_a R_a + I_{se} R_{se} + V_{brush}$

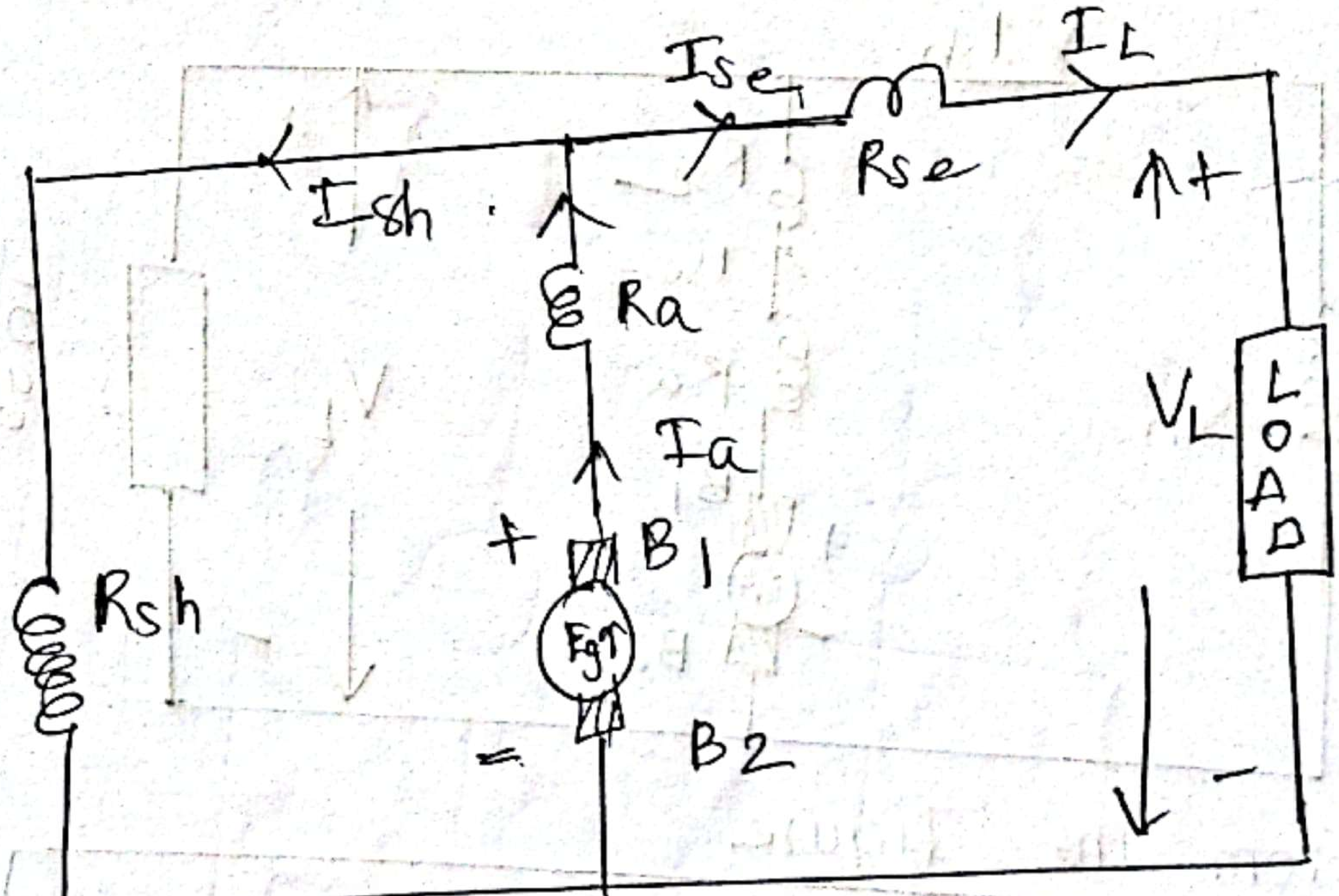
$$E_g = V + I_a(R_a + R_{se}) + V_{brush} \quad [\because I_a = I_{se}]$$
(V)

Power developed in armature $\boxed{P_g = E_g I_a}$ (W)

Power delivered to load $\boxed{P_L = V_L I_L}$ (W)

(b) short shunt compound Generator

* Here shunt field winding is connected in Parallel with armature and this combination is connected in series with series field winding.



Generated Emf $\boxed{E_g = V_L + I_a R_a + I_{se} R_{se} + V_{brush}}$ (V)

Series field current $\boxed{I_{se} = I_L}$

$I_L \rightarrow$ load current.

Armature current $I_a = I_{sh} + I_{se}$

Shunt field current

Apply KVL Across shunt field

$\therefore V_{sh} = V_L + I_{se} R_{se}$

$I_{sh} R_{sh} = V_L + I_{se} R_{se}$

$$\boxed{I_{sh} = \frac{V_L + I_{se} R_{se}}{R_{sh}} \text{ (A)}}$$

Power developed in armature $P_g = E_g I_a$ (W)

Power delivered to load $P_L = V_L I_L$ (W)

Characteristics of DC Generator

There are three types of characteristics

(1) Open circuit characteristics (or) Magnetisation characteristics (E_g Vs I_f)

(2) Internal characteristics (or) total characteristics (E_g Vs I_a)

(3) External characteristics.

Seperately excited DC Generator characteristics

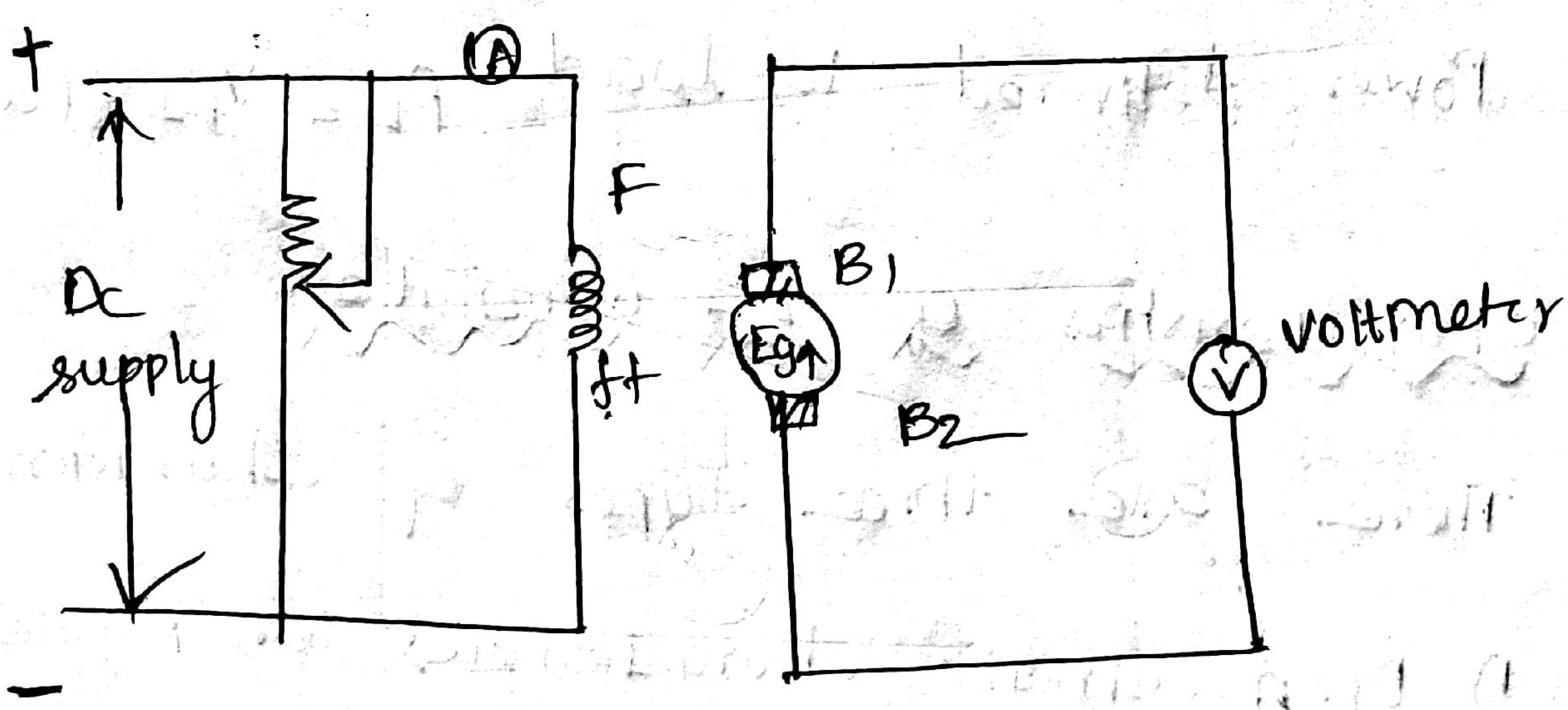
W.K.T Emf equation of Generator is

$$E_g = \frac{\phi Z P N}{60 A}$$

$E_g \propto \phi N$ If N = constant

If $\phi\uparrow$ $E_g\uparrow$ i.e, if flux increases E_g increases.

the variation of flux with the induced emf is called the open circuit characteristics (OCC) of the generator.

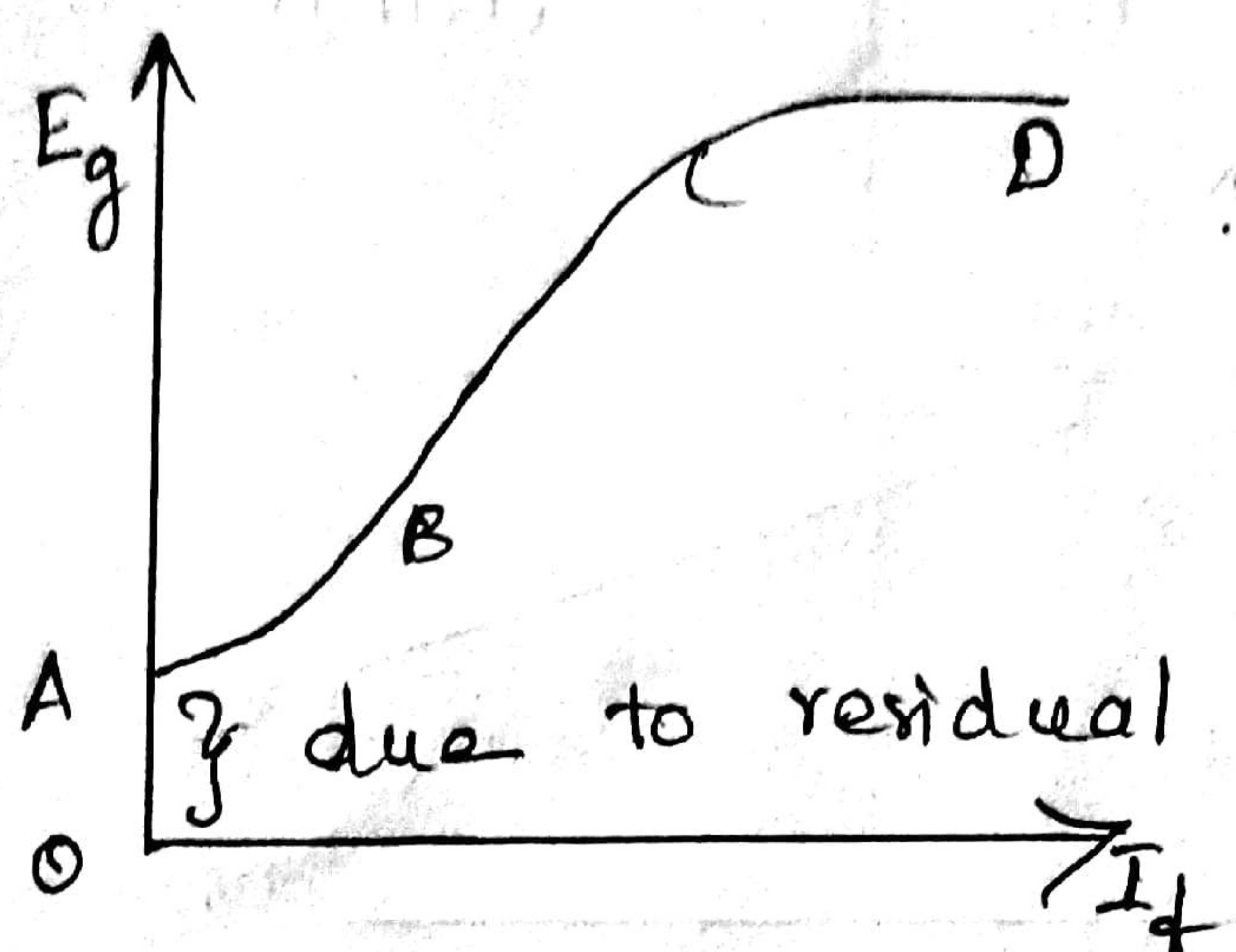


Open circuit characteristics (Eg Vs If)

As the field current is increased,

the induced emf increases, increasing linearly from A to B.

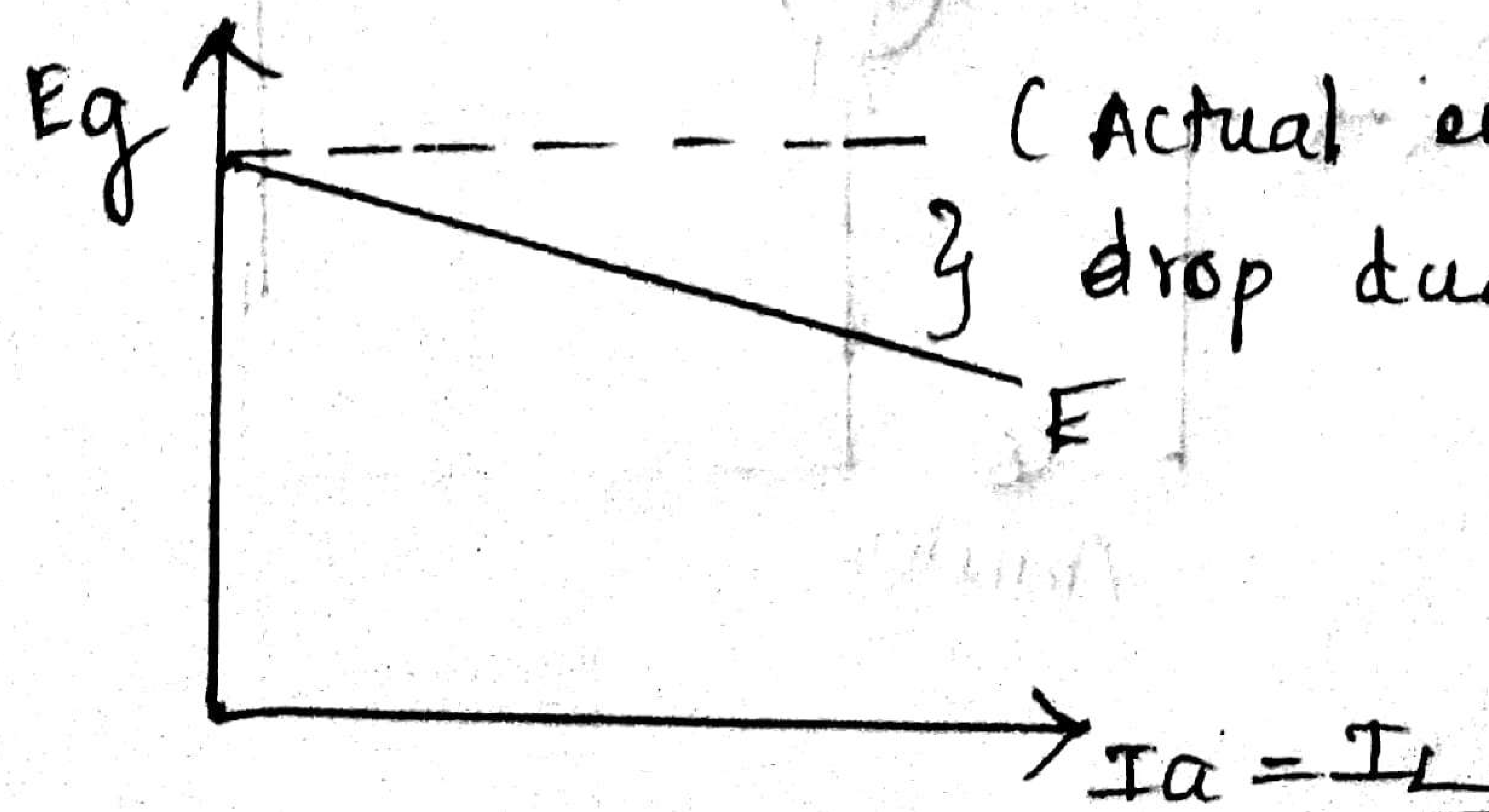
* As the field current is further increased, the increase in flux is much smaller and hence the emf also increases slowly. At point D saturation has set in.



Internal Characteristics (Eg Vs Ia)

* this curve is drawn between Emf induced and armature current (Ia)

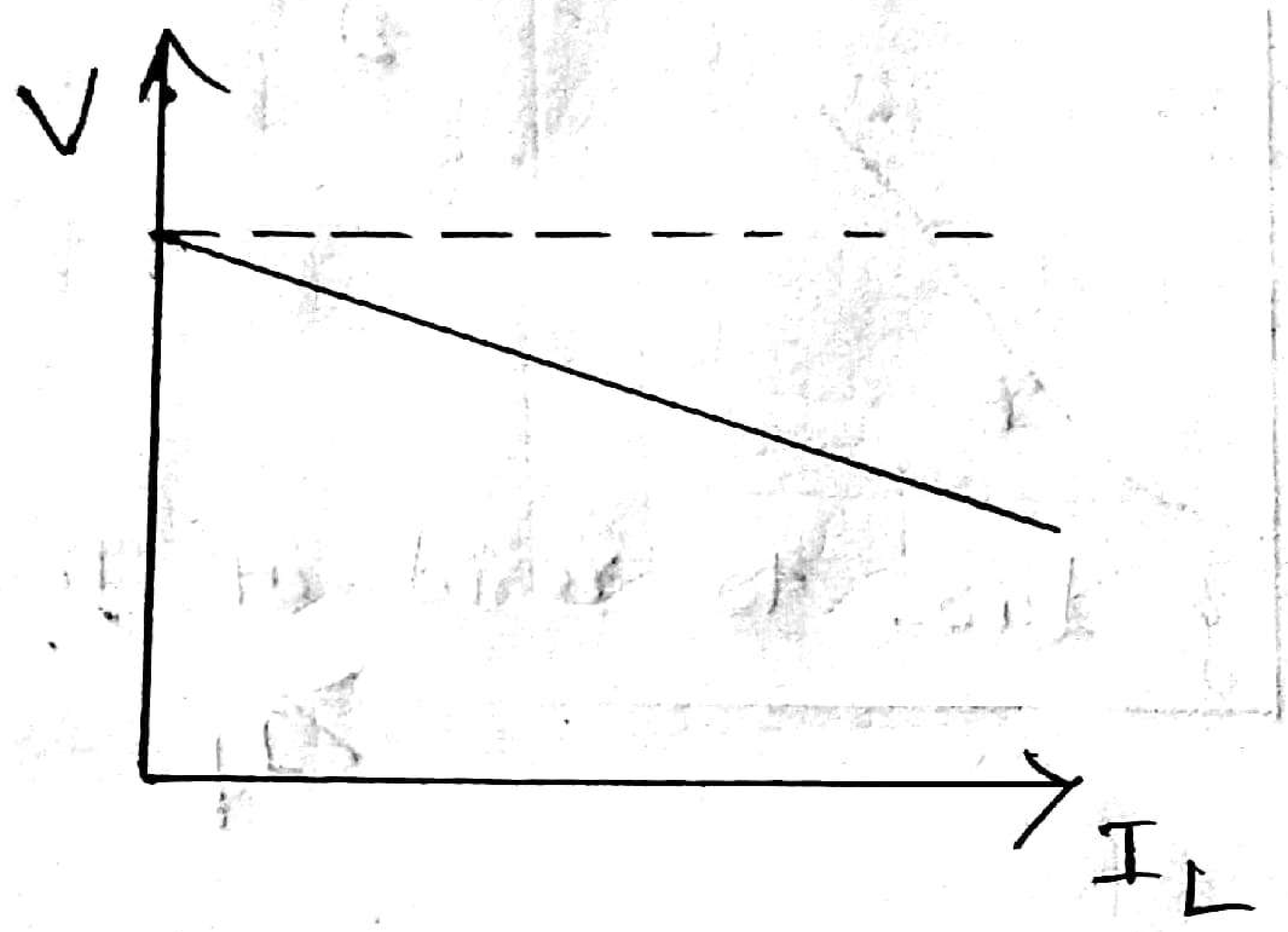
* Here by increasing the Armature current induced emf (E) will decrease due to Armature reaction.



External characteristics (V Vs I_L)

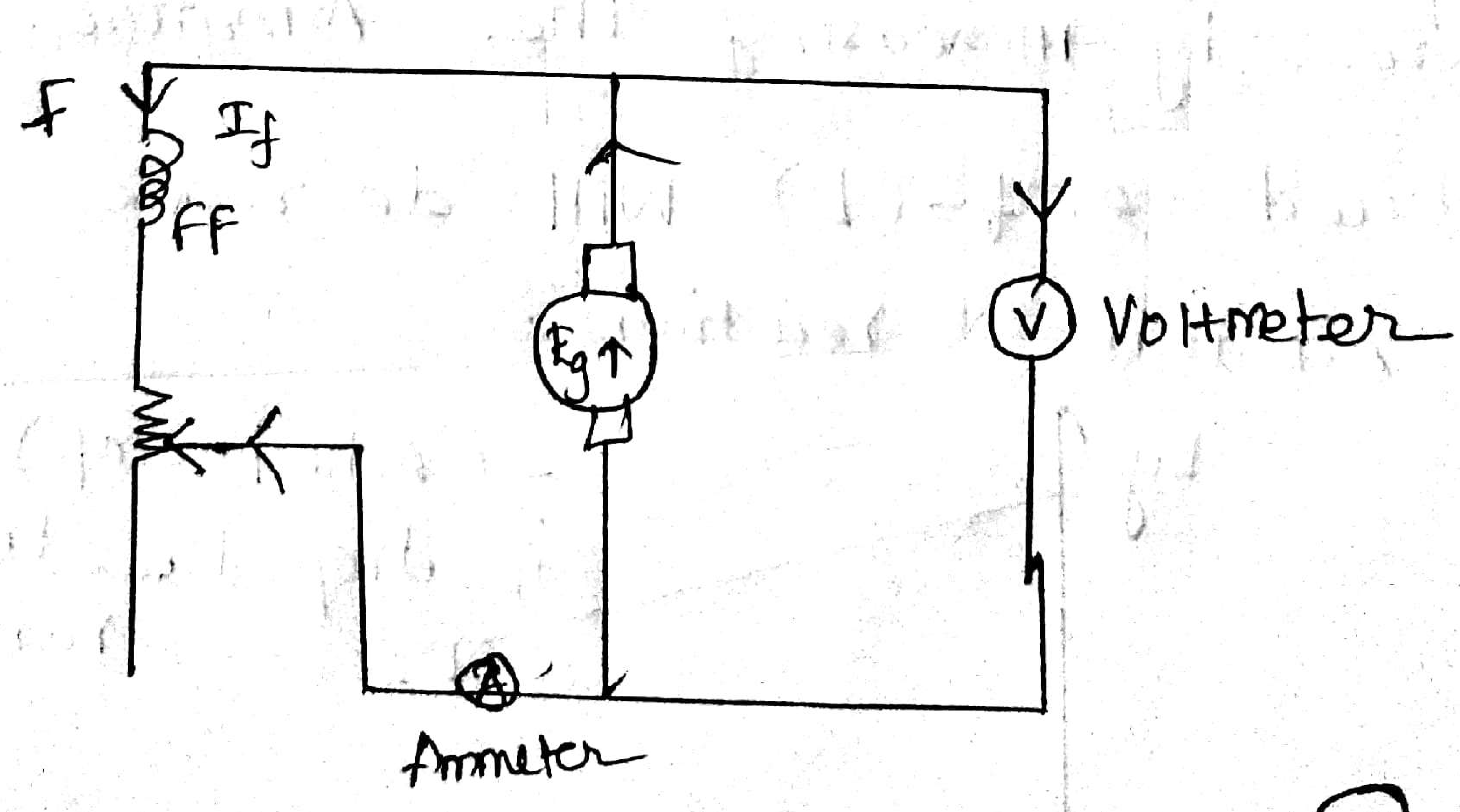
* This curve is drawn between the terminal voltage and armature current.

* Here by increasing armature current (or) load current then induced emf again decreases due to armature resistance.



DC shunt Generator characteristics.

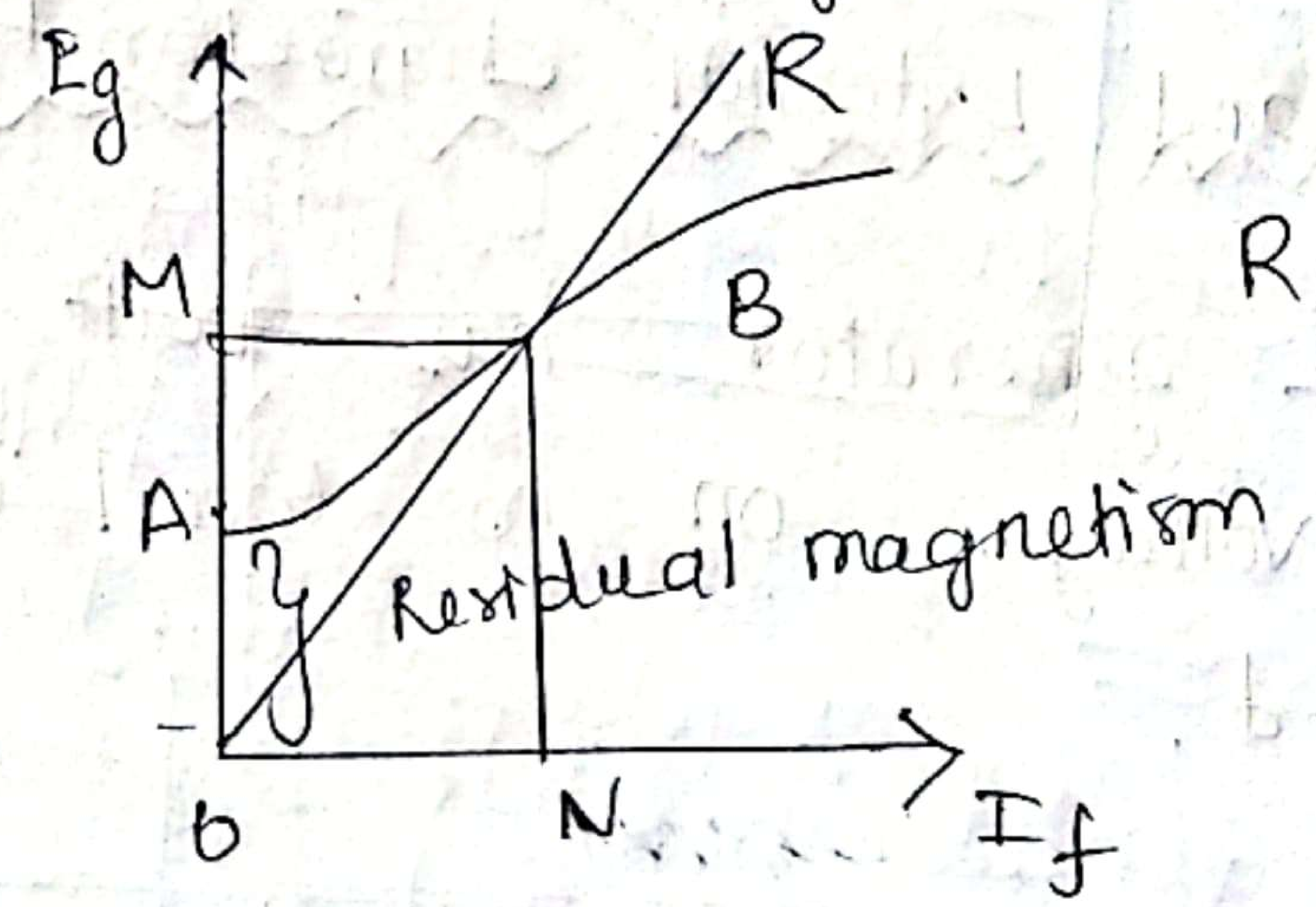
* Fig shows dc shunt generator



Open circuit characteristics

* This curve can be drawn between field current and induced emf.

* Initially the field current is zero, but emf (OA) is induced in the generator due to residual magnetism.



$$R_c = \frac{OM}{ON} = \frac{\Delta E_g}{\Delta I_f}$$

$$R_c = \frac{\Delta E_g}{\Delta I_f}$$

* Due to this voltage field current increases and emf also increases and it reaches point B.

* There is no further increase in field current (or) induced emf.

* This curve is open circuit characteristic.

Critical Resistance (R_c)

* OR is the tangent drawn to the portion of OCC from origin

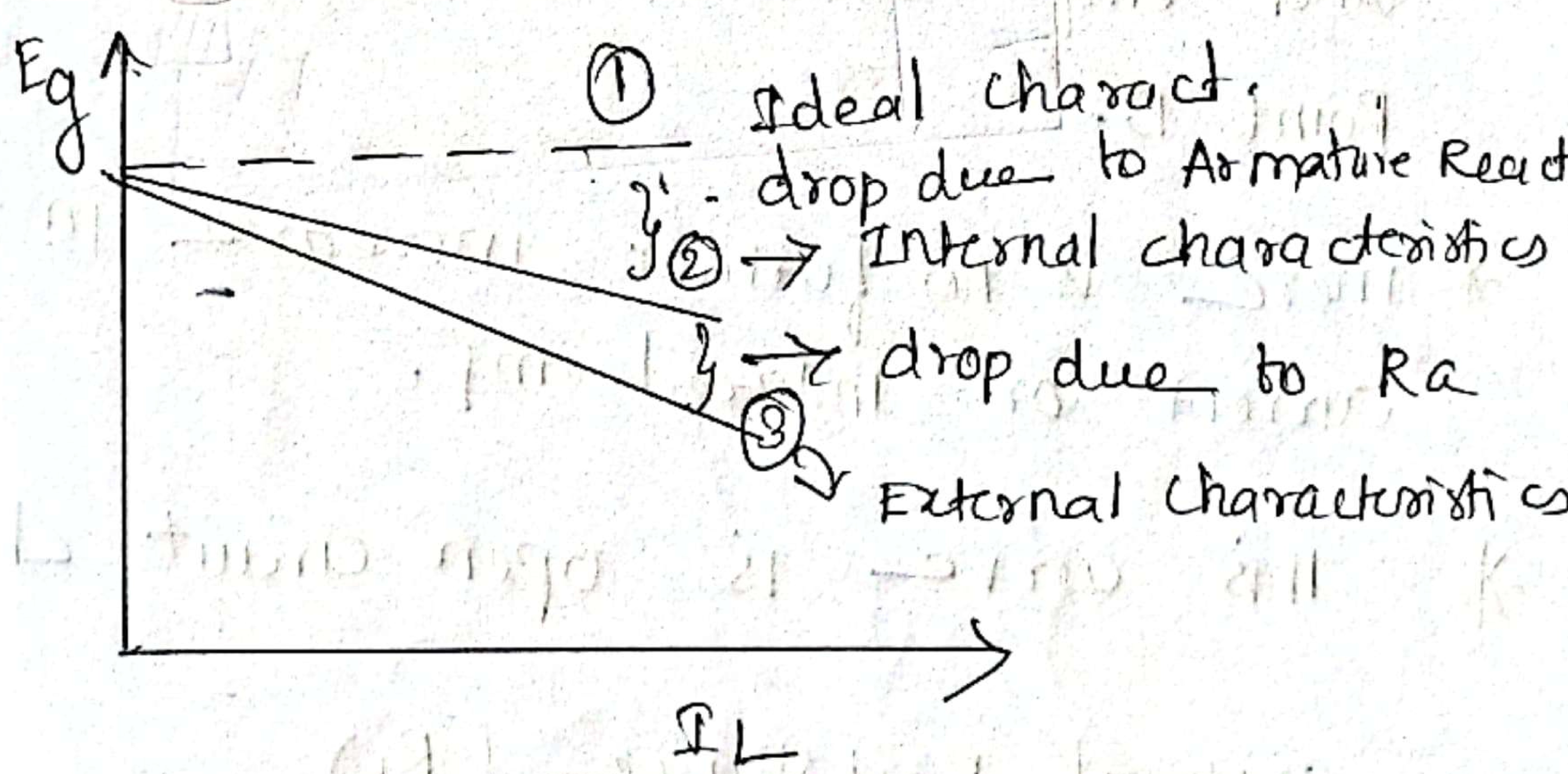
* The slope of this tangent OM/ON gives the value of critical resistance, when Generator just excites.

$$R_c = \frac{\Delta E_g}{\Delta I_f}$$

(ii) Internal and External characteristics.

* Once the generator has built upto the specified voltage on no load it may be loaded.

* If we increase the load on the generator, the voltage drop across also increases.



* the curve (1) shows the Ideal dc generator. there is no drop in the armature ie $E_g = V$

* The curve (2) shows the internal characteristics. Here the drop is due to armature reaction.

* The curve can be drawn for load current versus (E).

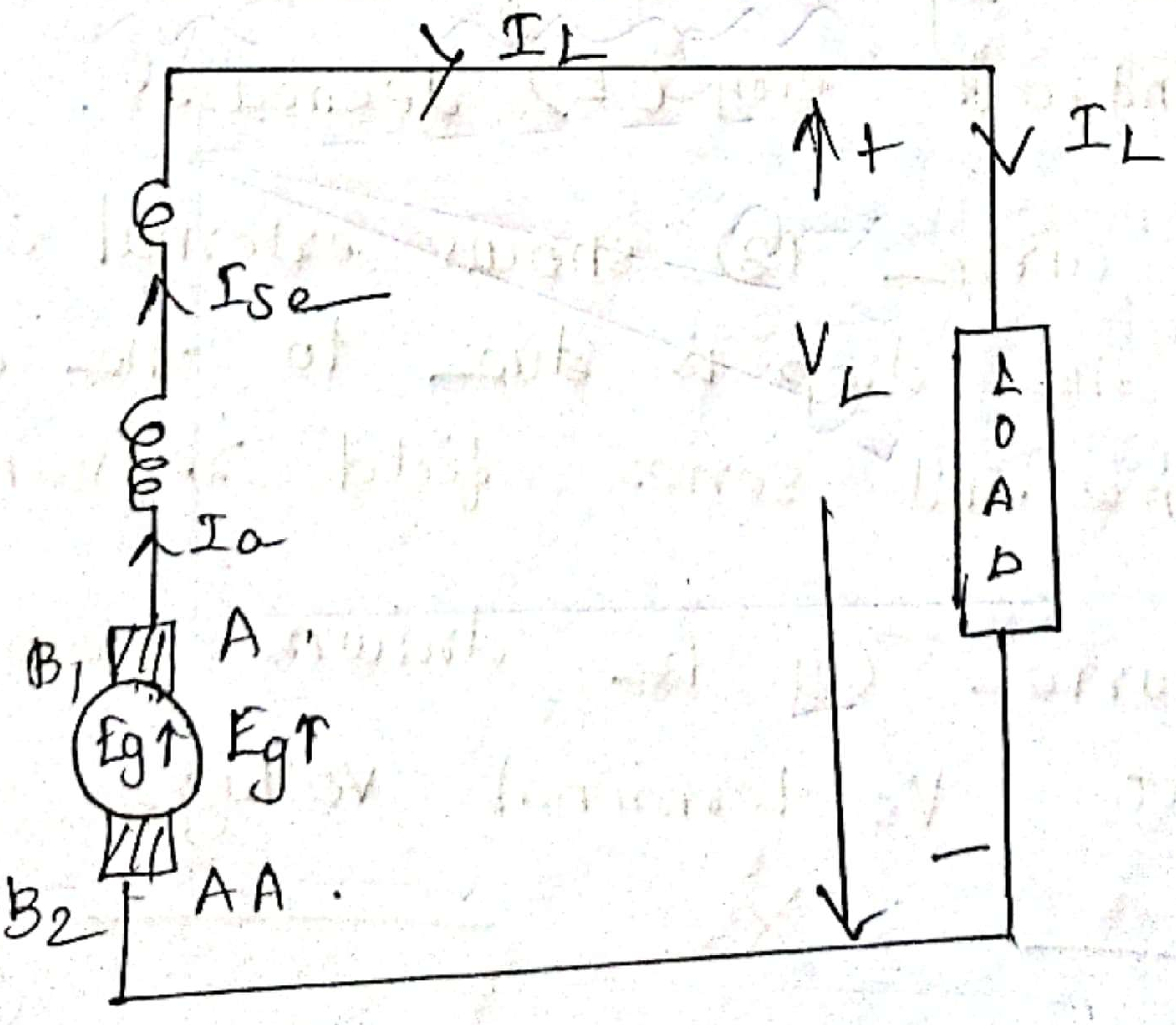
* The curve (3) shows external characteristics. Here drop is due to Armature Resistance (R_a).

* By increasing the load current terminal voltage decreases.

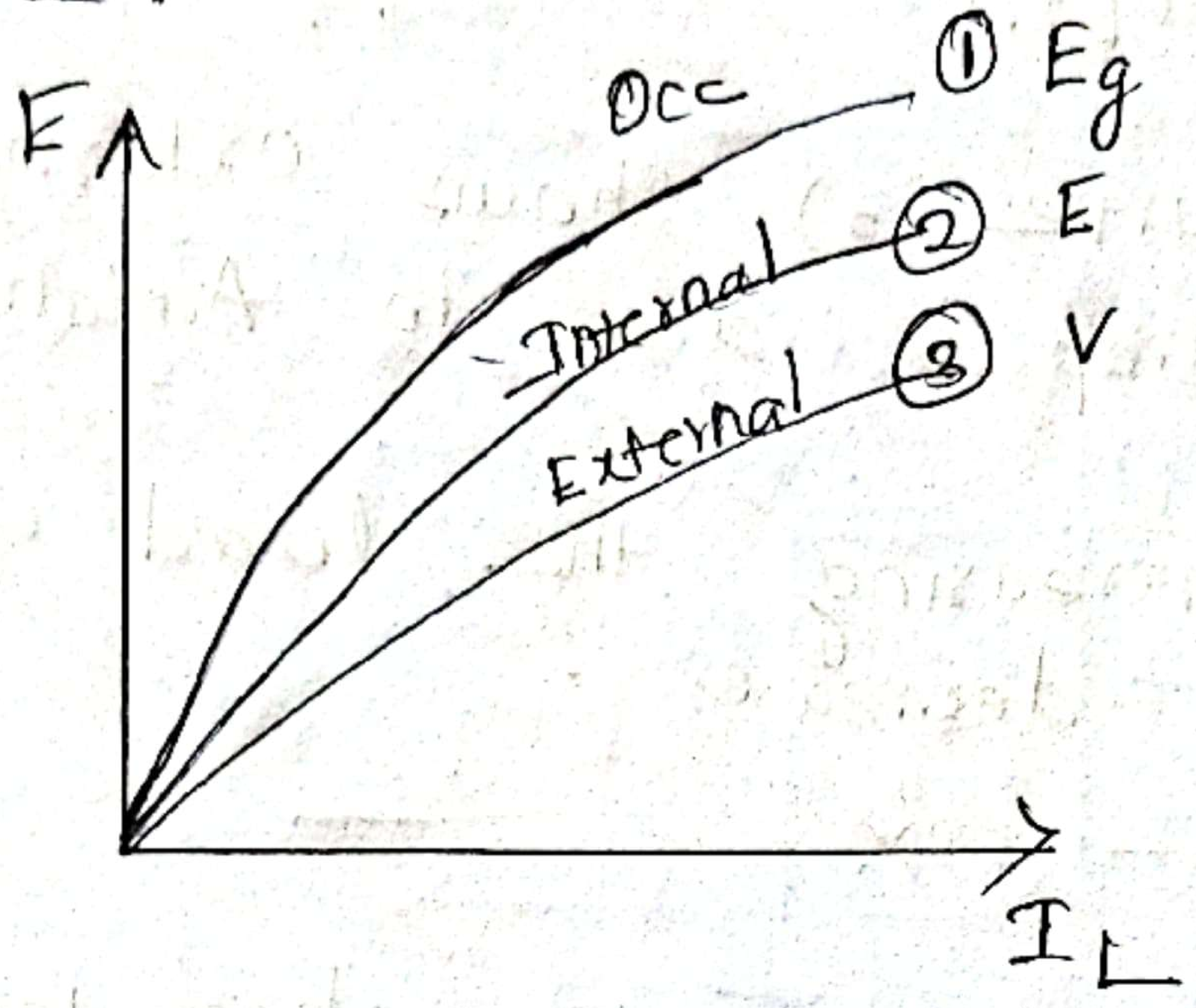
X

DC Series Generator characteristics

The connection for the dc series generator is shown in fig



* The curve (1) shows open circuit characteristics. This curve can be obtained by disconnecting the field winding from the machine and excited by seperate dc source.



* The curve (2) shows internal characteristics. Here the drop is due to armature reaction. By increasing the load current the induced emf (E) decreases.

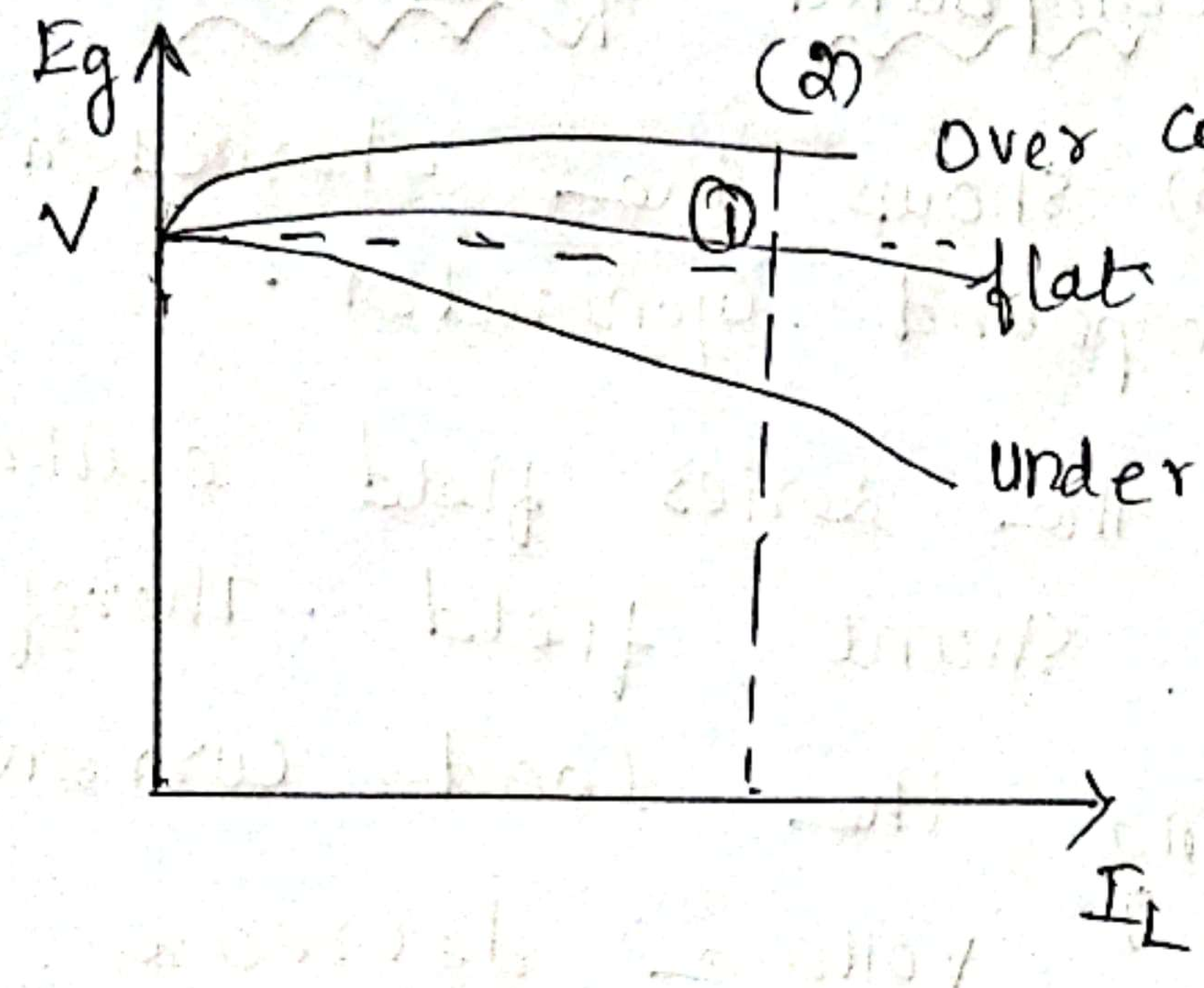
* The curve (3) shows external characteristics. Here the drop is due to the armature resistance and series field resistance.

* The curve can be drawn from load current Vs terminal voltage

———— X ————

Compound Generator characteristics :

* It consists of series field and shunt field windings. Fig shows external characteristics of compound generator.



(a) Flat compound Generator

* A compound generator has both shunt and series field and if the drop in flux in the shunt field is exactly compensated for by the rise in flux in series feild then it is possible to have constant voltage characteristics

i.e $\boxed{E_g = V}$

(b) Over compound Generator

* Curve (2) shows the characteristics of over compound Generator.

* Here the series field excitation is more than shunt field.

i.e $V > E_g$

* (c) Under compound Generator

* curve (3) shows the characteristics of under compound Generator.

* Here the series field excitation is less than shunt field. Therefore by increasing the load current the terminal voltage decreases.

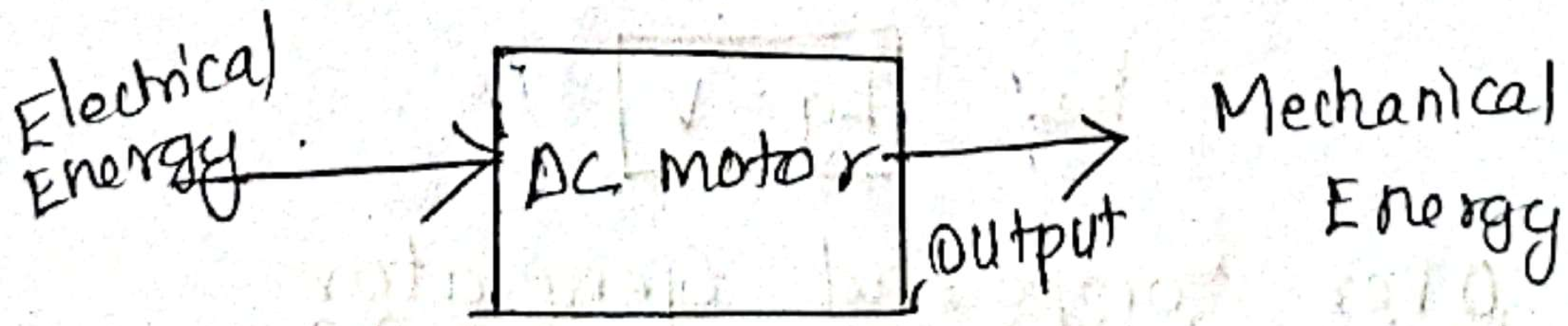
$V < E_g$

---- x ---- x

DC Motors.

"The DC motor converts Electrical Energy into Mechanical Energy".

It is shown in fig.



Construction

The DC motor has the following parts

(i) Magnetic Frame (or) yoke
(ii) poles, Interpoles, windings, pole shoes
(iii) Armature (iv) commutator
(v) Brushes, Bearings and shafts.

(i) Magnetic frame (or) yoke

It is used for two purpose

* It acts as a protecting cover for whole machine and provides mechanical support for poles.
* It carries the magnetic flux produced by the poles.

(ii) Poles

The pole consists of (i) pole cores
(ii) pole shoes
(iii) pole coils

* The pole core and pole shoes form the field magnet.

* A field winding is wound over the Pole core.

* The pole coils are made up of copper or strip.

Interpoles

* Commutating poles (or) interpoles are Provided to improve commutation.

* The commutating poles also have exciting coils which are connected in series with Armature.

* The coils are madeup of fewer turns of thicker conductor to reduce the resistance.

Armature

* the armature consists of an armature core and Armature windings.

* the armature core houses the armature conductors or coils.

Commutator

* The commutator converts the alternating emf into unidirectional (or) direct emf.

* It is made up of wedged shape copper, insulated from each other by thin layers of built-up-mica

Brushes

* The brushes which are made up of carbon or graphite

* It collects the current from the commutator and to convey it to the external load resistance.

* They are rectangular in shape.

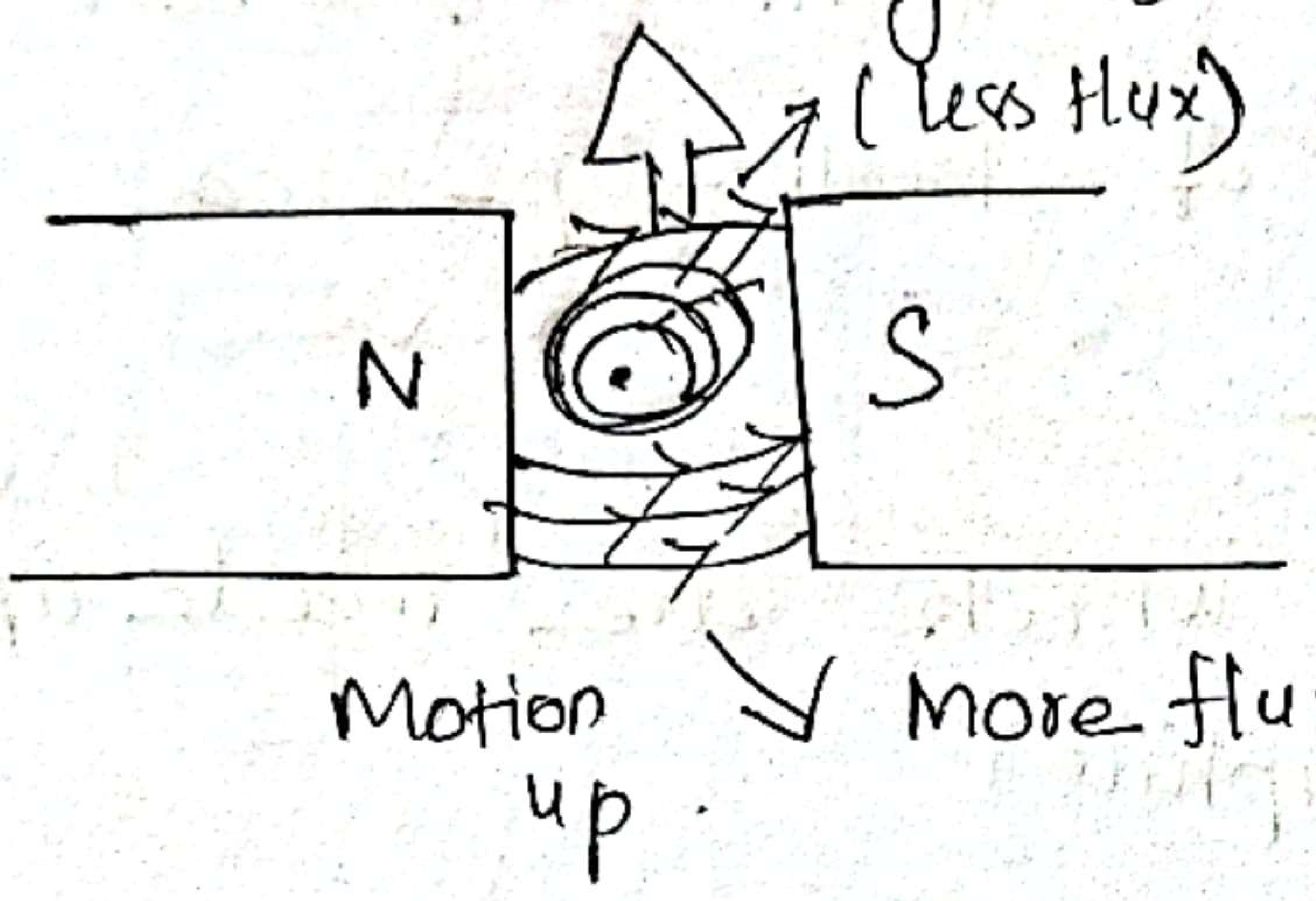
Bearings

* Ball bearings are usually employed as they are reliable for light machines.

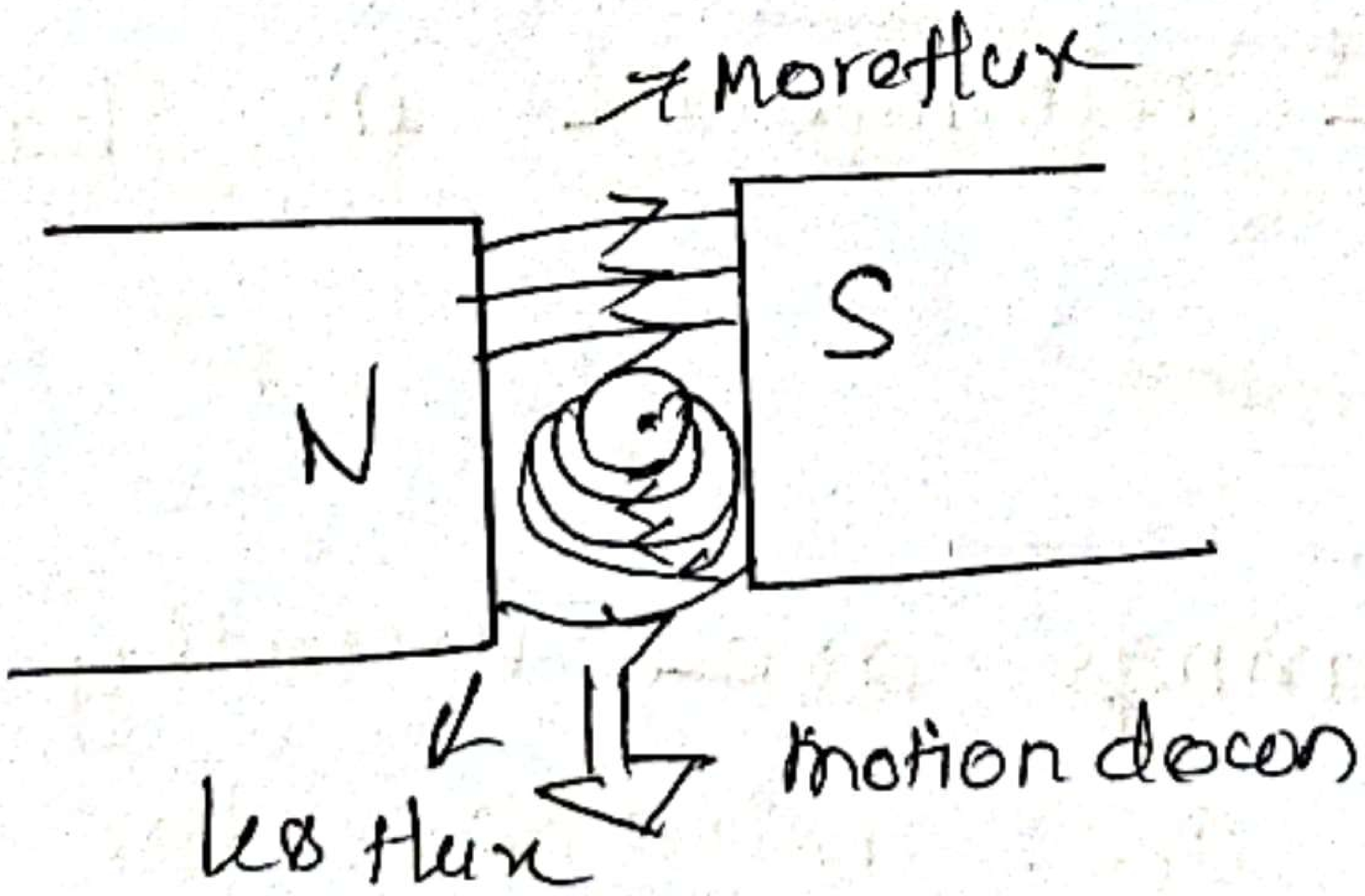
* For heavy duty machines roller bearings are used.

Principle of Operation

* The basic principle of operation of DC motor is that "whenever a current carrying conductor is placed in a magnetic field, it experiences a force tending to move it".



* Above the conductor the flux is less and below the conductor, the field is more causes the motor to move upwards



* Then the direction of current through the conductor is reversed as shown in fig. Here the field below the

conductor is less and field above
Conductor is more.

* then the conductor tends to move downwards.

* The magnitude of force experienced by the conductor in a motor is given by

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

where B = magnetic field intensity
I = current in Amperes.
L = Length of conductors in metres.

* The direction of motion is given by Fleming's left hand rule

———— x ————

Types of DC Motors

The types of DC motors are

(I) Separately excited DC motor

(II) self excited DC motor

(a) Series motor

(b) shunt motor

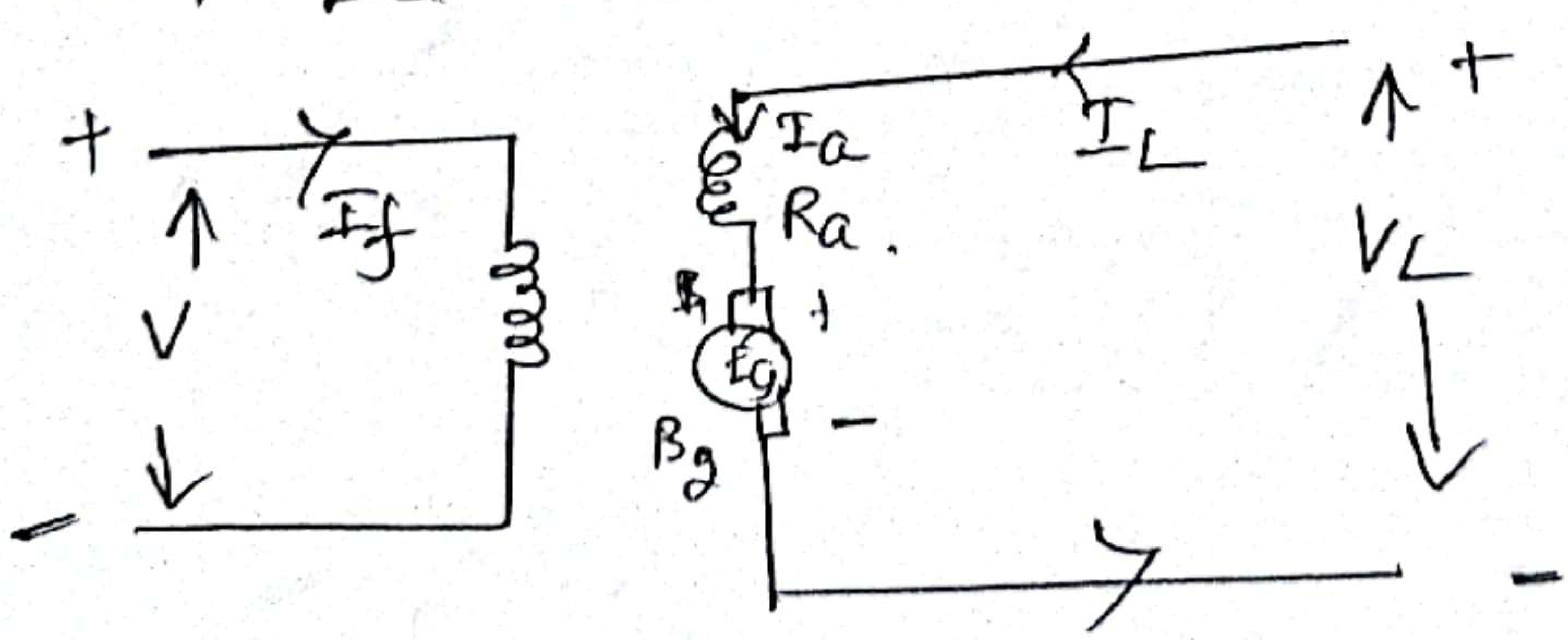
(c) Compound motor.

- long shunt compound motor
- Short shunt compound motor

Separately excited DC Motor

* Here the field winding and armature are seperated. The field winding is excited by seperate dc source.

* That is why it is called as separately excited DC motor.



* From the diagram

Armature current I_a = line current I_L

$$I_a = I_L \quad (A)$$

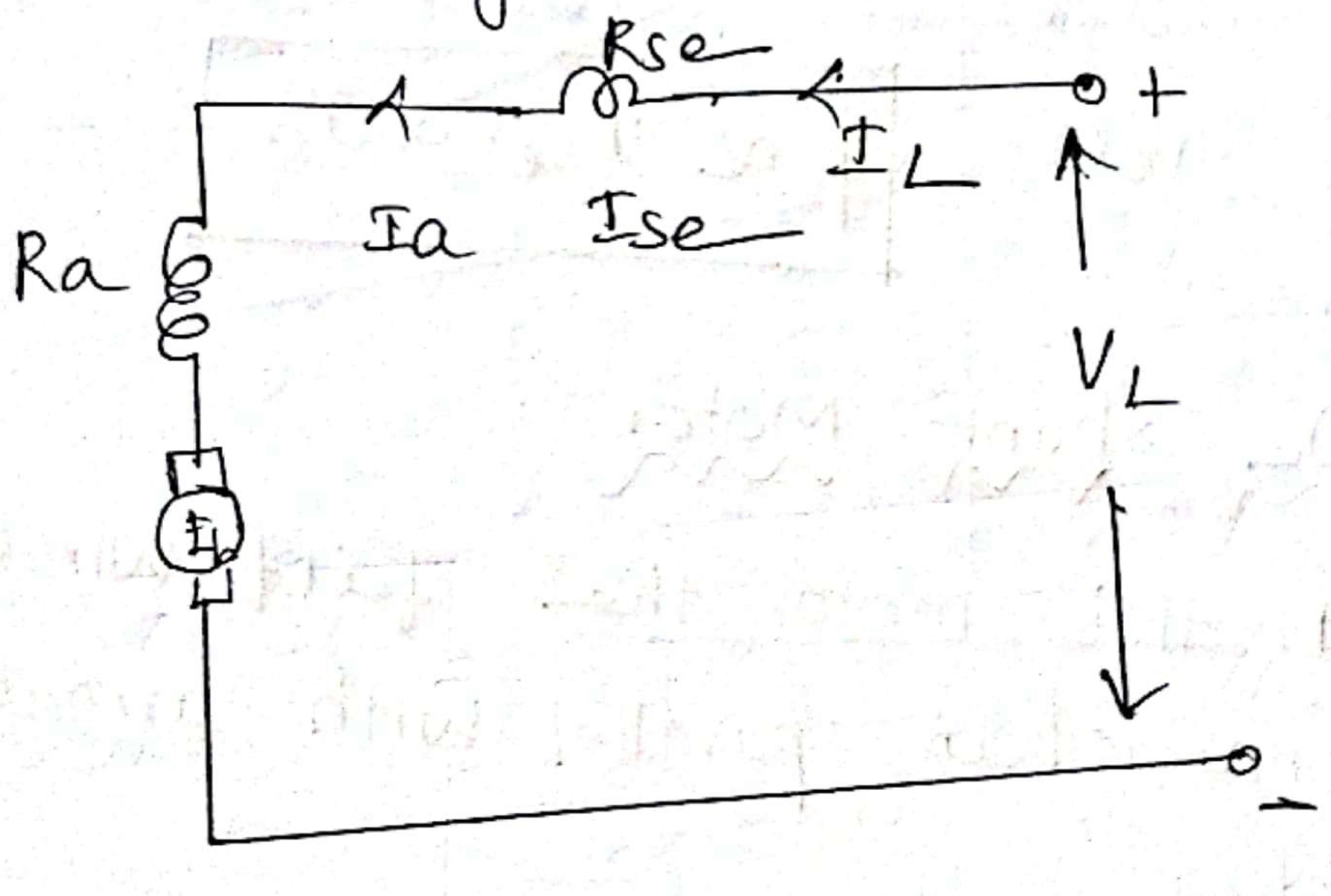
$$V_L = I_a R_a + E_b + V_{brush} \quad (V)$$

(ii) Self Excited DC motor

(a) DC series motor.

* Here the field winding is connected in series with Armature winding.

* Here the field winding has less no. of turns of thick wire. "Rse" is resistance of series field winding. Its value is very small.



The voltage equation is given by,

$$V = I_{se} R_{se} + I_a R_a + E_b + V_{brush} \quad (v)$$

In DC series motor

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

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

where

I_L → Line current

V_{brush} → Brush drop.

E_b → back emf.

* In series motor flux produced is directly proportional to armature current

ie $$\phi \propto I_{se} \propto I_a$$

(ii) DC shunt Motor :

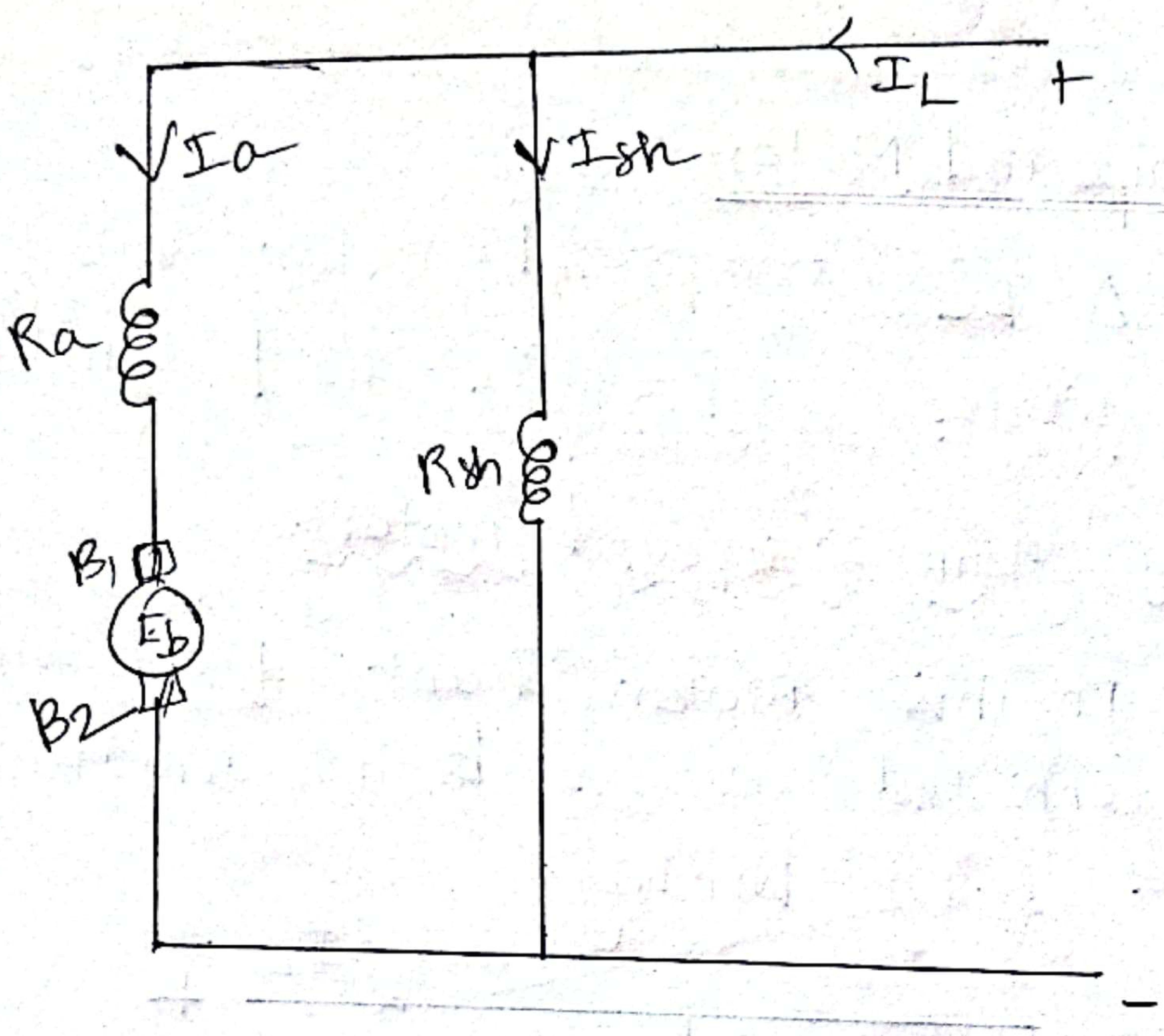
* In this motor the field winding is connected in parallel with armature winding.

* It has more no. of turn with thin wire.

* R_a → Armature Resistance

* R_{sh} → shunt field Winding Resistance

* I_L → Line current drawn from the supply



from the diagram $I_L = I_a + I_{sh}$ (A)

$$I_{sh} = \frac{V_L}{R_{sh}} \text{ (A)}$$

voltage equation of DC shunt motor is

$$V = E_b + I_a R_a + V_{brush} \text{ (V)}$$

* In shunt motor flux produced by field winding is proportional to field current (I_{sh})

i.e $\boxed{\phi \propto I_{sh}}$

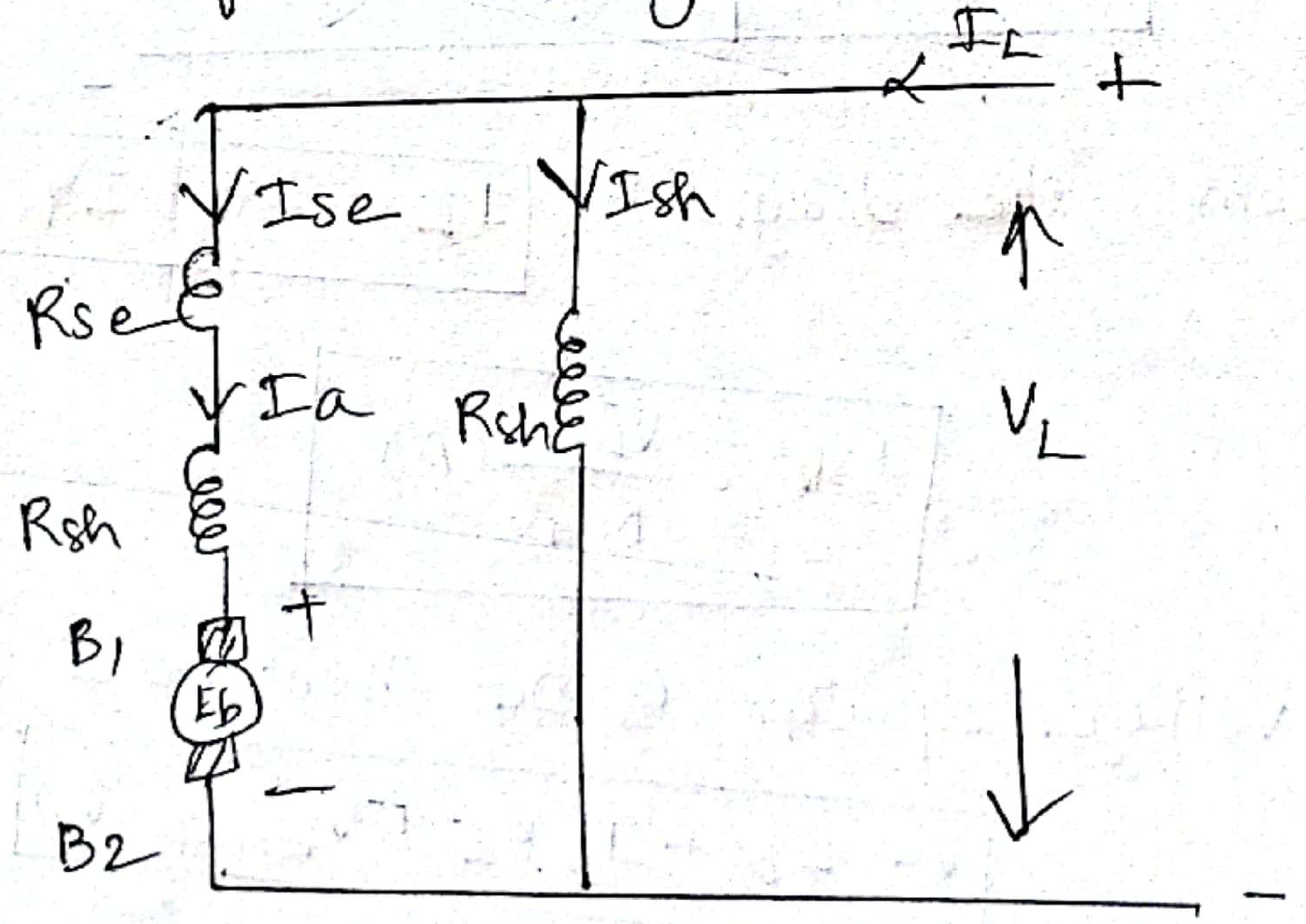
* DC shunt motor also called a constant flux motor (or) constant speed motor.

DC Compound Motor

A DC compound motor consists of both series and shunt field windings.

(a) Long shunt compound motor:

In this motor shunt field winding is connected across both armature and series field winding



* From the diagram.

$$V_L = E_b + I_a R_a + I_{se} R_{se} + V_{brush} \text{ (V)}$$

$$I_a = I_{se} \text{ (A)}$$

$$I_L = I_{sh} + I_{se} \text{ (A)}$$

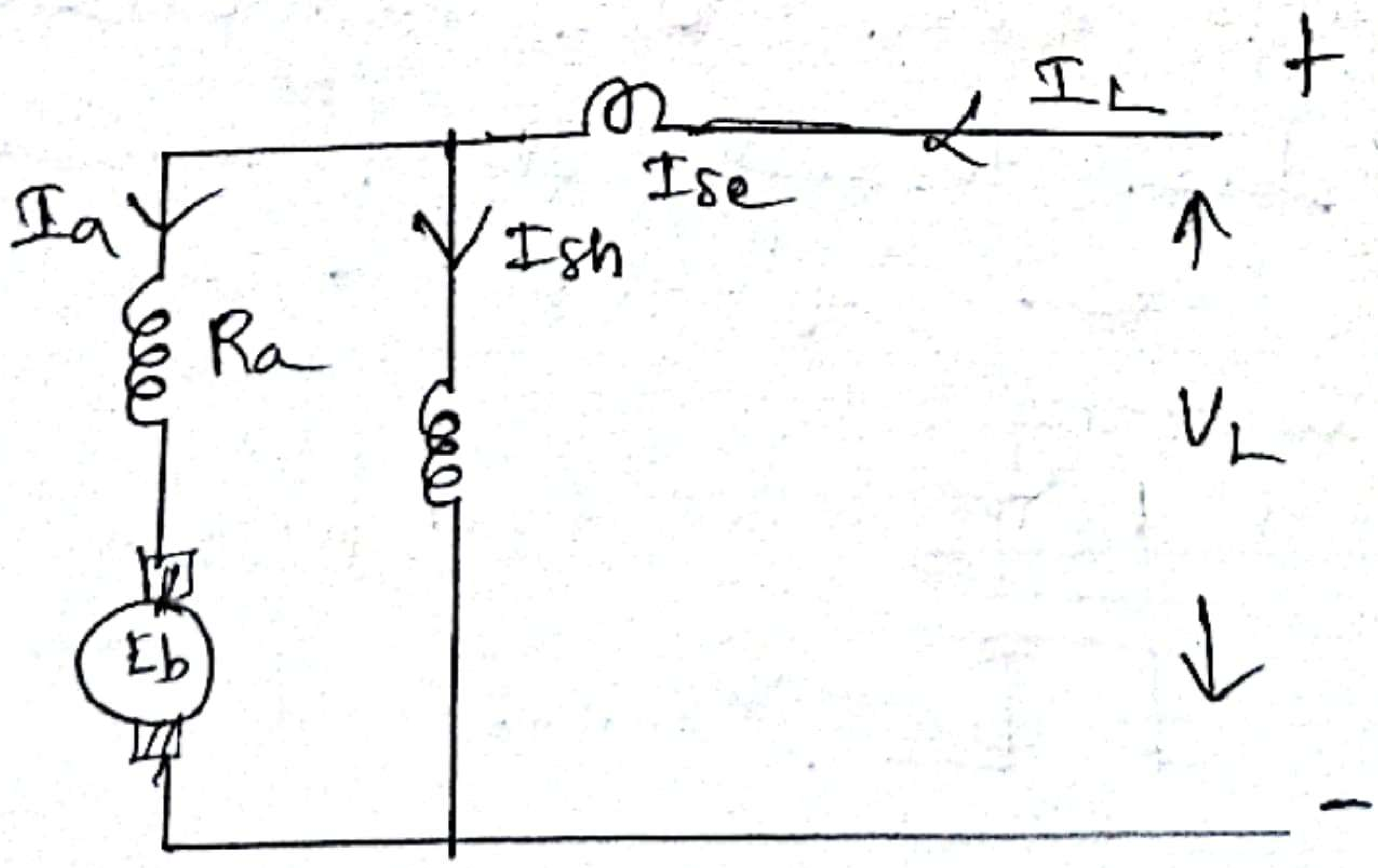
$$I_{sh} = \frac{V_L}{R_{sh}} \text{ (A)}$$

Now, $V_L = E_b + I_a(R_a + R_{se}) + V_{brush}$

$[\because I_{se} = I_a]$

(b) Short Shunt Compound Motor:

* In this type of motor, the shunt field winding is across the armature and series field winding is connected in series with this combination.



From the diagram :

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

$$I_{se} = I_L$$

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

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

Voltage drop across shunt field winding is

$$I_{se} R_{se} + V_{sh} = V_L$$

$$\therefore V_{sh} = V_L - I_{se} R_{se}$$

$$I_{sh} R_{sh} = V_L - I_{se} R_{se}$$

$$I_{sh} = \frac{V_L - I_{se} R_{se}}{R_{sh}} \quad (A)$$

The compound motor again classified into two types

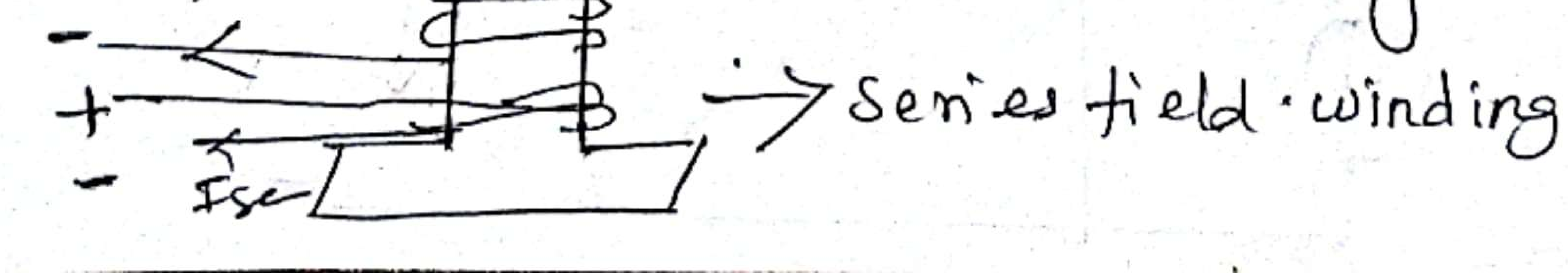
(I) cumulative compound motor

(II) Differential compound motor :

Cumulative compound motor

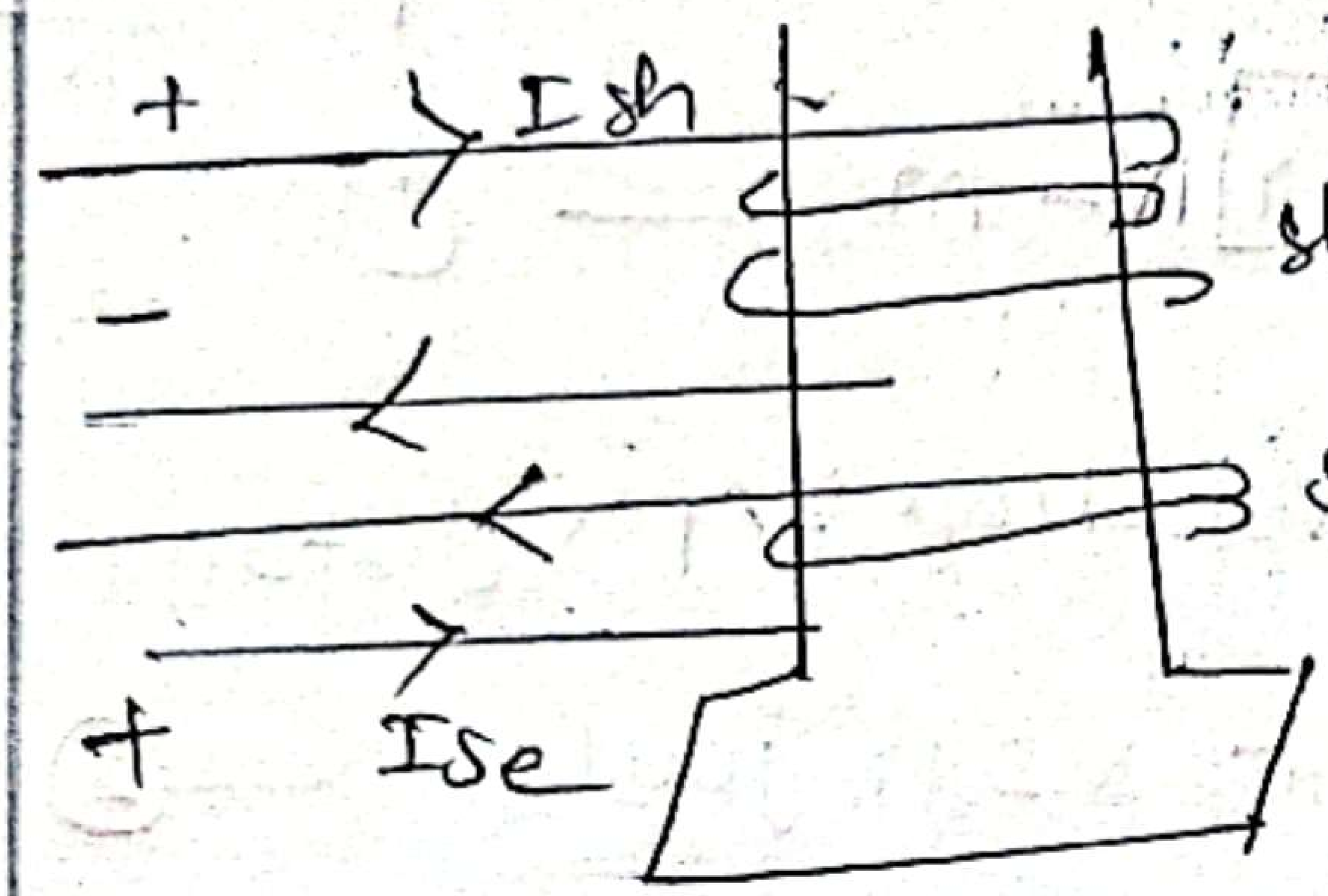
* In this type of motor the two field winding fluxes and each other.

* Flux due to series field winding strengthens the flux due to shunt field winding



Differential compound motor.

In this type of motor the two field winding fluxes oppose each other. i.e field due to series field winding reduces the field due to shunt field winding

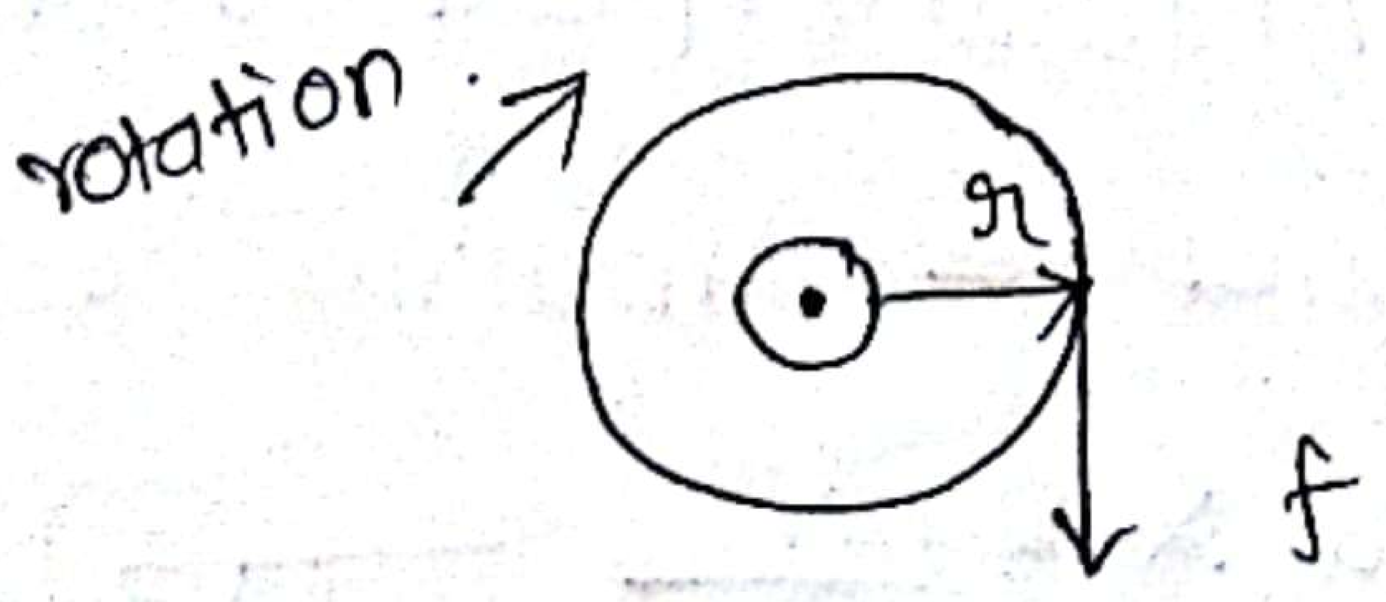


Torque Equation.

"Torque is nothing but turning (or) twisting force about an axis.

* Torque is measured by product of force and the radius at which the force acts.

* consider a wheel of radius "r" metres acted on by a circumferential force 'F' newton as shown in fig.



* Let the force 'F' cause the wheel to rotate at 'N' rpm. The angular velocity of wheel is

$$\omega = \frac{2\pi N}{60} \text{ rad/sec}$$ [N rpm = 60 sec; 1 rpm = $\frac{60}{N}$ sec]

Torque $\boxed{T = f \times r}$ N-m — ①

Work done per revolution = F × distance moved

$= F \times 2\pi r$ joules — ②

Power developed p = work done / time

$$= \frac{f \times 2\pi r}{\text{time for 1 rev}} = \frac{F \times 2\pi r}{60/N} \quad \text{— ③}$$

$$P = (f \times r) \frac{2\pi N}{60}$$

$\boxed{P = T\omega \text{ (watts)}}$ — ④

where T = Torque in N-m

ω = Angular speed in rad/sec

Power in Armature = Armature torque × ω

$$E_b I_a = T_a \times \frac{2\pi N}{60} \quad \text{— ⑤}$$

[$\because P = E_b I_a$]

W.k.T, $E_b = \frac{\phi Z N P}{60 A}$ — (6)

sub (6) in (5)

$$\frac{\phi Z N P}{60 A} I_a = T_a \times \frac{2\pi N}{60}$$

$$T_a = \frac{\phi Z N P}{60 A} \times I_a \times \frac{60}{2\pi N}$$

$$T_a = \frac{\phi I_a Z P}{2\pi A}$$

$$\therefore T_a = 0.159 \phi I_a \frac{PZ}{A} \text{ N-m}$$ — (7)

The above equation is torque equation of DC motor

$\therefore T_a = K \phi I_a$ where $K = 0.159 \frac{\phi Z}{A}$

$\therefore T_a \propto \phi I_a$

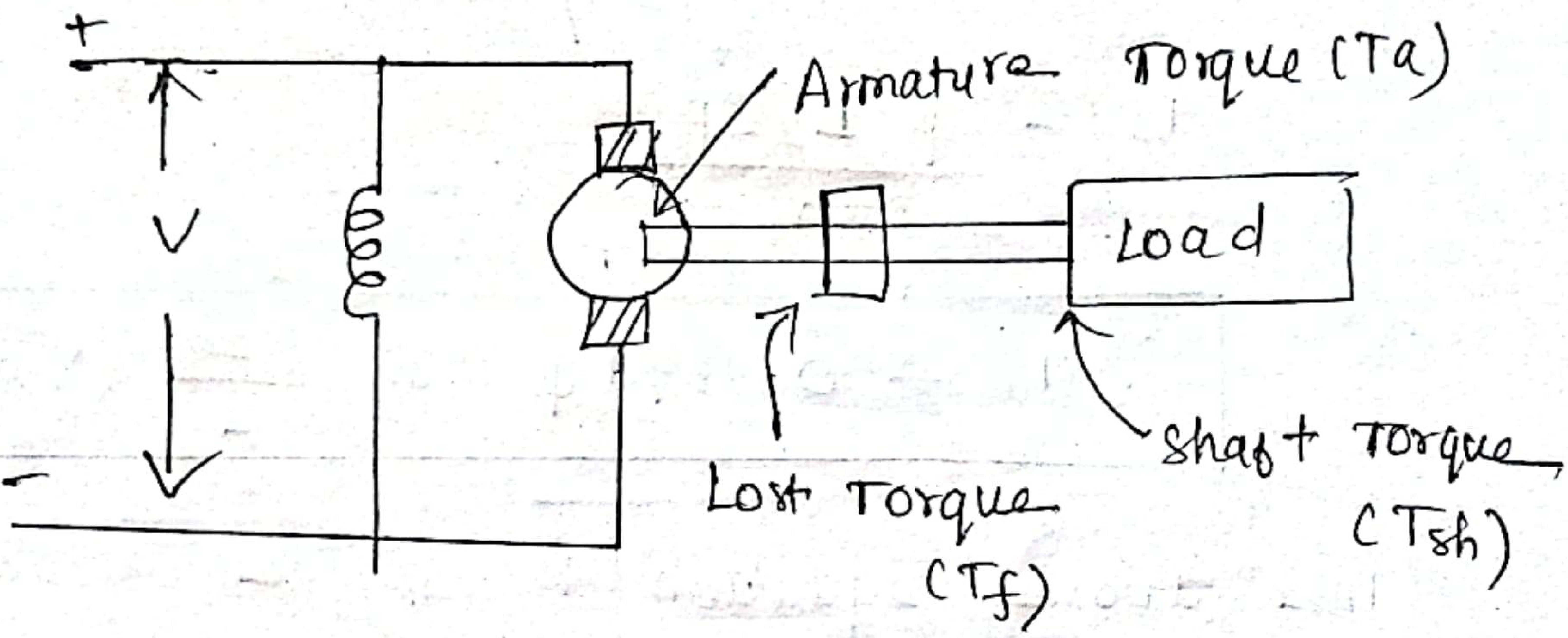
Shaft Torque

* The full armature torque is not available for doing useful work.

Some amount of torque is used for supplying iron loss and friction loss in the motor.

* This torque is called lost Torque (T_f)

* The remaining torque is available for doing useful work. This torque is known as shaft torque (or) useful Torque (T_{sh})



* The armature torque is sum of lost torque and shaft torque

$$\therefore \boxed{T_a = T_f + T_{sh}}$$

The o/p power of motor is

$$P_{out} = T_{sh} \times \frac{2\pi N}{60} \text{ watts}.$$

$$T_{sh} = \frac{P_{out}}{2\pi N} \times 60$$

$$\boxed{T_{sh} = 9.55 \frac{P_{out}}{N} \text{ N-m}}$$

Speed and Torque Equation

For DC motor the speed equation is obtained as follows

W.K.T $V = E_b + I_a R_a$ —— ①

$$E_b = \frac{\phi Z N P}{60 A} \quad —— ②$$

Sub ② in ①

$$V = \frac{\phi Z N P}{60 A} + I_a R_a$$

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

$$N = \frac{(V - I_a R_a) \times 60 A}{\phi Z P}$$

The values A, Z and P are constant

$$N = \frac{K (V - I_a R_a)}{\phi} \qquad \left[K = \frac{60 A}{Z P}\right]$$

where K → constant.

Speed equation becomes $N \propto \frac{V - I_a R_a}{\phi}$

(or) $$N \propto \frac{E_b}{\phi} \quad \text{--- (3)}$$

Hence speed of the motor is directly Proportional to back emf (E_b) and inversely Proportional to flux ϕ.

Torque equation

Torque equation of DC motor is given by

$$T \propto \phi I_a \quad \text{--- (4)}$$

Hence the flux ϕ is proportional to the current flowing through the field winding

$$\phi \propto I_f \quad \text{--- (5)}$$

DC shunt motor

* For DC shunt motor, the shunt field current (I_{sh}) is constant. Therefore flux ϕ is constant.

$T \propto \phi I_a$ becomes

$$T \propto I_a \quad \text{--- (6)}$$

DC Series Motor

The series field current is equal to Armature current I_a. Therefore flux $\phi \propto I_a$

Hence $T \propto \phi I_a$ becomes

$$T \propto I_a^2$$

* The speed and torque equations are mainly used for analyzing the characteristics of DC motors.

— X —

Characteristics of DC motor.

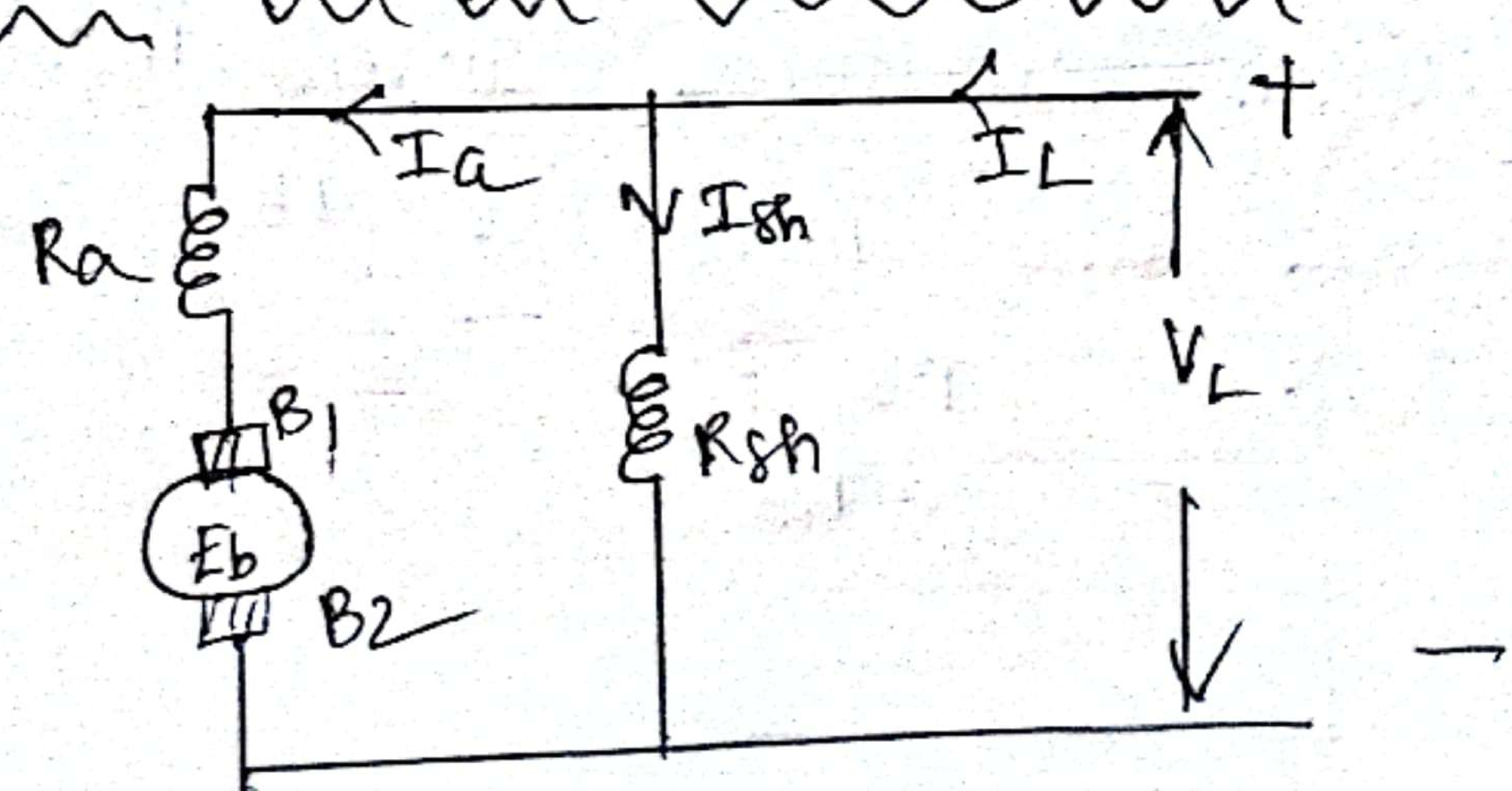
There are three types of characteristics.

① Speed - armature current characteristics.

② Torque - armature current characteristics.

③ Speed Torque characteristics.

DC Shunt motor characteristics.



(i) Speed armature current characteristics.

W.K.T $N \propto \frac{E_b}{\phi}$

In this m/c flux is constant $\therefore N \propto E_b$

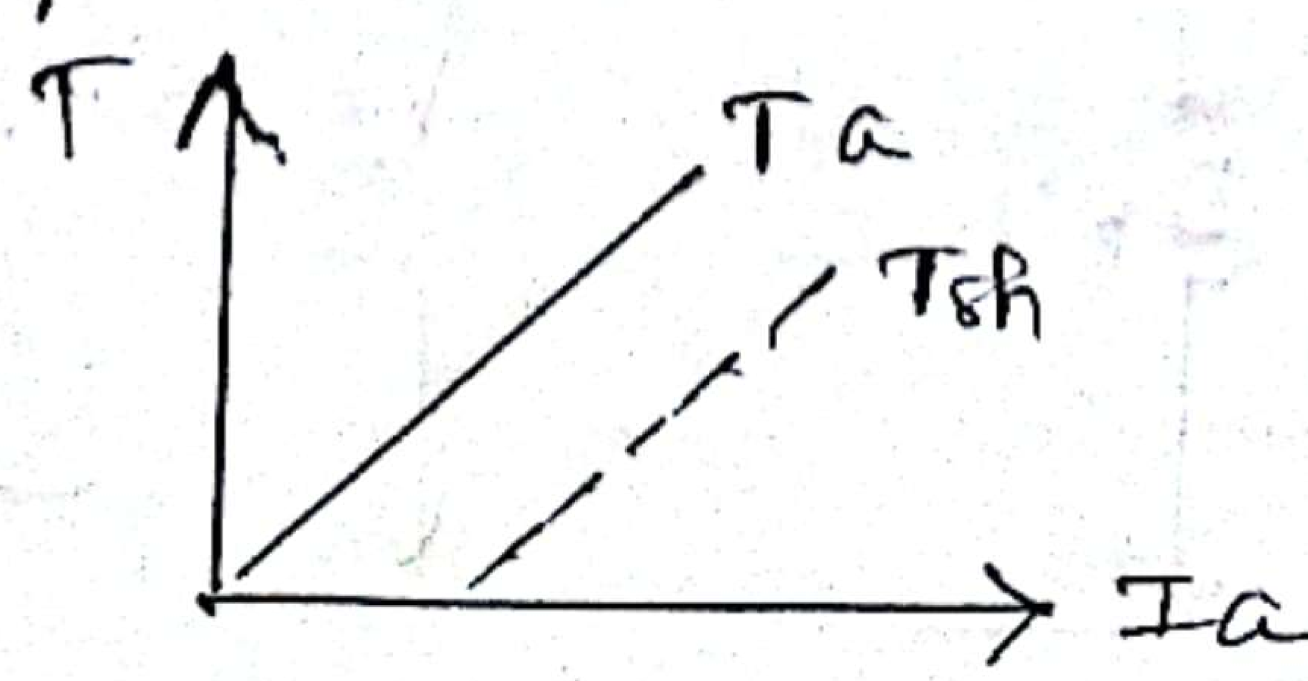
$\therefore N \propto V - I_a R_a$ This implies that speed is nearly constant except for a small drop.

This is shown in fig

(ii) Torque - armature characteristics (T Vs Ia)

* In Dc shunt motor Torque is directly proportional to armature current i.e $T \propto I_a$.

* So, when armature current increases, the torque also increases. It is shown in fig

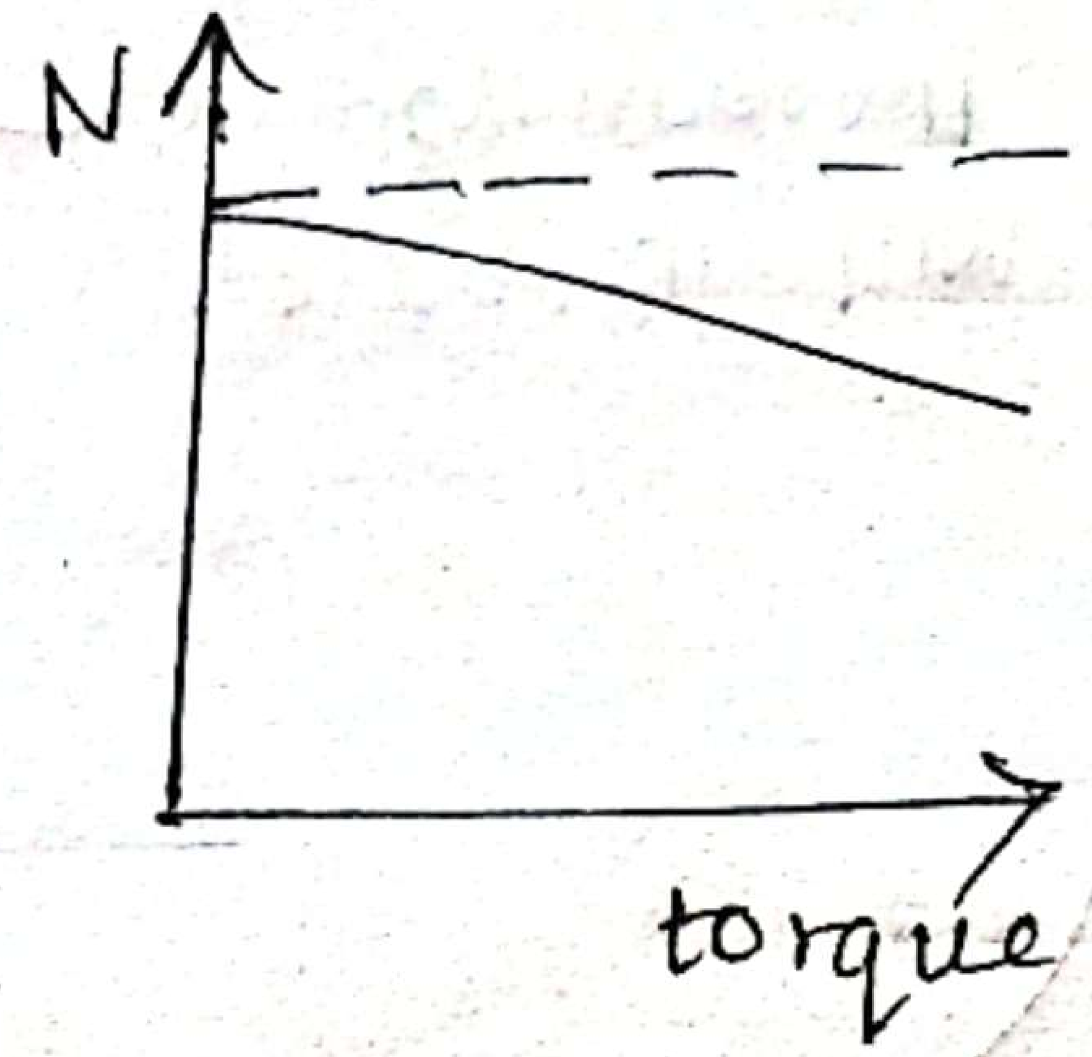


(iii) Speed - Torque characteristics (N Vs T)

* It is also called mechanical characteristics

* This characteristics can be got from the above two characteristics.

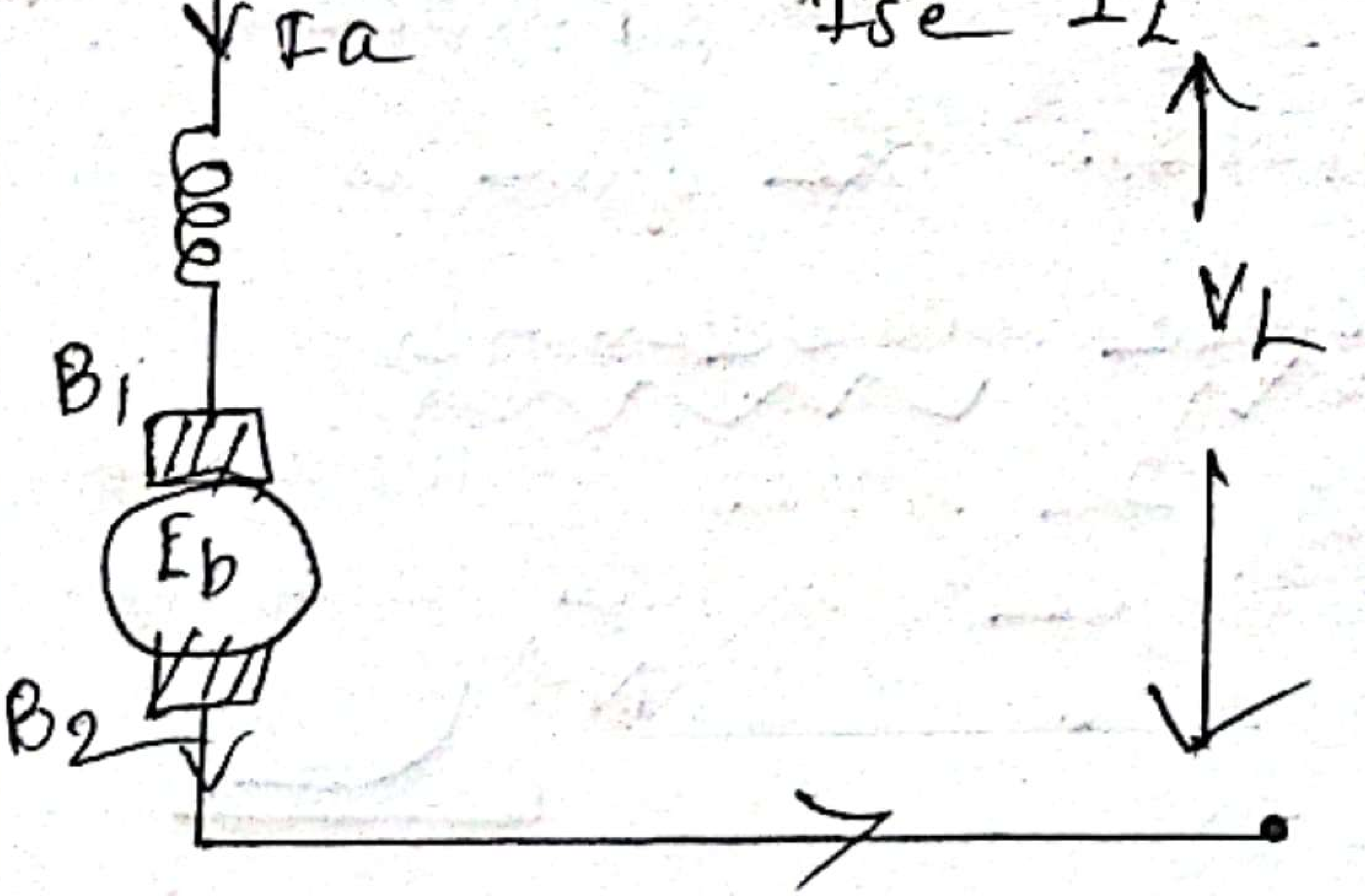
* Here when the load torque increases, the speed slightly decreases.



(b) DC series motor characteristics.

* In D.C series motor the field winding and armature winding in series.

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

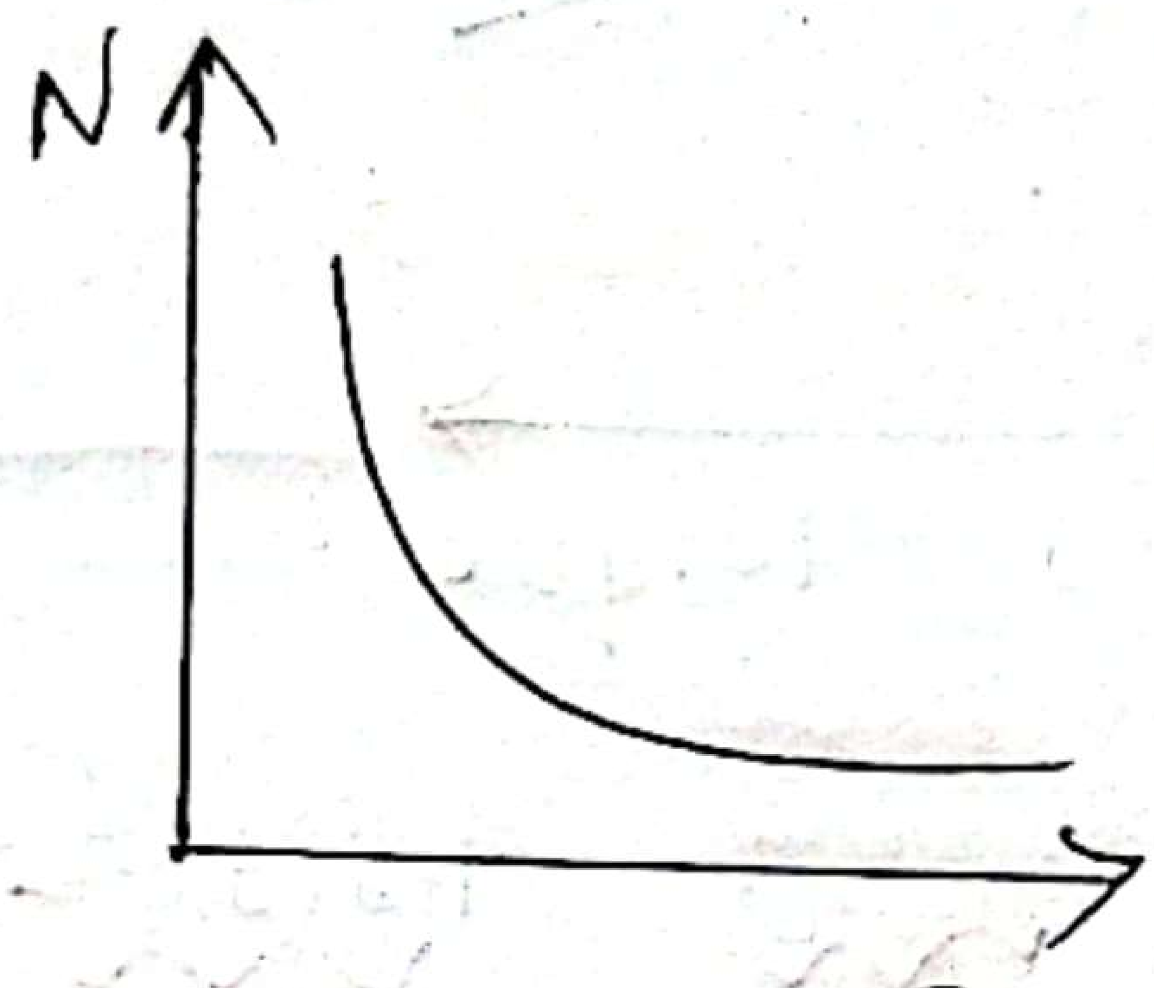


(i) Speed - Armature current Characteristics.

* In this machine field flux (ϕ) depends on field current through it. i.e. $\phi \propto I_{se} \propto I_a$

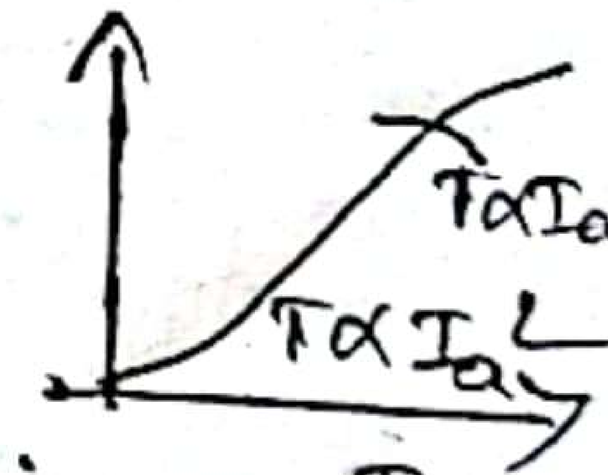
$\therefore \phi \propto I_a$

* $N \propto \frac{E_b}{I_a}$. From this equation, it is clear that by increasing the armature current speed will increase.



(ii) Torque Armature current characteristics.

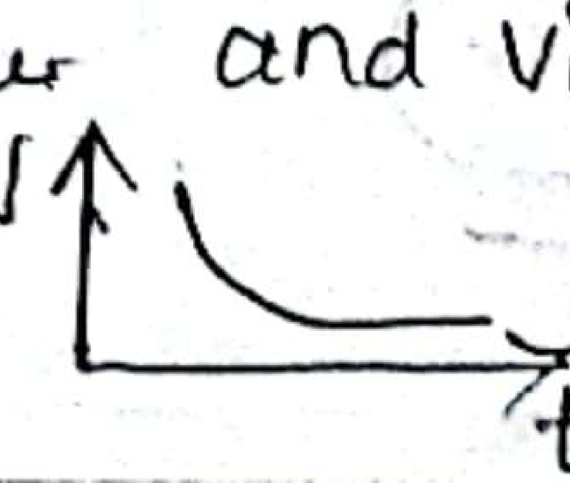
* In DC series motor $T \propto I_a^2$. As I_a increases T_a increases as the square of the current.



* This characteristics is a parabola.
* After saturation the flux is constant.

(iii) Speed - Torque characteristics

Here the DC series motor speed is high, the torque is low and viceversa. It is shown in fig.



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Starting and speed control.

Starter for DC motors :

Necessity of a starter :

The voltage equation of a DC motor is

$$V = E_b + I_a R_a$$

where $V \rightarrow$ supply voltage

$E_b \rightarrow$ back emf

$I_a \rightarrow$ armature current

$R_a \rightarrow$ armature resistance

$I_a \Rightarrow$ armature current ;

$$I_a = \frac{V - 0}{R_a} = \frac{V}{R_a}$$

Normally, the armature circuit resistance is always less than 1 Ω and for example let the supply voltage be 220V and

$R_a = 0.4\,\Omega$

$$I_a = \frac{220}{0.4} = 550\,A.$$

But for 5 kW motor, full load current

$$I = \frac{5000}{220} = 22.7A.$$

This excessive current has to be prevented, because

① It would cause heavy sparking at the brushes which may destroy the commutator and brush gear.

② It causes sudden depression of voltage of supply (large voltage drop) system causing disturbances to other loads connected in the system.

* To avoid this, a resistance is introduced in series with the armature (for the duration of starting period only), which limits the starting current to a safe value.

* The starting resistance is gradually cut out as the motor gains speed and develops the back emf, which then regulates the speed of the motor.

Types of DC motor starters.

1. Two point starter.
2. Three point starter.
3. Four point starter.

Speed control of DC shunt motor.

The speed of a dc motor is given by

$$N = \frac{V - I_a R_a}{Z\phi}\left(\frac{A}{P}\right).$$

(or)

$$N = \frac{K(V - I_a R_a)}{\phi}$$

where V = applied voltage.

I_a = armature current.

R_a = armature Resistance.

ϕ = flux per pole.

K = constant.

Stepper Motors

* Stepper Motor is a brushless DC motor whose rotor rotates through a fixed angular step in response to each input current pulse received by its controller.

* A Stepper motor is a digital actuator whose input is in the form of programmed energization of the stator windings and whose output is in the form of discrete angular rotation.

* The stepper motor is ideally suited for an actuator in computer control system, digital control system etc.

* The main feature of a stepper motor is that rotor rotates in discrete angular intervals or steps, one step being taken each time a command pulse is received.

* When definite number pulses are applied to the motor, the rotor rotates through a definite known angle.

* Due to this stepper motor is mainly used for open-loop position control because of no feedback signal from the motor shaft.

Step Angle

Step angle is defined as the angle through which the stepper motor shaft rotates for each command pulse. It is denoted by β

(i) $$\beta = \frac{N_s \sim N_r}{N_s \cdot N_r} \times 360°$$

N_s – Number of stator poles.

N_r – Number of rotor poles.

(ii) $$\text{Step angle } \beta = \frac{360°}{m N_r}$$

$m \rightarrow$ Number of stator phases

Resolution ⇒ defined as the Number of steps needed to complete one revolution of the rotor shaft.

$$\text{Resolution} = \frac{\text{Number of steps}}{\text{revolution}} = \frac{360}{\beta}.$$

Applications

1. Robotics 2. Computer peripherals.
3. Facsimile machine 4. Aerospace.

Brushless DC Motors

* A Brushless DC electric motor (BLDC motor) also known as electronically commutated motor or Synchronous DC motor, is a synchronous motor using a direct current (DC) electric power supply.

* A motor converts supplied electrical energy into mechanical energy.

* Brushless DC motors (BLDC) feature high efficiency and excellent controllability and are widely used in many applications.

* The BLDC motor has power-saving advantages relative to other motor types.

* The controller provides pulses of current to the motor windings which control the speed and torque of the synchronous motor.

Applications

Linear Motors
Servo motors.
Actuators for industrial robots.
Extruder drive motors and feed drives for CNC machine tools.

Universal Motor

* Universal motor is a type of electric motor that can operate on either DC or AC power and uses an electromagnet as its stator to create magnetic field.

* It is commutated series - wound motor where the stator's field coils are connected in series with the rotor windings through a commutator.

* It is often referred to as an AC series motor.

There are two basic types of universal motors.

(i) compensated type
(ii) uncompensated type.

Applications

* Used in table fans, hairdryers and grinders
* portable drill machines
* polisher, blowers and kitchen appliances.

UNIT-III

AC Rotating Machines

Principle of operation of three-phase induction motors - construction - Types - Equivalent circuit, speed control - single phase Induction motors - construction - Types - Starting Methods. Alternator : working principle - Equation of Induced EMF - voltage regulation, Synchronous motors - working Principle - starting methods - Torque Equation.

Three phase Induction Motor.

* Three phase induction Motors are extensively used for electric drives

Advantages

* It is simple and extremely rugged construction
* High reliability.
* Low cost
* High efficiency.
* It requires little maintenance.
* Its ability to start off from rest unlike synchronous motors which have to be started and run up by seperate prime movers.

Disadvantages

(i) The speed is not constant, when load is varied.

(ii) Low starting torque compared to DC shunt motor.

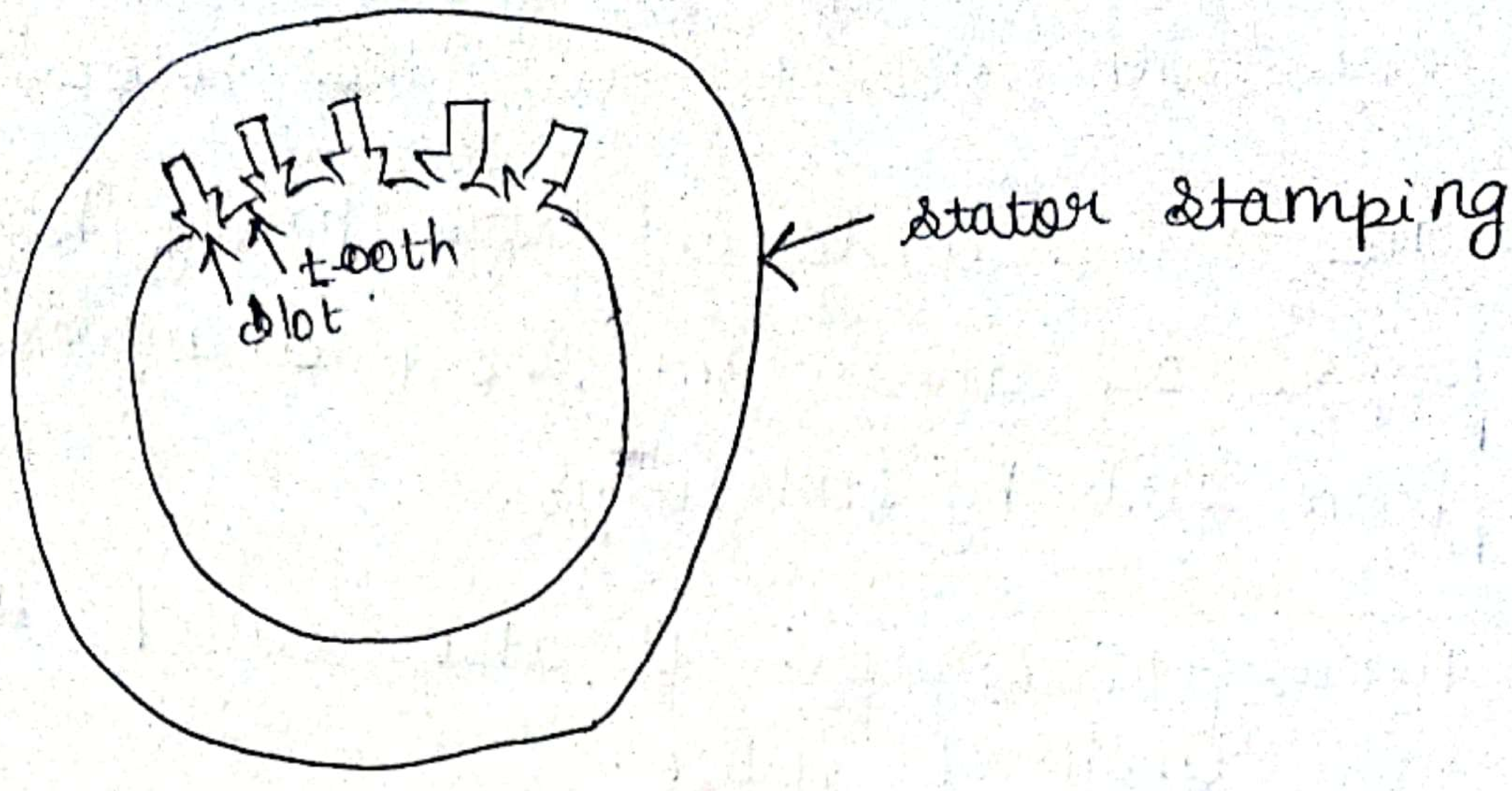
(iii) Reduction in efficieny when speed is varied.

Construction

The induction motor consists of two main Parts. Viz (a) Stator
(b) rotor.

Stator

* The stator is made up of a number of stampings with alternate slot and tooth.
* Stampings are insulated from each other
* Each stamping is 0.4 and 0.5 mm thick.
* Number of stampings are stamped together to build the stator core.
* The stator core is then fitted in a casted or fabricated steel frame.
* Three-phase winding is called stator winding
* It may be connected either in star or delta.



Rotor

There are two types of rotors used in induction motors.

They are 1. squirrel cage rotor
2. slip ring or wound rotor.

(1) Squirrel cage rotor

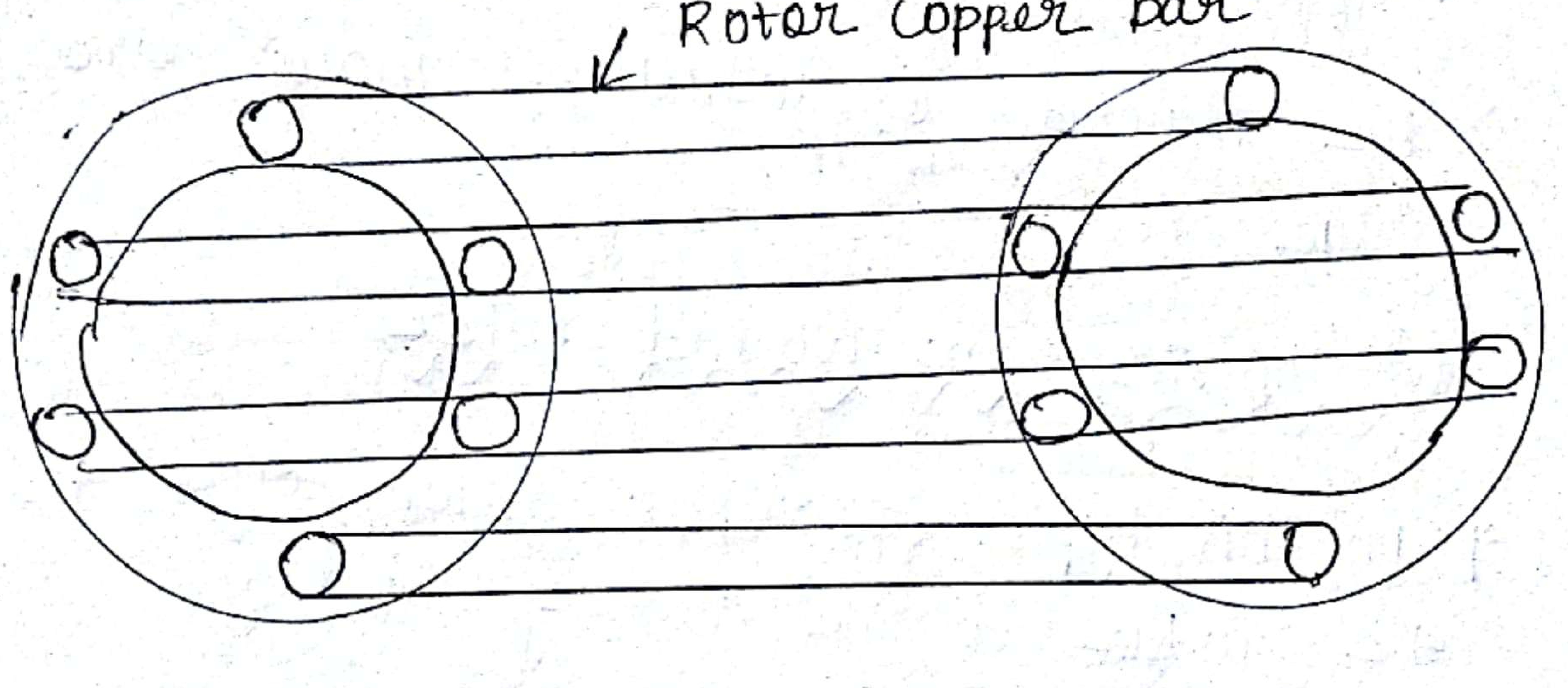


Fig : Squirrel cage rotor.

* This is made up of a cylindrical laminated core with slots to carry the rotor conductors.

* The rotor conductors are heavy bars of copper or aluminium short circuited at both ends by end rings.

* Hence this rotor is also called a short circuited rotor.

* The entire rotor resistance is very small.
* External resistance cannot be connected in the rotor circuit.

* Such motors are extremely rugged in construction.

* Motors using such rotors are called squirrel cage induction motors.

* The majority of induction motors are cage rotors.

② Slip ring or Wound rotor

* In this type of rotor, rotor windings are similar to the stator winding.

* The rotor winding may be star or delta connected, distributed winding.

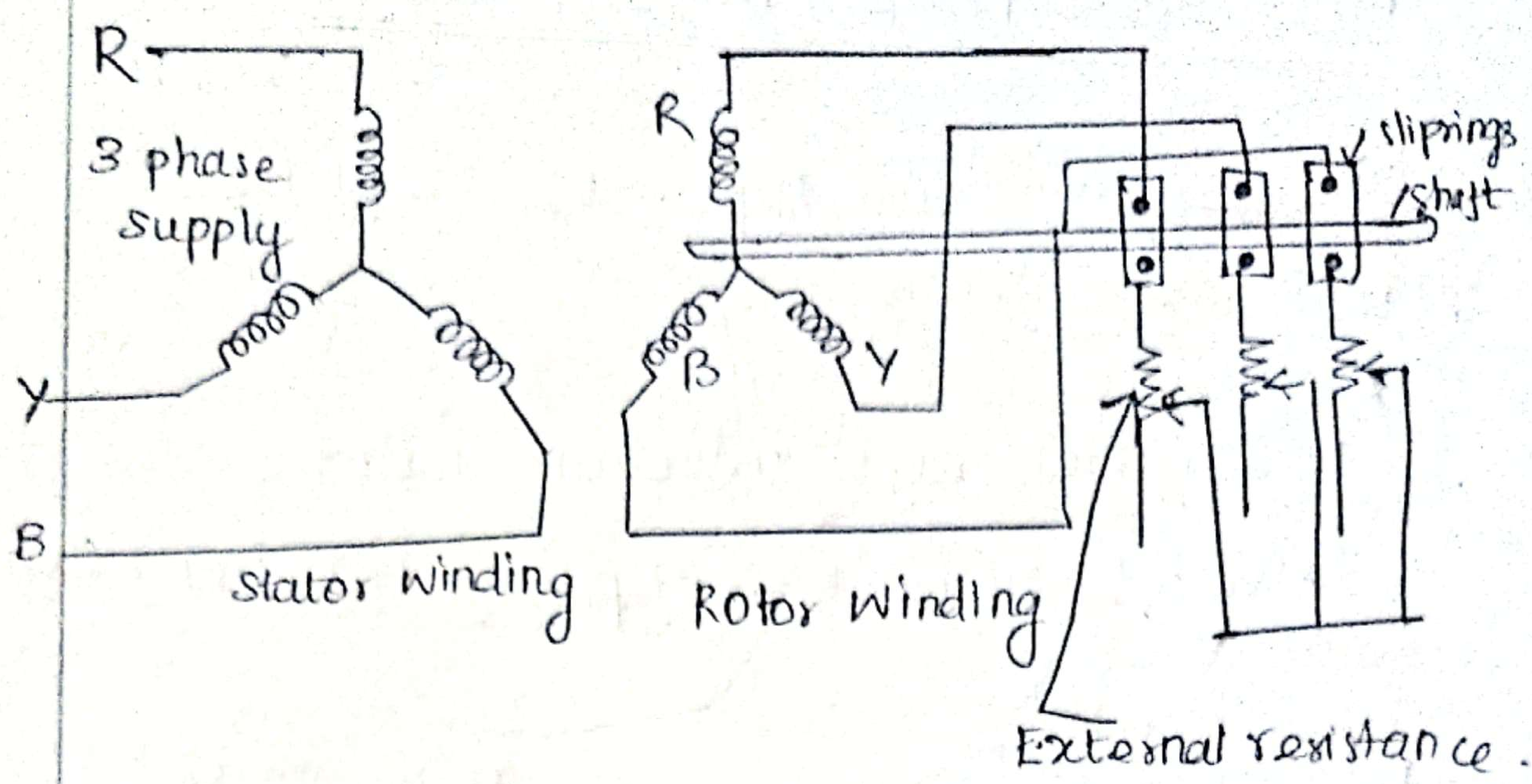


Fig: SlipRing (or) wound Rotor

* The ~~two~~ three phases are connected to slip rings mounted on the rotor shaft.

* Variable External resistance can be connected in the rotor circuit, with the help of brushes and slip ring arrangements.

* By varying the external resistance in the rotor circuit, the motor speed and torque can be controlled.

* This motor is called slipring Induction motor or wound rotor induction motor.

Types of 3- Phase induction motors.

There are two types of 3- phase induction motors.

1. squirrel cage induction motor
2. Wound rotor or slip ring induction motor.

Principle of operation of three phase Induction motor

* three -Phase supply is given to the stator winding.
* Due to this, current flows through the stator winding.
* This current is called stator current.
* It produces a rotating magnetic field in the space between stator and rotor.
* This magnetic field rotates at synchronous speed given by

$$N_s = \frac{120f}{P}$$

N_s = Synchronous speed

f - Supply Frequency

P = number of poles for which the stator is wound.

* As a result of the rotating magnetic field cutting the rotor conductors, an emf is induced in the rotor.

* If the rotor winding is shorted, then the induced emf produces current.

* This current produces a rotor field.

* The interaction of stator and rotor fields develops torque.

* Then the rotor rotates in the same direction as the rotating magnetic field.

* When the rotor is at standstill, the frequency of rotor emf is equal to the supply frequency.

* As the rotor speed picks up, the frequency of rotor emf and the magnitude of rotor emf decrease.

* The rotor tries to catch up with the rotating magnetic field.
* However, the rotor cannot really catch up and rotate at the synchronous speed, because if it does so, the relative speed would become zero.
* And then there is no rotor induced emf, no current and hence no torque.
* Therefore, the rotor runs at a speed slightly less than the synchronous speed.
* In an induction motor, the rotor speed is always less than the synchronous speed.
* Therefore this machine is called an asynchronous machine.
* The difference between synchronous speed and rotor speed is called the slip speed.

$$\text{Slipspeed} = N_s - N$$

$$\text{Slip, } s = \frac{N_s - N}{N_s}$$

$$N = N_s(1-s)$$

$$\% \text{ slip} = \frac{N_s - N}{N_s} \times 100$$

* At no load, the difference between synchronous speed and rotor speed is only about 1%.

* At loaded condition, the rotor slows down.

* The emf induced in the rotor and hence the rotor current increase.

* Due to this, torque also increases.

* Under steady state conditions, the electromagnetic torque is equal to the load torque.

* The variation of speed from no load to full load is very small.

* Thus a three phase induction motor is also called a constant speed motor.

Advantages of squirrel cage induction motor

1. cheaper
2. Light Weight.
3. Rugged Construction.
4. More efficient.
5. Requires less maintenance
6. It can be operated in dirty & explosive environment

Disadvantages of squirrel cage induction Motor

1. Moderate starting torque.
2. External resistance cannot be connected to rotor circuit. So starting torque cannot be controlled.

Applications of squirrel cage induction Motor

Lathes, drillilling machines, fans, blowers, Water pumps, grinders, printing machines.

Advantages of slip ring induction motor.

1. the starting torque can be controlled by varying the rotor circuit resistance.
2. The speed of the motor can be controlled.

Disadvantages of slip ring induction motor

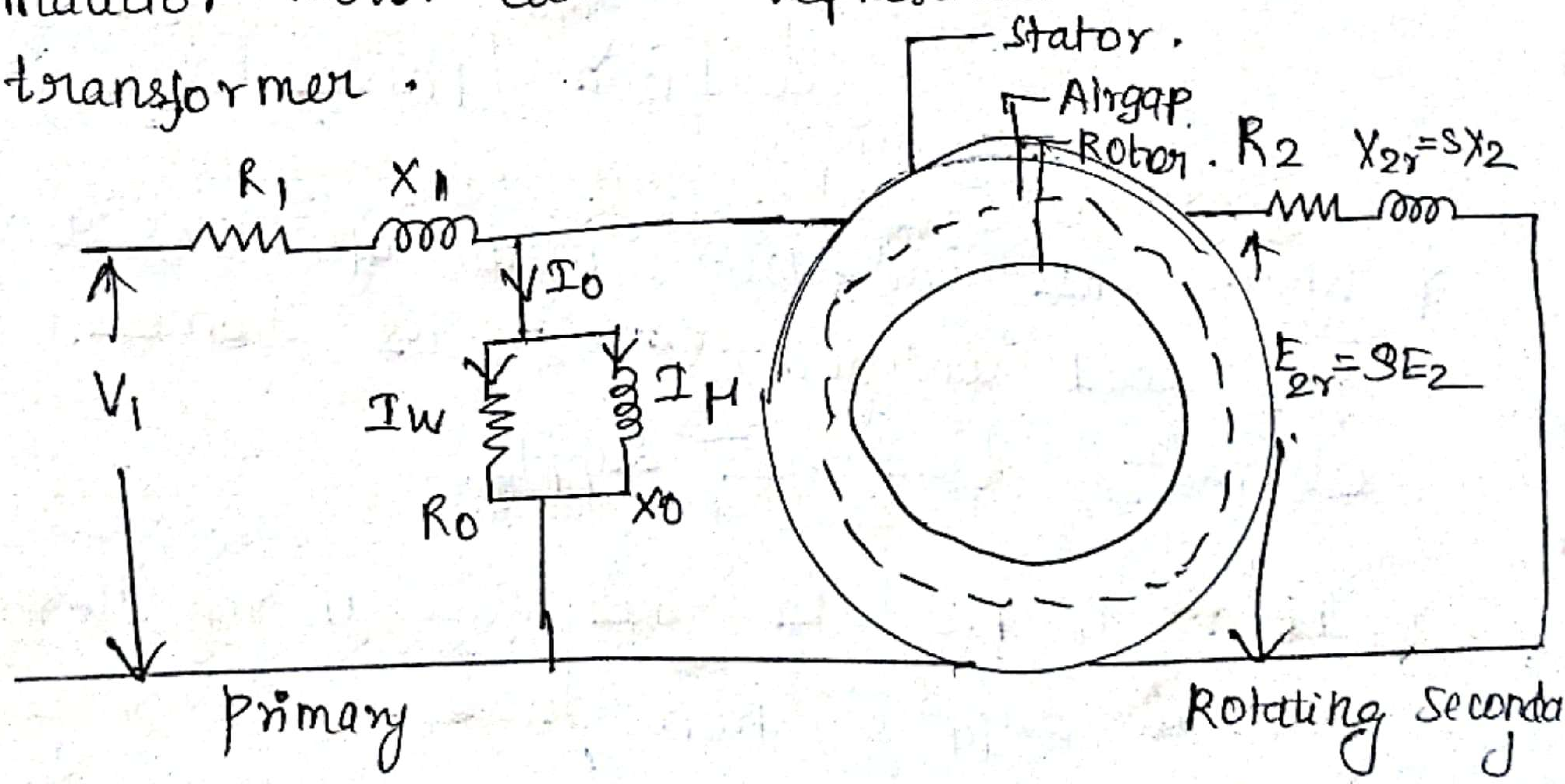
1. High cost
2. High rotor inertia.
3. High speed limitation.

Application

Lifts, hoists, cranes, elevators, compressors.

Equivalent circuit of Three phase Induction Motor

* The three phase Induction motor is generally treated as a rotating transformer.
* The transformer has two windings one is Primary and another one, secondary winding.
* Similarly in an induction motor, stator acts as primary and rotor acts as rotating secondary (or short circuited).
* Hence, the transfer of energy from stator to rotor in an induction motor takes place entirely inductively linking the two.
* The diagram below shows how an Inductor motor can be represented as a transformer.



Let

V_1 = supply voltage per phase

E_1 = The induced emf in stator / phase due to self induction

E_2 = The induced emf in the rotor due to mutual induction at standstill.

R_1 = Stator resistance / phase

X_1 - Stator reactance / phase

R_2 = Rotor resistance / Phase

X_{2r} ⇒ Rotor reactance / Phase in running condition (sX_2)

E_{2r} ⇒ Rotor induced emf in running condition / phase (sE_2)

* When the induction motor operates under no load condition, it draws some current from the supply.

* It is to produce the flux in the air gap and to supply iron losses.

* Normally the no load current consists of two components i.e I_W. I_μ.

$$\bar{I_0} = \bar{I_W} + \bar{I_\mu}$$

Where

I_W = Working component which supplies no load losses.

I_μ = Magnetising component which sets up flux in core and airgap.

R_0 = No-load resistance / phase $= \frac{V_I}{I_W}$

X_0 = No-load reactance / phase $= \frac{V_I}{I_\mu}$

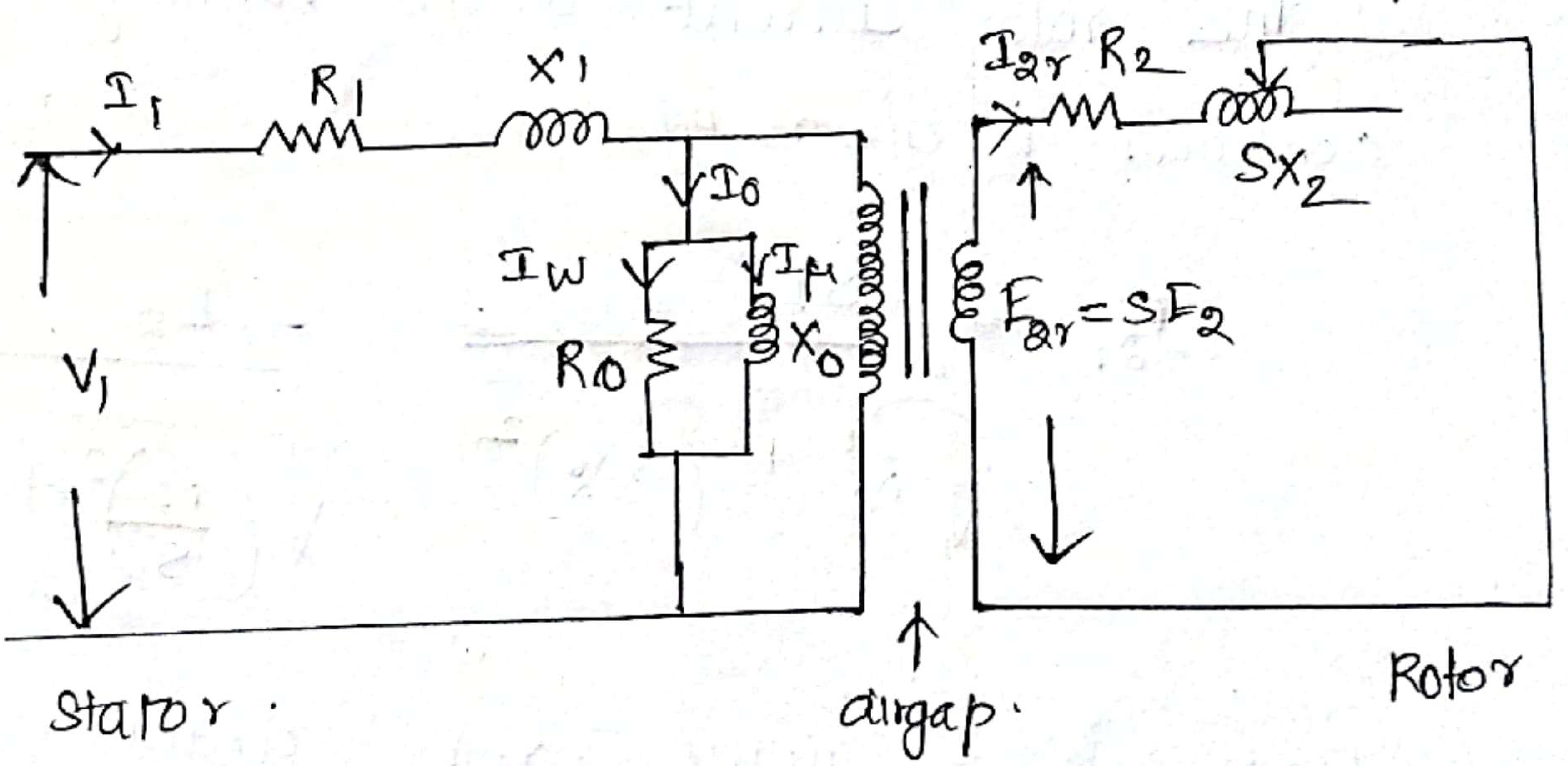


Fig: Equivalent circuit of an induction motor.

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I_{2r} = Rotor current under running Condition.

$$= \frac{E_{2r}}{Z_{2r}} = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

* When the Induction motor load changes, the motor speed also changes.
* correspondingly slip also changes
* Due to this reactance X_{2r} Changes.

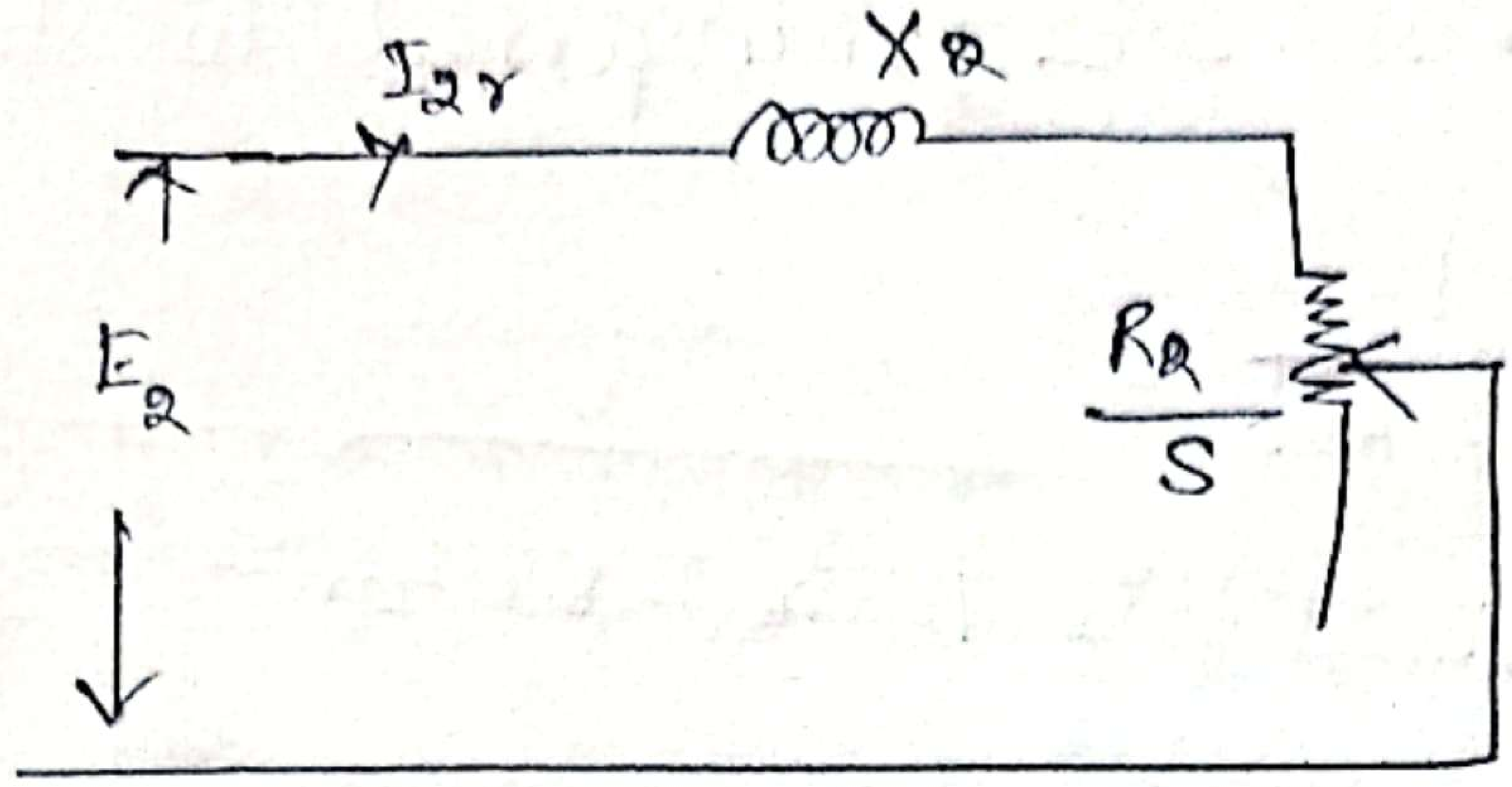
So it is Indicated as a Variable element.

Equivalent circuit of the rotor

The rotor current under running condition is given by,

$$I_{2r} = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}} = \frac{E_2}{\sqrt{\left(\frac{R_2}{S}\right)^2 + X_2^2}}$$

From this equation, rotor circuit consists of a fixed reactance X_2 in series with a Variable resistance $\frac{R_2}{S}$ and supplied with fixed Voltage E_2 as shown in fig.



Now the variable resistance can be written as,

$$\frac{R_2}{S} = R_2 + \frac{R_2}{S} - R_2$$

$$= R_2 + R_2\left(\frac{1}{S} - 1\right) = R_2 + R_2\left(\frac{1-S}{S}\right).$$

* Now the Variable resistance $\frac{R_2}{S}$ consists of two parts ie, R_2, $R_2\left(\frac{1-S}{S}\right)$

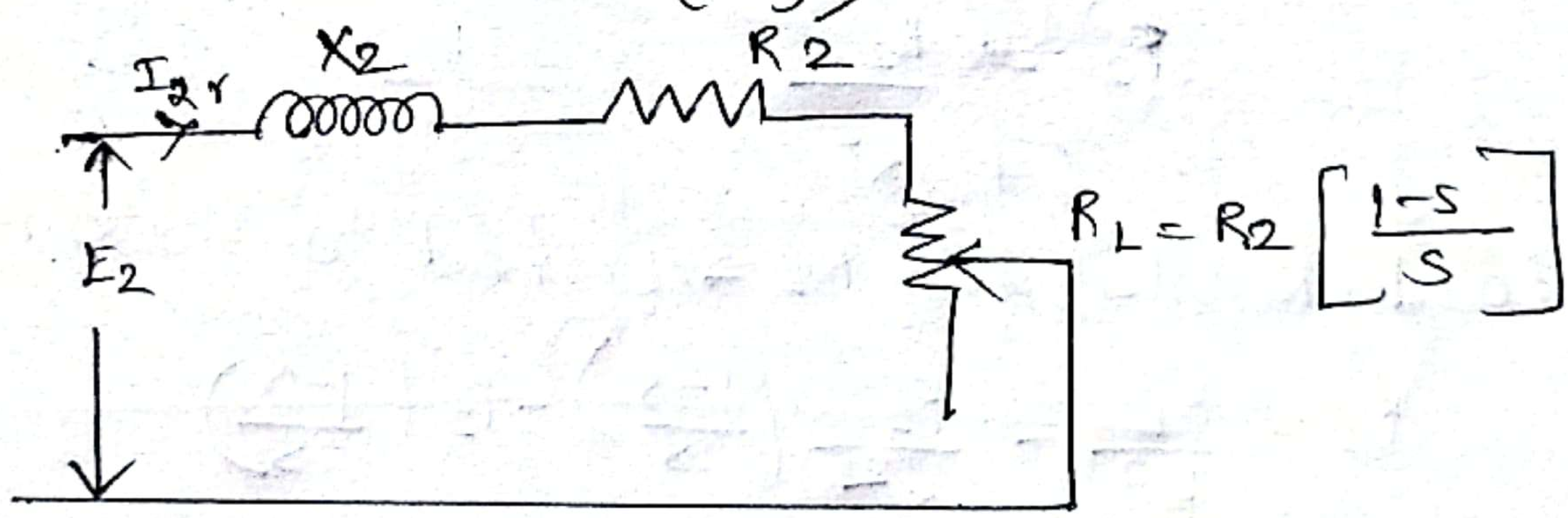


fig: equivalent circuit of rotor along with load Resistance R_L.

Equivalent circuit referred to stator

K = Transformation ratio = $\frac{E_2}{E_1}$

Rotor parameters are transferred to stator.

$$E_2' = \frac{E_2}{K}$$

Rotor current referred to stator :

$$I'_{2r} = K\, I_{2r} = \frac{K S E_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

Rotor Reactance referred to stator (X_2')

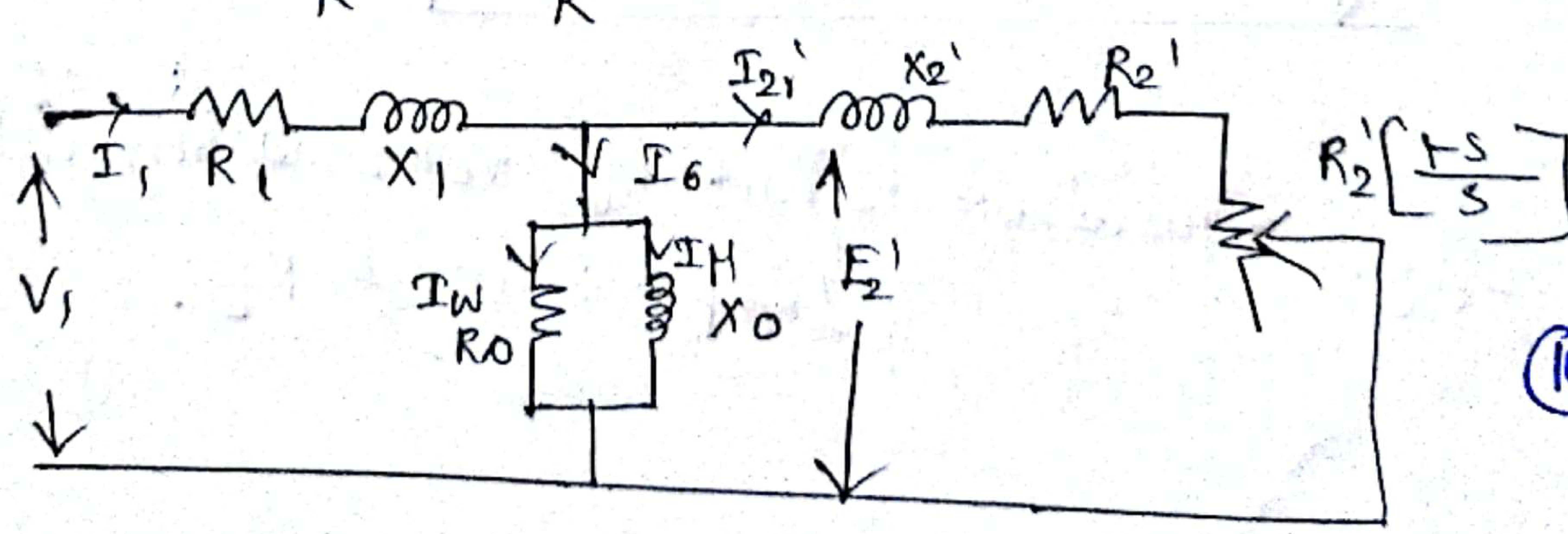
$$X'_2 = \frac{X_2}{K^2}$$

Rotor Resistance referred to stator (R_2')

$$R_2' = \frac{R_2}{K^2}$$

Load Resistance R_L referred to stator

$$R_L = \frac{R_L}{K^2} = \frac{R_2}{K^2}\left(\frac{1-S}{S}\right) = R_2'\left(\frac{1-S}{S}\right)$$



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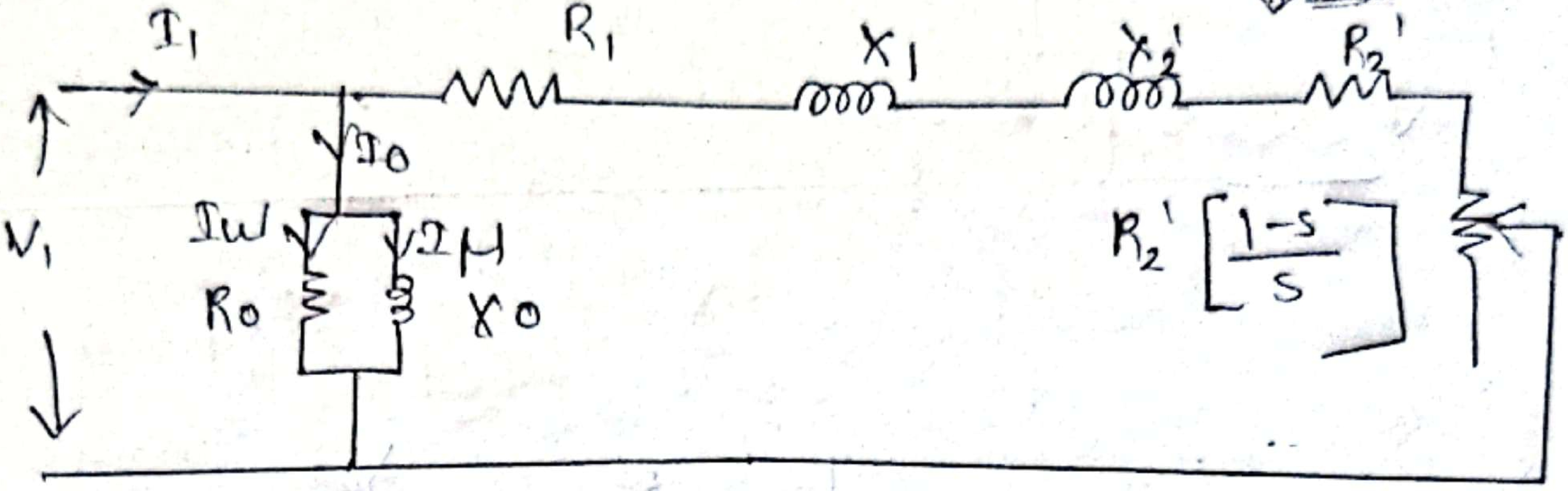
Approximate equivalent circuit.

* The exciting circuit consists of R_o and X_o.
* This exciting circuit is transferred to the left of R_1 and X_1
* This is known as approximate equivalent circuit.

⇓ Fig.



Now the circuit is further simplified combined resistance R_1 and R_2' similarly reactance X_1 and X_2'

R_{01} = Equivalent resistance referred to stator

$$= R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

X_{01} = Equivalent reactance referred to stator

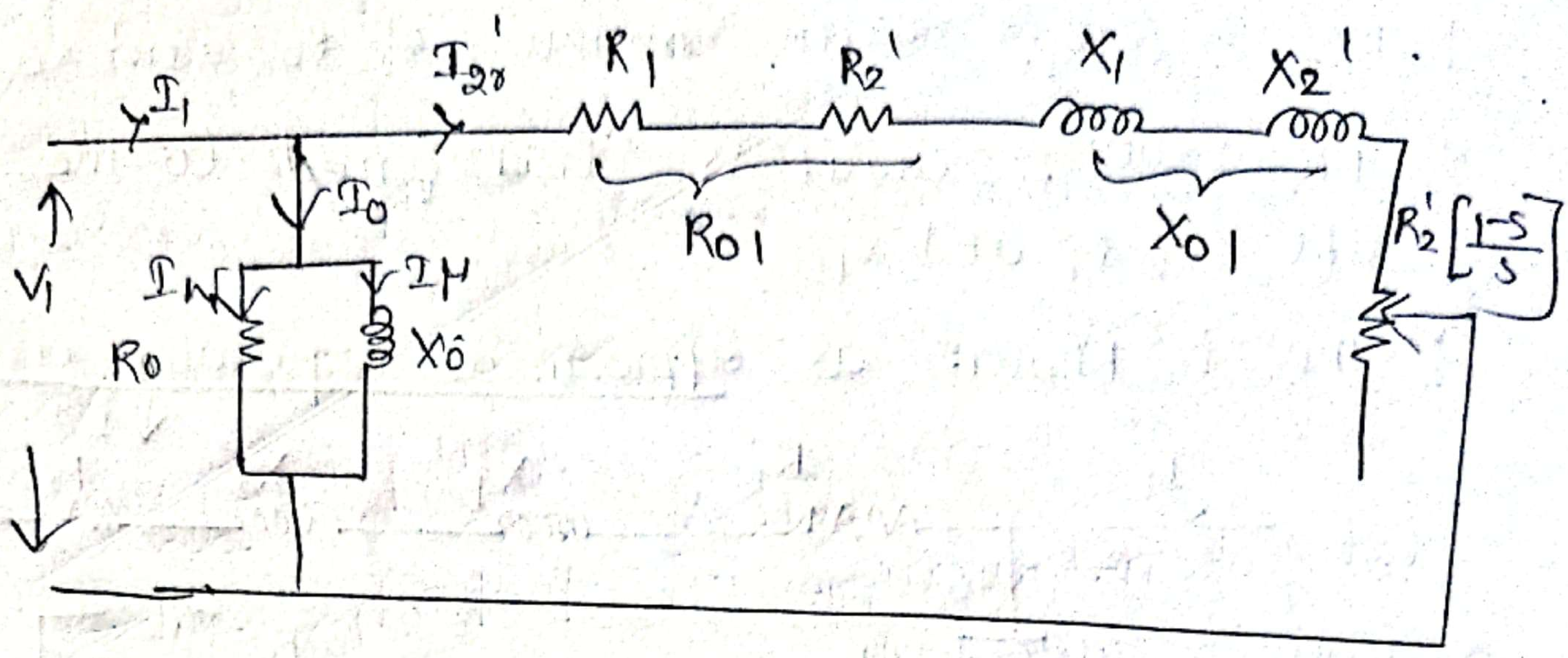
$$= X_1 + X_2'$$

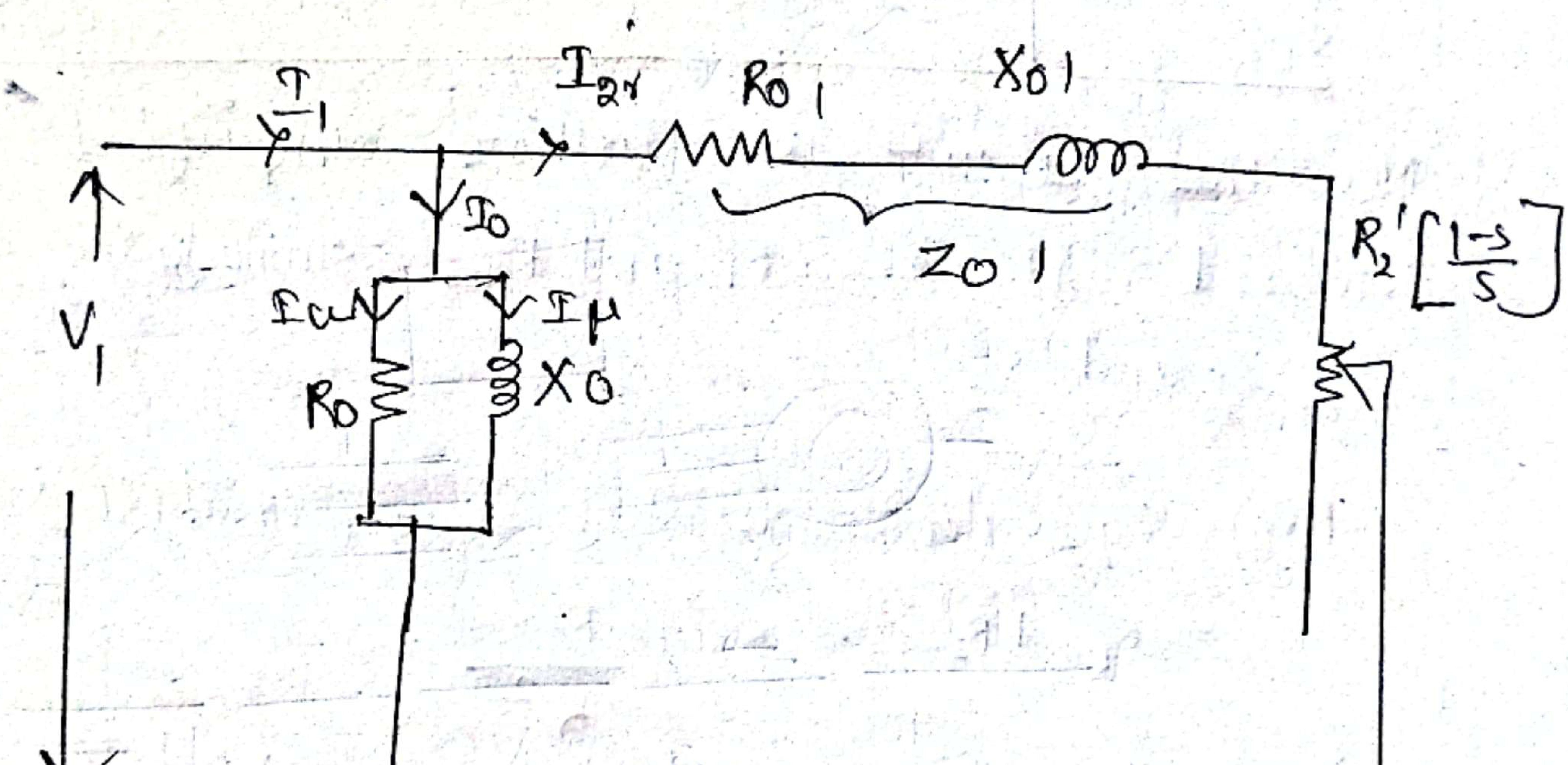
$$= X_1 + \frac{X_2}{K^2}$$

$$\bar{I}_1 = \bar{I}_0 + \bar{I}_{2r}'$$

$$\bar{I}_0 = \bar{I}_W + \bar{I}_\mu$$

The equivalent circuit is shown in figure.





Speed control of Three phase Induction Motor

⇒ The speed of an induction Motor can be controlled by two major methods.

⇒ They are

* Stator side control
* Rotor side control.

* The first method is applicable for both squirrel-cage and wound-rotor motors.
* The second Method can be used only for Wound-rotor motors.

* Stator side control means, we have to vary the stator side parameters i.e, supply voltage, frequency, no. of Poles etc.

* Rotor side control means, we have to vary the ~~Stator~~ Rotor side parameters, i.e rotor resistance.

~~Types of speed control~~

Types of stator side control

1. Stator Voltage control
2. Stator Frequency control.
3. V/f control
4. Pole changing Method.

Types of rotor side control.

1. Adding external resistance in the rotor circuit
2. Cascade control.
3. Slip power recovery voltage.

Stator side control.

① Change in Stator Voltage

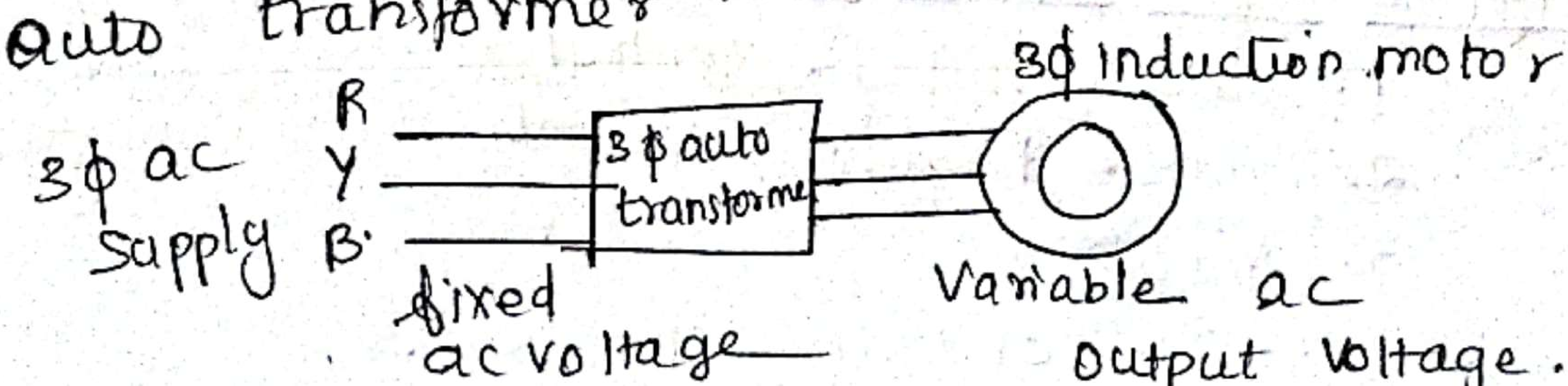
The speed of the induction motor can be controlled by varying the stator voltage. This method of speed control is known as stator voltage control. Here, the supply frequency is constant. The stator voltage can be controlled by two methods.

(i) Using auto transformer.

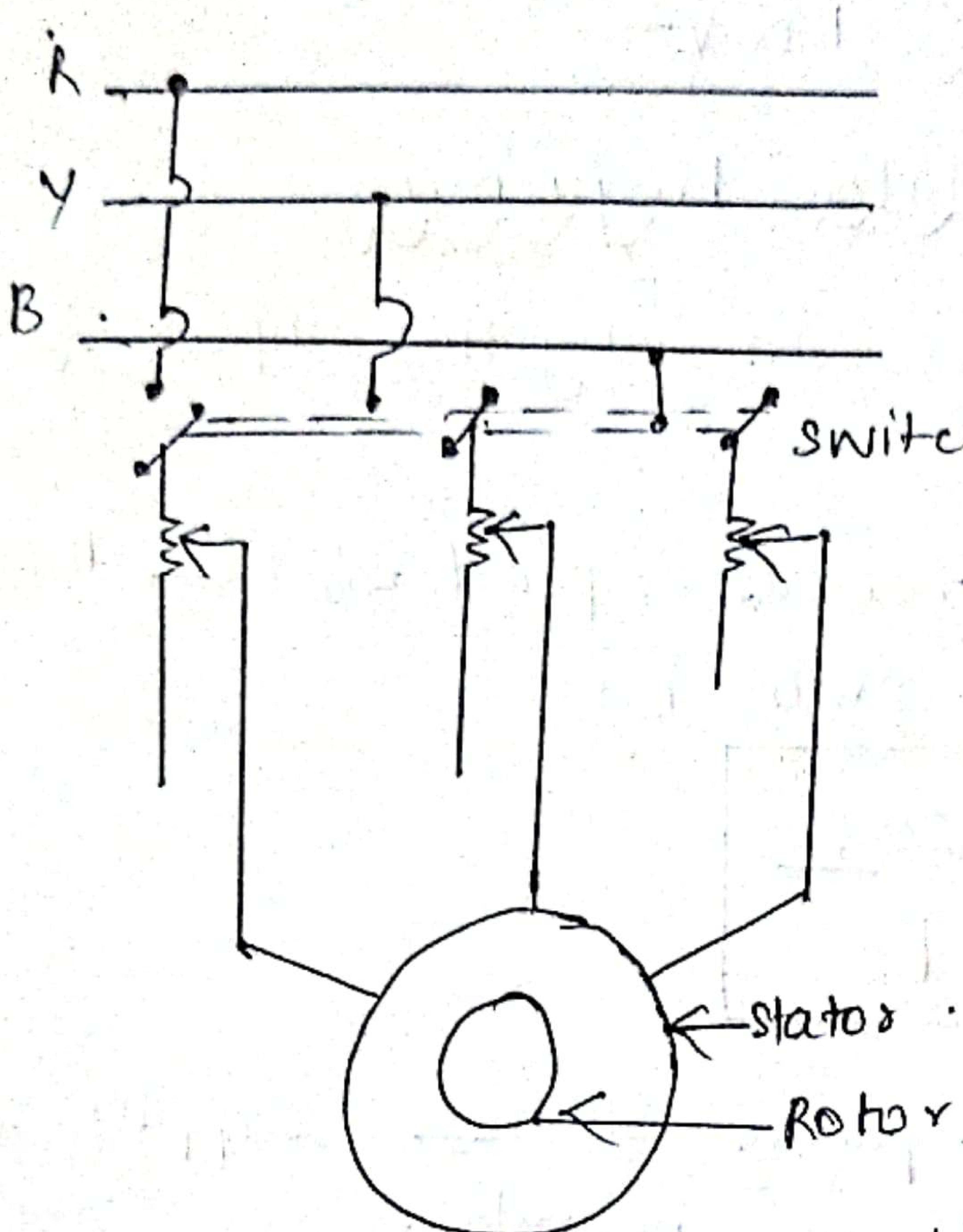
(ii) Primary resistors connected in series with stator winding.

(i) Using Auto transformers.

The speed of the induction motor can be controlled by using auto transformer.



(ii) Primary Resistors connected in series with Stator winding

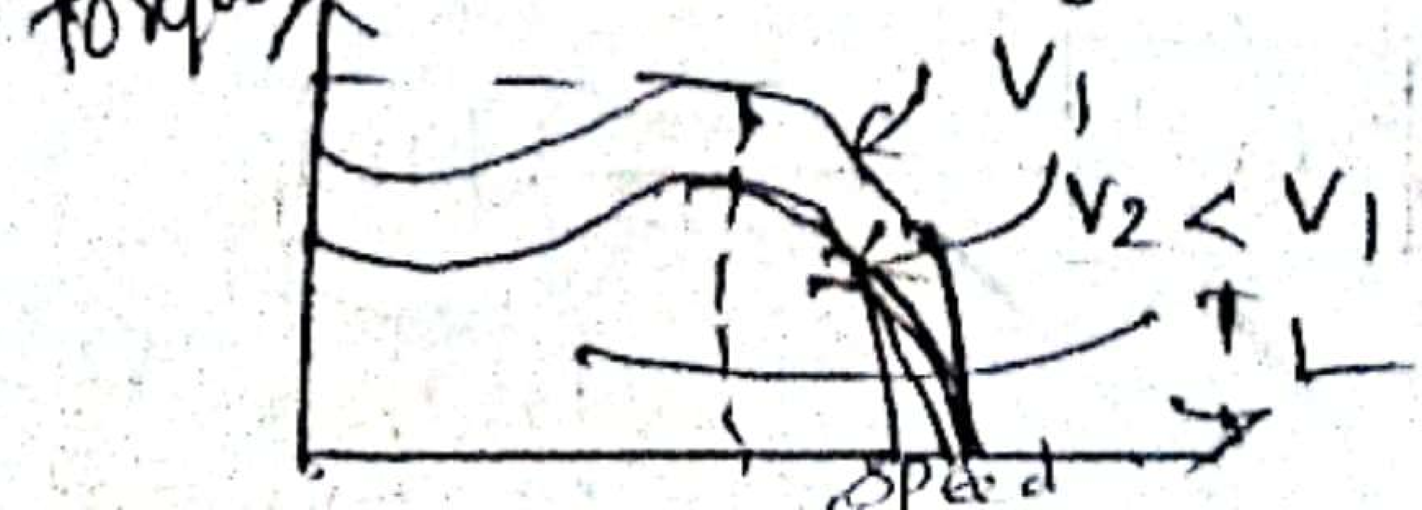


* By varying the primary resistance, the voltage drop across the motor terminals is reduced.

* That is, reduced voltage is fed to the motor.

* Then the motor speed can be reduced.

Fig: Speed Torque characteristics of Induction motor Under Stator voltage control.



Torque is proportional to the square of its stator voltage

i.e. $T \propto V^2$

② Change in stator Frequency

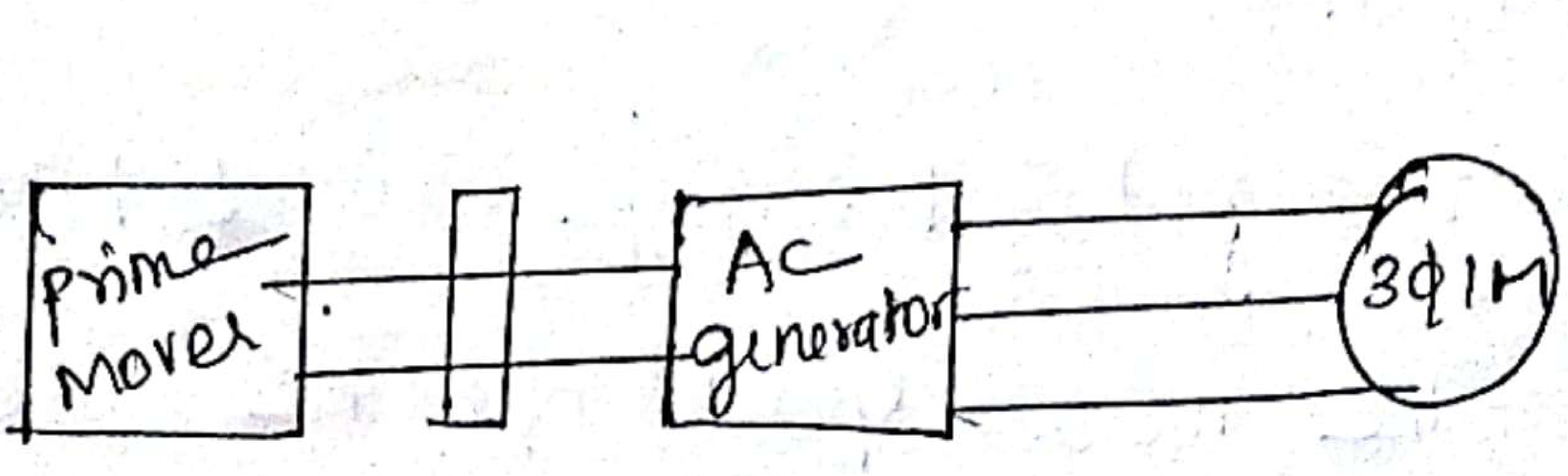
* Here, we can vary the input frequency of the motor.

The synchronous speed of the induction motor is given by

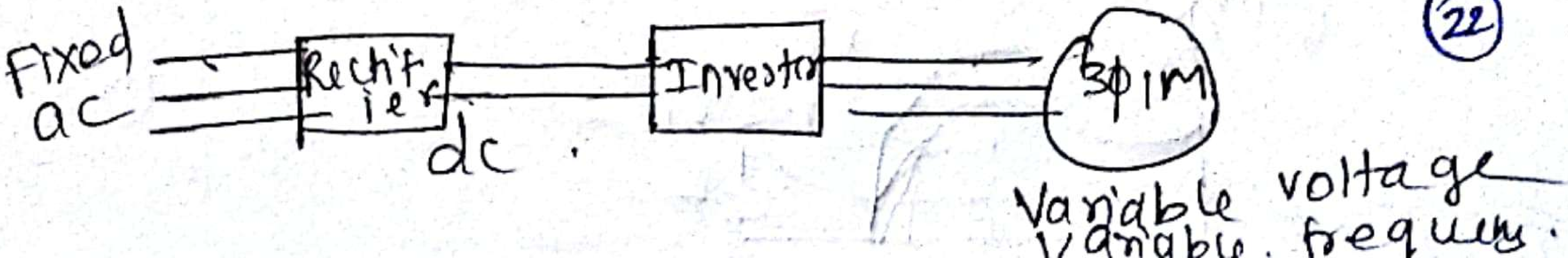
$$N_s = \frac{120 f}{P}$$

Where, f = frequency of the supply voltage.
P = Number of poles.

* In this equation synchronous speed of the motor is directly proportional to the frequency of the supply voltage.



③ Voltage / Frequency control:



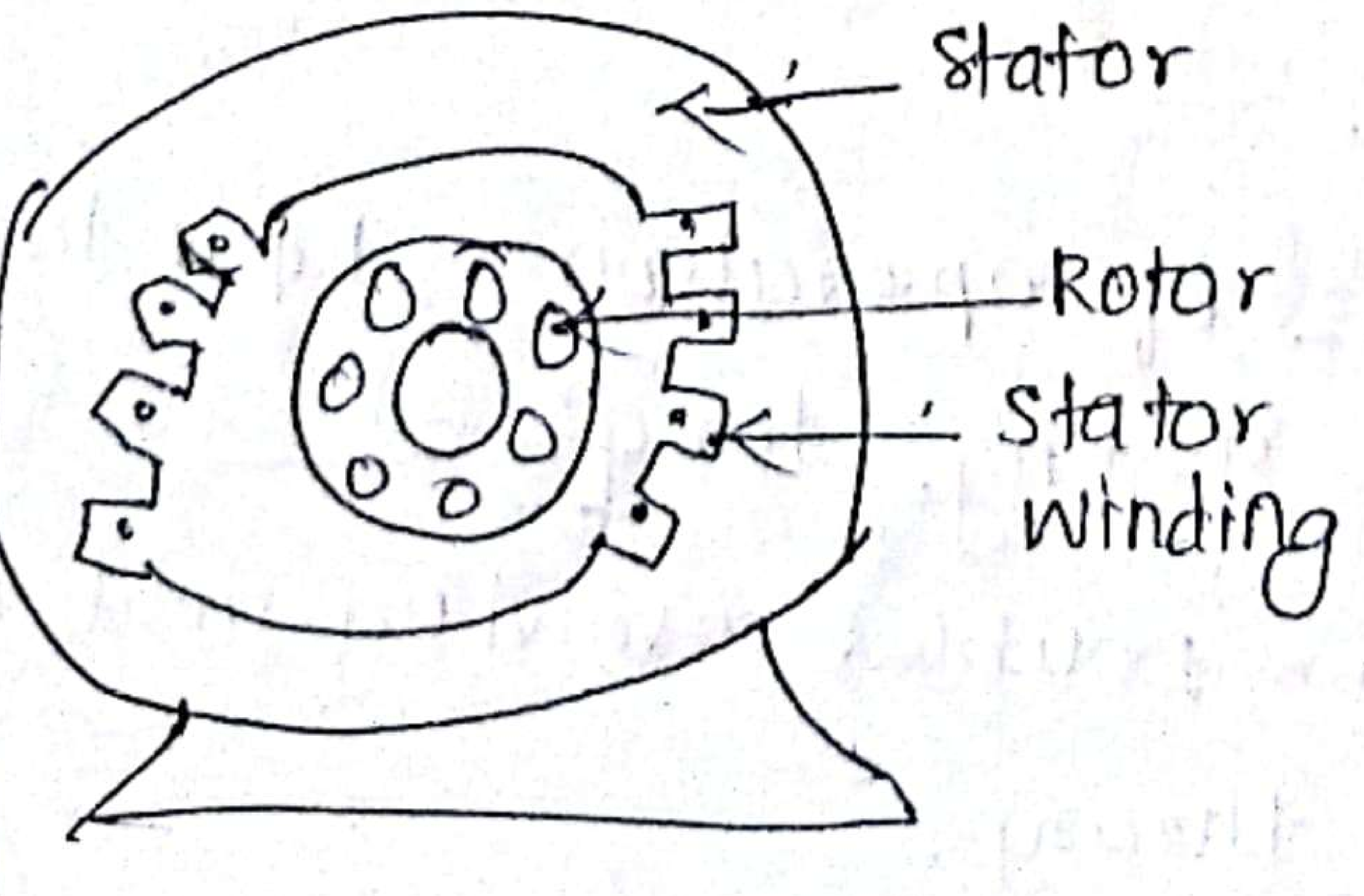
Single Phase Induction Motors

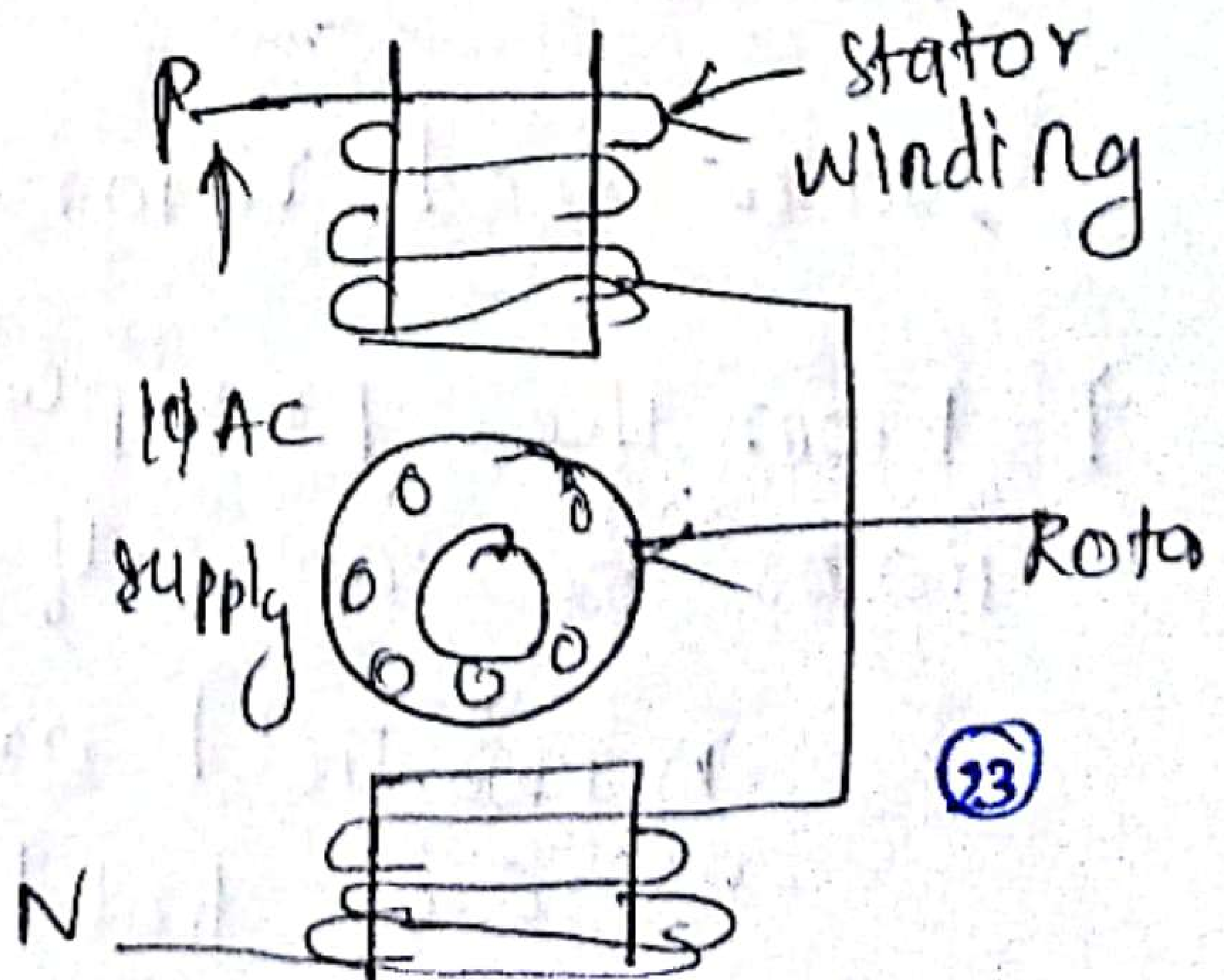
* The single phase motors are small motors.
* These motors have power rating in fractional horse power range.
* These motors are used in homes, offices shops and factories.
* They provide motive power for fans, washing machines, hand tools like drillers, record players, refrigerators, juice makers etc.

→ The main disadvantages of these motors are

1. Lack of starting Torque.
2. Reduced power factor.
3. Low Efficiency.

Construction of single-phase induction motor





* The construction of a single phase induction motor is similar to three phase squirrel cage induction motor.

*. The rotor is the same as that of a three - phase induction motor, but the stator has only a single phase distributed winding.

* Diagram shows the construction of a single phase induction motor.

* It consists of two parts.

* One is stator and another one is rotor.

* The airgap b/w stator and rotor is uniform.

* There is no external connection b/w stator and rotor.

* From the principle of operation, 1 ϕ induction motor has no self starting torque.

(i) Two field (or) Double revolving field theory

(ii) Cross field theory.

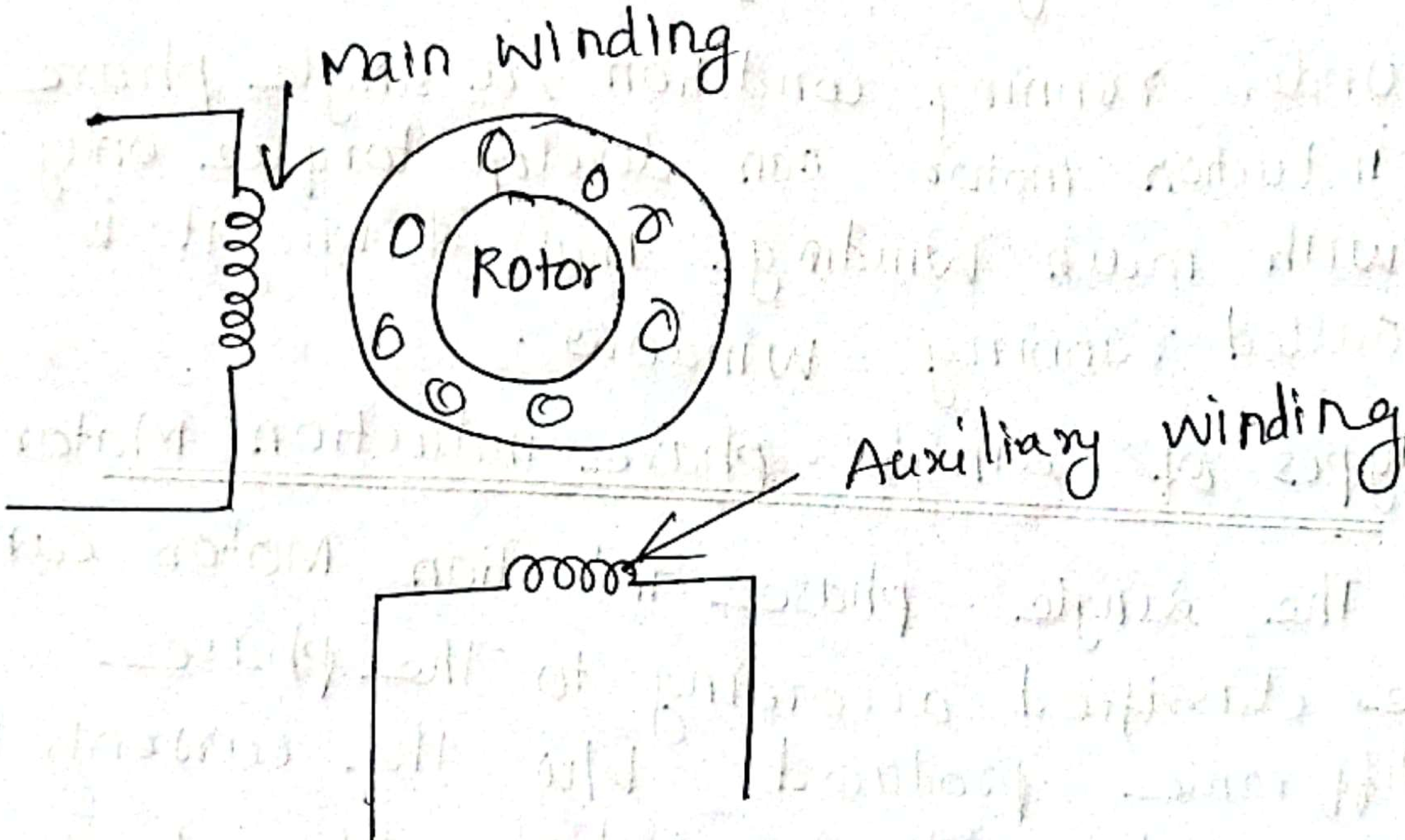
Starting Method.

Starting of single - phase induction Motor.

* The starting method of single-phase induction motor is very simple.

* An auxilliary winding in the stator is provided in addition to the main winding.

* Then the induction motor starts as a two phase motor. It is shown in figure



* The main winding axis and auxiliary winding axis are displaced by 90 electrical degrees.

* The impedances of the windings differ and currents in the main and auxiliary

winding are phase shifted from each other. As a result of this, a rotating Stator field is produced and the rotor rotates.

* When the motor speed is about 75% of synchronous speed, the auxiliary winding is disconnected from the circuit.

* This is done by connecting a centrifugal switch in the auxiliary winding which is used for starting purpose only. That is why it is called Starting winding.

* Under running condition, a single phase Induction motor can develop torque only with main winding. That is why it is called running window.

Types of single-phase Induction Motor.

The single-phase induction Motors can be classified according to the phase difference produced b/w the currents in the main and auxilliary windings. The classifications are,

1. split-phase motors
2. Capacitor - Start motors
3. Capacitor - run motors
4. Capacitor - start and run motors
5. Shaded - pole motors.

Alternator

* The machine which produces 3 phase power from mechanical power is called an alternator or synchronous generator.

* An alternator works on the same fundamental principle of electromagnetic induction as a d.c. generator. i.e when the flux linking a conductor changes, an emf is induced in the conductor.

Working of Alternator.

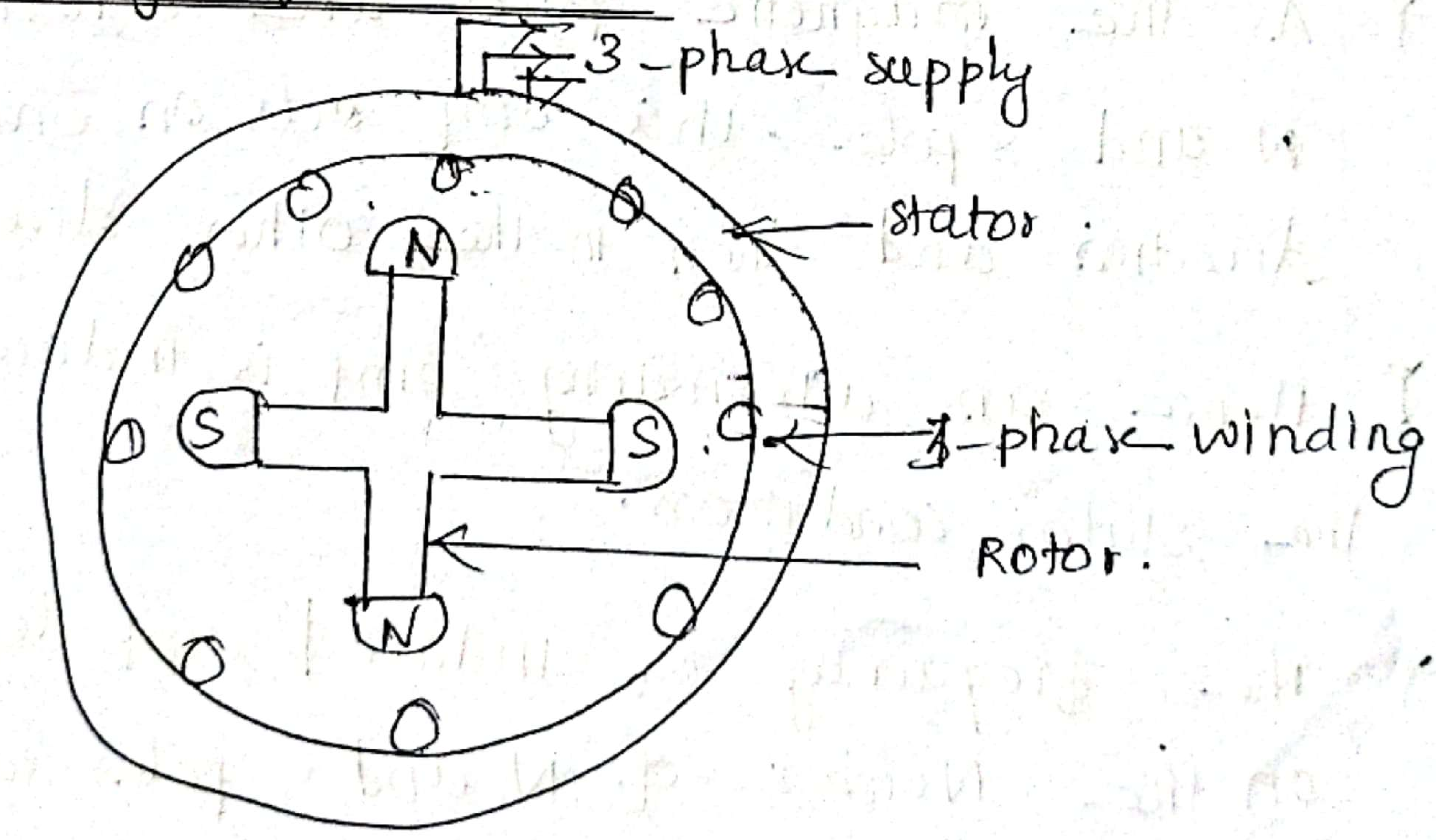


Fig: sectional view of a salient pole alternator.

* The field magnets are magnetised by applying 125 volts or 250 volts through slip rings.
* The field windings are connected such that, alternate N and S poles are produced.
* The rotor and hence the field magnets are driven by the prime mover.
* As, the rotor rotates, the armature conductors are cut by the magnetic flux.
* Hence an emf is induced in the armature conductors.
* As the magnetic poles are alternately N and S pole, this emf acts in one direction and then in the other direction.
* Hence an alternating emf is induced in the stator conductors.
* The frequency of induced emf depends on the Number of N and S poles moving past an armature conductor in one second.
* The direction of induced emf can be found by fleming's right hand rule and

frequency is given by

$$f = \frac{PN}{120}$$

where N → speed of the rotor in r.p.m

P → Number of rotor poles.

Equation of Induced EMF

Let Z = number of conductors or coil sides in series/phase

Z = 2T where T is the number of coils or turns per phase

P = number of poles

f = frequency of induced emf in Hz

ϕ = flux/pole in webers

$$K_d = \text{distribution factor} = \frac{\sin \frac{m\beta}{2}}{m \sin \frac{\beta}{2}}$$

K_c or K_p = pitch factor (or) coil span factor

$= \cos \alpha/2$

K_f = form factor = 1.11 - if emf is assumed sinusoidal

N = rotor speed in r.p.m.

* For one revolution of the rotor each stator conductor is cut by a flux of ϕP webers.

$$d\phi = \phi P \quad \text{and} \quad dt = \frac{60}{N} \text{ second.}$$

Average emf induced per conductor

$$= \frac{d\phi}{dt} = \frac{\phi P}{60/N} = \frac{\phi P N}{60}$$

W.K.T, $f = \frac{PN}{120}$ (or) $N = \frac{120f}{P}$

sub value of N, we get average emf per conductor

$$= \frac{\phi P}{60} \times \frac{120f}{P} = 2f\phi \text{ volt.}$$

If there are Z conductors in series/phase, then, Average e.m.f / phase = $2f\phi Z$ volts = $4f\phi T$ Volts.

RMS value of e.m.f / phase = $1.11 \times 4f\phi T$

$= 4.44 f\phi T$ volts.

The above equation is true only, if the winding is concentrated in one slot.

* But practically it is not true, as the winding for each phase under each pole is distributed and for such cases K_p and K_d must be considered.

∴ Actually available voltage / phase

$= 4.44 K_p K_d f \phi T$ volts.

If the alternator is star connected, then the line voltage is $\sqrt{3}$ times the phase voltage.

Voltage Regulation.

Voltage Regulation of an alternator is defined as the increase in terminal voltage when full Load is thrown off, assuming field current and speed remaining the same. The percentage regulation is defined as the ratio of change in terminal voltage from full load to no Load to rated terminal voltage.

$$\text{Percentage regulation} = \frac{E_0 - V}{V} \times 100$$

Where

E_0 = No load terminal voltage

V = Full Load terminal voltage.

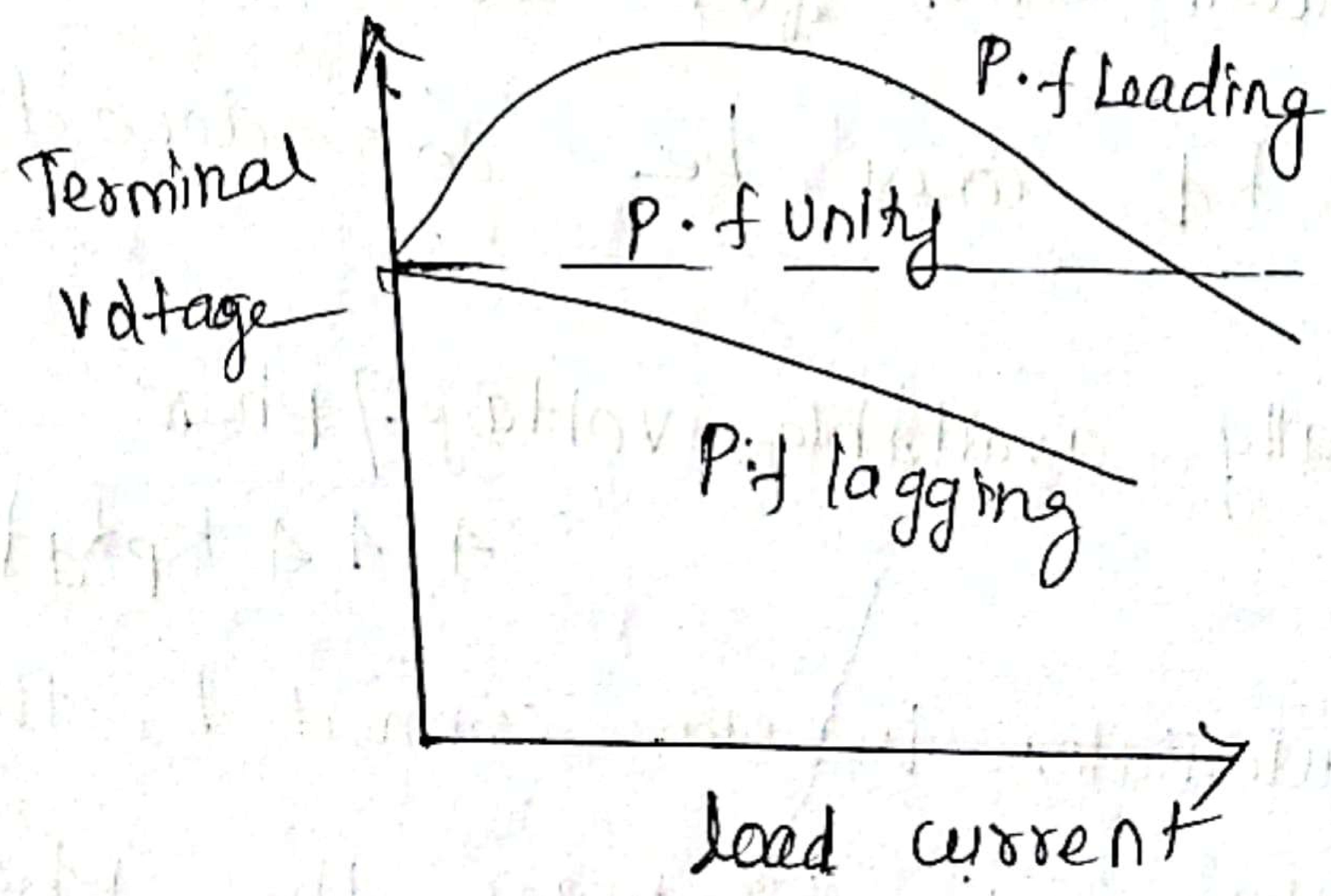


fig: voltage characteristics of an alternator.

Synchronous Motor

* The synchronous motor is one type of 3 phase A.C motors which operate at a constant speed from no load to full load.

* It is similar in construction to 3 phase A.C generator in that it has a revolving field which must be separately excited from a D.C source.

* By changing the D.C field excitation, the power factor of this type of motor can be varied over a wide range of lagging and leading values.

* This motor is used in many applications because of its fixed speed from no load to full load, its high efficiency and low initial cost.

* It is also used to improve the power factor of 3-phase AC industrial circuits.

Working Principle

* When a sinusoidal (single phase) voltage is applied to a winding, the magnetic

field produced by the resultant current flow will also be sinusoidally varying with respect to time.

* This means that the field is pulsating.

* Now when a three-phase voltage is applied to a three phase winding, the flux produced will be the resultant of all the three pulsating fields.

* It can be shown that the resultant field has a magnitude of $1.5\phi_m$ where ϕ_m is the maximum value of the flux due to a single phase current.

* Further, it can also be shown that the direction of the field changes continuously, i.e, the field is rotating in space at a speed given by

$$N_s = \frac{120 \times f}{P}$$

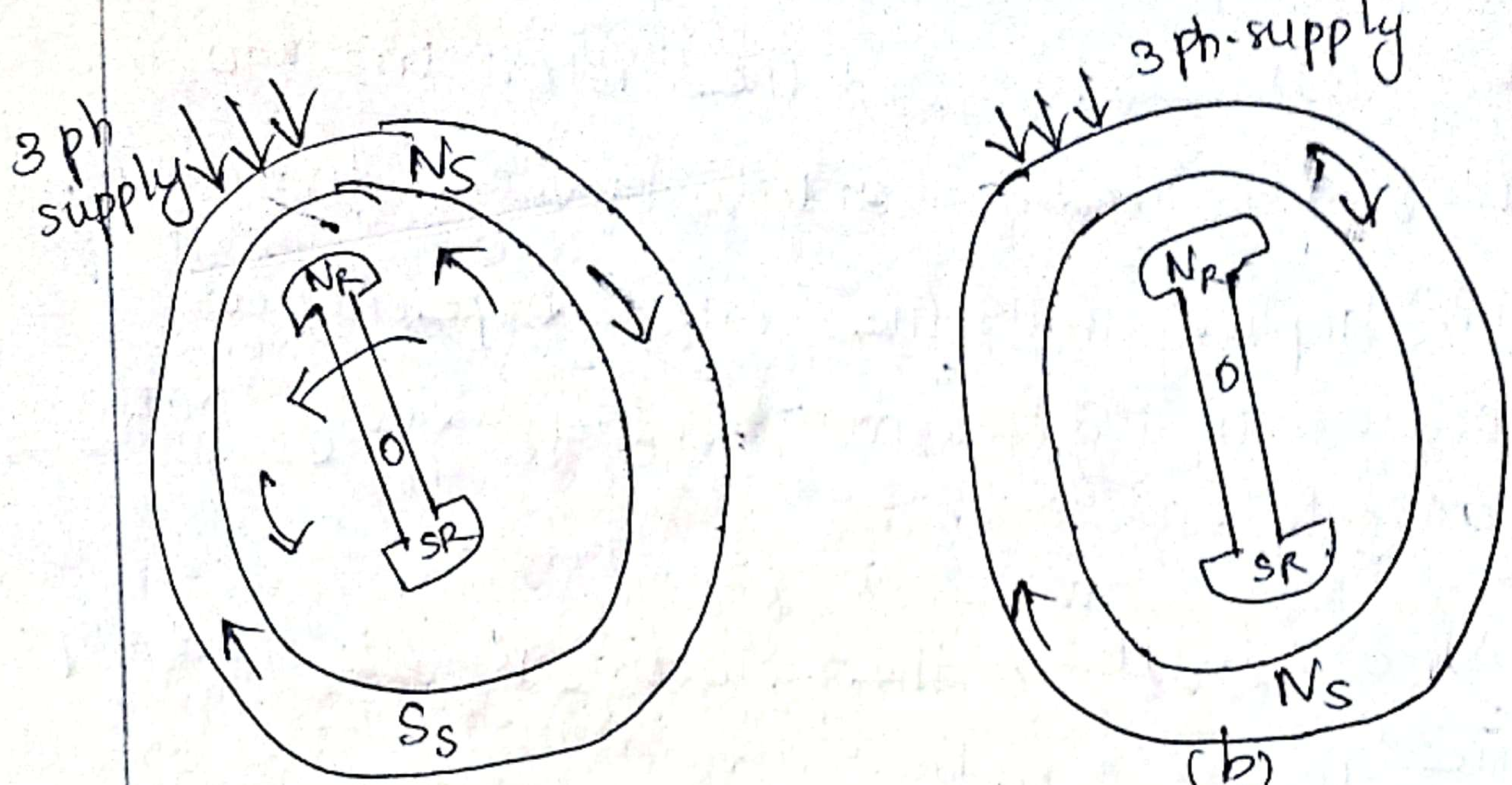
where f is the frequency of supply

P is the Number of poles.

$N_s \Rightarrow$ synchronous speed.

* When a three-phase supply is given to a three-phase winding a magnetic field of constant magnitude but rotating

at a constant speed, Ns is produced.



(b)

(a)

* Diagram above shows the two fictitious assumed stator poles marked Ns and Ss to rotate clockwise at a synchronous speed Ns.

* The rotor poles NR and SR are formed by the dc excitation.

* When Ns and NR are together likes poles repel each other, since Ns and Ss are moving in the clockwise direction, NR and SR tend to figure (a).

* Half a cycle later, the stator poles have moved, whereas the rotor poles have moved significantly is shown fig (b).

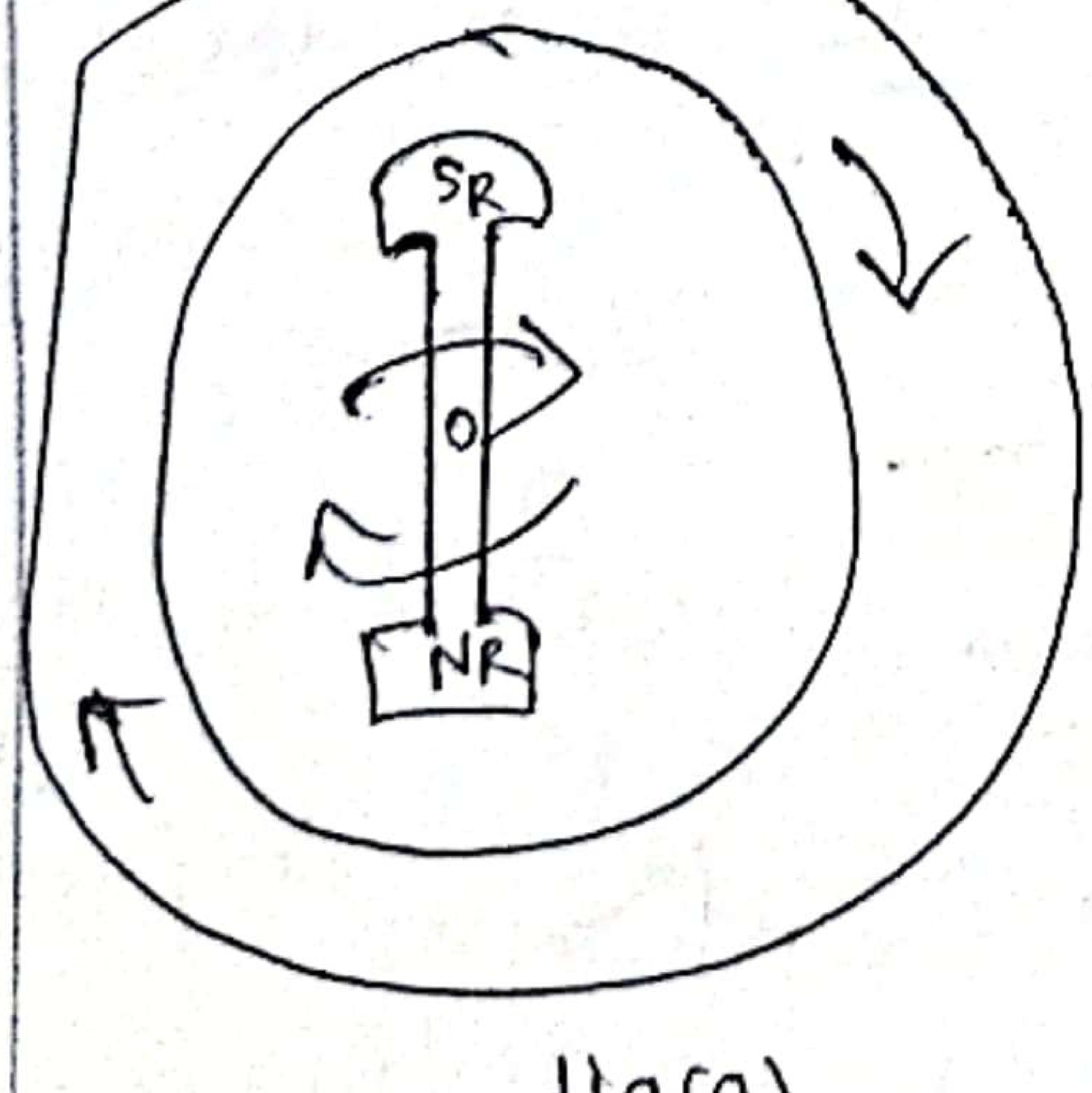
* N_S and S_R and similarly S_S and N_R get attracted and the rotor tries to rotate in the anticlockwise direction..

* This implies that the rotor experiences torque in different directions every half a cycle.

* As a result, the rotor is at standstill due to its large inertia.

* This explains why a synchronous motor has no starting torque and cannot start by itself.

* If the rotor is now rotated seperately by a prime mover in the same direction as the synchronously rotating stator field and at a speed near N_s, then it is possible that at some instant N_s and S_R and similarly S_S and N_R. get attracted and locked to one another.



fig(a)

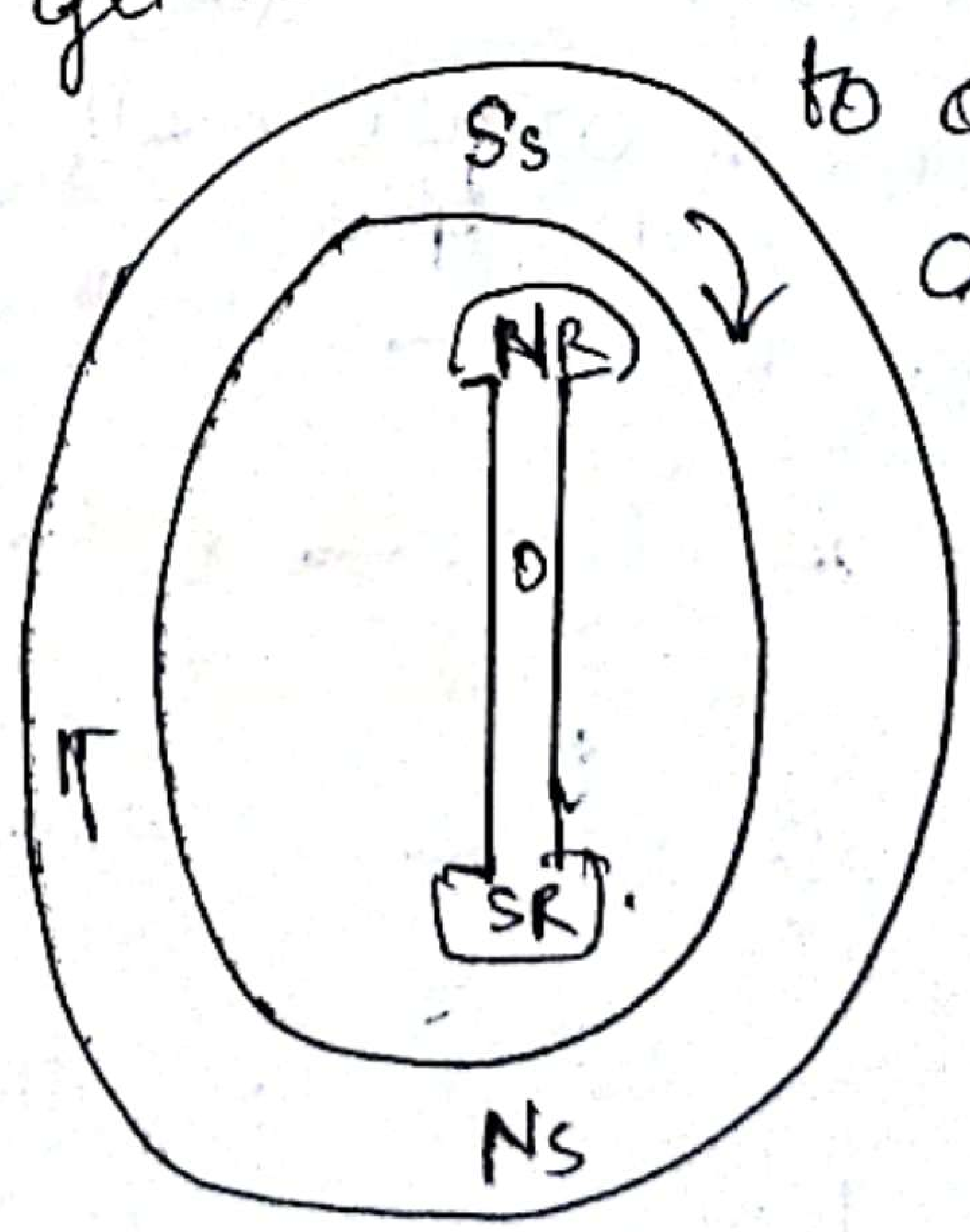


fig (b).

* Hence a synchronous motor, though not self starting, starts working as a motor if it is started up by some means.

* It needs two seperate supplies – one a d.c source for excitation of the rotor and other, a three phase supply for the stator.

* Because of the Interlocking between the stator and rotor poles, the motor runs only at one speed, the synchronous speed.

Starting Methods of Synchronous Motor.

① From DC source

* When DC supply and dc compound motor are available, the synchronous motor is coupled and started by means of a dc compound motor.

* The speed of dc motor is adjusted by the speed regulator

* The synchronous motor is then excited and synchronised with AC supply mains.

* At the moment of synchronising, the synchronous motor is switched on with the AC mains and either the dc motor is disconnected from the dc supply mains.

* Now the synchronous machine is operating as a motor, from ac supply mains and dc machine acts as load on it.

* The synchronous motor can also be started by the exciter mounted on an overhung synchronous motor bracket and shaft extension.

* An available dc source operates the exciter as a motor during the starting period then after the synchronous machine is brought up to speed and synchronised, the exciter assumes its normal function.

Torque of a Synchronous Motor.

① Starting Torque

* It indicates the ability of the motor to accelerate the load. It is also sometimes called "break away Torque"

* It may be as low as 10%. In case of centrifugal pumps and as high as '200 or 250% of full load Torque". as in case of loaded reciprocating two-cylinder compressors.

* The synchronous motor possesses no self starting torque, in modern synchronous motors, by making changes in the design of damper windings, torque can be developed.

② Running Torque.

* Running Torque is the torque developed by the motor under running condition.

* It is determined by the o/p power and speed of the driven machine.

* Peak output power determines the maximum torque that would be required

by the driven machine.

* The breakdown or maximum running Torque of a motor must be greater than this value in order to avoid stalling of the machine.

* Pull ③ Pull in Torque

* It pertains to the ability of the machine to pull in to synchronism when changing from induction to synchronous motor operation.

④ Pull out Torque.

* It is the maximum Torque that the synchronous motor will develop without pulling out of synchronism.

* Its value ranges from 1.25 to 3.5 times the full load torque.

Measurements and Instrumentation

Functional elements of an instrument, Standards and calibration, Operating Principle, Types - Moving coil and Moving iron meters, Measurement of three phase power, Energy Meter, Instrument Transformers - CT and PT, DSO - Block diagram - Data acquisition.

① Functional Elements of an instrument

* The measurement of a given parameter or quantity is the act or result of a quantitative comparision between a predefined standard and an unknown quantity to be measured.

* Instruments -> An instrument is a device in which we can determine the magnitude or value of the quantity to be measured. The measuring quantity can be voltage, current, power and energy etc.

* Measurand => The physical, chemical, electrical quantity, property, process, variable or a condition to be measured is referred as Measurand.

* Most of the Measurement systems contain three main functional elements. They are.

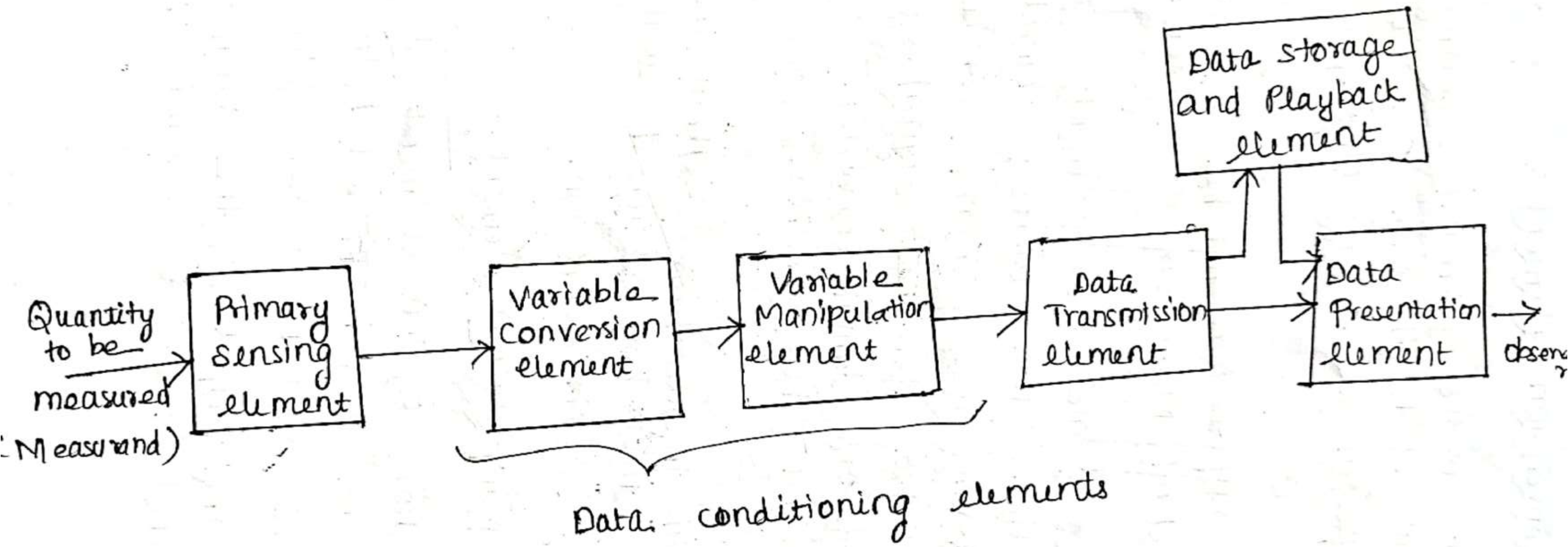
1. Primary sensing element
2. Data conditioning elements
3. Data presentation element.

* Any instrument or a measuring system can be described in general with the help of a block diagram.

① Primary sensing element

* An element of an instrument which makes first, contact with the quantity to be measured is called primary sensing element.
* Thus first detection of the measurand is done by the primary sensing element.
* In ammeter, coil carrying current to be measured is a primary sensing element.
* In most of the cases, a transducer follows primary sensing element which converts the measurand into a corresponding electrical signal.

FUNCTIONAL ELEMENTS OF AN INSTRUMENT



② Variable Conversion Element.

* The output of the primary sensing element is in electrical form such as voltage, frequency or any other electrical Parameter.

* such an output may not be suitable for the actual Measurement System.

* For Example if the measurement system is digital then the analog signal obtained from the primary sensing element is not suitable for the digital system. Thus analog to digital converter is required which is nothing but Variable Conversion element.

* The original Information about the measurand must be retained as it is while doing such conversion.

③ Variable Manipulation element:

* The function of this element is to manipulate the signal presented to it Preserving the original nature of the signal.

* Sometimes, the output of the transducer may get affected due to unwanted signals like noise.

* Thus, such signals are required to be processed with some processes like modulation, clipping, clamping etc.
* This process of conversion is called <u>signal conditioning</u>.

④ Data Transmission Element.

* When the elements of the system are physically seperated, it is necessary to transmit the data from one stage to other
* This is achieved by the data transmission element.
* The signal conditioning and data transmission together is called <u>intermediate stage</u> of an instrument

⑤ Data Presentation Element

* The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring control, or analysis purposes. This function is done by data presentation element.

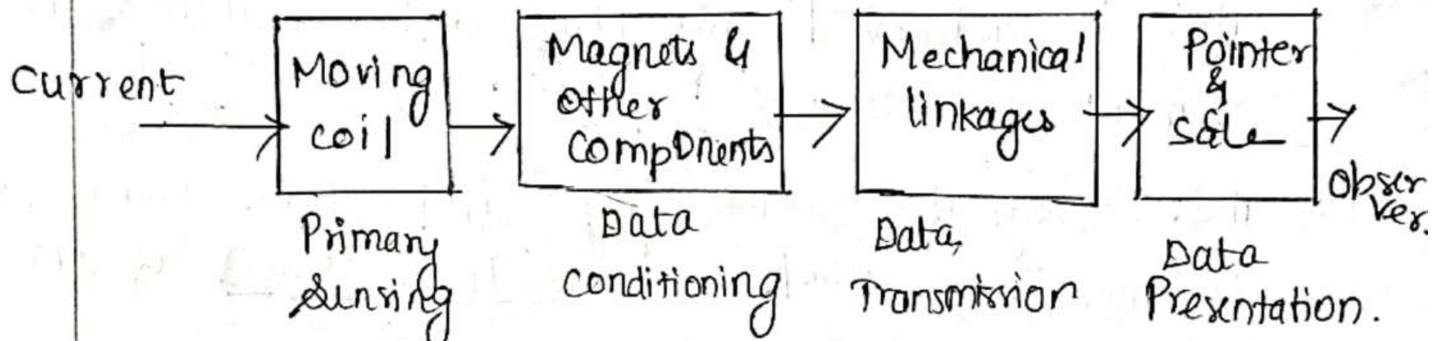
Ex! Ammeters, Voltmeters, magnetic tapes, high speed cameras & TV equipment, printers etc.

* For control & Analysis purpose microprocessor or computers are used.

* The final stage in a measurement system is known as terminating Stage.

Example

For Example, consider a simple analog meter used to measure current or voltage as shown in figure.



* The moving coil is primary sensing element.
* The magnets and coil together act as data conditioning stage to convert current in a coil to a force.

* This force is transmitted to the pointer through mechanical linkages which act as data transmission element.

* The pointer and scale act as data Presentation element.

② Standards in Measurement

* All the instruments are calibrated at the time of manufacture against a measurement standards.

* A standard of measurement is a physical representation of a unit of measurement.

* A standard means known accurate measure of physical quantity.

* The different types of standards of measurement are classified as,

1. International standards
2. Primary standards
3. Secondary standards
4. Working standards.

International standards

* International standards are defined as the international agreement.
* These standards as mentioned above are maintained at the international bureau of weights and measures and are periodically evaluated and checked by absolute measurements in terms of fundamental units of Physics.

Standard Chart.

International Standards
↓
National standard Laboratories
↓
Industries & secondary laboratories.
↓
Measurement Laboratory
↓
Process Instrument.

* these international standards are not available to the ordinary users for the calibration purpose.

Primary Standards.

* These are highly accurate absolute standards, which can be used as ultimate reference standards.

* These primary standards are maintained at National standard laboratories in different countries.

* These standards representing fundamental units as well as some electrical and

③ Calibration

* The calibration is the procedure for determining the correct values of measurand by comparison with the standard ones.

* The standard of device with which comparison is made is called a standard instrument.

* The instrument which is unknown and is to be calibrated is called test instrument.

* Thus in calibration, test instrument is compared with the standard instrument.

* The calibration procedure involves the steps like visual inspection for various defects, installation according to the specifications, zero adjustment etc.

* The calibration characteristics can be determined by applying known values of quantities to be measured and recording the corresponding output of the instrument. Such output values are then compared with the input, to determine the error.

* Such a record obtained from calibration is called calibration record.

* ~~If~~ It is generally recorded in the tabular form. If it is represented in the graphical form, it is called calibration curve.

* If the device has been repaired, aged, adjusted or modified, then recalibration is carried out.

④ Operating principle, Types, Moving coil and Moving Iron Meters

Moving coil Instruments

* There are two types of Moving coil instruments namely
  ⇒ Permanent Magnet moving coil Type (PMMC)
  ⇒ Dynamometer Type

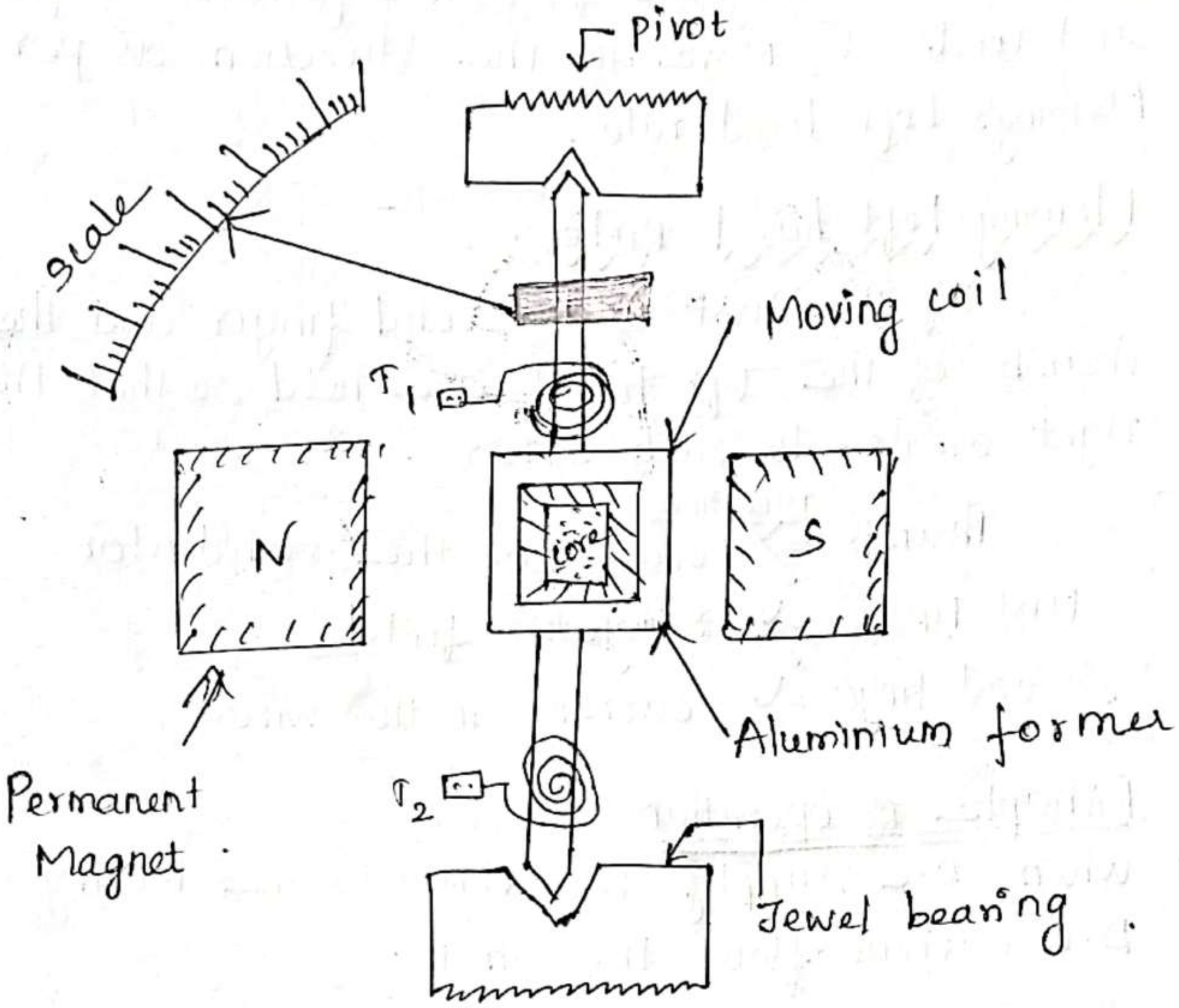
Permanent Magnet Moving coil Instrument (PMMC)

* This type can be only used for direct current, Voltage Measurements.

Construction

* A Permanent Magnet is used in this type Instrument.
* Aluminium former is provided in the cylindrical in between two Poles of the Permanent magnet.
* Coils are wound on the aluminium former which is connected with the spindle.
* This spindle is supported with Jeweled bearing.

PMMC



* Two springs are attached on either end of the spindle.
* The terminals of the moving coils are connected to the spring.
* The current flows through spring 1, moving coil & spring 2.

Damping : Eddy current damping is used. This is produced by aluminium former.

Control : Spring control is used.

Principle. When the current carrying conductor is placed in a magnetic field, it experiences a force and tends to move in the direction as per Fleming's Left hand rule.

Fleming Left hand Rule.

If the first and second finger and the thumb of the left hand are held, so that they are right angle to each other.

Direction

Thumb ⇒ Force on the conductor

First Finger ⇒ Magnetic field

Second finger ⇒ current in the wire.

Principle of operation.

* When D.C supply is given to the moving coil, D.C current flows through it.
* When the current carrying coil is kept in the magnetic field, it experiences a force.
* This force produces a torque and the former rotates.
* The pointer is attached with the spindle.
* When the former rotates, the pointer moves over the calibrated scale.
* When the polarity is reversed a torque is produced in the opposite direction.

Deflecting Torque The force F will be perpendicular to both the direction of current flow & magnetic field.

⇒ By Fleming Left hand Rule, $F = NBIL$ N → Number of turns of wire

B → flux density I ⇒ current in the coil

L → Vertical Length of coil

Energy Meter.

* Energy meters are the basic part to measure the Power consumption.
* It is also known as Watt-hour meter.
* The essential components of Energy meter are.

1. Driving system.
2. Moving system.
3. Braking system.
4. Registering system.

1. Driving system.

* The components of this system are two silicon steel laminated electromagnets.
* The upper electromagnet is called shunt Magnet.
* It carries a voltage coil consisting of many turns of thin wire.
* The lower electromagnet is called series magnet.
* It carries the two current coils consisting of a few turns of thick wire.

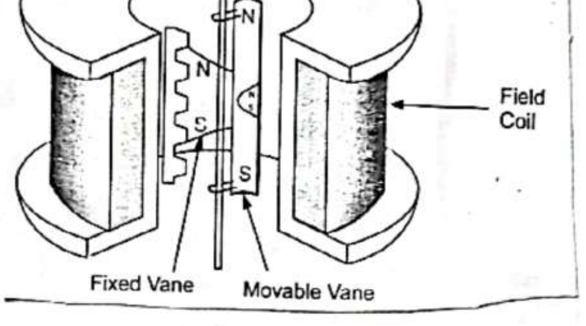
2. Moving system.

* There is a thin aluminium disk placed in the gap between the two electromagnets.
* It is mounted on a vertical shaft.
* The eddy currents are induced in the aluminium disk when it cuts the flux produced by both the magnets
* As a result, two magnetic fields constitute a deflecting torque in the disk.
* The disk slowly starts rotating & the several rotation of the disk displays the power consumption.

* The current through the coil is alternating.
* There is always repulsion between the like poles of the fixed and the movable vane.
* The deflection of the pointer is always in the same direction.
* The deflection is proportional to the current.
* The scale is calibrated directly to read amperes or volts.

Co-axial vane Type.

* In this type, the fixed and moving vanes are sections of co axial cylinders.
* The controlling Torque is provided by springs.
* The instrument has two concentric vanes.
* One is attached to the coil frame.
* Other can rotate coaxially inside the stationary vane.
* Both the vanes are magnetised to the same polarity.
* movable vane rotates under the repulsive force.
* The pointer deflection is proportional to the current in the coil.

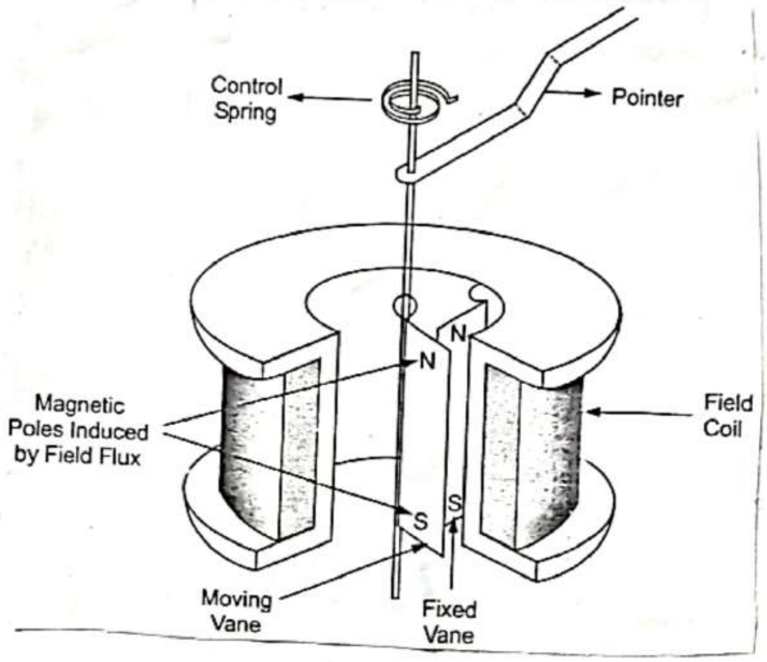


(ii) Repulsion Type

* These instruments have two vanes inside the coil,
* One is fixed & other is movable.
* When the current flows in the coil, both the Vanes are magnetised with like polarities induced on the sameside.
* There is a force of repulsion between the two vanes resulting in the movement of the moving vane.
* The repulsion type instruments are the most commonly used instruments.
* The two different designs of repulsion type instruments are:
  (i) Radial vane Type.
  (ii) Co-axial vane Type.

Radial vane Type.

* In this type, the vanes are radial strips of iron.
* The fixed vane is attached to the coil & the movable one to the spindle of the instrument.



Moving Iron Meter

Classification of Moving Iron Meters

* Moving Iron Meters are of two Types.
  - (i) Attraction Type
  - (ii) Repulsion Type

(1) Attraction Type

* The working Principle of these instruments is very simple, that a soft iron piece if brought near the magnet gets attracted by the magnet

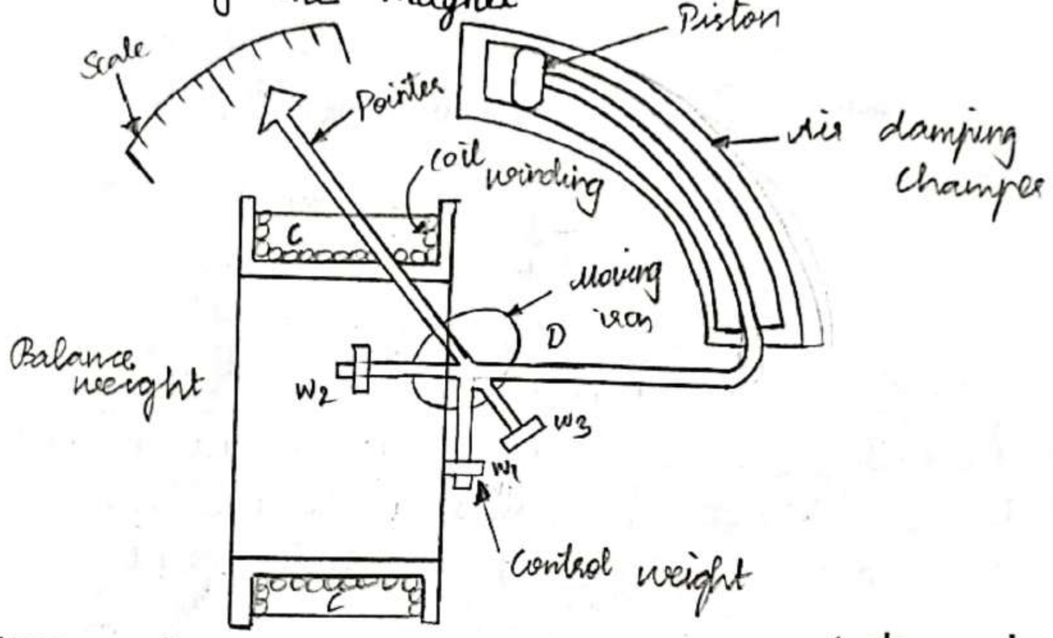


fig. Moving iron attraction type instrument

Construction

* It consists of a fixed coil C and Moving iron piece D.
* The coil is flat and has a narrow slot like opening.
* The Moving Iron is a flat disc or a sector eccentrically mounted on the spindle
* The spindle carries a pointer which moves over a graduated scale.
* The controlling Torque is provide by springs but gravity control can be used.
* Damping is provided by air friction with the help of a light aluminium piston.

Measurement of three phase power

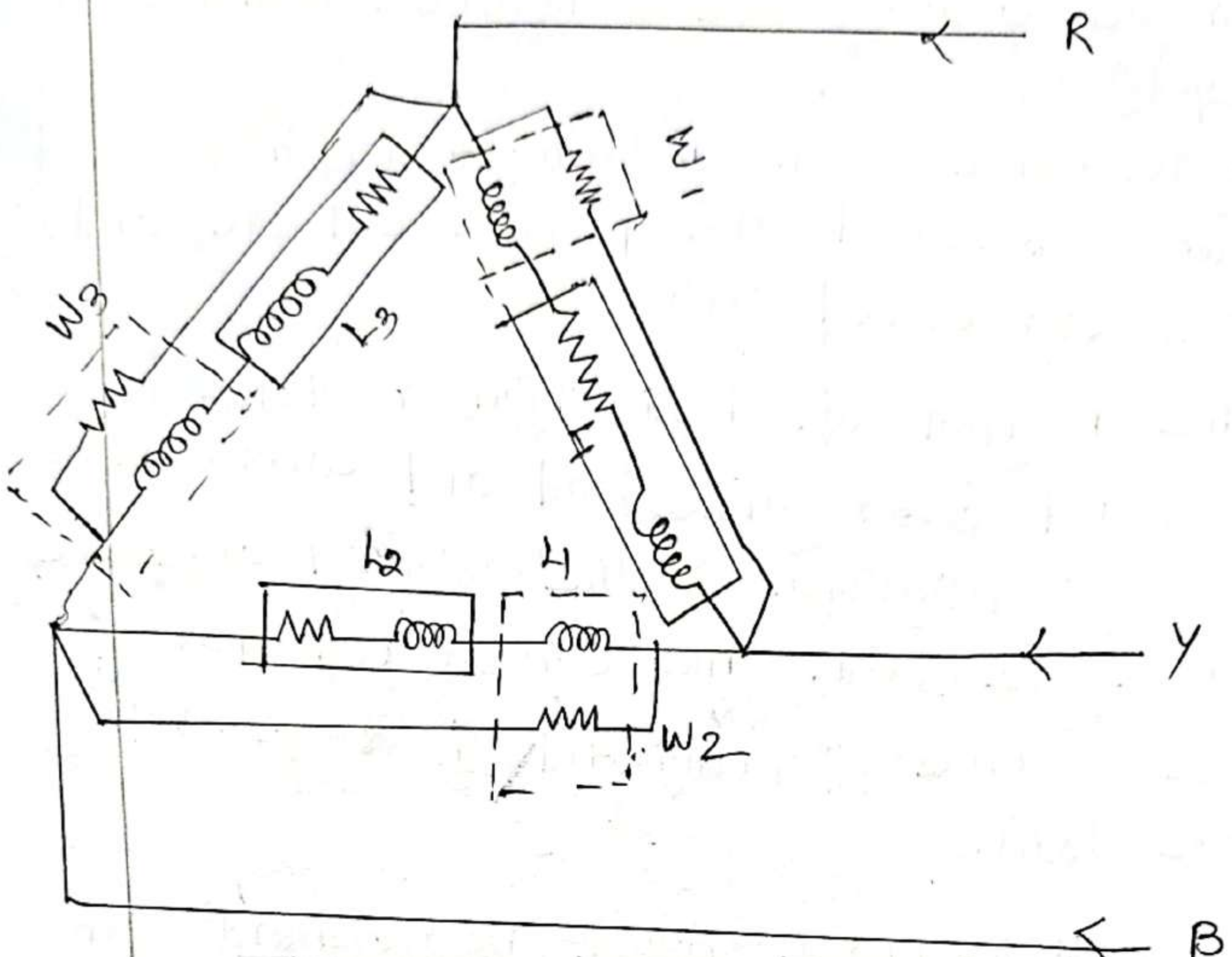
* In ac circuits, Power is measured with the help of wattmeter.
* A wattmeter is an instrument, which consists of two coils called the potential coil (PC) and the current coil (CC)
* The Potential coil having high resistance is connected across the load and carries the current proportional to the potential difference across the load. The current coil having low resistance is connected in series with the load.
* The three phase power measurement can be carried out using the following Methods.

  ⇒ One wattmeter Method.
  ⇒ Two Wattmeter Method.
  ⇒ Three Wattmeter Method.

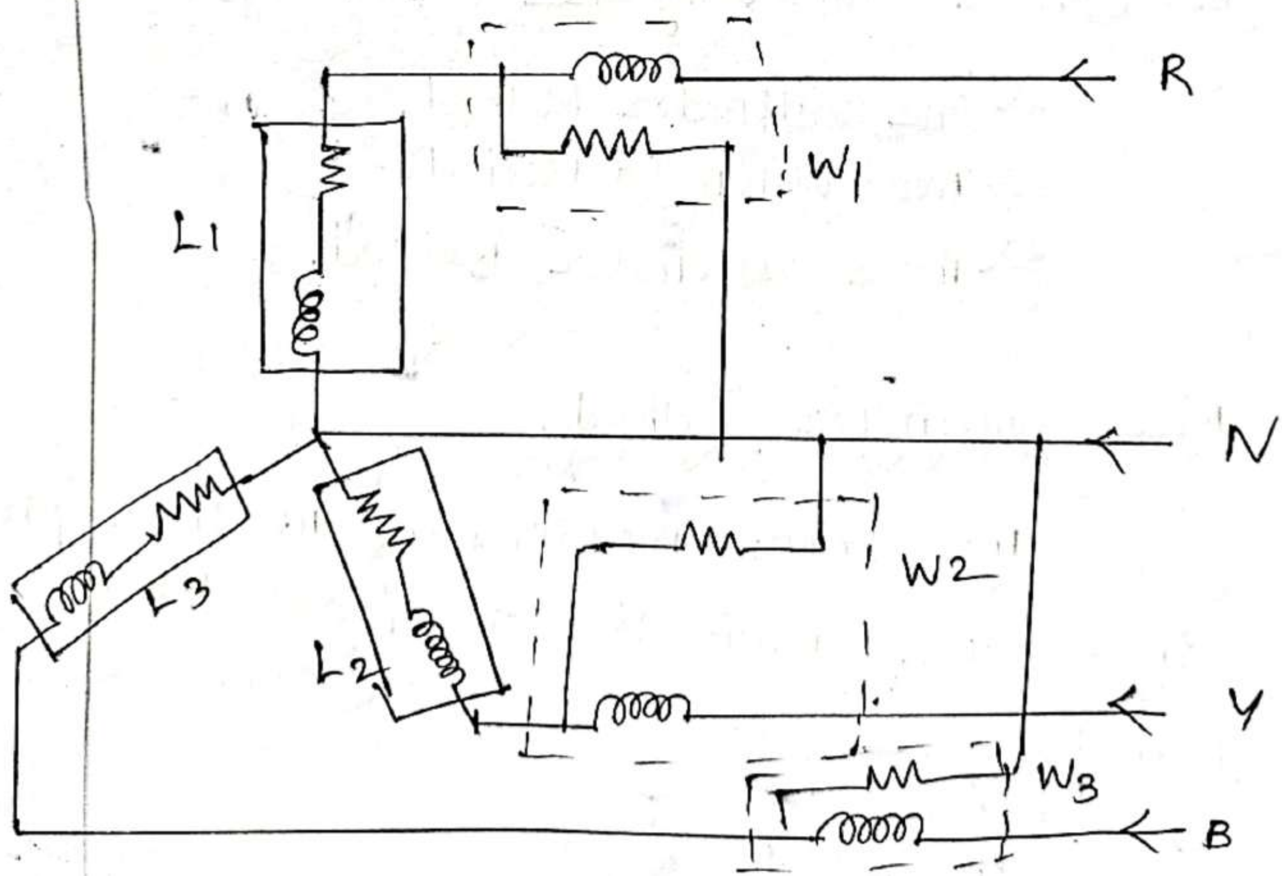
Three Wattmeter Method.

The power measurement in three-phase, three-wire circuit is carried out by this Method.

Delta connection load.



Star connection Load.



* As the neutral wire is common to the three phases, each wattmeter reads power in its own phase, and the total power is given by the sum of the readings of three wattmeters.

Total power of load circuit, $P_{3-\phi} = W_1 + W_2 + W_3$

* In the case of delta connected circuits, Power measurement by three wattmeter method is very difficult because phase coils of load are required to be broken for inserting the current coils of wattmeters.

Instrument Transformers.

* In power system, the currents and voltages are very large, Therefore, their direct Measurements are not possible.

* For such cases, specially constructed ratio transformers are used in conjunction with measuring instruments called Instrument transformers.

* Instrument Transformer generally classified as.

  (i) current Transformer (C.T) → used for current Measurement

  (ii) Potential transformer (P.T) → used for voltage Measurement.

Current Transformer (CT)

* CT consists of two windings called primary and secondary.

* Primary winding is connected in series with the line carrying current which is to be measured.

* The primary winding consists of very few turns and the secondary winding has large number of turns (step up).

* The secondary winding is connected to the ammeter.

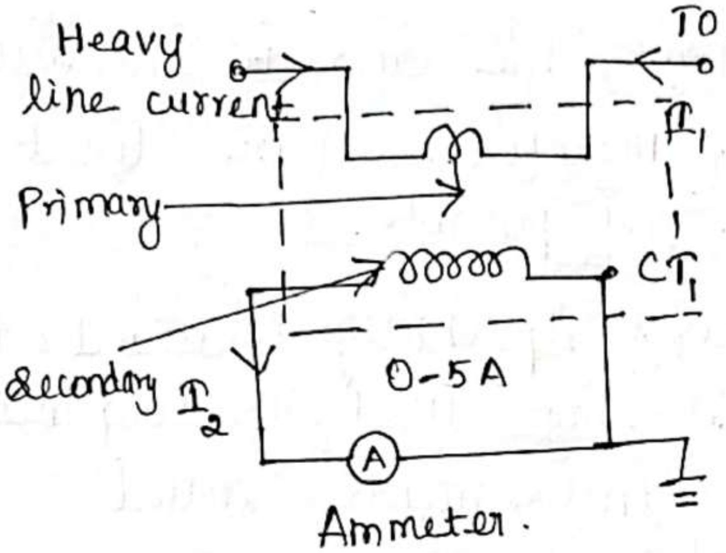


fig: current Transformer

Working Principle of CT

* These transformers are basically step up transformers
* Thus the current reduces from primary to secondary
* So from current point of view, these are step down transformers, stepping down the current value considerably from primary to secondary.

Let N_1 = Number of turns of primary

N_2 = Number of turns of secondary

I_1 = Primary current

I_2 = secondary current.

For a Transformer

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

* As N_2 is very high compared to N_1, the ratio I_1 to I_2 is also very high for current transformers.

* Such a current ratio is indicated for representing the range of current transformer.

* Example : Consider a 500 : 5 range then it indicates that C.T steps down the current from primary to secondary by a ratio 500 to 5.

$$\frac{I_1}{I_2} = \frac{500}{5}$$

Knowing this current ratio and the meter reading on the secondary, the actual high primary line current flowing through the primary can be obtained.

Example Problem

A 250 : 5 CT is used along with an ammeter. If ammeter reading is 2.7 A, estimate the line current.

Soln $\frac{I_1}{I_2} = \frac{250}{5}$

But, as ammeter is in secondary $I_2 = 2.7\,A$

$$\frac{I_1}{2.7} = \frac{250}{5} \qquad I_1 = 135A.$$

So line current is 135 A.

Why secondary of C.T should not be open?

* It is very important that the secondary of C.T should not be kept open.
* Either it should be shorted or must be connected in series with a low resistance coil such as current coils of wattmeter, coil of ammeter etc.
* If it is left open, then current through secondary becomes zero hence the ampere turns produced by secondary which generally oppose primary ampere turns becomes zero.
* This produce excessive core losses, heating the core beyond limits.
* Similarly heavy emfs will be induced on the primary and secondary side.
* This may damage the insulation of the winding.
* This is danger from the operator point of view as well.
* It is usual to ground the C.T on the secondary side to avoid a danger of shock to the operator.

Potential Transformers (P.T)

* The basic principle of these transformers is same as current Transformers.

* Primary winding consists of large number of turns while secondary has less number of turns.

* The Primary is connected across the high voltage line while secondary is connected to the low range voltmeter coil.

* One end of the secondary is always grounded for safety purpose.

* The connections are shown in the figure.

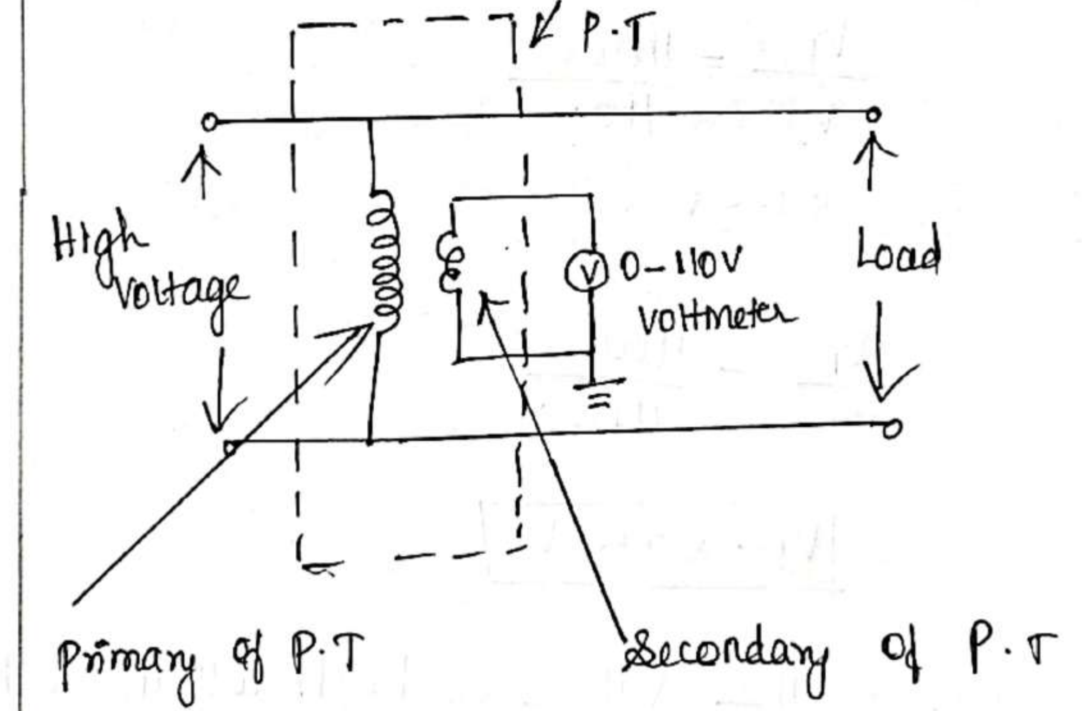


fig: Potential Transformer.

* As a normal Transformer, its ratio can be specified as,

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}.$$

* So if the voltage ratio of P.T is known and the Voltmeter reading is known then the high voltage to be measured, can be determined.

Example

A 1100 : 110 potential transformer is used along with a voltmeter reading 87.5V. Estimate the value of Line voltage.

Soln for a P.T

$$\frac{V_1}{V_2} = \frac{11000}{110}.$$

& $V_2 = 87.5V$

$$\frac{V_1}{87.5} = \frac{11000}{110}.$$

$$\boxed{V_1 = 8750V}$$

This is the value of high voltage to be measured.

DSO

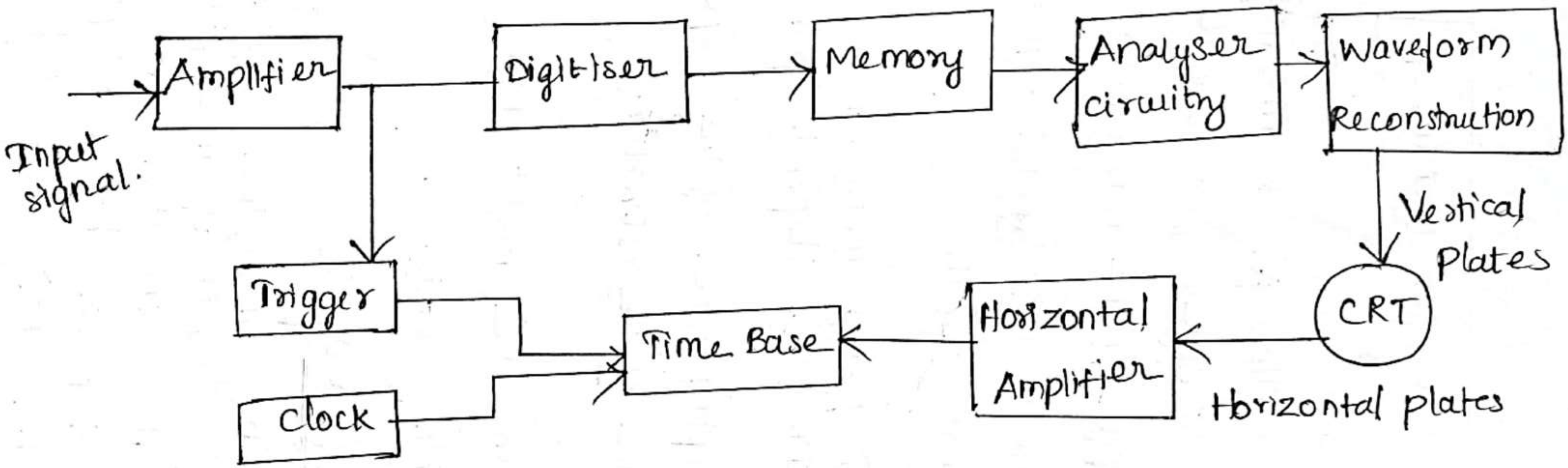
DSO - Digital Storage Oscilloscope

* Digital storage oscilloscope is an instrument which gives the storage of a digital waveform or the digital copy of the waveform. or the
* It allows us to do the digital signal processing techniques over that signal.
* The maximum frequency measured on the digital signal oscilloscope depends upon two things. They are: => sampling rate of the scope.
  => Nature of the converter.
* The traces in DSO are bright, highly defined and displayed within seconds.

Block diagram of DSO

The block diagram of the digital storage oscilloscope consists of an amplifier, digitizer, memory, analyzer circuitry, Waveform reconstruction, Vertical plates, horizontal plates, cathode Ray tube (CRT), horizontal amplifier, time base circuity, trigger and clock.

Block diagram of Digital storage Oscilloscope.



* Then the ramp signal is amplified by the horizontal amplifier, and this horizontal amplifier will provide input to the horizontal plate.

* On the CRT screen, we will get the waveform of the input signal versus time.

* The digitizing occurs by taking a sample of the input waveform at periodic intervals.

* At the periodic time interval means, when half of the time cycle is completed then we are taking the samples of the signal.

* The process of digitizing or sampling should follow the sampling theorem.

* The sampling theorem, says that the rate at which the samples are taken should be greater than twice the highest frequency present in the input signal.

* When the analog signal is properly converted into digital then the resolution of the A/D converter will be decreased.

* As seen in the diagram, at first digital storage oscilloscope digitizes the analog input signal, then the analog input signal is amplified by amplifier if it has any weak signal.

* After amplification, the signal is digitized by the digitizer and that digitized signal stores in memory.

* The analyzer circuit process the digital signal after that the waveform is reconstructed & then that signal is applied to vertical plates of Cathode Ray tube (CRT)

* The Cathode Ray tube has two inputs they are vertical input and horizontal input.

* The vertical input signal is the 'y' axis and the horizontal input signal is the 'x' axis.

* The time base circuit is triggered by the trigger and clock input signal, so it is going to generate the time base signal which is a ramp signal.

* when the input signals stored in analog store registers can be read out at a much slower rate by the A/D converter, then the digital output of the A/D converter stored in the digital store and it allows operation up to 100 Mega samples per second.

* This is the working principle of digital storage Oscilloscope.

Data Acquisition

* The system used for data processing, data conversion, data transmission, data storage is called Data acquisition system.

* The typical data acquisition system consists of sensors with necessary signal conditioning, data conversion, data Processing, data handing & transmission, storage and display systems.

Objectives of Data Acquisition

* Must acquire the necessary data at correct speed and at the correct time.

* It must monitor the operation of complete Plant so that optimum online safe operations are maintained.

* It must be able to collect, summarise and store data properly for diagnosis and record purpose of any operation.

* It must be flexible. Also the expansion facility for the future requirement must be provided by its.

* It must provide effective human communication system which helps in identifying the Problem areas.

* The data acquisition systems are basically used to measure.

UNIT-5

BASICS OF POWER SYSTEMS

Power system structure - Generation, Transmission and distribution, Various voltage levels, Earthing - Methods of Earthing, Protective devices - Switch fuse unit - Miniature circuit breaker - Moulded case circuit breaker - earth leakage circuit breaker, safety precautions and First Aid.

① Power system structure

Power system

* Electricity is generated at central power stations and then transferred to loads (i.e, Domestic, commercial and Industrial) through the transmission and distribution system. A combination of all these systems is collectively known as an electric power system.

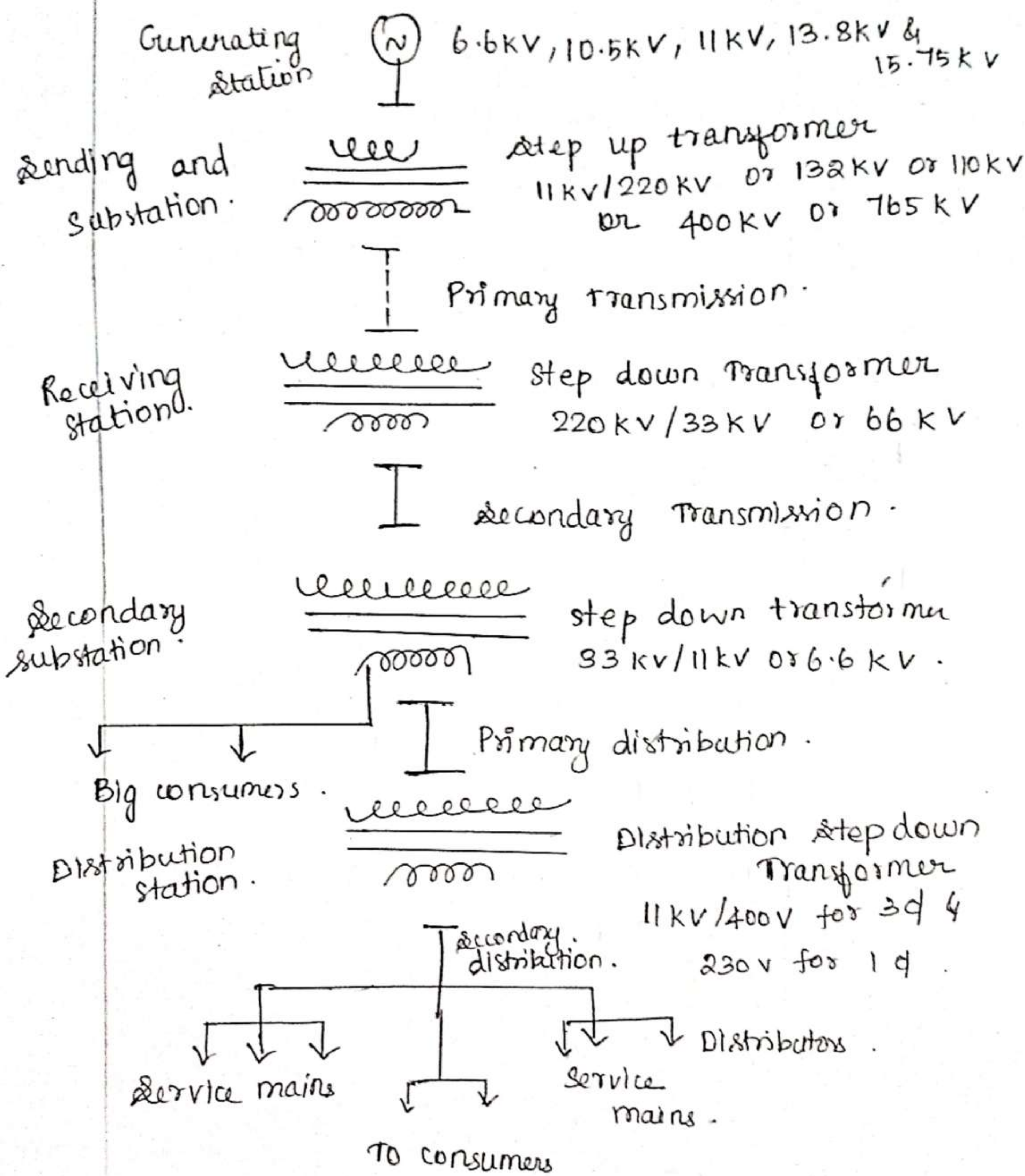
* It uses the form of energy (like coal and diesel) and converts it into electrical energy.

* Electrical energy is generated in hydro, thermal and nuclear power stations.

* Sometimes, electrical energy is generated from non-renewable energy sources like wind,

waves, fossil fuels etc. The generating voltages are usually 6.6KV, 10.5KV, 11KV, 13.8KV, 15.75KV etc.

Figure: structure of Power system.



Components of an electric power system.

- ⇒ Generators
- ⇒ Transformer
- ⇒ Transmission Lines
- ⇒ Control Equipment.
- ⇒ Primary Transmission.
- ⇒ Secondary Transmission.
- ⇒ Primary distribution
- ⇒ Secondary distribution.

Generators

* Generators is a device which converts mechanical energy into electrical energy. Generating voltages are normally 6.6kV, 10.5kV or 11kV.
* This generating voltage can be step up to 110kV/132kV/220kV at the generating (indoor or outdoor) to reduce the current in transmission line and to reduce transmission losses.
* Generators produce real power (MV) and reactive power (MVAR)

Transformers

* It is a static device which transfers power or energy from one circuit to another circuit without change of frequency.
* The main function of transformers is step up voltages from lower generation levels to the higher generation voltage levels and also step down voltages from higher transmission voltage levels to lower distribution levels.
* When we are increasing the transmission voltage, current flowing through the current flowing through the grid decreases, thereby transmission losses (I^2R) reduces.

Control Equipment:

Circuit breaker (CB): Circuit breakers are used for opening or closing a circuit normal and abnormal (fault) condition.

* Different types of circuit breaker are oil circuit breaker, air-blast circuit breaker, vacuum circuit breaker, SF6 circuit breaker.

of two or more generating stations.

* Tolerance of transmission line voltage is ± 5 to ± 10% due to the Variation of loads.

Primary Transmission.

* If the generated power is transmitted through transmission line without stepping up the generated voltage, the line current and powerloss would be very high.

* So the generated voltage is stepped up to higher value by using the step up transformer located in substations known as sending end substations near the generating stations.

* The high voltage transmission lines Transmit power from sending end substation to the receiving end substation.

* Primary transmission voltages are 110KV, 132 KV or 220 KV or 400 KV or 760 KV.

* It uses 3 phase and 3 wire system.

* During fault conditions relay will give command to the circuit breaker to operate.

Isolators :

* Isolators are placed in substations to isolate the part of system during Maintenance.
* It can operate only during no-load condition.
* Isolated switches are provided on each side of the circuit breaker.

Busbars

* Busbars are used to connect number of lines Operating at the same voltage electrically.
* It is made up of copper or aluminium.
* Different types of busbar arrangements are single busbar arrangement, single busbar with sectionalisation, double bus bar arrangements, ring bus bar scheme etc.

Transmission system.

* It supplies only Large blocks of power to bulk power station or to big consumers.
* It interconnects the neighbouring generating stations into a powerpool i.e, interconnection

Secondary Transmission

* At the receiving end substation, the voltage is stepped down to a value of 66 or 33 or 22 KV using step down transformers.

* The secondary transmission line forms the link between the receiving end substation and the secondary station.

* It uses 3 phase, 3 wire system and the conductors used are called feeders.

Distribution system.

* the component of an electrical power system connecting all the consumers in an area to the bulk power sources or transmission line, is called a distribution system.

* A distribution station distributes power to domestic, commercial and relatively small consumers.

* Distribution Transformers are normally installed on poles or on plinth mounted or near the consumers.

Primary distribution.

* At the secondary substations, the voltage is stepped down to 11KV or 6.6KV using step down transformers.
* The primary distributor forms the link between secondary substation and distribution substation and the power is fed in to the primary distribution system.
* It uses 3 phase, 3 wire system.

Secondary Distribution

* At the distribution substation the voltage is stepped down to 400V (for 3 phase) or 230V (for 1 phase) using step down transformers.
* The distribution lines are drawn along the roads and service connections to the consumers are tapped off from the distributors.
* It uses 3 phase, 4 wire system.
* Single phase loads are connected between one phase wire and one neutral wire.

Generation, Transmission and distribution.

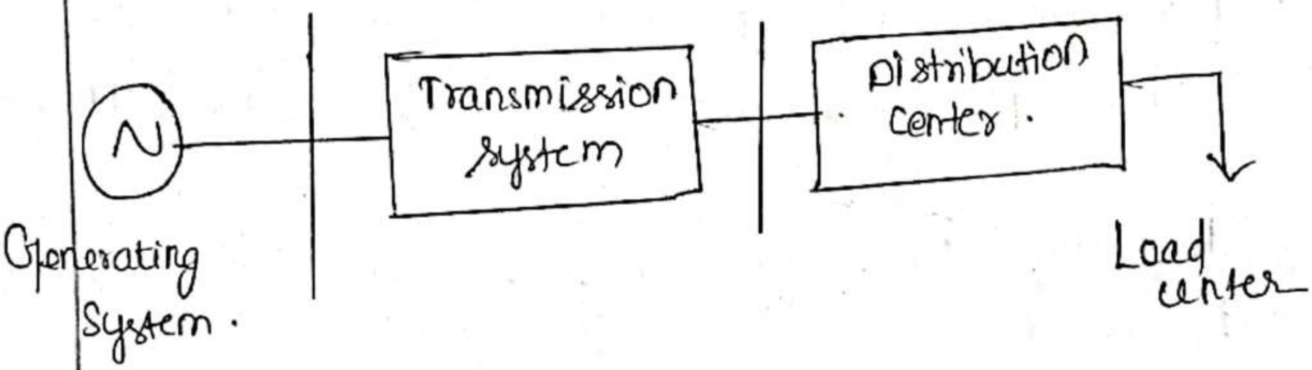
there are Three stages of electric power supply.

(i) Generation

(ii) Transmission

(iii) Distribution.

fig: Block diagram of power system.



Generation.

* The Place where electric power produced by the parallel connected three phase alternators / generators is called Generating station (i.e, power plant).

* the ordinary powerplant capacity and generating voltage may be 11kV, 11.5kV, 12 kV or 13KV.

* Generation is the part of power system where we convert some form of energy

into electrical energy.

* This is the source of energy in the Power system. It keeps running all the time.

* It generates power at different voltage and power levels depending upon the type of station and the generators used.

* The maximum number of generators generate the power at voltage level around 11kv – 20kv.

* Presently the generating stations we employ mainly are,

1. Thermal power plant.
2. Hydel power plant (Hydro-electric)
3. Nuclear power plant.
4. Diesel power plant.
5. Gas power plant.
6. Solar power plant.
7. Tidal power plant
8. Wind power plant etc.

* We generate electric energy through these power plants at different voltage levels.

Various voltage levels.

The different type of voltage levels used in the power system transmission and distribution. are.

* Rated voltage
* Nominal voltage
* Extra-low voltage
* Low voltage.
* Medium voltage.
* High voltage.
* Extra-High voltage.

Rated voltage

* The maximum standard voltage that can be produced by a generating station is called rated voltage, under safety margin.
* The rated voltage is typically said to be generator's maximum voltage.

Nominal voltage

* The predetermined system voltage is called a nominal voltage. i.e an

alternator has designed to produce 11kV + (or) -5%, but it produces 11kv.

* 1 kv means the nominal voltage of the alternator is 11kV and the rated voltage is 11.1kV.

Extra Low Voltage

* The voltage level of below 70 volts is called Extra-low voltage.
* The human can touch the live conductor and which do not harm.
* But under wet condition, the human can experience a mild shock.

EX: Electronics instrument auxillary supply, 12v, 24V Battery, phone charger output, mechanical equipment.

Low voltage

* The voltage level is between 70 volts to 600 Volts called low voltage.
* Humans does not touch these live wire at normal hand.
* Under, the wet condition, human get a dangerous shock which leads to coma stage or death.

Ex : Domestic household or home appliances Power supply, single phase or two phase 230 volts, 440 volts and 110 volts electrical motor, home generator etc.

Medium voltage

* ANSI / IEEE 1585 - 2002 refers to : Medium voltage (0.6 KV - 33 KV).

* IEEE Std 1623 - 2004 refers to : Devices rated to medium voltage (1 KV - 33 KV).

Ex

Rural power transmission lines,
industrial power distribution,
690 volts to 33 KV circuit breakers.

High voltage

* The voltage level between 33 KV to 220 KV is called High voltage.

* Also, the transmission line carries the high voltages is called high voltage transmission lines. Ex : Heavy transmission towers.

Extra High voltage

* The voltage level between the 220 kV to 760 kV is called extra High voltages.

Example for 400 kV : Dohar - panipat line

Example for 760 kV : Anpara - Unnao.

Ultra-High voltage

* The ultra-high voltage lines are noting but a voltage level above 800 kV is called ultra-high voltage.

Ex

1200 kv Bina National

Earthing

* Earthing is used to protect ~~you~~ us from an electric shock.

* An earthing system or grounding system connects specific parts of an electric power system with the ground, typically the Earth's conductive surface, for safety and functional purposes.

Basic needs of Earthing

* To protect human lives as well as provide safety to electrical devices and appliances from leakage current.

* To keep voltage as constant in the healthy phase.

* To protect electric system and buildings from lighting.

* To serve as a return conductor in electric traction system and communication.

* To avoid the risk of fire in electrical installation systems.

Example

In a motor, if we have not earthed it and there is an electrical fault in this motor. will pass through the body and suppose this time someone touches the body even by mistake then he feels terrible grief.

But if we had earthed the body properly, this current would have easily gone into the ground with the help of earthing wire.

Methods of Earthing

1. Strip and wire Earthing
2. Rod Earthing
3. Pipe Earthing
4. Plate Earthing
5. Coil Earthing.

Strip and wire Earthing.

strip and wire earthing, this etching is done in a place where the ground is rocky which means there is more rock in the ground. This earthing is widely used in long distance transmission lines.

Rod Earthing

This type of earthing is done by digging very deep in the sandy area as the moisture content is high across the sandy place. That's why we use Pipe earthing in this

Pipe Earthing

This is the most commonly used earthing in which we put a pipe 5 to 10 feet in the ground.

Plate Earthing

Plate earthing is considered to be the best earth. This is used in Substation and power station Plate earthing nose. Such earthing is used in Places where a large number of current flows.

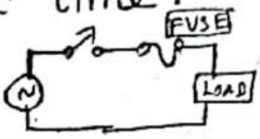
Coil Earthing

Coil earthing is used in the smallest amount. This earthing uses a coil made of G.I. wire. Such earthing is mostly used for electric poles.

Protective Devices.

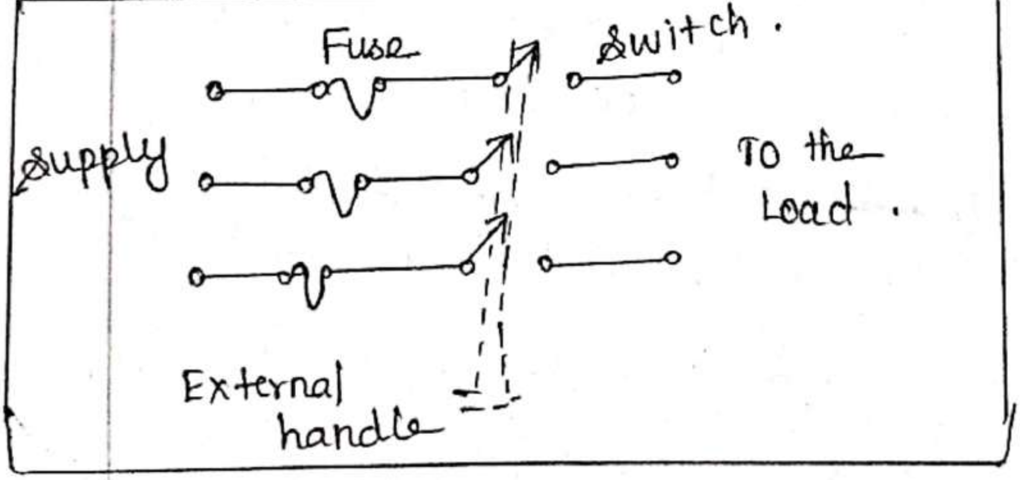
1. Switch Fuse Unit (SFU)
2. Miniature circuit Breaker (MCB)
3. Moulded case circuit Breaker (MCCB)
4. Earth Leakage circuit Breaker (ELCB)

Fuse ⇒ Short piece of wire which melts when excessive current flows through sufficient time.



① Switch Fuse Unit (SFU)

* It has one swith unit & one fuse unit.
* SFU is a combination of metal enclosed of a switch & a fuse.
* It is widely used for low and medium voltages
* The ratings of switch fuse units are in the range of 30, 60, 100, 200, 400, 600 & 800 amperes.
* SFU are available as 3 pole & 4 Pole units
* It works as switch to connect or disconnect supply to the Load. & they can interrupt power supply by blowing fuse.



(7) Miniature circuit Breaker (MCB)

* MCB guards an electrical circuit which automatically switches off electrical circuit during abnormal condition of the network means in overload condition of the network as well as faulty condition.

* It is alternative to fuse.
* It is a small trip switch operated by overload and used to protect an electric circuit.

* To secure our household appliances to heavy electrical short circuit and overload current, MCB is used.

* In domestic usage appliances like lights, heaters and fans require MCB to constantly check and Protect the connection.

* MCB operate on two principle
  - Thermal Tripping [normal overload protection]
  - Magnetic tripping [Short circuit Protection]

(8) Moulded case circuit Breaker (MCCB)

* MCCB are a type of electrical Protection device that is used when Load currents exceed the capabilities of miniature circuit breaker.

* It Can be used for a wide range of voltages & frequencies of both 50 Hz and 60 Hz.

* MCCB can have current rating upto 2500 amperes.

* Trip setting are normally adjustable.

* MCCBs are much Larger than MCBs
* MCCB has three Main functions,
  (i) Protection Against Overload.
  (ii) Protection against electrical faults.
  (iii) Switching a circuit ON & OFF.

(4) Earth Leakage circuit Breaker. (ECLB)

* An ECLB is a safety device used for installing an electrical device with high earth Impedance to avoid shock.
* The main purpose of ELCB is to stop damage to humans and animals due to electric shock.
* There are two types of ELCB
  - Voltage operated ELCB
  - current operated ELCB
* this circuit breaker connects the phase, earthwire and Neutral.

Safety And Precautions:

There are simple way to reduce risks

⇒ check all equipments is in good working order.

⇒ If you find or suspect a fault, stop using the equipment, disconnect from the electrical supply and label not to use.

⇒ You should also avoid overloading sockets by providing enough socket-outlets

⇒ Switch off and unplug and unplug equipment before you clean it or make adjusments.

⇒ You should also ensure Controlled entry to electrical plant or switch gear

⇒ Choose electrical equipment that is intended for the specific working environment.

⇒ Seek specialist advice when choosing electrical equipment that is being used in flammable or explosive atmosphere.

⇒ Use lock off systems and correct signage to inform staff and prevent access.

⇒ Use plans and cable-avoiding tools to locate cables.

First aid :

The 911 emergency personnel may instruct you on the following.

1. Separate the person from current source

=) To turn off the power source

2. Do CPR, if necessary

=) when you can safely touch the person, do CPR if the person is not breathing or does not have a pulse.

=) For a child, start CPR for children
For an adult, start adult CPR

3. Check for other injuries

=) There may be a fracture if the shock caused the person to fall.

=) For burns, see burn treatment

4. Wait for 911 to Arrive

5. Follow up

=) A doctor will check the person for burns, fractures, dislocations and other injuries.