UNIT- IV

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CLASSIFICATION & CONSTRUCTION OF D. C. MACHINES

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D.C. MACHINES

1 INTRODUCTION

There are two types of d.c. machines

(1) D.C. Generator.

(2) D.C.Motor.

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D.C. MACHINES

D.C. Generator

- **D.C. Generator. The d.c. generator converts mechanical energy into electrical energy.**

- **The d.c. generator is based on the principle that when a conductor is rotated in a d.c. magnetic field, a voltage will be generated in the conductor.**

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D.C. MACHINES

D.C. Motor

- D.C.Motor. The d.c: motor converts electrical energy into mechanical energy.
- The d.c. motor is based on the principle that when a conductor (coil is) carrying current rotated in a magnetic field, a mechanical force acts on the conductor.

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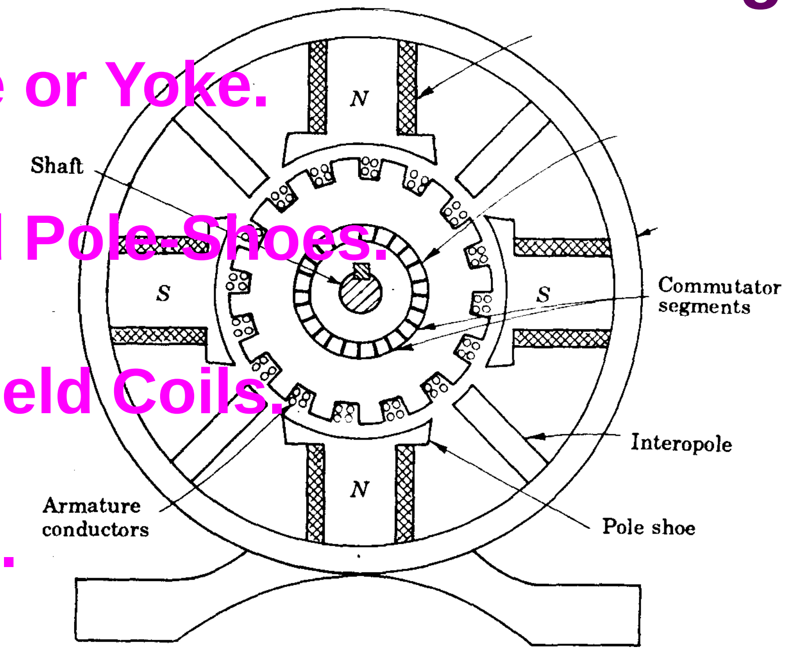
D.C. MACHINES

Construction

A d.c. Machines consists Following main parts.

1. Magnetic Frame or Yoke.
2. Pole-Cores and Pole-Shoes.
3. Pole Coils or Field Coils.
4. Armature Core.
5. Armature Windings or Conductors.
6. Commutator
7. Brushes and Bearings
8. Interpoles.



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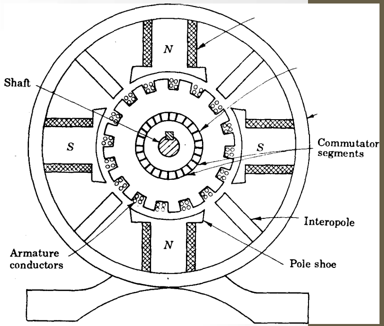
D.C. MACHINES



Construction

1. Magnetic frame or yoke

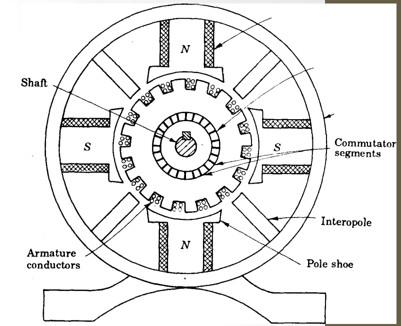
1. The outer frame or yoke is a hollow cylinder of cast steel or rolled steel.

The yoke serves the following two purposes:

a) It supports the pole cores and acts as protecting cover to the machine.

b) It forms a part of the magnetic circuit.

D.C. MACHINES



Construction

2.Pole Core And Pole Shoes

- An even number of pole cores are bolted to the yoke.
- The pole cores are made of sheet steel laminations that are insulated from each other and riveted together. The poles are laminated to reduce eddy-current loss.
- Each pole core has one or more field coils (windings) placed over it to produce a magnetic field.

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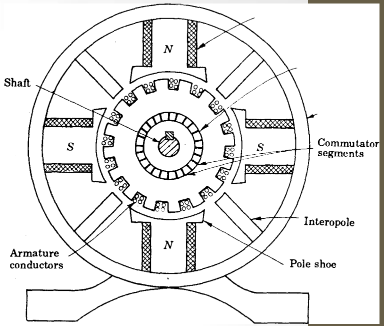
D.C. MACHINES



Construction

2. Pole Core And Pole Shoes

- Each pole core has a pole shoe having a curved surface.

The pole shoe serves two purposes:

- (i) It supports the field coils.
- *(ii)* It increases the cross.-sectional area of the magnetic circuit and reduces its reluctance.

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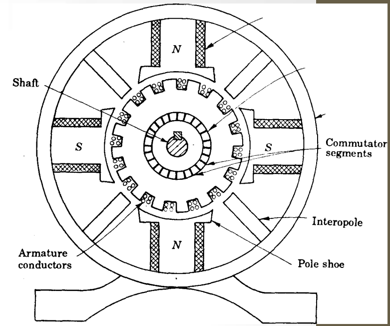
D.C. MACHINES



Construction

3. Pole Coils Or Field Coils

- Each pole core has one or more field coils (windings) placed over it to produce a magnetic field
- The field coils (or exciting coils) are connected in series with one another such that when the current flows through the coils, alternate north and south poles are produced.

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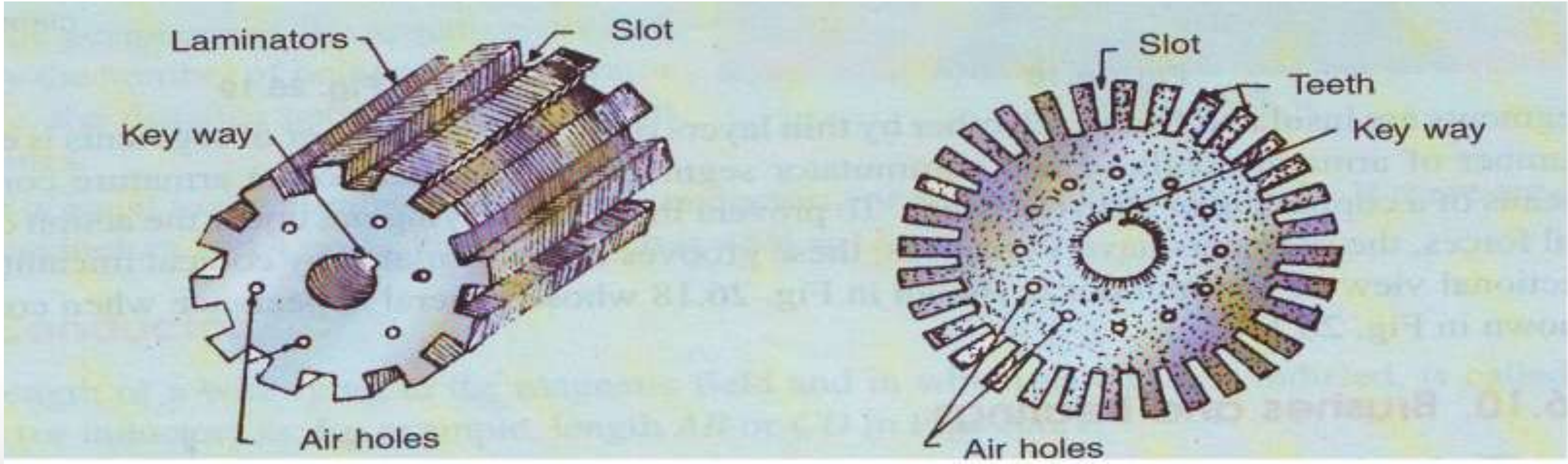
D.C. MACHINES

Construction

4. Armature Core

- *The rotating part of the d.c. machine is called the* **armature.**
- **The armature consists of a laminated grooves or slots.**



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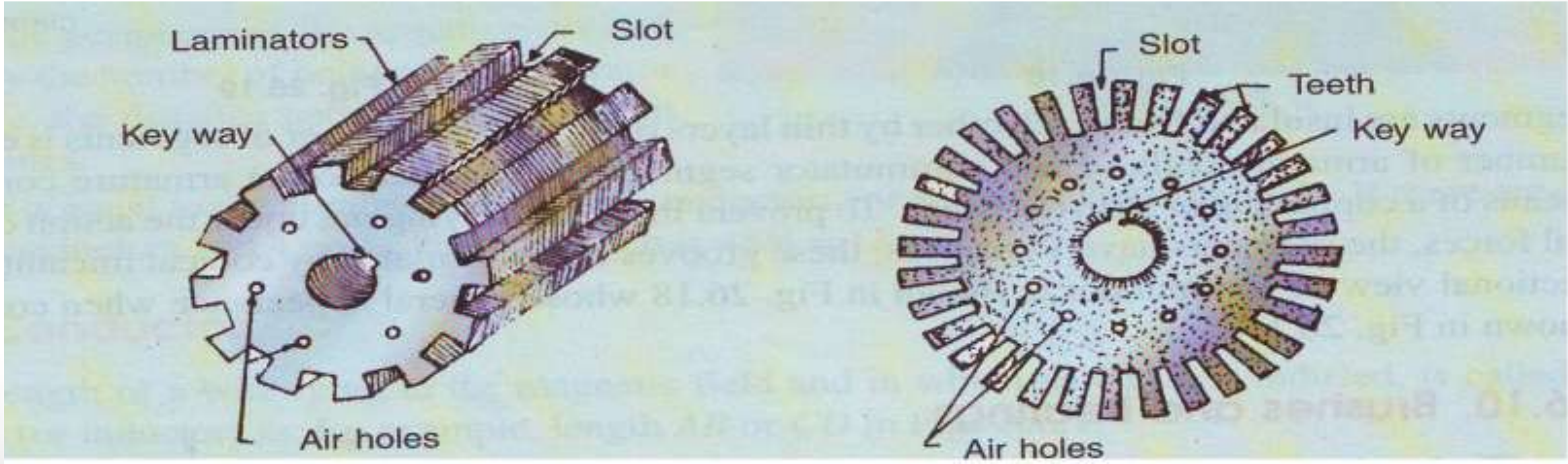
D.C. MACHINES

Construction

4. Armature Core

The armature core has grooves or slots on its outer surface.

The insulated conductors are put in the slots of the armature core



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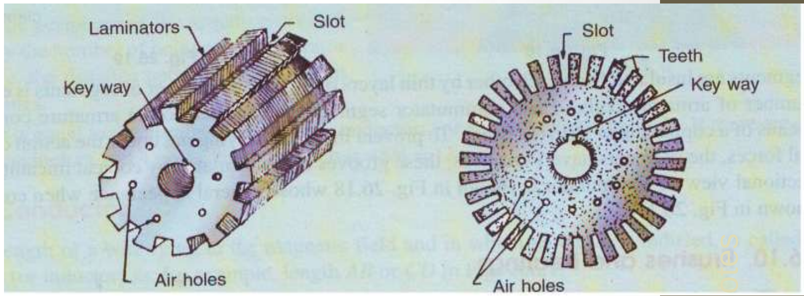
D.C. MACHINES



Construction

5. Armature Windings

- The insulated conductors are put in the slots of the armature core
- The purpose of using laminations is to reduce eddy-current loss.
- The conductors are suitably connected. This connected arrangement of conductors is called armature winding.

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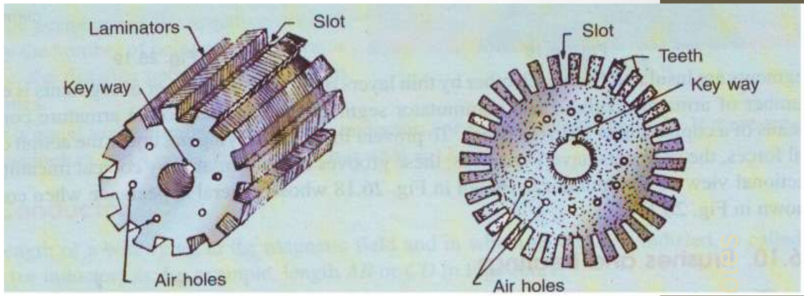
D.C. MACHINES

Construction

5. Armature Windings



- **Armature winding connections are two ways :**
- **Lap Winding**
- **Wave Winding**

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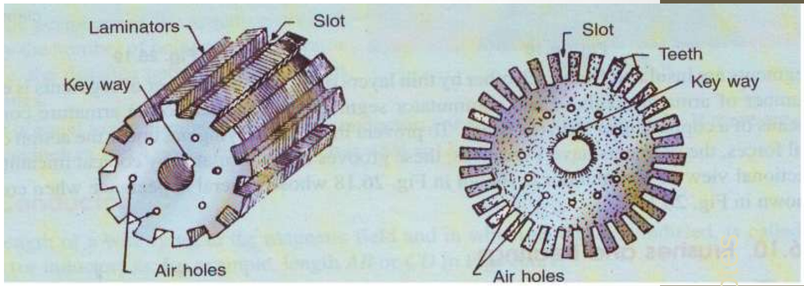
D.C. MACHINES

Construction

5. Armature Windings



- **Lap Winding** :

The ends of each armature coil are connected to adjacent segments on the commutators so that the total number of parallel paths is equal to the total number of poles.
That is, for LAP winding A = P.
This may be remembered by the letters A and P in LAP.

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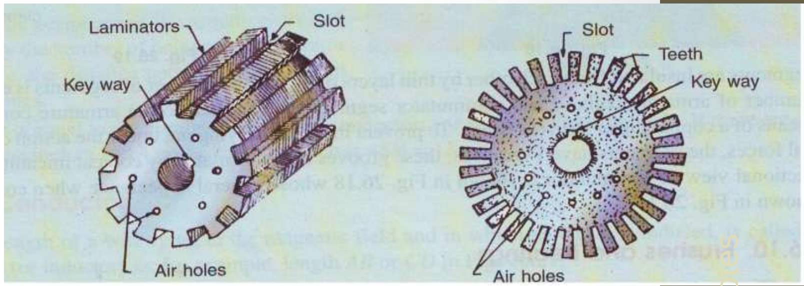
D.C. MACHINES

Construction

5. Armature Windings



- **Wave Winding**
- **The ends of each armature coil are connected to armature segments some distance apart, so that only two parallel paths are provided between the positive and negative brushes.**
- **That is, for WAVE winding A = 2.**

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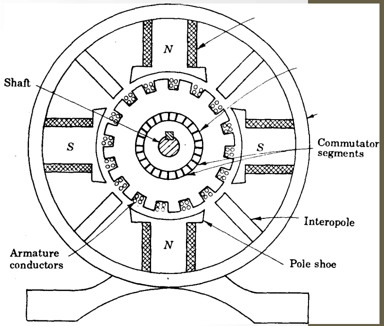
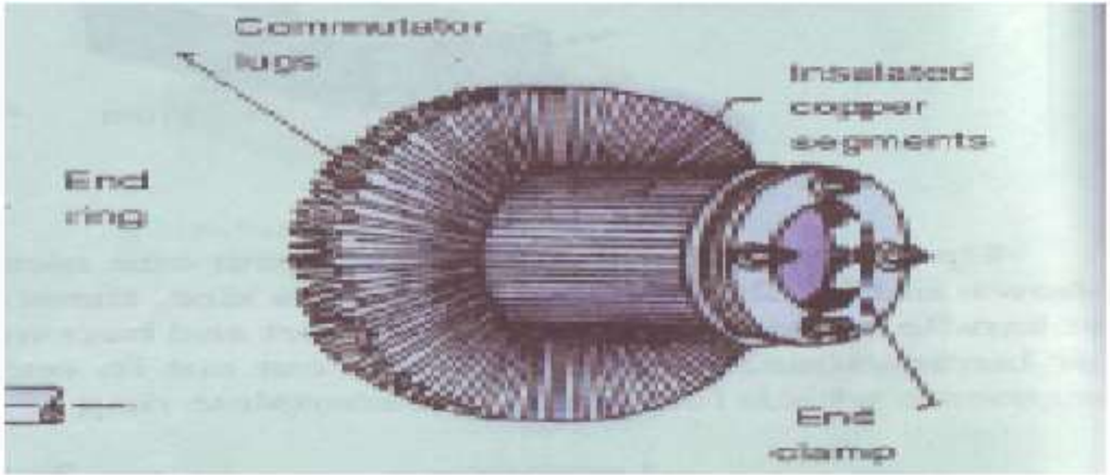
D.C. MACHINES



Construction

6.Commutator

- **Alternating voltage is produced in a coil rotating in a magnetic field.**
- **To obtain direct current in the external circuit a commutator is needed.**



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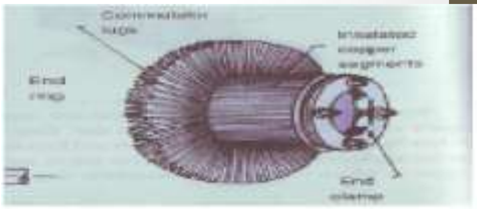
D.C. MACHINES

Construction

6.Commutator



- **The commutator, which rotates with the armature, is made from a number of wedge-shaped hard-drawn copper bars or *segments* insulated from each other and from the shaft.**
- **Each commutator segment is connected to the ends of the_armature coils.**
- **Commutator is a mechanical rectifier which convert AC generated in armature to DC in external circuit.**

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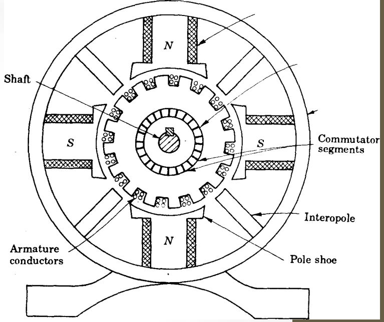
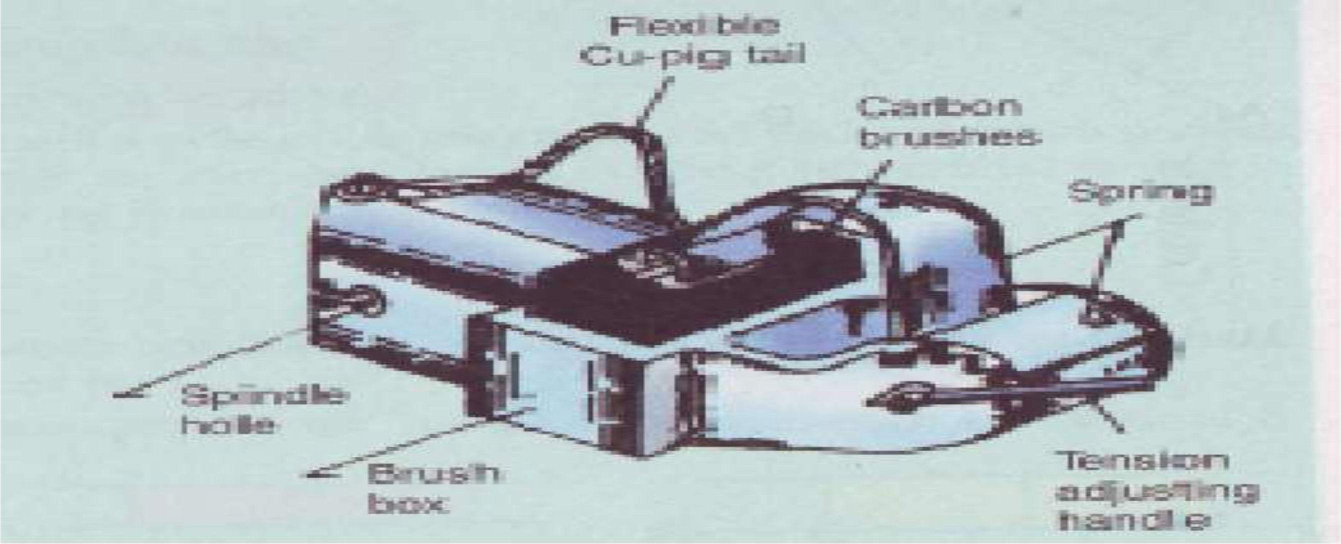
D.C. MACHINES



Construction

7. Brushes and Bearings

- Current is collected from the armature winding by means of two or more carbon **brushes** mounted on the commutator.



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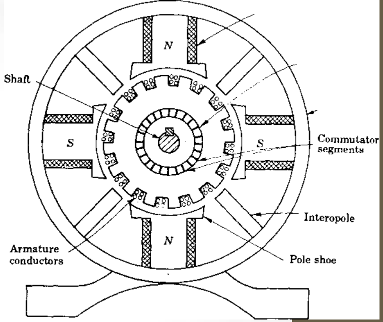
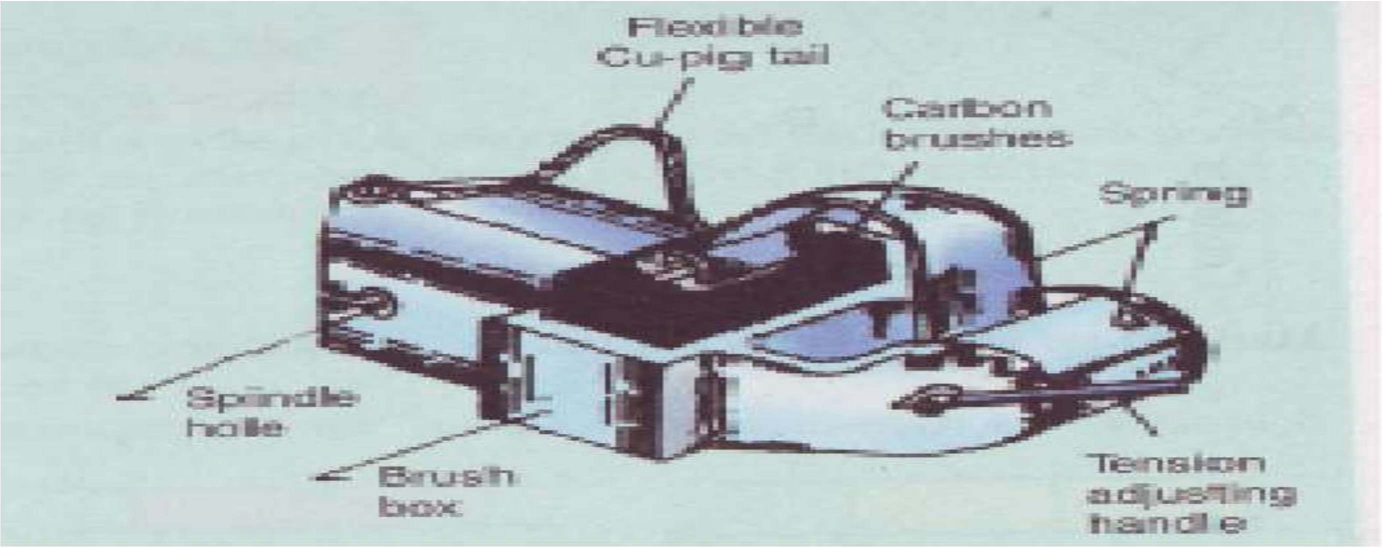
D.C. MACHINES



Construction

7. Brushes and Bearings

- **The pressure exerted by the brushes on the commutator can be adjusted and is maintained at a constant value by means of springs.**
- **Bearings are used to reduce friction losses.**



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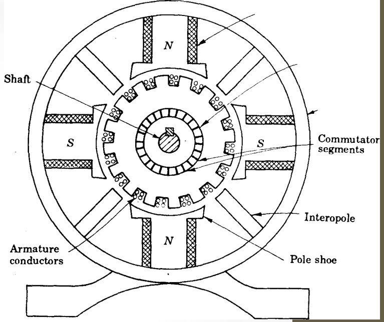
D.C. MACHINES



Construction

8. INTERPOLES

- These are narrow poles with small cross-sectional area placed midway between the main poles.
- Also called compoles or commutating poles
- Function is to reduce sparking at the commutator.

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EQUIVALENT CIRCUIT OF A D.C. MACHINE ARMATURE

- The armature of a d.c. generator can be represented by, an equivalent electric circuit. It can be represented by three series-connected elements *E*, R_a, and V_b, The element E is the generated voltage, R_a is the armature resistance, and V_b is the brush contact voltage drop.

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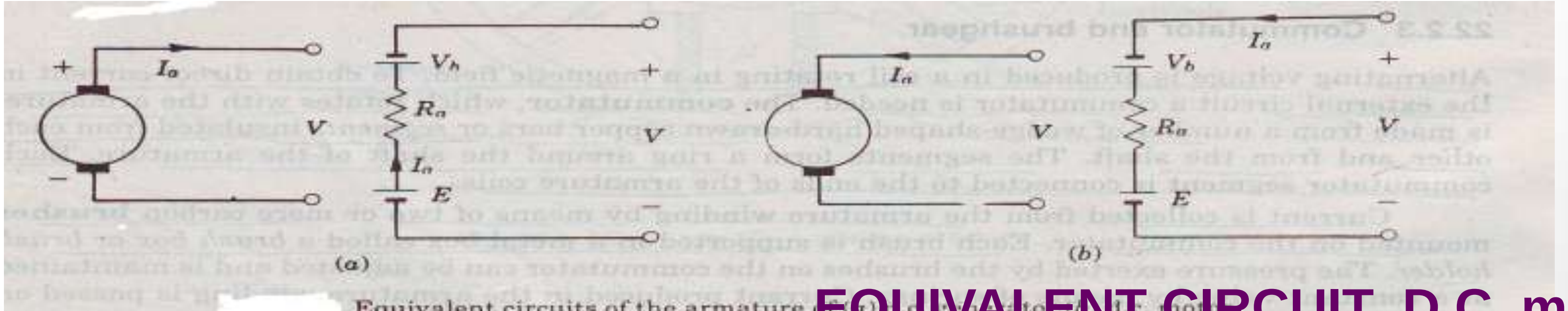

Equivalent circuits of the armature

EQUIVALENT CIRCUIT DC generator

EQUIVALENT CIRCUIT D.C. motor

TYPES OF D.C. MACHINE

The type of DC machine depends upon the methods of excitation.

- (1) separate excitation In separate excitation the field coils are energized by a separate d.c. source.
- (2) self-excitation. In self-excitation the field coils are energized by machine itself.

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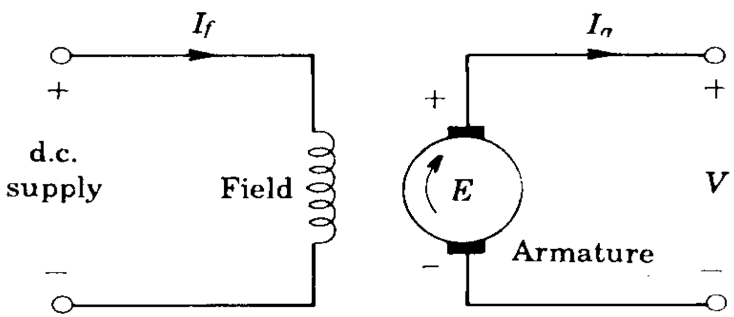
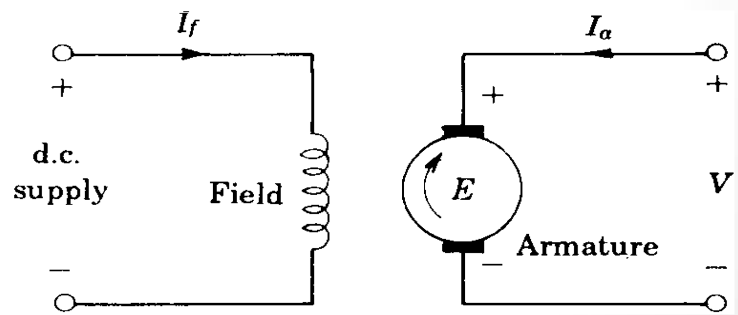
TYPES OF D.C. MACHINE

Separately excited d.c. machine

As the name implies, the field coils are energized by a separate d.c. source.
The connections showing the separately excited d.c. machines are given in Fig.



Separately excited d.c. generator



Separately excited d.c. motor

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TYPES OF D.C. MACHINE

self-excitation

- **In self-excitation the field coils are energized by machine itself.**
- **Named according to the connection of the field winding with the armature. The principal types self-excitation of d.c. machine are**
- **1. shunt machine.**
- **2. series machine.**
- **3. compound machine.**

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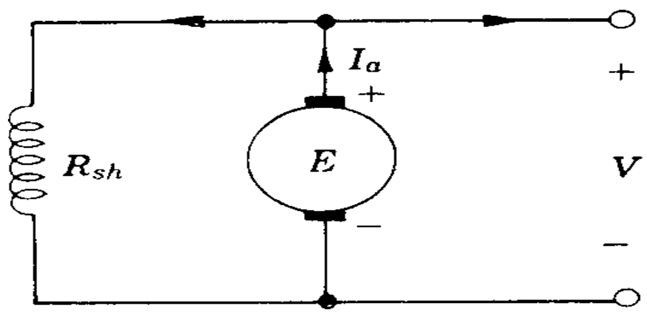
TYPES OF D.C. MACHINE

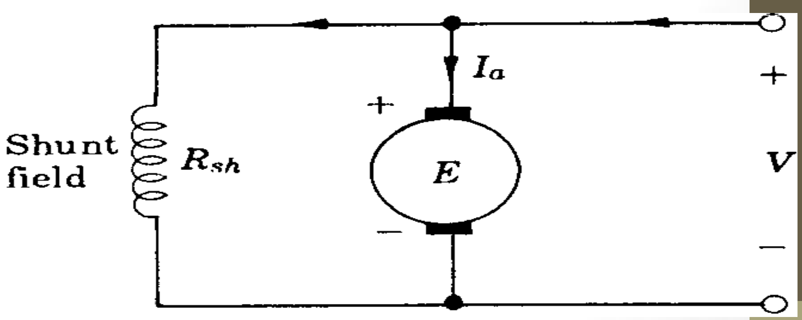
self-excitation

1. shunt machine.

- ***A*** **machine** ***in which the field coils are connected in*** **parallel with** ***the armature is called*** **shunt machine.**



shunt generator



shunt motor

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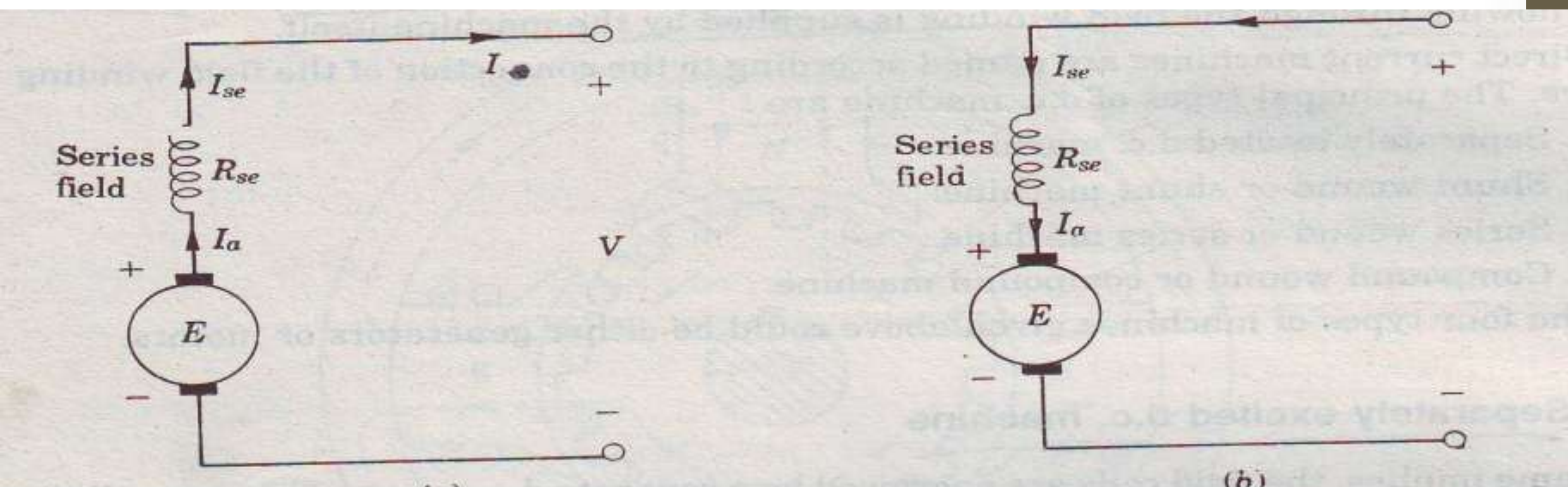
TYPES OF D.C. MACHINE

self-excitation

series machine

- *A d.c. machine in which the field coils are connected in* series *with the armature is called a* series machine.



series generator series motor

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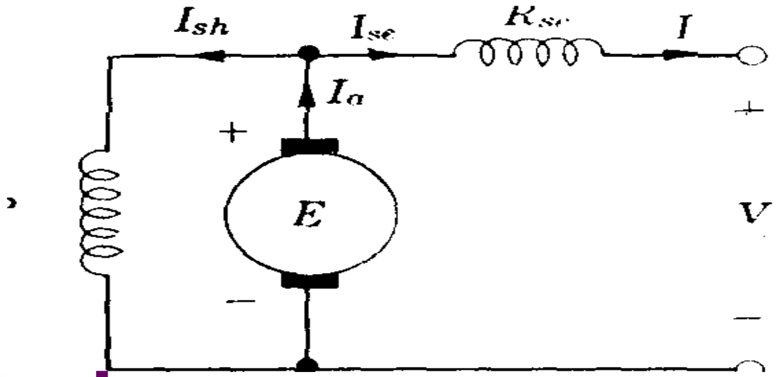
TYPES OF D.C. MACHINE

self-excitation

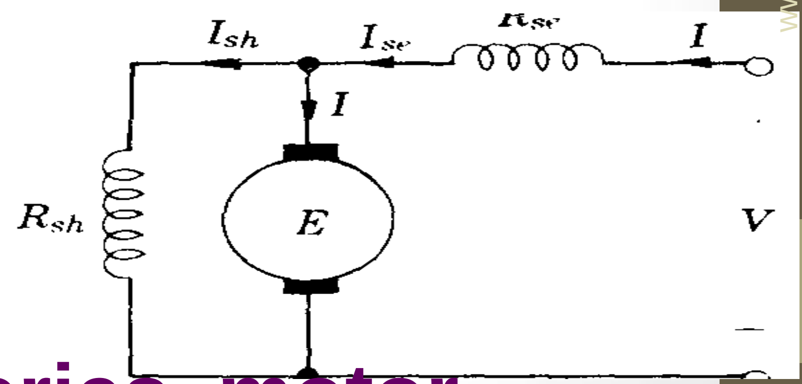
Compound machine

short shunt Compound machine

- *D.C. machine having both shunt and series fields is called a compound machine.*
- *If* the shunt field is connected in parallel with the armature *alone* the machine is called the short-shunt compound machine.



series generator



series motor

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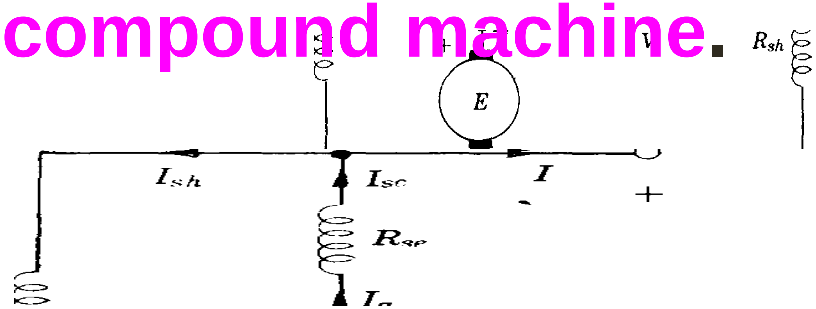
TYPES OF D.C. MACHINE

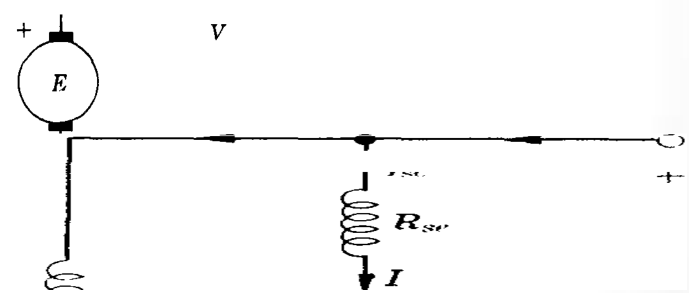
self-excitation

Compound machine

Long shunt Compound machine

If **the shunt field is in parallel with both armature and series field the machine is called-the long-shunt compound machine.**





series generator

series motor

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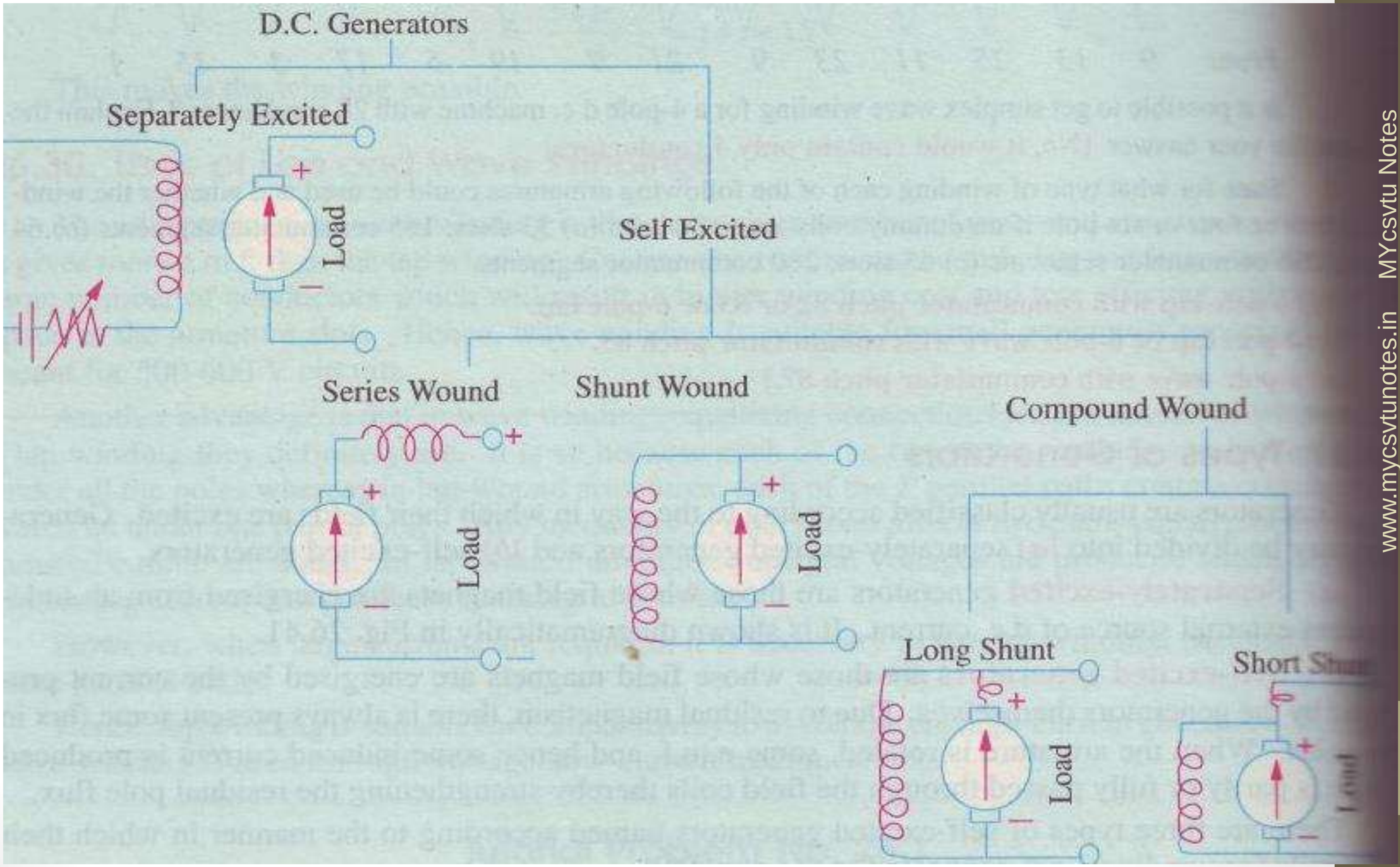
TYPES OF D.C. MACHINE



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EMF EQUATION OF D. C. MACHINES

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E.M.F. EQUATION OF D.C. MACHINE

- As the armature rotates, a voltage is generated in its coils.
- In case of a generator, the e.m.f. of rotation is called the *generated e.m.f. Eg.*
- In case of a motor, the e.m.f. of rotation is known as *back e.m.f* (or counter e.m.f.), Eb.
- The expression, however, is the same for both conditions of operation.

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E.M.F. EQUATION OF D.C. MACHINE

- Let (ϕ) = Useful flux per pole in webers(Wb)
- P =Total number of poles
- Z = Total number of *conductors* in the armature
- n = Speed of rotation of armature in revolutions per second (rps)
- *A* = Number of *parallel* paths.
- Z = Number of armature conductors in series for each parallel path A
- N= Speed of rotation of armature in revolutions per Minute (RPM)

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E.M.F. EQUATION OF D.C. MACHINE

- Since the flux per pole is ϕ , each conductor cuts a flux P ϕ in one revolution.
- Generated voltage per conductor

$$= \frac{(\text{ flux cut per revolution in Wb})}{(\text{ time taken for one revolution in seconds})}$$

- Since n revolutions are made in one second, then one revolution will be made in *1/n* second.
- Therefore the time for one revolution of the armature is 1/n second.

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E.M.F. EQUATION OF D.C. MACHINE

- The average voltage generated per conductor =(Pϕ)/(1/n) volts
- The generated voltage Eg is determined by the number of armature conductors in series in any one path between the brushes.
- Therefore the total voltage generated
- Eg = (average voltage per conductor) x (number of conductors in series per path)

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E.M.F. EQUATION OF D.C. MACHINE

- that is, $E_g = nP\phi(Z/A)$ *where n in rps*

or,

$E_g = (NP\phi/60)(Z/A)$ *where N in rpm*

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A = number of *parallel* paths.

= 2 for Wave Winding

= P for Lap Winding

Equation is called the e.m.f. equation of a d.c. machine

PROBLEMS

- **GENERAL PROCEDURE FOR SOLVING PROBLEMS ON GENERATED VOLTAGE AND ARMATURE CURRENT**

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The following general procedure may be-used conveniently to solve problems on generated voltage and armature current in a.d.c. machine.

1. Draw the equivalent circuit for the particular machine.

2. Mark symbols for electrical quantities on the circuit diagram at proper places.

3. Write down the KCL, KVL and power equations for the given machine.

PROBLEMS

- **Important Formulas**
- *Eg =* ϕZn*(P/A) where n in rps*

  Eg = (ϕZN/60) *(P/A) where N in rpm*
- *A* = number of *parallel* paths *= 2 for Wave Winding*

  = P for Lap Winding
- (ϕ) = Useful flux per pole in webers(Wb)
- P =Total number of poles
- Z = Total number of *conductors* in the armature
- n = Speed of rotation of armature in revolutions per second (rps)
- N= Speed of rotation of armature in revolutions per Minute (RPM)

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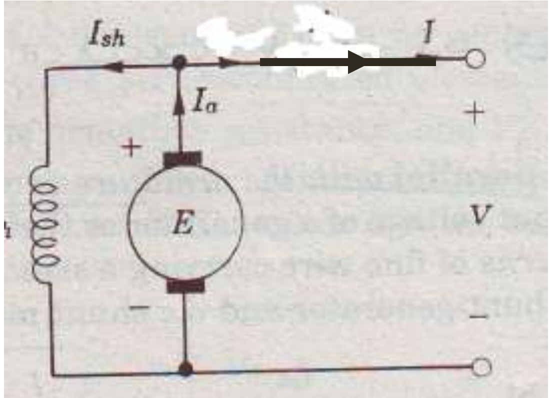
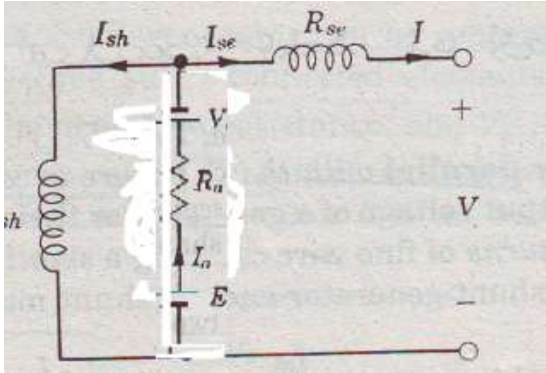
PROBLEMS

- **Important Formulas**

1. shunt Generator





Ia = Ish + I   amp
Ish = V / Rsh amp
Output power P = V I   Watt
Eg = V + Ia Ra + Vb   Volts

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PROBLEMS

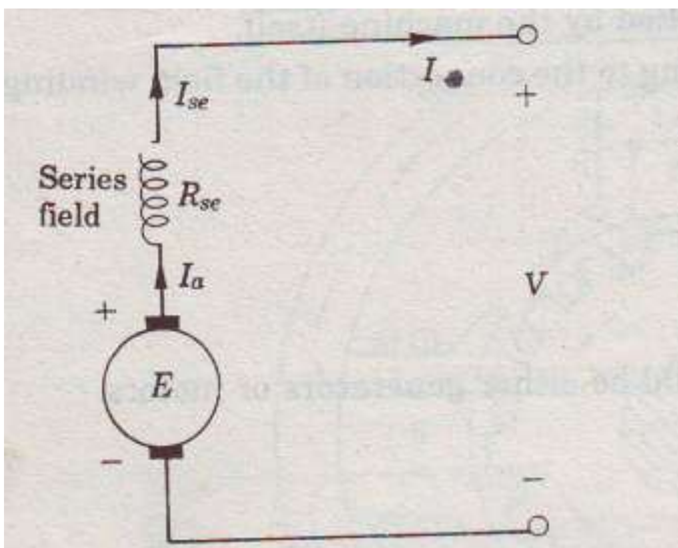
Important Formulas

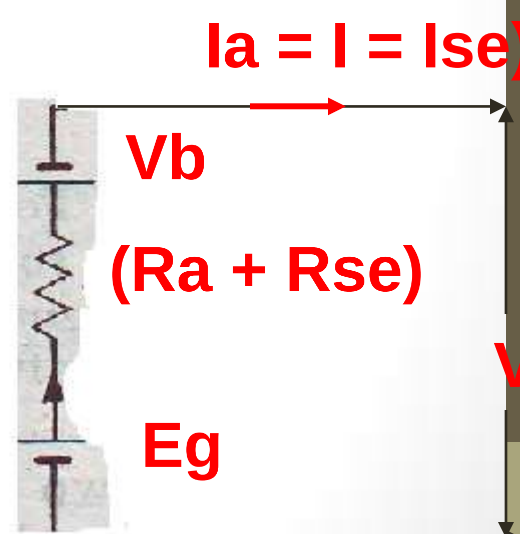
- Series Generator

Ia = Ise = I

Eg = V+ Ia (Ra + Rse) + Vb

Output power P = V Ia   Watt





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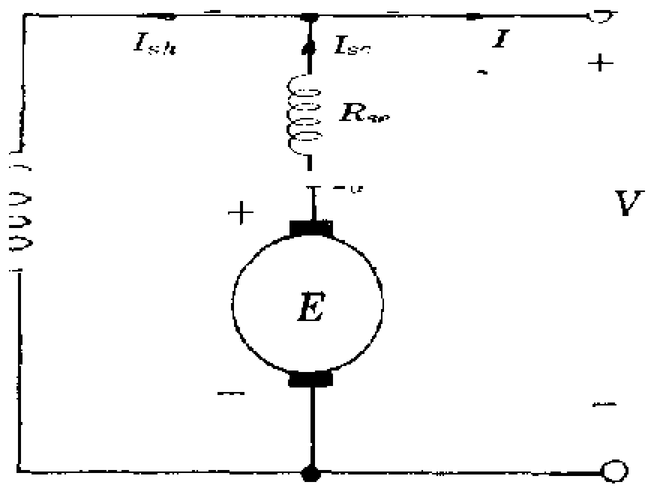
PROBLEMS

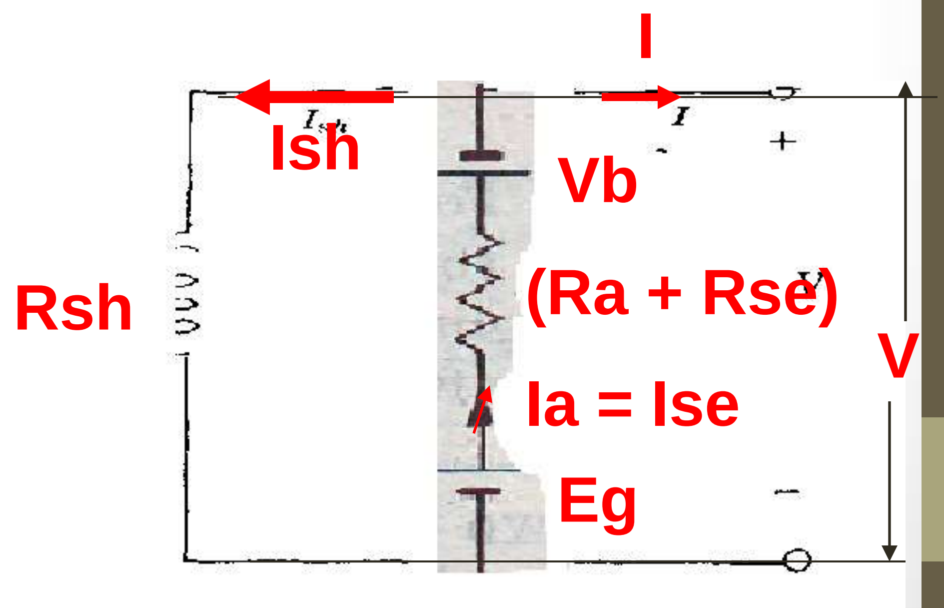
Important Formulas

Long shunt Compound Generator

- Ia = Ise = I + Ish
- Eg = V+ Ia (Ra + Rse) + Vb
- Output power P = V I Watt

  Ish = V / Rsh amp





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PROBLEMS

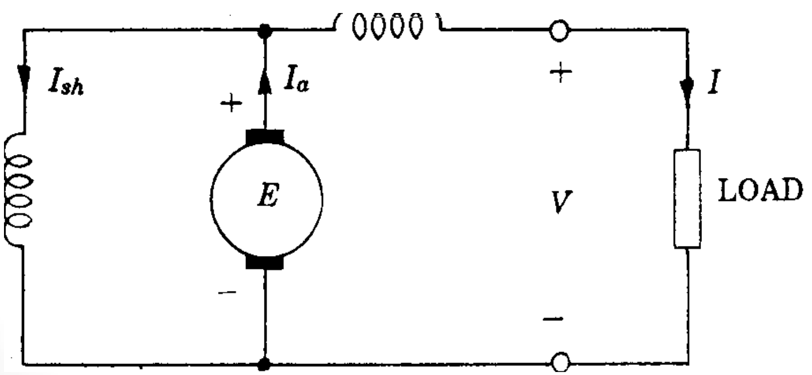
Important Formulas

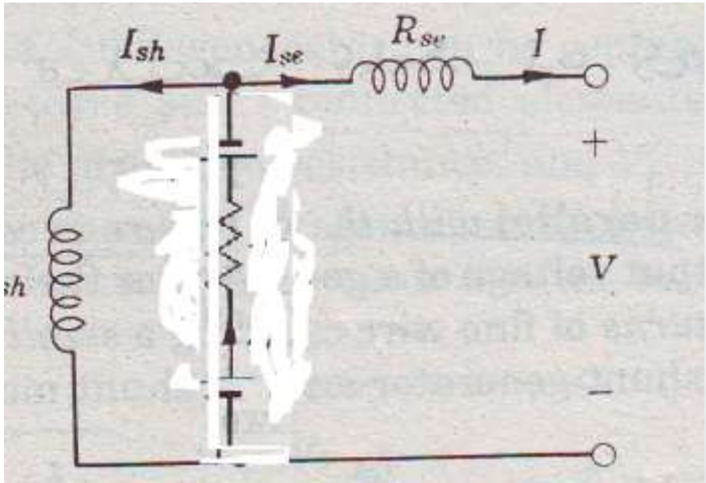
Short shunt Compound Genarator

- **I = Ise**
- **Eg = IseRse +V+Ia Ra + Vb**

  = I Rse +V+ Ia Ra + Vb
- **Output power P = V I Watt**

  Ish = V / Rsh amp





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PROBLEMS

- **EXAMPLE 1**

- A 4-pole, wave-wound armature has 720 conductors and is rotated at 1000 rev/min. If the useful flux is 20 mWb, calculate the generated voltage.
- **SOLUTION**
- Here P = 4, A = 2, Z = 720
- N= 1000 r.p.m.
- ϕ = 20 mWb = 20 x 10-3 Wb
- *E = (NP ϕ/60) (Z/A) where N in rpm*
- *=(1000*4** 20 x 10-3 */60)(720/2)*
- *= 480 V*

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PROBLEMS

- EXAMPLE 2

- **An 8-pole lap-connected armature has 40 slots with 12 conductors per slot generates a voltage of 500 V. Determine the speed at which it is running if the flux per pole is 50 mWb.**

- SOLUTION

- **Here P = 8. For lap winding A = P i.e. A = 8**
- **Total number of conductors = (number of slots) x (conductors per slot)**
- **Z=40x12=480**
- ***E = 500* volts,**
- **ϕ *= 50* mWb = 50 x 10 -3 Wb**
- ***E = (NP ϕ/60) (Z/A) where N in rpm***
- ***500 = (N *8** 50 x 10 -3 /60)(480/8)**
- **N = 1250 RPM**

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PROBLEMS

- **EXAMPLE 3**

- A d.c. generator has an armature e.m.f. of 100 V when the useful flux per pole is 20 mWb and the speed is 800 r.p.m. Calculate the generated e.m.f. *(a)* with the same flux and a speed of 1000 r.p.m., *(b)* with a flux per pole of 24 mWb and a speed of 900 r.p.m.

- **SOLUTION**

- $E = (\phi ZN/60)(P/A)$
- Since P, Z and *A* are constants for a given machine, (P*Z/60A)* also a constant say *k.*
- The generated voltage can therefore be written as $E = kN\phi$
- If the subscripts 1 and 2 denote the initial and final values
- $E_l = kN_l(\phi_1$ and , $E2 = kN_2\phi_2$ or $E_{2/}/E_1 = (kN_2\phi_2)/kN_1\phi_1)$
- *(a)* *For same flux* $\phi_1 = \phi_2$ = 20 mWb = 20 x 10 -3 Wb
- N_1 = 800 r.p.m., $N_2 = 1000$ r.p.m.
- $E_2 = E_1 * (N_2\phi_2)/N_1\phi_1) = E_1 * (N_2)/N_1) = 125\ V$

- *(b)*ϕ_1 = 20 mWb = 20 x 10 -3 Wb and ϕ_2 = 24 mWb = 24 x 10 -3 Wb
- N_1 = 900 r.p.m *and* N_2 = 900 r.p.m.
- $E_2 = E_1 * (N_2\phi_2)/N_1\phi_1)$ = 135 V

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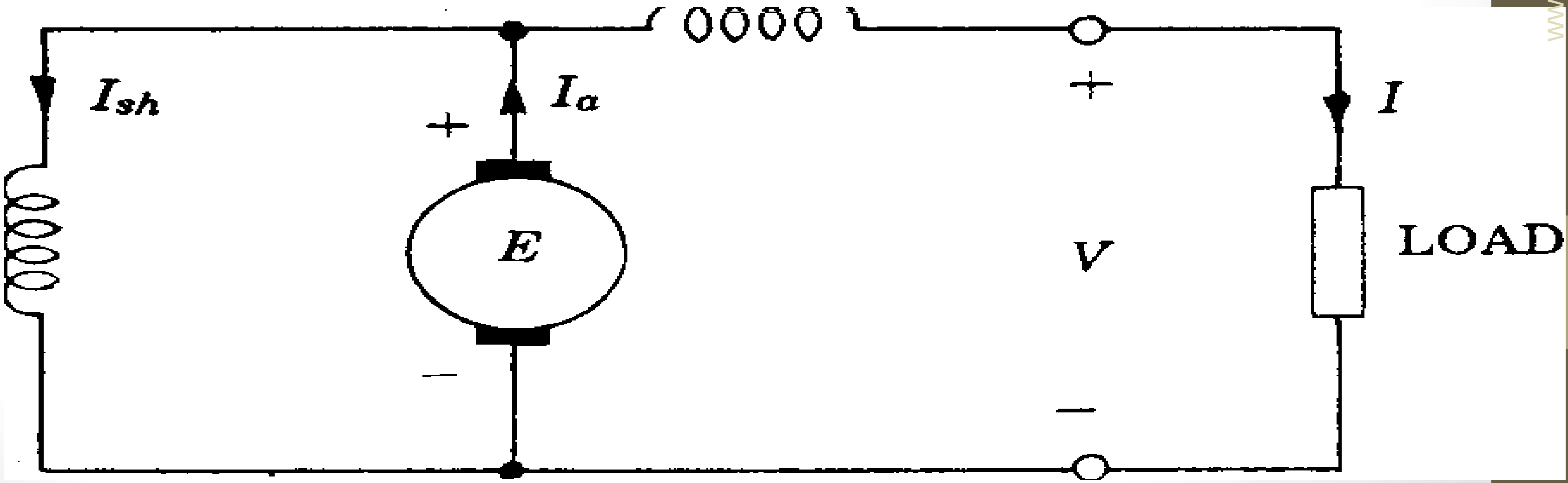
PROBLEMS

- **EXAMPLE 4**

- **A short-shunt compound d.c. generator delivers 100 A to a load at 250 V. The generator has shunt field, series field and armature resistance of 130 Ω , 0.1Ω and 0.1Ω respectively. Calculate the voltage generated in armature winding. Assume IV drop per brush.**

- **SOLUTION**

  - The circuit diagram of a short-shunt compound d.c. generator is shown in Fig.



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Here I = 100 A, V = 250 *V*,

$R_{Sh}= 130\ \Omega$

$R_{se} = 0.1\Omega,\ \ R_{,a} = 0.1\ \Omega$

Brush voltage drop

$V_b = 2 \times 1 = 2\ V$

By KVL in the outer loop ABCDA

$I_{sh}R_{sh} - E + I_a R_a + V_b = O \quad (1)$

and loop AEFDA

$I_{se}R_{se} + V - E + Ia\ Ra + Vb = 0$ (2)

For parallel branches

$I_{sh}R_{sh} = V + I_{se}R_{se} = V + I\ R_{se}$

$= 250 + 100 * 0.1 = 260$ V

$I_{sh} = V / R_{sh} = 260 / 130 = 2$ A

$I_a = I + I_{sh} = 100 + 2 = 102$ A

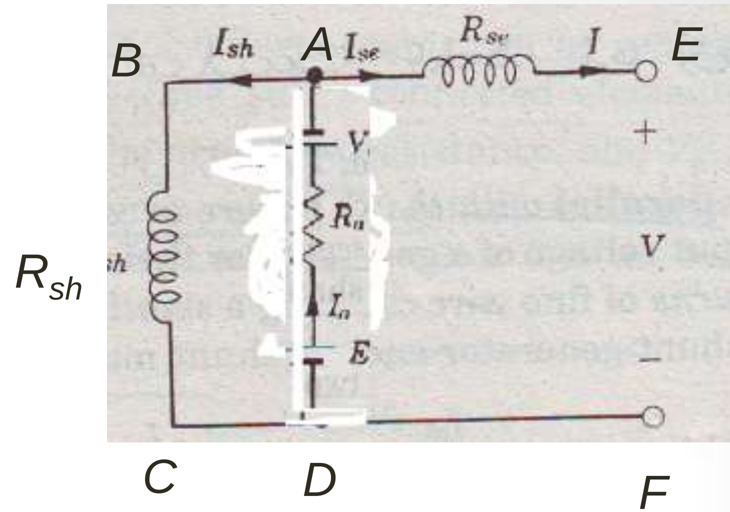
From eq (2)

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

$= I\ R_{se} + V + I_a R_a + V_b$

$= 100 * 0.1 + 250 + 102 * 0.1 + 2$

$= 272.2$ V



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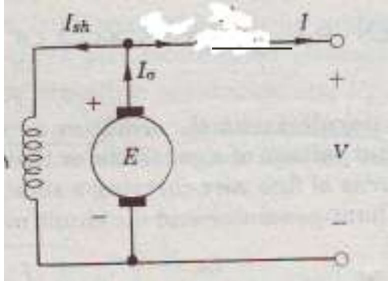
PROBLEMS

$I_a = I_{sh} + I$ amp

$I_{sh} = V / R_{sh}$ amp

Output power $P = V I$ Watt

$E_g = V + I_a R_a + V_b$ Volts



- **Example 5**
- ***A shunt generator delivers 450 A at 230 V and the resistance of the shunt and armature are 50Ω and 0.03 Ω respectively. Calculate the generated e.m.f***
- **Solution.**
- **Generator circuit is shown in Fig.**

Current through shunt field winding is I_{sh} = 230/50 = 4.6 A

- **Load current I = 450A**
- **Armature current $I_a = I + I_{sh}$ = 450 + 4.6 = 454.6 A**
- **Armature voltage drop $I_a R_a$ = 454.6 x 0.03 = 13.6 V**
- **$E_g = V + I_a R_a$**
- **e.m.f. generated in the armature**
- **E_g = 230 + 13.6 = 243.6 V**

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PROBLEMS

Ia = Ise

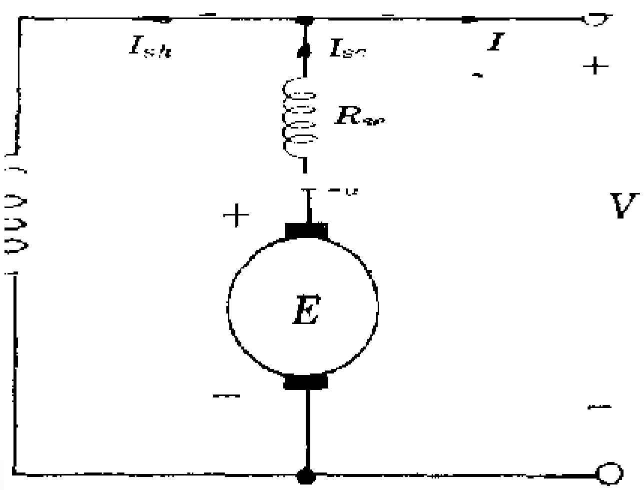
Eg = V+ Ia (Ra + Rse) + Vb

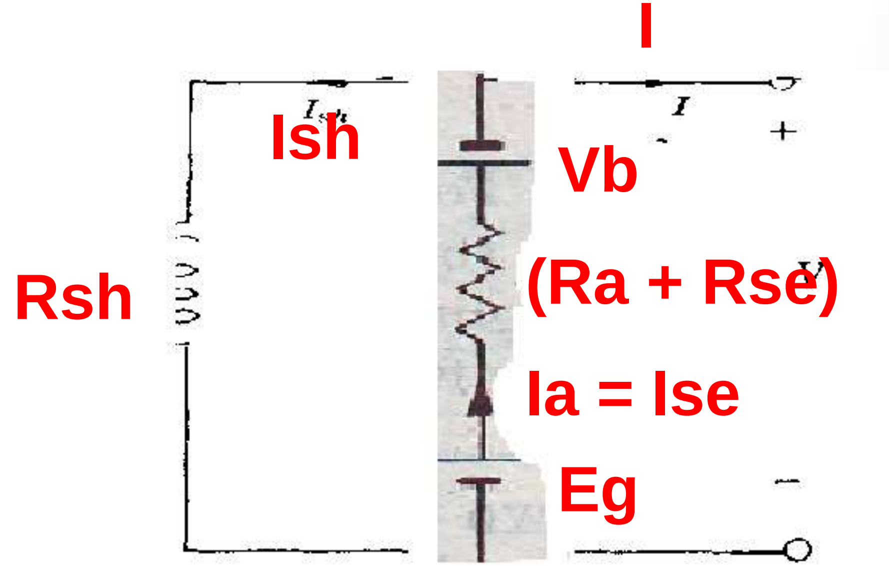
Output power P = V I Watt

Ish = V / Rsh amp

- **Example 6**

- *A long-shunt compound generator delivers a load current of 50 A at 500 V and armature, series field and shunt field resistances of 0.05 Ω 0.03 Ω and 250 Ω respectively. calculate the generated voltage and the armature current. Allow 1 V per brush for contact drop.*





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Ia = Ise = I + Ish
Eg = V+ Ia (Ra + Rse) + Vb
Output power P = V I Watt
Ish = V / Rsh amp

PROBLEMS

- **Solution.**
- Generator circuit is shown in Fig.
- *Ish* = 500/250 = 2 A
- current through armature and series winding is
- Ia = Ise = I + Ish = 50+2 =52A
- voltage drop on series field winding Ia Rse
- = 52 x 0.03 = 1.56 V
- voltage drop on armature winding *IaRa*
  = 52X0.05=2.6V

voltage drop at brushes = 2 x 1= 2 V

- Eg = V + Ia (Ra + Rse) + Vb
- = 500 +2.6+1.56 +2 = 506.16V

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PROBLEMS

- 1. *A short-shunt compound generator delivers a load current of 30 A at 220 V, and has armature, series field and shunt field resistances of 0.05 Ω 0.30 Ω and 200 Ω respectively. calculate the generated voltage and armature current Allow 1 V per brush for contact drop.*
- 2. *In a long-shunt compound generator, the terminal voltage is 230 V when geners 150 A. Determine (i) induced e.m f. (ii) total power generated and Given that shunt field, series field, and armature resistance are 92 Ω, 0.015 Ω and 0.032 Ω respectively*

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PROBLEMS

- **3. A long-shunt compound generator delivers a load current of 50 *A* at *500* V, and the resistances of armature, series field and shunt fields are *0.05 Ω, 0.03 Ω,* and *250 Ω* respectively. Calculate the generated e.m.f. and the armature current. Allow 1.0 V per brush for contact drop.**
- **4. An 8 pole generator has 500 armature conductors and has a useful flux per pole of 0.065 Wb. What will be the emf generated if it is lap connected and runs at 1000 RPM ? What must be the speed at which it is to be driven to produce the same emf if it is wave connected?**
- **5. A lap wound dc shunt generator having 80 slots with 10 conductor per slot generator at no load an emf of 400 V when running at 1000 RPM. At what speed should it be rotated to generate a voltage of 220 V 0n open circuit?**

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PROBLEMS

- 6. An 8 pole lap connected dc generator armature has 950 conductors, a flux of 40 mWb and a speed of 400 RPM. Calculate the emf generated on open circuit. If the same armature is wave connected at what speed must the armature be driven to generate 400 V.
- 7. A 4-pole wave wound dc shunt generator having 51 slots with 48 conductor per slot . The flux per pole 7.5 mWb. At what speed should it be rotated to generate a voltage of 440 V 0n open circuit
- 8. A 8-pole dc generator having 100 slots with 8 conductor per slot . The winding so connected to have 8 parallel paths. Determine the speed to generate a voltage of 240 V the flux per pole 30 mWb.

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PROBLEMS

- **9. a 4- pole d.c.generator has a wave-wound armature with 792 conductors. The flux per pole is 0.012 Wb.calculate speed at which it should be run to generate 240 V on no-load. [751.3 r.p.m.]**
- **10. A 20 KW compound generator works on full-load with a terminal voltage of 230 V. The *armature, series field and shunt field resistances of 0.1 Ω ,0.05 Ω and 115 Ω respectively. calculate the generated*. e.m.f. when -_(a) Short shunt (b) Long**
- **11. A 4-pole wave wound dc shunt generator having 51 slots with 48 conductor per slot . The flux per pole 7.5 mWb. At what speed should it be rotated to generate a voltage of 440 V 0n open circuit**

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PROBLEMS

- **12. A dc shunt generate an e.m.f. of 520 V. It has 2,000 armature conductors, flux per pole of 0.013 7.5 mWb and speed 1200 RPM and the armature winding has four parallel paths. Find the number of poles.**
- ***13. A 6 pole lap connected D. C. Shunt Generator has 410 armature conductors .generated 400 v on no load. The flux per pole is 0.05 web. Determine the speed of the motor.***
- **14. When driven a 1000 RPM with a flux per pole of 0.02 Wb, a d.c. generator has an e.m.f. of 200 V. If speed is increased to 1100 RPM   and at the same time the flux per pole is reduced to 0.019 Wb per pole, What is then the induced emf.**

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PROBLEMS

- **15. Calculate the flux in a 4-pole dynamo with 722 armature conductors generating 500 V when running at 1000 r.p.m. when the armature is (a) lap connected (b) wave connected.**
- **16. A 4-pole machine running at 1500 r.p.m. has an armature with 90 slots and 6 conductors per slot. The flux per pole is 10 mWb. Determine the terminal e.m.f. as d.c. Generator if the coils are lap connected.If the current per conductor is 100 A, determine the electrical power.**
- **17. A long-shunt, compound generator delivers a load current of 50 A at 500 V and the resistances armature, series field and shunt field are 0.025 ohm, 0.025 ohm and 250 ohm respectively. Calculate the generated emf and the armature current. Allow 1.0 V per brush for contact drop.**

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PROBLEMS

- 18. A shunt generator producess 450 A at 230 V. The resistance of the shunt field and armature are 50 ohm and 0.025 ohm respectively. Find out the armature voltage drop.
- 19. A 2-pole generator with wave wound armature has 51 slots each having 24 conductors.The flux per pole is 0.01 Wb. find speed at which the generator should run. If generated emf is 500 V.
- 20. In a 10-pole, lap wound d.c. generator, the number of active armature conductors per slot is 50 each having 24 slots . The flux per pole is 0.01 Wb. Find generated emf if speed at which the generator should run is 1000 RPM.

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PROBLEMS

- 21. A 100 kW, 250 rpm, d.c. generator has 6 poles. The armature has 83 slots each holding 8 conductors, and the winding is wave wound. Find out the no-load flux per pole at which and e.m.f. of 500 volts is induced.
- 22. A 4-pole, 1200 rpm generator with a lap wound armature has 65 slots and 12 conductors per slot. The flux per pole is 0.02 Wb. Calculate the e.m.f. induced in the armature.
- 23. A 4-Pole, 1200 rpm, lap wound dc generator has 760 conductors. If the flux per pole is 0.02 wb. Calculate the e.m.f generated.

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PROBLEMS

- **24. In a dc generator running at 1600 rpm gives 240 V d.c. If the speed is propped to 1400 rpm without change in flux. Calculate the new e.m.f.**
- **25 A shunt generator running at 600 rpm has an induced e.m.f. of 200 Volts. If the speed increases to 750 rpm. Calculate the induced e.m.f.**
-

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BACK EMF

&

TORQUE EQUATION

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Direct-Current Motors

INTRODUCTION

- ***A motor is a machine that concerts electrical energy into mechanical energy.***
- **The d.c. motor is very similar to a d.c. generator in construction.**

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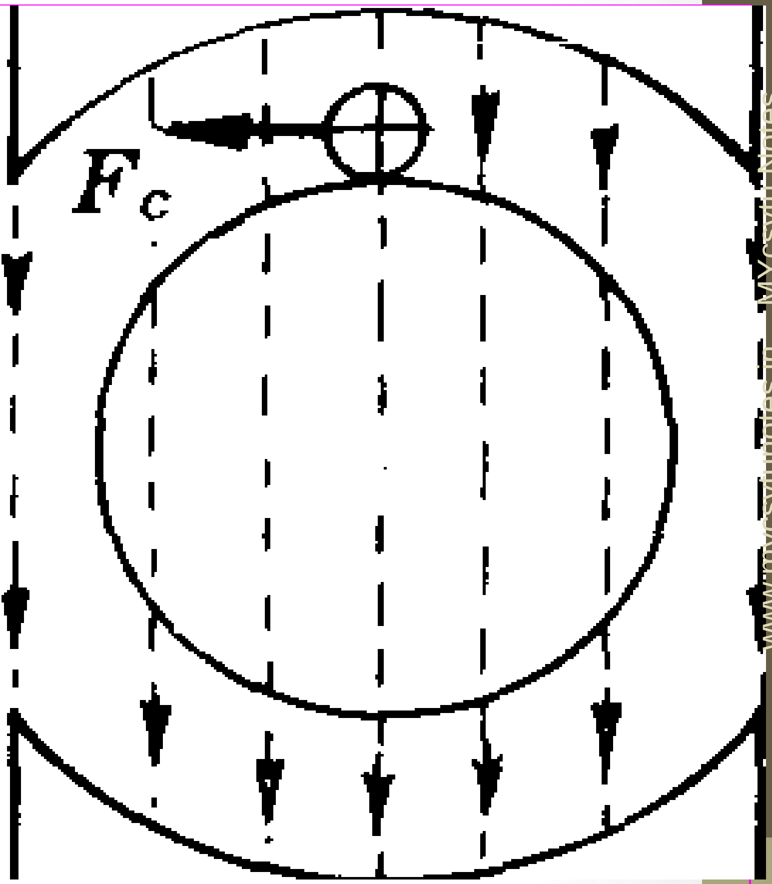
Direct-Current Motors

N

PRINCIPLE

- When a conductor carrying current is put in a magnetic field a force is produced on it.
- The effect of placing a Current-carrying conductor in a magnetic field is shown in Fig.



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A current-carrying conductor placed in a magnetic field

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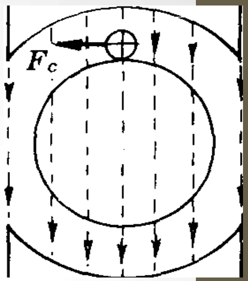
Direct-Current Motors



PRINCIPLE

- Let us consider one such conductor placed in a slot of armature and suppose that it is acted upon by the magnetic field from a north pole of the motor.
- By applying left-hand rule it is found the conductor has a tendency to move to the left-hand side.
- Since the conductor is in a slot on the circumference of the rotor, the force F_c acts in a tangential direction to the rotor.
- Thus, a torque (turning effect) is developed on the rotor.
- Similar torques are produced on all the rotor conductors. Since the rotor is free to move, it starts rotating in the anticlockwise direction

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Direct-Current Motors

BACK E.M.F

- When the motor armature rotates, its conductors cut the magnetic flux.
- Therefore, the e.m.f. of rotation E_b is induced in them.
- In case of a motor, the e.m.f. of rotation is known as back e.m.f. or counter e.m.f.
- The back e.m.f. opposes the applied voltage.
- Since the back e.m.f. is induced due to generator action its magnitude is, therefore, given by the same expression as that for the generated e.m.f. in a d.c. generator.
- That is, $E_b = (\phi ZN/60)(P/A)$

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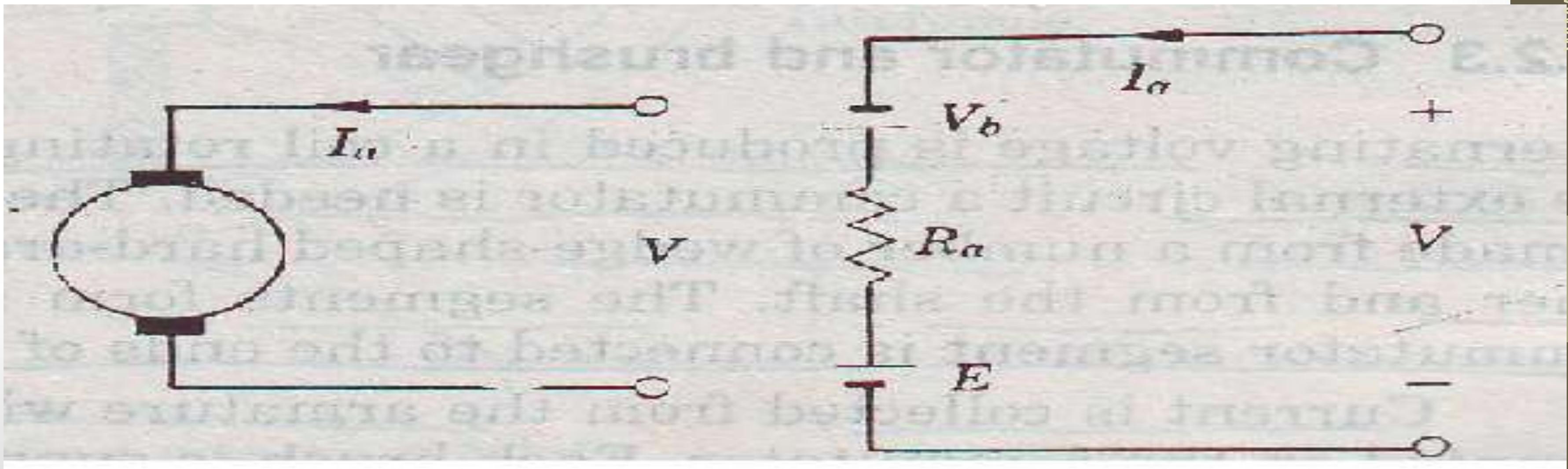
EQUIVALENT CIRCUIT OF A D.C. MOTOR ARMATURE

- **The armature of a d.c. motor can be represented by an equivalent circuit.**
- **It can be represented by three series-connected elements *Eb, R,* and *Vb.***
-



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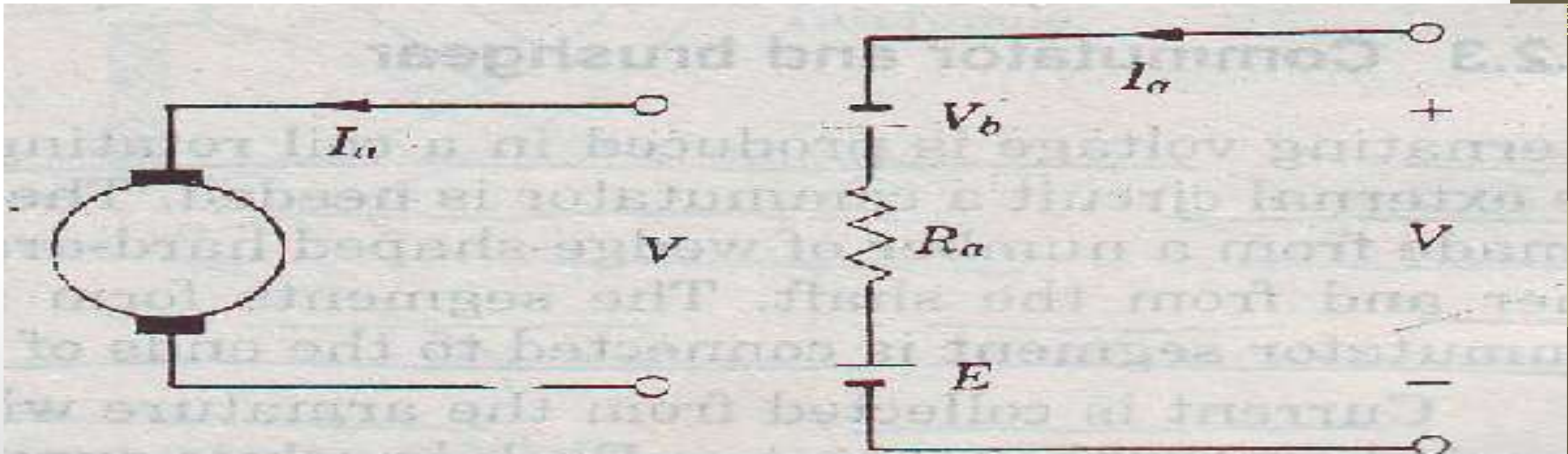
EQUIVALENT CIRCUIT OF A D.C. MOTOR ARMATURE

- The element Eb is the back e.m.f., the element Ra, is the armature resistance and Vb is the brush contact voltage drop. The equivalent circuit of the armature of a d.c. motor is shown in Fig.



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EQUIVALENT CIRCUIT OF A D.C. MOTOR ARMATURE

- **In a motor. current flows from the line *into* the armature against the generated voltage.**
  - ***V = Eb + IaRa (1)***
- ***V = motor terminal voltage***
- ***Eb = back e,m.f.***
- ***Ia = armature current***
- ***Ra = armature-circuit resistance***
- ***Equation (1) is the*** fundamental motor equation.
- ***If* the voltage drop Vb, in the brushes is also considered, then *V = Eb +IaRa +Vb,***

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TORQUE OF A DC MACHINE

- when a dc machine is loaded either as a motor or as a generator, the rotor conductors carry current.
- These conductors lie in the magnetic field of the air gap.
- Thus each conductor experiences a force.
- Hence a torque is produced around the circumference of the rotor and the rotor starts rotating.

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TORQUE OF A DC MACHINE

- The expression of the torque in DC motor
- The voltage equation of a d.c. motor is
  - $V = E_b + I_a R_a$
- Multiplying both the sides by Ia
  - $V I_a = E_b I_a + I_a^2 R_a$ (1)
- $V I_a$ = *electrical power input to the armature*
- $I_a^2 R_a$ = *copper loss in the armature*
- $E_b I_a$ = electrical equivalent of gross mechanical power developed by the armature (electromagnetic power).

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TORQUE OF A DC MACHINE

- We also know that
  - input = output + losses (2)
- Comparison of Eqs. (1) and (2) shows that
- EIb = electrical equivalent of gross Mechanical power developed by the armature (electromagnetic power)
- Let T = average electromagnetic torque developed

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TORQUE OF A DC MACHINE

- Mechanical power developed by the armature,
- $Pm = \omega T = 2\pi nT \quad (\omega = 2\pi n)$
- Therefore
- Pm $= EbIa = \omega T = 2\pi nT$
- But $E_b = (\phi ZN/60)\,(P/A)$
- *Therefore* $(\phi ZN/60)\,(P/A)Ia = 2\pi nT$
- $T = (1/2\pi)\phi Z\, Ia\, (P/A) \qquad (3)$
- $= 9.55\,(Eb\, Ia / N)$
- *Equation (3) is called the torque equation of d.c. motor .*
- Useful or shaft torque $T_{useful} = 9.55$ Output/ N

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TORQUE OF A DC MACHINE

- For a given d.c. machine, P, Z and A are constant, therefore
- *($PZ/2\pi A$) is also constant*
- *Let $K = (PZ/2\pi A)$*
- *$T = K \phi Ia$*
- *$T \alpha \phi Ia$*
- Hence *the torque developed by a* d.c. *motor is directly proportional to the flux per pole and armature current*

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TYPES OF D.C. MOTORS

- Direct current motors are named according to the connection of the field wingding with the armature.
- There are three types of d.c. Motors.
- 1. Shunt motor.
- 2. Series motor.
- 3. Compound motor.

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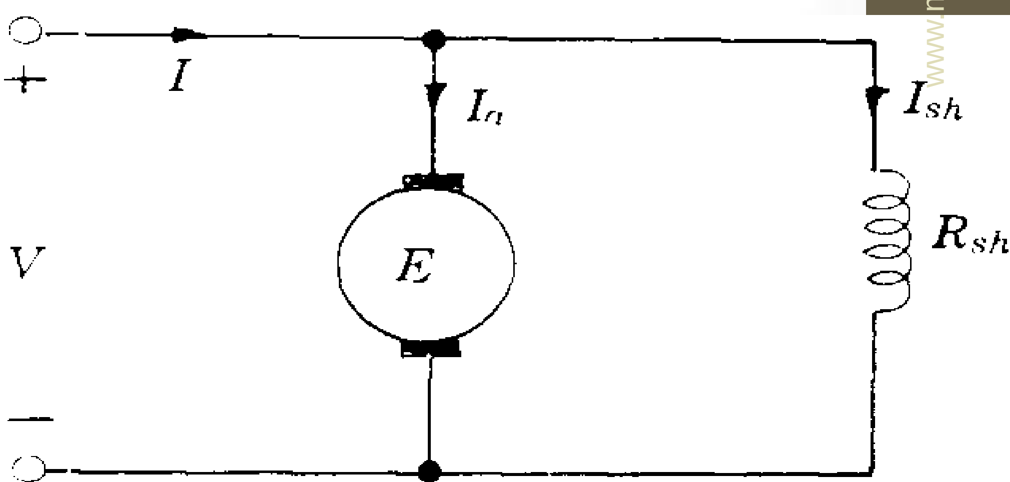
TYPES OF D.C. MOTORS

Shunt motor

- This is the most common types of d.c. motor.
- The field winding is connected in parallel with the armature, as shown in Fig.
- **Equations for a shunt motor :**
- **Equations current**
- **$I = I_a + I_{sh}$**
- **Equations voltage**
- **$V = E_b + I_a R_a + V_b$**



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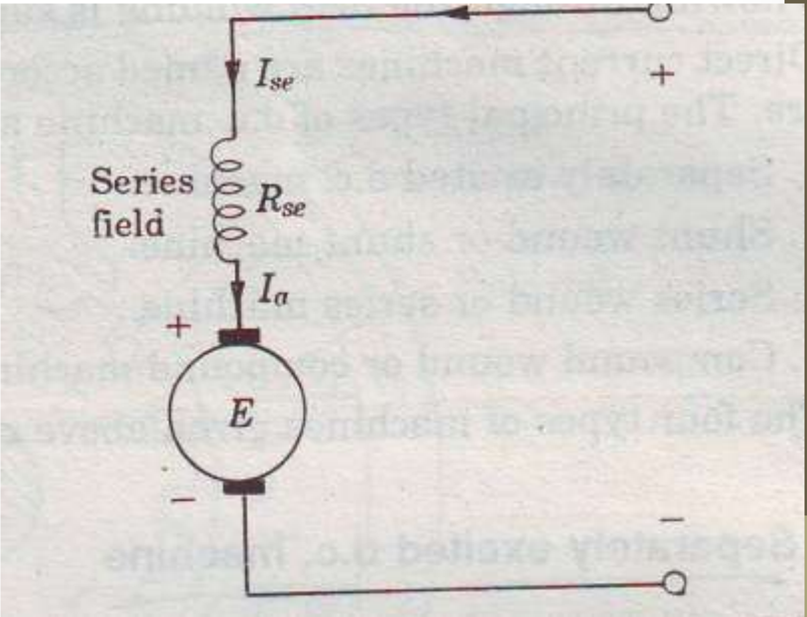
TYPES OF D.C. MOTORS

Series motor

- **In the series motor the field winding is connected in series with the armature**
- **Equations for a series motor :**
- **Equations current**
- **$I = I_a = I_{sh}$**
- **Equations voltage**
- **$V = E_b + I(R_a + R_{Se}) + V_b$**



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TYPES OF D.C. MOTORS

Compound motor

Short shunt Compound motor

D.C. motor having both shunt and series fields is called a compound motor.

***If* the shunt field is connected in parallel with the armature *alone* the motor is called the short-shunt compound motor**

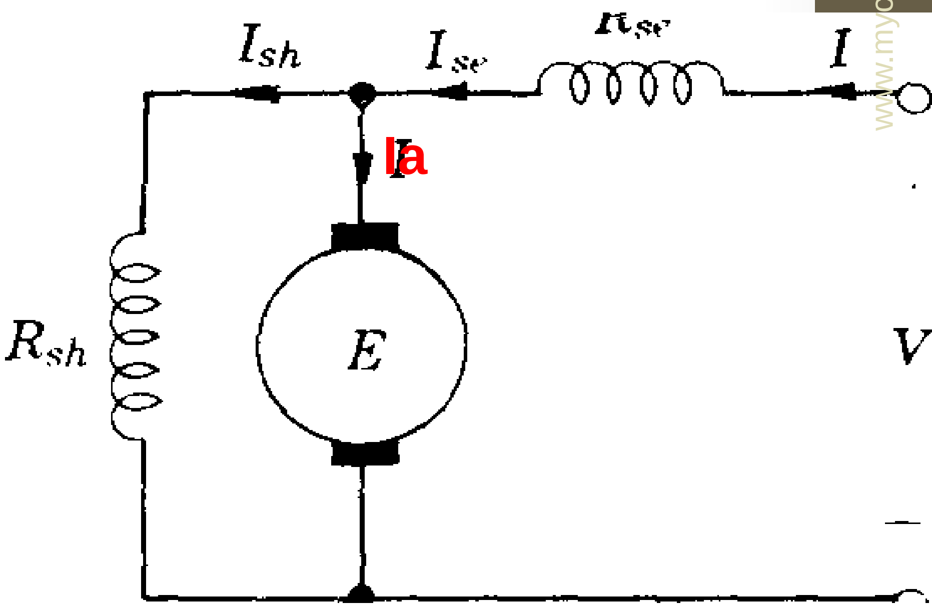
Equations for a short shunt Compound motor :

Equations current

I = Ise = Ish + Ia

Equations voltage

V = *Eb* + *I aRa* + Vb – I Rse



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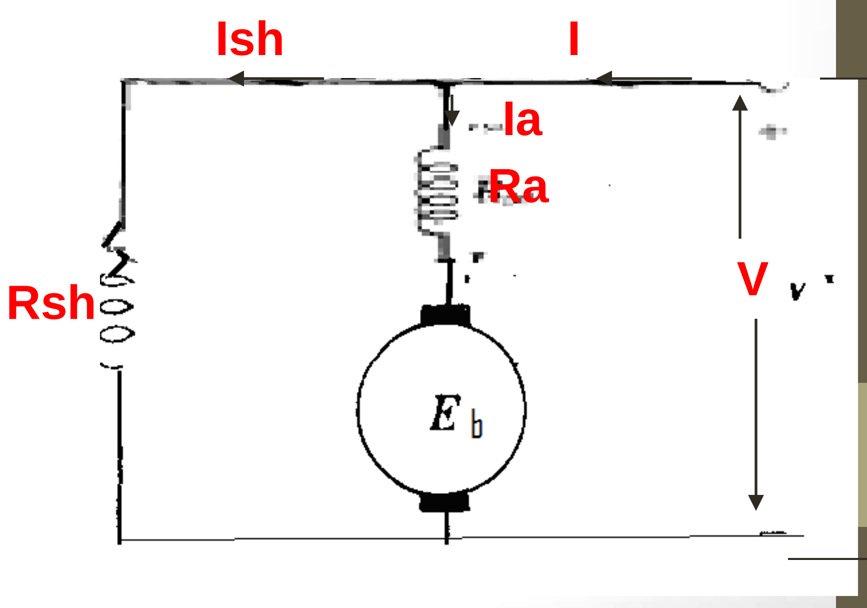
TYPES OF D.C. MOTORS

Compound motor

- **Long shunt Compound motor**
- ***If* the shunt field is in parallel with both armature and series field the machine is called-the long-shunt compound motor.**



Equations for a long shunt Compound motor :

Equations current

$I = I_{sh} + I_a$

Equations voltage

$V = E_b + I_a R_a + V_b + I_a R_{se}$

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CHARACTERISTIC & APPLICATION OF D. C. MACHINES

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D.C. Motor Characteristics

- **characteristic curves of a motor are those curves which show relationships between the following quantities.**
- **Torque and armature current *i.e.* T/ Ia characteristic.**

  It is known as *electrical characteristic.*
- **Spe*ed* and armature current *i.e.* N/Ia characteristic.**
- **Speed and and torque *i.e. N/T* characteristic.**

  It is also known as *mechanical characteristic*

While discussing motor characteristics, the following two relations should always be kept in mind

$$T \alpha \ \phi Ia \quad \text{and} \quad N \alpha Eb / \phi$$

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D.C. Motor Characteristics

Series motor

Torque and armature current

- We have seen that $T \alpha \phi Ia$
- In Series motor field windings also carry the armature current, $\phi \alpha Ia$ up to the point of magnetic saturation.
- Hence, before saturation,
- $T \alpha \phi Ia$ or $T \alpha I^2_a$
- At light loads, *Ia* and hence ϕ is small. But as Ia increases, T increases as the square of the current Hence, *T/Ia* curve is a parabola as shown Fig.

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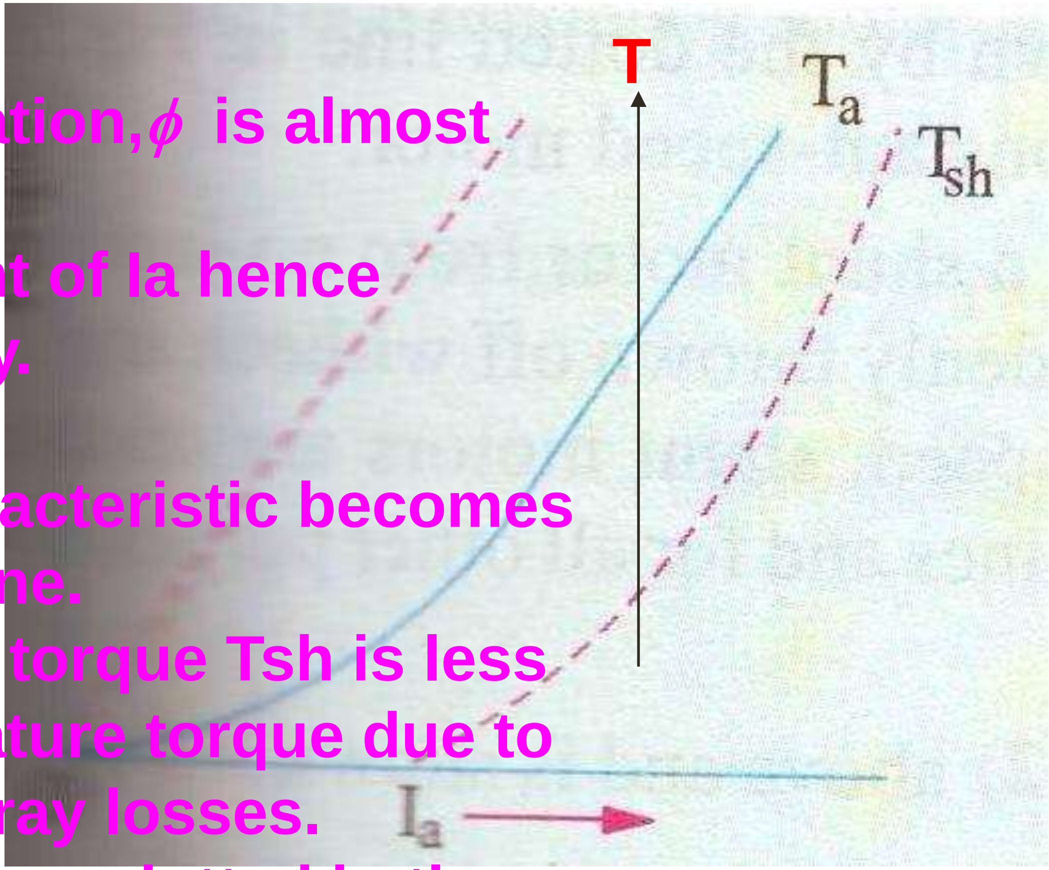
D.C. Motor Characteristics

Series motor

Torque and armature current



After saturation, ϕ is almost independent of Ia hence $T \alpha$ *Ia* only.

So the characteristic becomes a straight line.

The shaft torque Tsh is less than armature torque due to stray losses.

It is shown dotted in the figure.

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D.C. Motor Characteristics

Series motor

Torque and armature current

So we conclude on heavy loads, a series motor exerts a torque proportional to the square of armature current. Hence, in cases where high starting torque is required series motor is used for examples hoists and electric trains etc.,

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D.C. Motor Characteristics

Series motor

Speed and armature current

- Variations of speed can be deduced from the formula $N \alpha Eb / \phi$
- **In Series motor field windings also carry the armature current, $\phi \alpha Ia$**
- ***Eb, for various load currents is small and hence may be neglected for the time being.***

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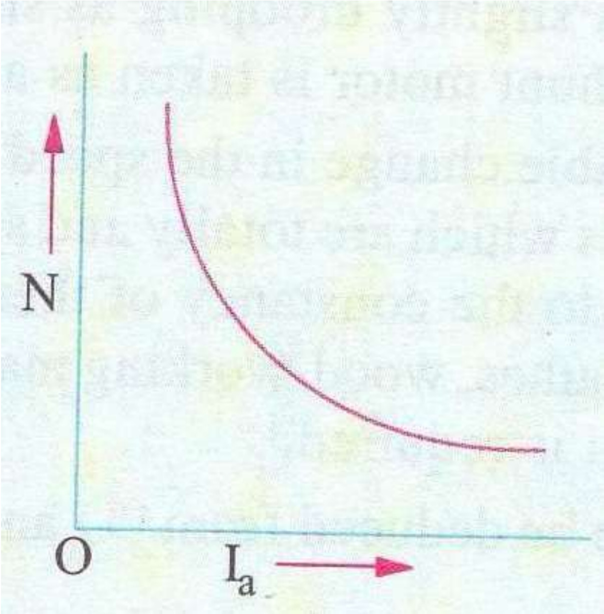
D.C. Motor Characteristics

Series motor

Speed and armature current

- Hence, speed varies inversely as armature current as shown in fig.

When load current and hence Ia falls to a small value, speed becomes dangerously high. Hence a series motor should never be started without some mechanical load on it otherwise it may develop excessive speed and get damaged.



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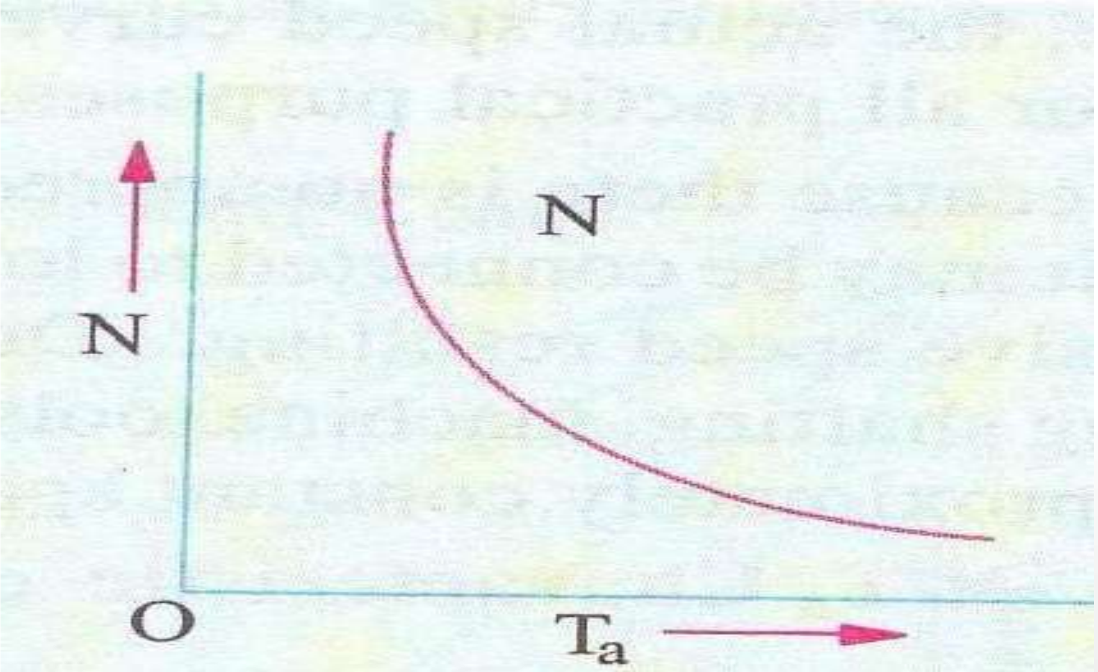
D.C. Motor Characteristics

Series motor

Speed and and torque

- When speed is high, torque is low and vice-versa. The relation between the two is as shown in Fig



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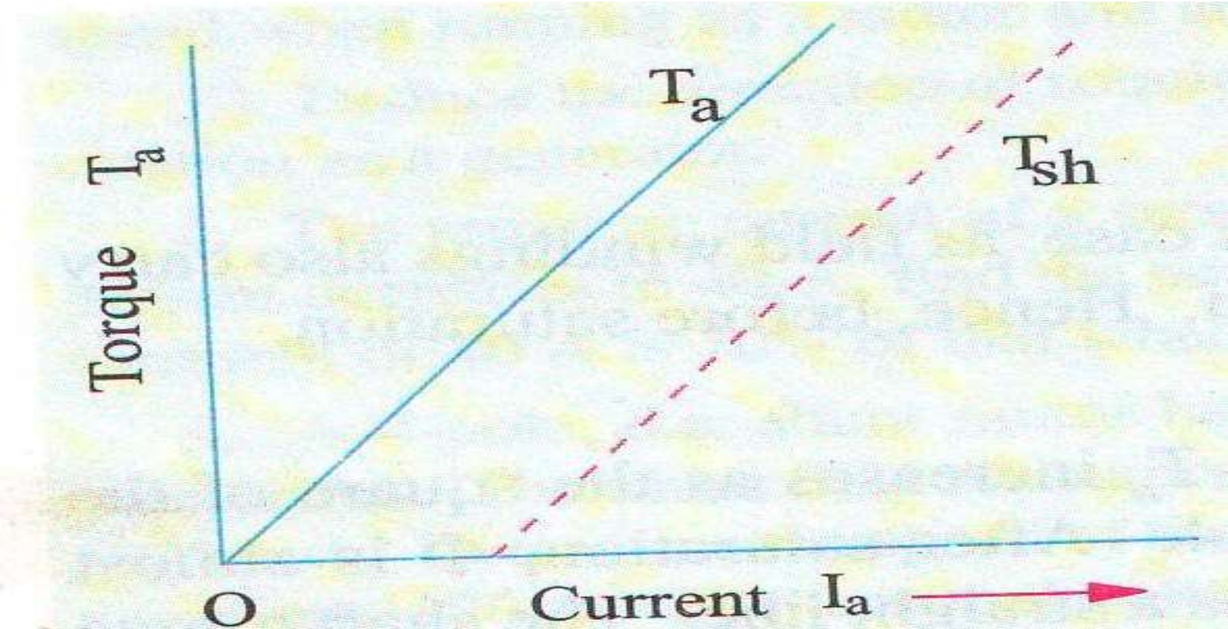
D.C. Motor Characteristics

Shunt motor

Torque and armature current

- Assuming ϕ to be practically constant. $T \alpha \; Ia$
- Hence, the electrical characteristic as shown in Fig. is practically a straight line through the origin. Shaft torque is shown dotted.



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D.C. Motor Characteristics

Shunt motor

Spe*ed* and armature current

- If ϕ is assumed constant, then $N \alpha Eb$.
- As *Eb* is also practically constant, speed is most purposes constant.
- But both *Eb* and ϕ decrease with increasing load.

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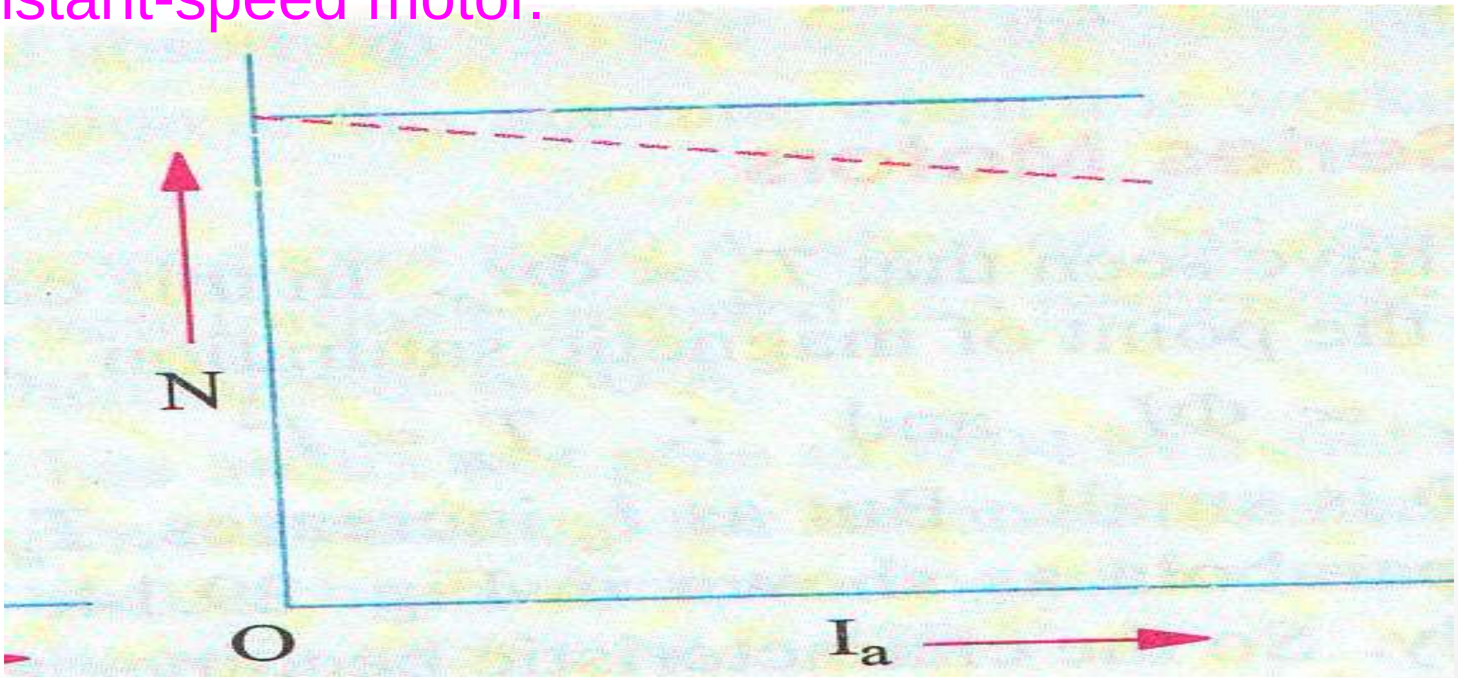
D.C. Motor Characteristics

Shunt motor

Speed and armature current

However the actual speed curve is slightly drooping as shown by the dotted line in Fig.

But, for all practical purposes, shunt motor is taken as a constant-speed motor.



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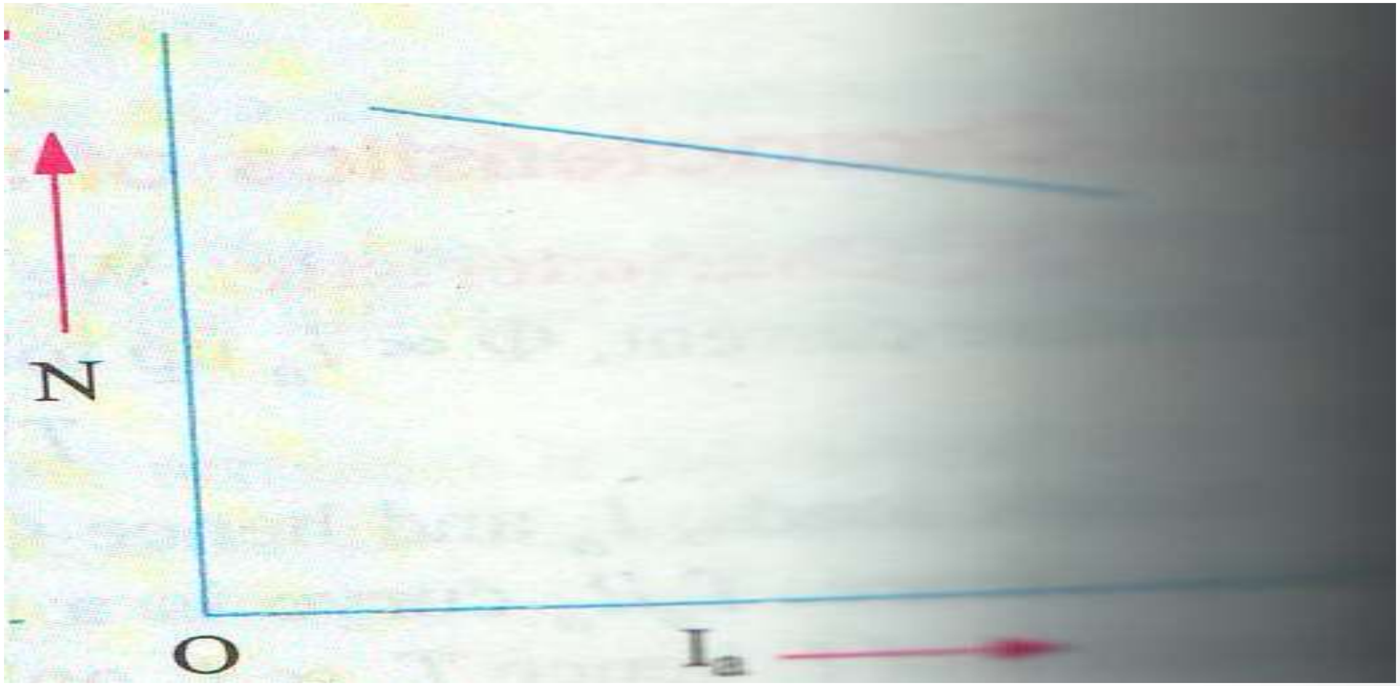
D.C. Motor Characteristics

Shunt motor

Spe*ed* and torquet

- ***N/Ta* Characteristic** can be deduced from (1) and (2) above and is shown in Fig



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D.C. Motor Applications

Shunt motor

Approximately constant speed Required such as :

1)Centrifugal pumps
2) Machine tools
3) Blowers and fans
4) Reciprocating pumps

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D.C. Motor Applications

Series motor

Adjustable varying speed and High Starting torque required :

Such as

1) Electric locomotives(traction work)
2) Trolley, cars etc.
3) Cranes
4) Conveyors

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D.C. Motor Applications

compound motor

Constant speed and
High starting torque required
Such as :

1)Elevators
2)Conveyors
3)Rolling mills
4)Printing Presses
5) Air compressors

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D.C. Motor
STARTING D.C. MOTORS

- A starter is a device to start and accelerate a motor. A controller is a device to start, control speed reverse, stop and protect the motor.
- **Need for starters**
- The armature current of a motor is given by
- $I_a = (V - E_b)/R_a$
- I_a depends upon E_b and R_a if V is kept constant.

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D.C. Motor
STARTING D.C. MOTORS

- When a motor is first switched on, the armature is stationary so the back e.m.f. E_b is zero. The initial starting armature current I_a is given by
- $I_a = (V - 0)/R_a = V/R_a$
- Since the amrmature resistance of a motor is very small, generally less than one ohm; therefore the starting current Ia, would be very large.
- For example, if a motor with armature resistance

  0.5 ohms is connected directly to a *230-V* supply,
- Then $I_a = V/R_a = 230/0.5 = 460$ A.

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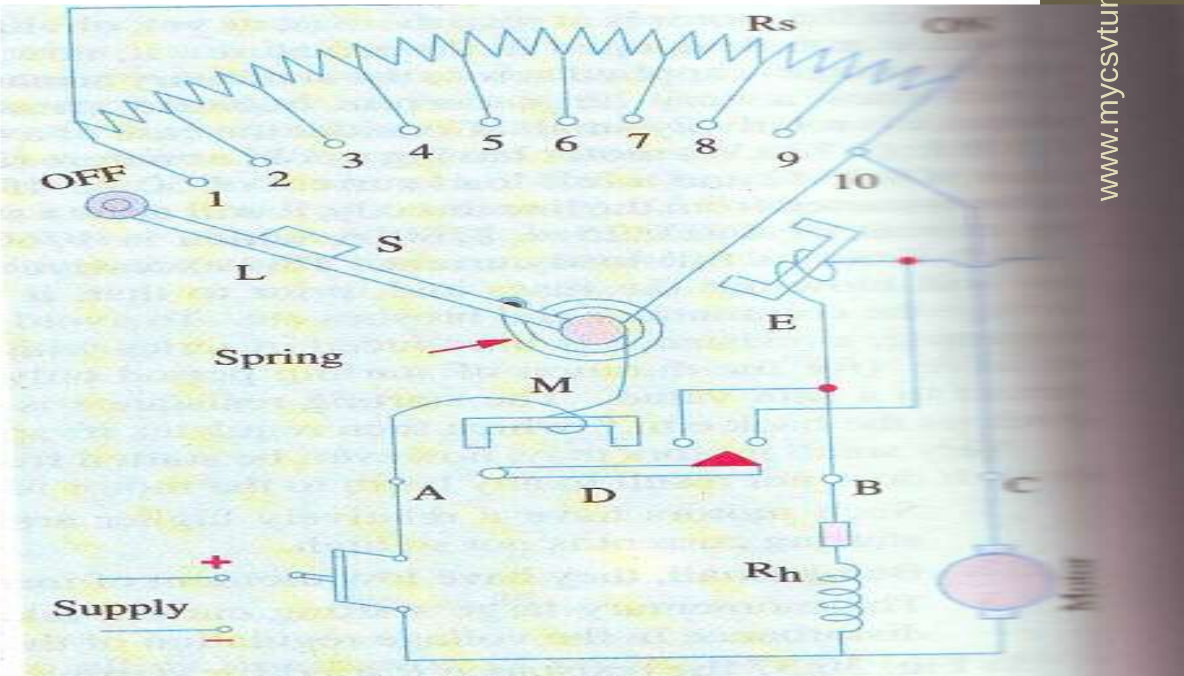
D.C. Motor
STARTING D.C. MOTORS

- Thus large current would damage the brushes, commutator, or windings.
- As motor speed increases, the back e.m.f. increases and the difference (V - Eb) goes on decreases. This results in the gradual decrease of *Ia* until the motor attains its stable speed and corresponding back emf. Under this condition the armature current reaches its desired value.



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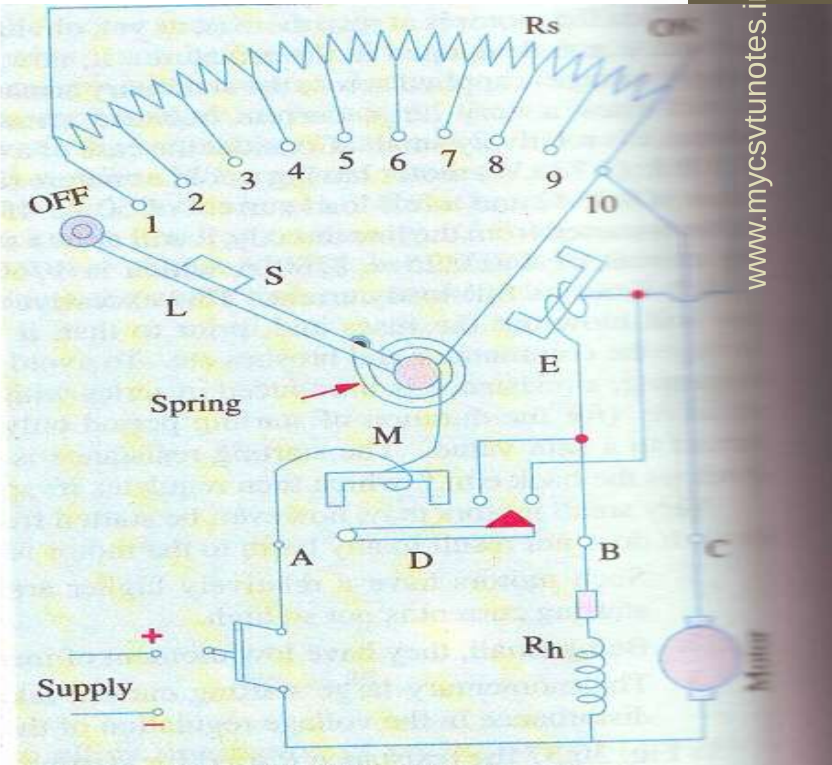
D.C. Motor
STARTING D.C. MOTORS

- *Thus it is found that the back* e.m.f. helps the armature resistance in limiting the current through the armature.
- Since the starting current is very large, at the time of starting of all d.c. motors an extra resistance must be connected in series with the armature. This would limit the initial current to a safe value.



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PROBLEMS

- **Important Formulas**
- ***Eb =*** **ϕZn*(P/A) where n in rps***

  Eb = (**ϕZN/60)** ***(P/A) where N in rpm***
- ***A*** **= number of *parallel* paths *= 2 for Wave Winding***

  = P for Lap Winding
- **(ϕ) = Useful flux per pole in webers(Wb)**
- **P =Total number of poles**
- **Z = Total number of *conductors* in the armature**
- **n = Speed of rotation of armature in revolutions per second (rps)**
- **N= Speed of rotation of armature in revolutions per Minute (RPM)**

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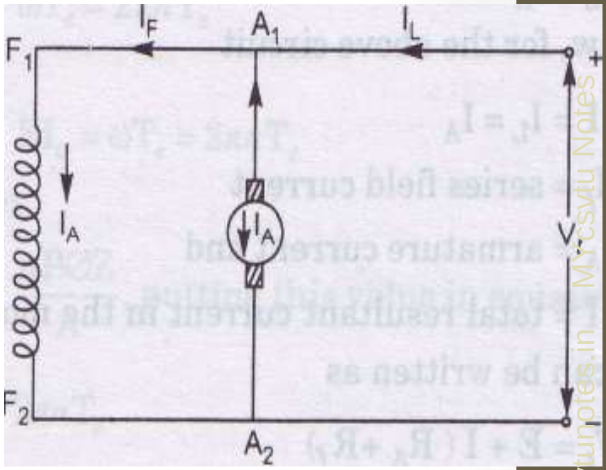
PROBLEMS

- **Important Formulas**

- ***D.C. shunt Motor***
- $I = I_{sh} + I_a$
- $V_{sh} = I_{sh} R_{sh}$
- $V = E_b + I_a R_a$
- $E_b \alpha N / \phi$
- $I_{sh} \alpha \phi$ (constant)
- $T = (1/2\pi)\phi Z Ia (P/A) = 9.55 (Eb Ia / N)$
- $T_{useful} = 9.55$ Output/ N
- $T \alpha \phi I_a$ (If $\alpha \phi \alpha I_{sh}$ (const.))
- $T \alpha I_a$
- $E_{b1}/E_{b2} = N_1 / N_2$



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PROBLEMS

- **Example**
- ***1:*** *A 400 V pole shunt motor has an armature current 60 A the flux per pole 0.08. The armature resistance is 0.3 ohm and brush contact drop is 1 volt per brush. If the motor has 780 armature conductors and a lap winding find the full load speed of the machine.*
- **Solution:**
- $E_b = 400 - 60 \times 0.3 + 2 = 380\ V$
- ***Eb= (NP ϕ/60) (Z/A) or N = (60Eb/Z ϕ)(A/P).***
- ***N = (60 * 380 /780 * 0.08) (A/A) =***

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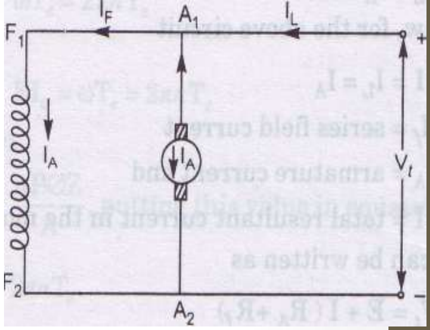
PROBLEMS

I = Ish + Ia
V = IshRsh
V = Eb + IaRa
Eb α N / ϕ   Ish α ϕ (constant)
T = (1/ 2π)ϕ Z Ia (P/A) =9.55 (Eb Ia / N)
Tuseful = 9.55 Output/ N
(If α ϕ α Ish (const.))   T α Ia
Eb1/Eb2 = N1 / N2



- **Example**

2. A 4-pole, 250 V, wave-connected shunt motor gives 10 kW when running at 1000 r.p.m. and drawing armature and field currents of 60 A and 1 A respectively. It has 560 conductors. Its armature resistance is 0.2 Ω. Assuming a drop of 1 V per brush, determine : *(a)* total torque ; *(b)* useful torque (c) useful flux per pole.

Solution:

- *Eb = V - Ia Ra* -brush drop = 250 - 60 x 0.2 - 2 x 1 = 236 V
- T = *9.55 (Eb Ia / N)* = 9.55 (236 * 60/1000)

  = 135 .22 Nm

T_{useful} = 9.55 Output/ N = 9.55 * 10 * 10^3/1000

- = 95.49 Nm
- *Eb = (ϕZN/60) (P/A) or ϕ = (60 Eb / ZN)) (A/P) = 0.0126 Wb*

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PROBLEMS

I = Ish + Ia

V = IshRsh

V = Eb + IaRa

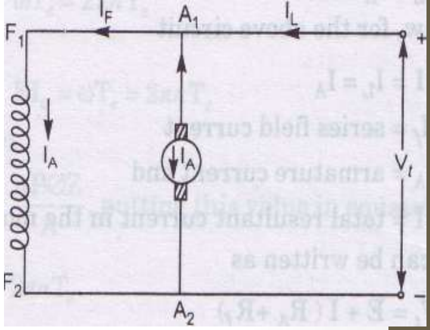
Eb α N / ϕ Ish α ϕ (constant)

T = (1/ 2π)ϕ Z Ia (P/A) =9.55 (Eb Ia / N)

Tuseful = 9.55 Output/ N

(If α ϕ α Ish (const.))   T α Ia

Eb1/Eb2 = N1 / N2



- **EXAMPLE**

- ***3. A 250 V* shunt motor on no load runs at 1000 r.p.m. and takes *5 A.* The total armature and shunt field resistance are respectively *0.2* Ω and *250*Ω. Calculate the speed when loaded and taking a current of *50 A,* if the armature reaction weakens the field by *3%.***

- **SOLUTION**

- **Ish = V/ Rsh = 250 /250 = 1 A**
- **Weaking of flux ϕ2 = .97 ϕ1**
- **At no load Iao = I – Ish = 5 – 1 = 4 A**
- **At no load Ebo = V – Iao *Ra = 250 – 4 * 0.2 = 249.2 V**
- **At load Ia = I – Ish = 50 -1 = 49 A**
- **At load Eb = V – Ia *Ra = 250 – 4 9* 0.2 = 240.2 V**
- **$E_{b1}/E_{b2} = N_1\phi_2 / N_2\phi_1$**
- **Or N2 = 994 RPM**

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LECT - 11

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THREE PHASE INDUCTION MOTOR

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Three-phase Induction Motors

Introduction

- Three-phase induction motor is the most popular type of a.c. motor.
- It is very commonly used for industrial drives
- since it is cheap, robust, efficient and reliable.
- It has good speed regulation and high starting torque.
- It requires little maintenance.
- It has a reasonable overload capacity

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Three-phase Induction Motors

Construction

- **A three-phase induction motor essentially consists of two parts:**
- ***Stator***
- ***Rotor***
- **The stator is the stationary part**
- **The rotor is the rotating part**

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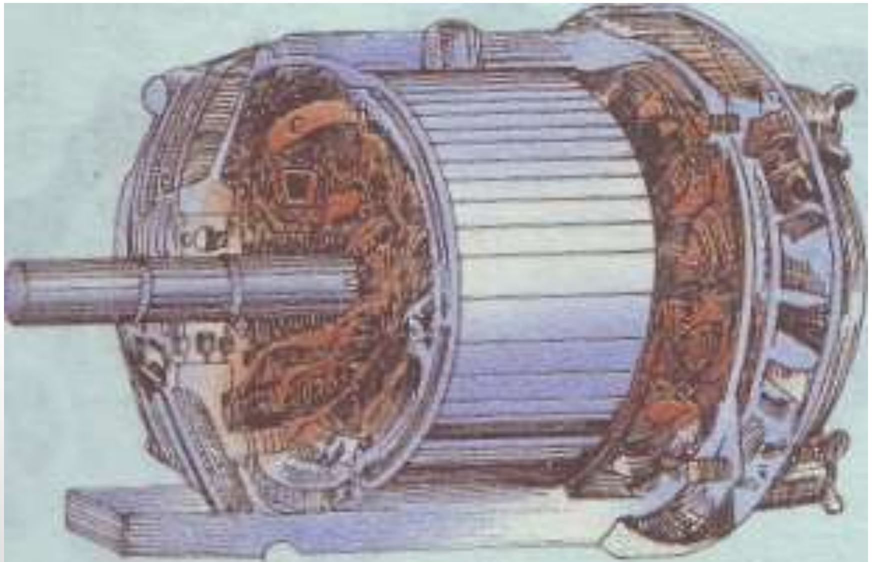
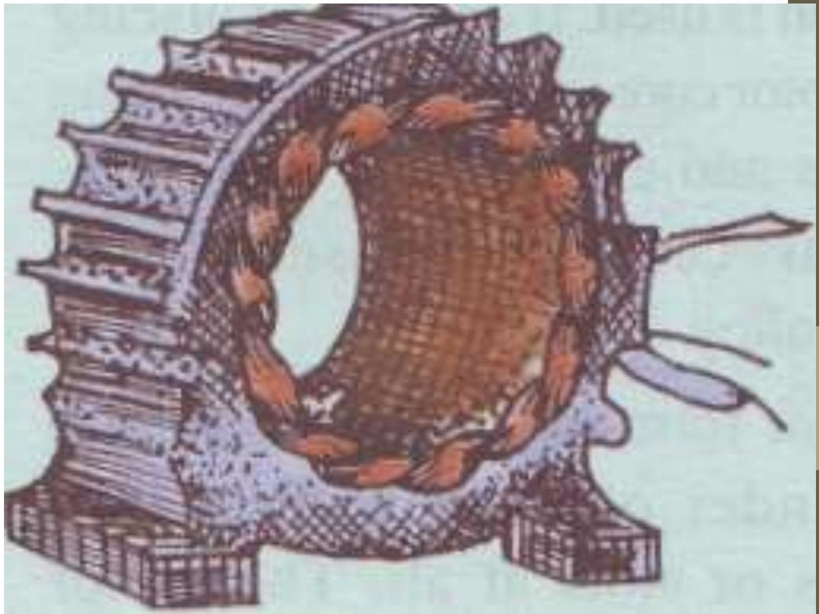
Three-phase Induction Motors

Construction

Stator

- The stator of an induction motor is, made up of a number of stampings, which are slotted to receive the 3-phase winding





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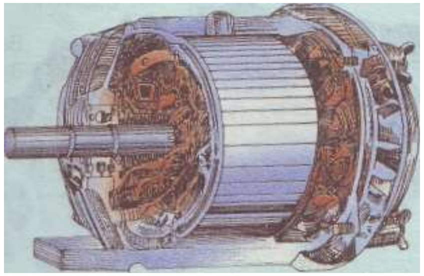
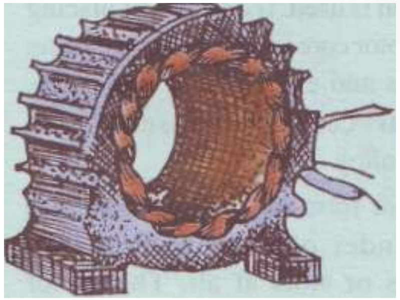
Three-phase Induction Motors





Construction

Stator

- 3-phase winding is fed from a 3-phase supply.
- It is wound for a definite number poles.
- The exact number of poles being determined by the requirements of speed
- Given by N_S. *=120 f/P*
- Greater the number of poles lesser the speed and *vice versa.*

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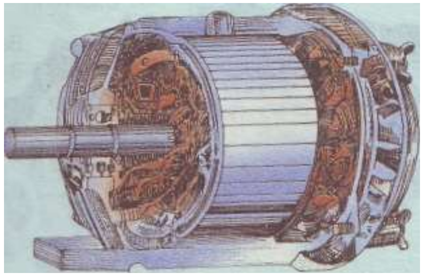
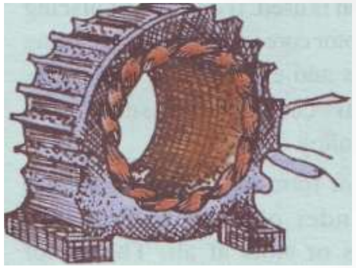
Three-phase Induction Motors

Construction

Stator





- The stator windings, when supplied with 3-phase currents, produce a magnetic flux, which is of constant magnitude but which revolves at synchronous speed
- Given by N_S. *=120 f/P.*
- This revolving magnetic flux induces an e.m.f. in rotor by mutual induction.

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Three-phase Induction Motors

Construction

Rotor

- *(i) Squirrel-cage rotor :* Motors employing this type of rotor are known as squirrel-cage induction motors.
- *(ii) Phase-wound or wound rotor :* Motors employing this type of rotor are variously known as ,phase-wound' motors or `wound' motors or as 'slip-ring' motors.

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Three-phase Induction Motors

Construction

Squirrel-cage Rotor

- The rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors.

Rotor with shaft and brings

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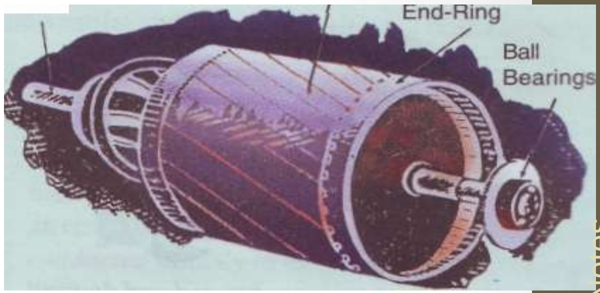
Three-phase Induction Motors

Construction

Squirrel-cage Rotor



- These conductors are not wires but consist of heavy bars of copper, aluminum or alloys.
- One bar is placed in each slot.
- These rotor bars are short-circuiting by two end-rings.

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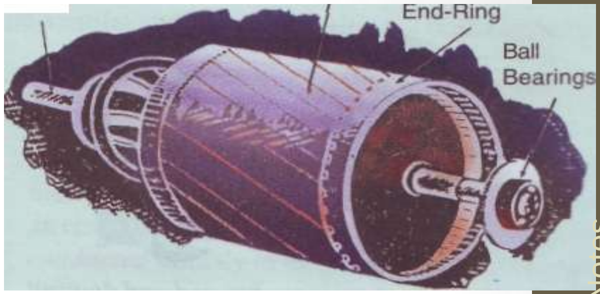
Three-phase Induction Motors

Construction

Squirrel-cage Rotor



- The rotor slots are usually not quite parallel to the shaft but are purposely given a slight skew.

  This is useful in two ways
- (i) it helps to make the motor run quietly by reducing the magnetic hum.
- *(ii)* it helps in reducing the locking tendency of the rotor.

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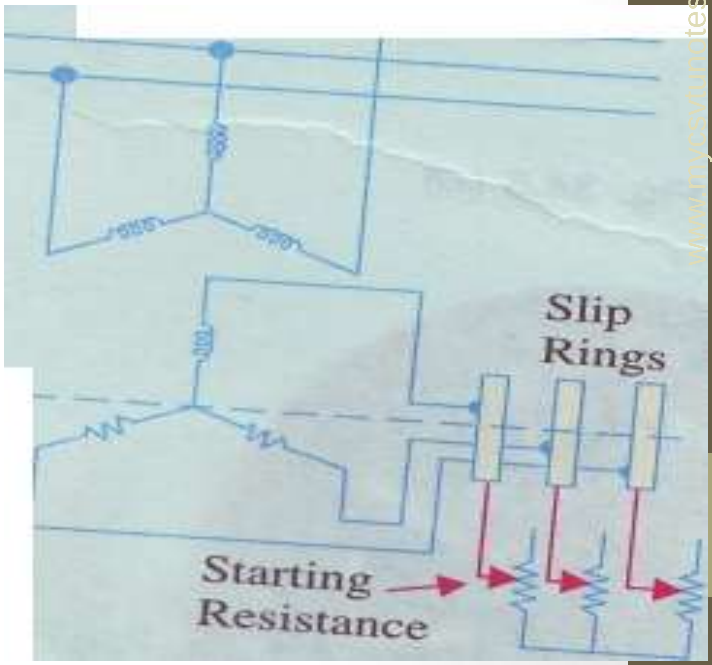
Three-phase Induction Motors

Construction

Phase-Wound Rotor

- This type of rotor is provided with 3phase, winding.
- The rotor is wound for as many poles as the number of stator poles.



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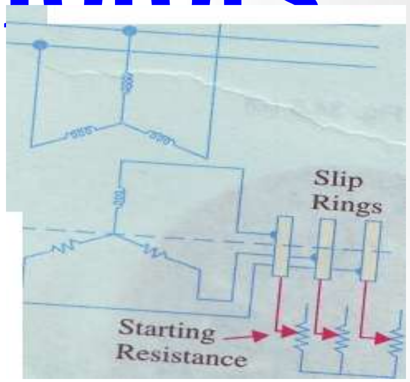
Three-phase Induction Motors

Construction

Phase-Wound Rotor



- The three phases are star connected internally other three winding terminals are brought out and connected to three insulated slip-rings mounted on the shaft with brushes resting on them.

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Three-phase Induction Motors

Slip

- Stator Magnetic field of induction motor run at synchronous speed.
- The rotor speed is slightly less than the synchronous speed.
- An induction motor cannot run at synchronous speed.
- An induction motor may also be called as *`Asynchronous motor'* as it does not run at synchronous speed.

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Three-phase Induction Motors

Slip

- *The difference between the synchronous speed and the actual rotor speed is called the* **slip speed.**
- Thus, the `slip speed' expresses the speed of the rotor *relative to the field.*
- N_S = synchronous speed in r.p.m.
- N = actual rotor speed in r.p.m.
- The slip speed $= N_S - N$ r.p.m.

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Three-phase Induction Motors

Slip

- The slip speed expressed as a fraction of the synchronous speed is called the per-unit slip or fractional slip.
- The per-unit slip is usually called the slip. It is denoted by **S**
- $S = (N_S - N) / N_S$
- Or $N = N_S(1 - S)$

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Three-phase Induction Motors

FREQUENCY OF ROTOR VOLTAGE AND CURRENT

- The frequency of current and voltage in the stator must be the same as the supply frequency given by
- $f = PN_S /120 \ldots\ldots\ldots\ldots\ldots\ldots(1)$
- The frequency in the rotor winding is variable and depends on the difference between the synchronous speed and the rotor speed.
- Hence the rotor frequency depends upon the slip.
- The rotor frequency is given by
- $f_r = P(N_S - N_r)/120 \ldots\ldots\ldots\ldots\ldots\ldots(2)$
- Division of Eq. (2) by Eq. (1) gives
- $f_r = Sf$

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Three-phase Induction Motors

Important Formulas

- $N_S = 120 f/P$
- $S = (N_S - N) / N_S$
- $N = N_S(1 - S)$
- $f = PN_S /120$
- $f_r = Sf$
- The slip speed $= (N_S - N)$ r.p.m.

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Three-phase Induction Motors

Problems

- **EXAMPLE 1**
- **A 12-pole, 3-phase alternator is coupled to an engine running at 500 r.p.m. It supplies an induction motor which has a full-load speed of 1440 r.p.m.**
- **Find the slip and the number of poles of the motor.**
- **SOLUTION**
- $N_S. = 120 f/P$ $\quad$ $P = 12, f = ?, N = 500$
- $f = PN_S / 120 = 12 * 500 / 120 = 50$ Hz
- **The speed of the induction motor is 1440 r.p.m. The supply frequency for induction motor is 50 Hz.**
- **The possible synchronous speeds for 50 Hz are 1500 r.p.m.**
- $S = (NS - N) / NS$
- $= (1500 - 1440) / 1500 = 0.04 = 4\%$
- $P = 120 f / N_S. = 120 * 50 / 1500 = 4$

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Three-phase Induction Motors

Problems

- **Example 2**

- **The frequency of the e.m.f in the stator of a 4 pole induction motor is 50 Hz, and that in the rotor is *1.5* Hz. What is the slip, and at what speed is the motor running ?**

- **SOLUTION**

$$f_r = Sf$$

$$S = f_r / f = 1.5 / 50 = 0.03 \text{ or } 3\%$$

- $N_S = 120 f/P = 120 * 50 / 4 = 1500$ RPM

$N = N_S(1 - S)$

$= 1500 (1 - 0.03) = 1455$ RPM

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Three-phase Induction Motors

Problems

- **EXAMPLE 3**

- A 3-phase, 6-pole, *50* Hz induction motor has a slip of 1% at no load, and 3% at full load. Determine

(a) synchronous speed ; *(b)* no-load speed ;

(c) full-load speed ; *(d)* frequency of rotor current at stand-still ;

(e) frequency of rotor current at full load.

- **SOLUTION**

(a) synchronous speed : $N_S = 120 f/P$

$= 120 * 50 / 6 = 1000$ RPM

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Three-phase Induction Motors

Problems

- **SOLUTION of EXAMPLE 3**
- *(b)* no-load speed : No = N_S(1 - So) = 1000(1-0.01)

  = 990 RPM

  (c) full-load speed : Nf = N_S(1 - Sf) = 1000(1-0.03)

  = 970 RPM

  ; *(d)* frequency of rotor current at stand-still : f_r = Sf

  f_r = 1 * 50 = 50 Hz

  (e) frequency of rotor current at full load. f_r = S_ff

  = 0.03 * 50

  = 1.5 Hz

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Three-phase Induction Motors

Problems

- Example 4

- *A slip-ring induction motor runs at 290 RPM at full load, when connected to 50 Hz supply. Determine the number of poles and slip.*

- **Solution.**

- **Since *N* is 290 rpm; N_S has to be somewhere near it, say 300 rpm. *assumed* N_S *= 300 RPM***
- $P = 120 f / N_S = 120 * 50 / 300 = 20$
- $S = (NS - N) / NS = (300 - 290)/300$
- $= 3.33\%$

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PRINCIPLE OF OPERATION OF A THREE-PHASE INDUCTION MOTOR

- **Let us consider one conductor on the stationary rotor as shown in Fig. (a).**
- **Let this conductor be subject to the rotating magnetic field produced when a three-phase supply is connected to the three-phase winding of the stator.**

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PRINCIPLE OF OPERATION OF A THREE-PHASE INDUCTION MOTOR

- By Faraday's law of electromagnetic induction, a voltage will be induced in the rotor conductor.
- Since the rotor circuit is complete, either through the end rings or an external resistance the induced voltage causes a current to flow in the rotor conductor.
- The current in the rotor conductor produces its own magnetic field

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PRINCIPLE OF OPERATION OF A THREE-PHASE INDUCTION MOTOR

- **We know that when a conductor carrying current is put in a magnetic field a force is produced on it. Thus, a force is produced on the rotor conductor. The direction of this force can be found by left-hand rule (Fig. *(d)).* It is seen that the force acting on the conductor is in the same direction as the direction of the rotating magnetic field..**

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PRINCIPLE OF OPERATION OF A THREE-PHASE INDUCTION MOTOR

- Since the rotor conductor is in a slot on the circumference of the rotor, this force acts in a tangential direction to the rotor and develops a torque on the rotor.
- Similar torques are produced on all the rotor conductors. Since the rotor is free to move, it starts rotating in the *same* direction as the rotating magnetic field. Thus, a three-phase induction motor is self-starting. Since the operation of this motor depends upon the induced voltage in its rotor conductors, it is called an induction motor.

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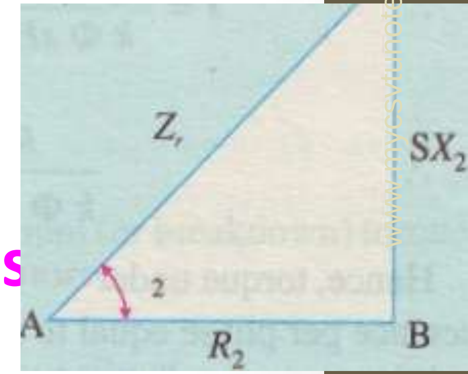
Three-phase Induction Motors

Torque Under Running Conditions

- $T \alpha \quad E_r I_r \text{COS}\phi_2 \quad (E_r \ \alpha E_2 \ \alpha \ \phi$ *at starting*)
- $T \quad \alpha \quad \phi \ I_r \text{COS}\phi_2$
- Where E_r = rotor e.m.f./phase under *running conditions.* *and* I_r = rotor current/phase under *running conditions.*
- $E_r = sE_2$ and $I_r = E_r/Z_r$
- $Ir = sE_2 / \sqrt{[(R_2)^2 + (sX_2)^2]}$
- $\text{COS}\phi_2 = R_2 / \sqrt{[(R_2)^2 + (sX_2)^2]}$

  $T \quad \alpha \quad \phi \ I_r \text{COS}\phi_2$
- $\alpha \quad \phi \ (\ sE_2 / \sqrt{[(R_2)^2 + (sX_2)^2]} \ )(R_2 / \sqrt{[(R_2)^2 + (s}$
- $\alpha \ E_2 \ (\ sE_2 / \ [(R_2)^2 + (sX_2)^2] \ )$
- $= k \ E_2 \ (\ sE_2 / \ [(R_2)^2 + (sX_2)^2] \ )$
- $T = k \ sE^2{}_2 \ / \ [(R_2)^2 + (sX_2)^2]$



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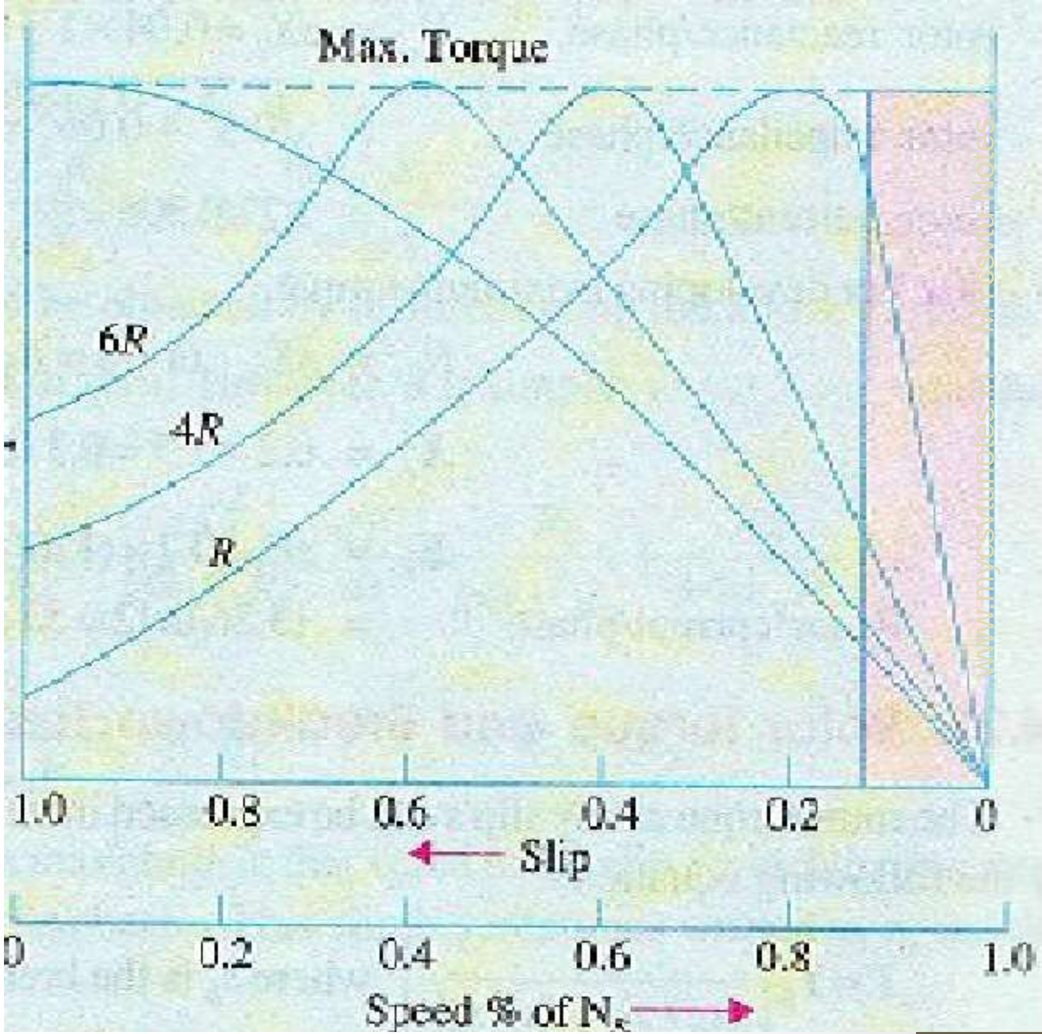
Three-phase Induction Motors

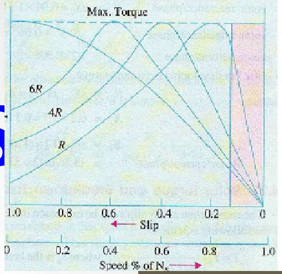
Relation Between Torque and Slip (speed)

- A family of torque/slip curves is shown in Fig. for a range of s = 0 to s = 1 with *R2* as the parameter.
- T =

  $k\, sE^2_2 \;/\; [(R_2)^2 + (sX_2)^2]$
- It is clear that when s = 0, T= 0, hence the curve starts from point O.



Three-phase Induction Motors



Relation Between Torque and Slip (speed)

- At normal speeds, close to synchnism the term*(sX_2)* is small and hence negligible *w.r.to*. R_2.
- *Hence for low values of slip, the torque/slip curve is approximately a straight line.*
- *As slip increases the torque also increases and becomes maximum when s= $R_2/(sX_2)$.*
- *As slip further increases then R_2 becomes negligible as compared to (sX_2).*

Therefore for large value of slip

- $T \propto s / (sX_2)^2 \propto 1/s$
- Hence, the torque/slip curve is a rectangular hyperbola.

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Three-phase Induction Motors

Problems

- **1. The frequency of the e.m.f. in the stator of a 4 pole induction motor is 50 Hz, and that in the rotor is 1.5 Hz. What is the slip, and at what speed is the motor running ?**
- **2. A 3-phase, 6-pole, 50 Hz induction motor has a slip of 1% at no load, and 3% at full load. Determine :**

  ***(a)* synchronous speed*(b)* no-load speed c) full-load speed *(d)* frequency of rotor current at stand-still**

  ***(e)* frequency of rotor current at full load.**
- ***3. A 4-pole, 3-phase induction motor operates from a supply whose frequency is 50 Hz what is the speed at which the magnetic field of the stator is rotating. the speed of the rotor when the slip is 0.04. the frequency of the rotor currents when the slip is 0.03.the frequency of the rotor currents at standstill***

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Three-phase Induction Motors

- *4. A 3 phase 6 pole 50 Hz induction motor has a slip of 2% at no-load and 4% at full : load. Calculate*

  (a) synchronous speed (b) no-load speed

  (c) full-load speed (d) frequency of rotor current at stand still

  (e) frequency of rotor current at full load .
- *5. A 3-Phase induction motor is wound for 4 poles and is supplied from 50-Hz system. Find (i) the synchronous speed (ii) the rotor speed, when slip is 4% and (iii) rotor frequency when rotor runs at 600 rpm.*

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Three-phase Induction Motors

STARTING INDUCTION MOTORS

- When the supply is connected to the stator of a three-phase induction motor, a rotating magnet field is produced and the rotor starts rotating. Thus, a three-phase induction motor is self-Starting. At the time of starting the motor slip is unity and the starting current is very large. The purpose of a starter *is* not to start the motor as the name implies.

  The starter of the motor performs two functions.
- I. To reduce the heavy starting current.
- 2. To provide *overload* and *no-load protection*

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Three-phase Induction Motors

STARTING INDUCTION MOTORS

- **STARTING OF CAGE MOTORS**
- **The following are the commonly used starters for cage motors**
- **1. Direct on-line starter.**
- **2. Star-delta starter.**
- **3. Autotransformer starter.**

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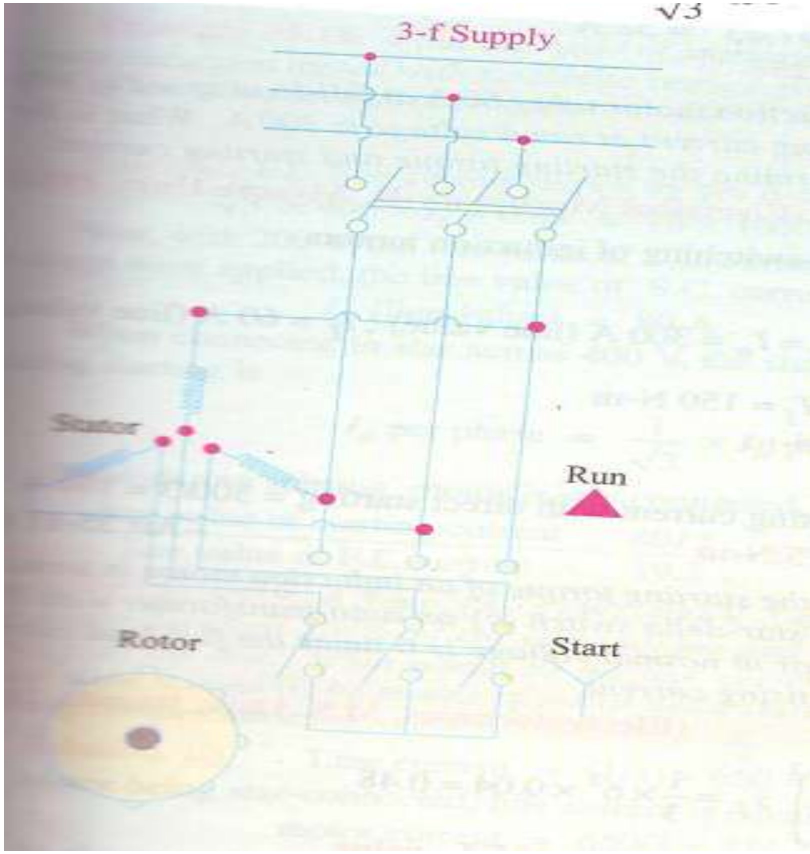
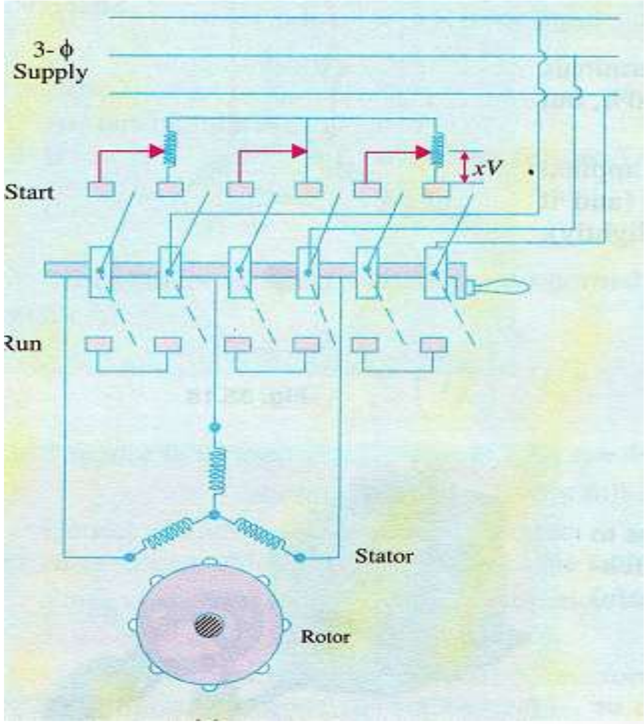
Three-phase Induction Motors

STARTING INDUCTION MOTORS





- Star-delta starter.

Autotransformer starter.

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SINGLE PHASE INDUCTION MOTOR

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Single-phase Motors

Introduction

- Construction of single phase induction motor is similar to three phase motor it consists (1) Stator (2) Rotor.
- Its stator provided with a single phase winding and rotor is squirrel-cage type.
- When fed from single phase supply, its stator winding produce a flux which is only alternating. An alternating flux acting on stationary squirrel cage rotor cannot produce rotation. That is why a single-phase motor is not self-starting.

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Single-phase Motors

Making Single-phase Induction Motor Self-starting

- A single-phase induction motor is not self-starting. To overcome this drawback make the motor self-starting, it is temporarily converted into a two-phase motor during starting.
- For this purpose, the stator of a single-phase motor is provided with an extra winding, known as starting (or auxiliary) winding, in addition to the *main* Main or running *winding*

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Single-phase Motors

Making Single-phase Induction Motor Self-starting

- **The two windings are spaced 90° electrically apart and are connected in *parallel across the s*ingle-phase supply as shown in Fig. It is so arranged that the phase-difference between the current in the two stator windings is very large. These two currents produce a revolving flux and hence make the motor self-starting.**

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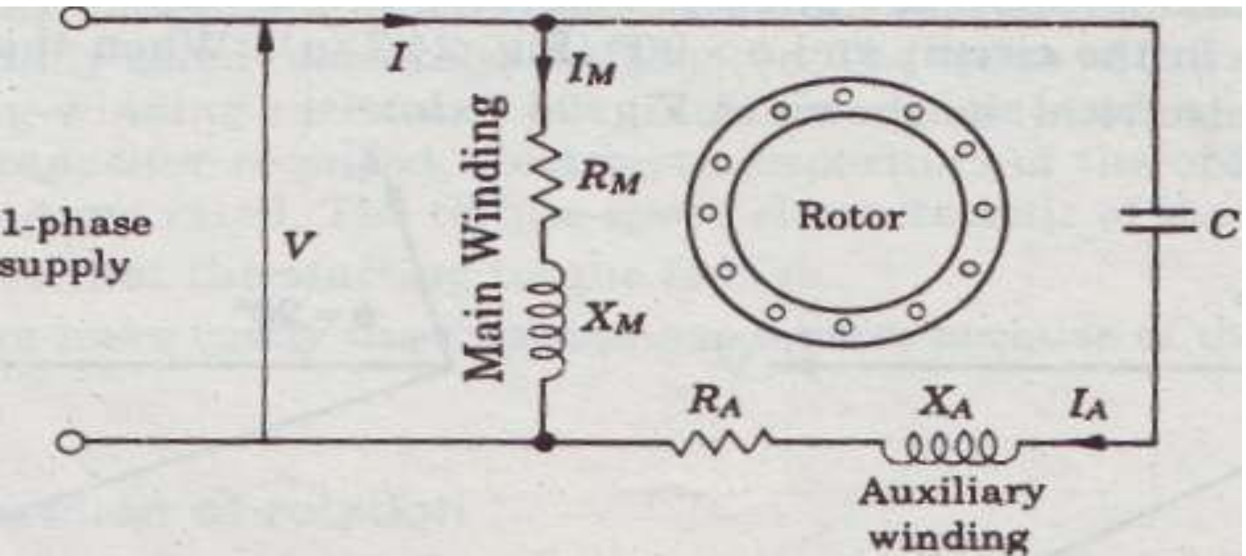

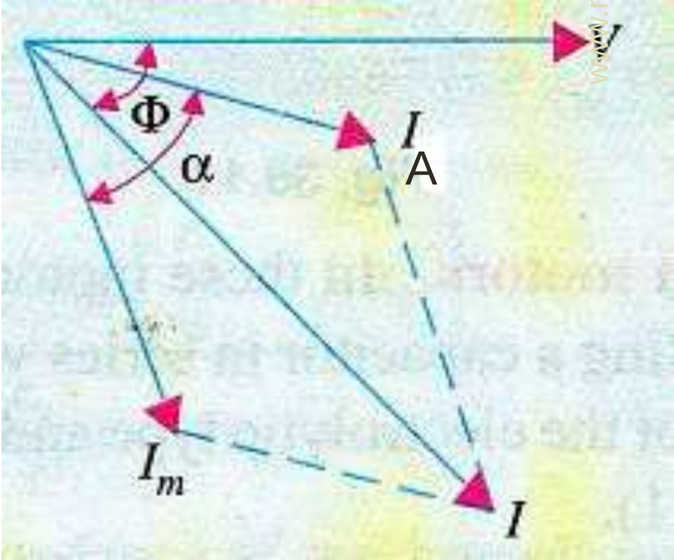

Single-phase Motors

Making Single-phase Induction Motor Self-starting

Methods by which make the motor self-starting.

- Split-Phase motor.
- Capacitor start motor.
- Capacitor and run Motor.
- Shaded- pole motor.
- Repulsion motor

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HOME WORKS
DC GENERATOR

1. Draw the circuit model of d.c. generator armature and obtain the expressing for induced e.m.f..
2. Explain construction of D.C. machines.
3. Explain Types of of D.C. generators with help of circuit diagrams.
4. Write down important formulas of dc generator.

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HOME WORKS DC MOTORS

1. Explain Types of of D.C. motors with help of circuit diagrams
2. Draw the circuit model of d.c. motors armature.
3. Explain back emf.
4. Derive the torque equation of a d.c. motor.
5. Sketch and explain   characteristics of following d.c. motors i) Series motor (ii) Shunt motor.
6. the starting current is very high in a d.c. motor and how the used of starter reduce the starting current to a safe value?
7. Draw diagrams of of starters used in D.C. motor.
8. Explain application of dc motors.
9. Write down important formulas of dc motors.

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HOME WORKS 3-ϕ IM

1. Explain construction of 3-phase induction motor.
2. Explain principles of operation of three phase induction motor.
3. Define slip.
4. Deduce an expression for the frequency of rotor current in an induction motor.
5. Why starters is necessary for starting of three phase induction motor.
6. Name different types of starters used in induction motor.
7. Draw diagrams of any two types of starters used in induction motor.
8. Explain torque-slip (speed) characteristics of three phase induction motor.
9. Write down important formulas of 3-phase induction motor.

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HOME WORKS 1-ϕ IM

1. Discuss why single-phase induction motor do not have a starting torque.
2. Describe with diagram and phasor diagram how single phase induction motor make self start.

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D.C. GENERATORS PROBLEMS

- 1. *A short-shunt compound generator delivers a load current of 30 A at 220 V, and has armature, series field and shunt field resistances of 0.05 Ω 0.30 Ω and 200 Ω respectively. calculate the generated voltage and armature current Allow 1 V per brush for contact drop.*
- 2. *In a long-shunt compound generator, the terminal voltage is 230 V when genrates 150 A. Determine (i) induced e.m f. (ii) total power generated and Given that shunt field, series field, and armature resistance are 92 Ω, 0.015 Ω and 0.032 Ω respectively*

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D.C. GENERATORS PROBLEMS

- 3. A long-shunt compound generator delivers a load current of 50 *A* at *500* V, and the resistances of armature, series field and shunt fields are *0.05 Ω*, *0.03 Ω*, and *250 Ω* respectively. Calculate the generated e.m.f. and the armature current. Allow 1.0 V per brush for contact drop.
- 4. An 8 pole generator has 500 armature conductors and has a useful flux per pole of 0.065 Wb. What will be the emf generated if it is lap connected and runs at 1000 RPM ? What must be the speed at which it is to be driven to produce the same emf if it is wave connected?
- 5. A lap wound dc shunt generator having 80 slots with 10 conductor per slot generator at no load an emf of 400 V when running at 1000 RPM. At what speed should it be rotated to generate a voltage of 220 V 0n open circuit?

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D.C. GENERATORS PROBLEMS

- 6. An 8 pole lap connected dc generator armature has 950 conductors, a flux of 40 mWb and a speed of 400 RPM. Calculate the emf generated on open circuit. If the same armature is wave connected at what speed must the armature be driven to generate 400 V.
- 7. A 4-pole wave wound dc shunt generator having 51 slots with 48 conductor per slot . The flux per pole 7.5 mWb. At what speed should it be rotated to generate a voltage of 440 V 0n open circuit
- 8. A 8-pole dc generator having 100 slots with 8 conductor per slot . The winding so connected to have 8 parallel paths. Determine the speed to generate a voltage of 240 V the flux per pole 30 mWb.

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D.C. GENERATORS PROBLEMS

- **9. a 4- pole d.c.generator has a wave-wound armature with 792 conductors. The flux per pole is 0.012 Wb.calculate speed at which it should be run to generate 240 V on no-load. [751.3 r.p.m.]**
- **10. A 20 KW compound generator works on full-load with a terminal voltage of 230 V. The *armature, series field and shunt field resistances of 0.1 Ω ,0.05 Ω and 115 Ω respectively. calculate the generated*. e.m.f. when (a) Short shunt (b) Long**
- **11. A 4-pole wave wound dc shunt generator having 51 slots with 48 conductor per slot . The flux per pole 7.5 mWb. At what speed should it be rotated to generate a voltage of 440 V 0n open circuit**

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D.C. GENERATORS PROBLEMS

- **12. A dc shunt generate an e.m.f. of 520 V. It has 2,000 armature conductors, flux per pole of 0.013 7.5 mWb and speed 1200 RPM and the armature winding has four parallel paths. Find the number of poles.**
- ***13. A 6 pole lap connected D. C. Shunt Generator has 410 armature conductors .generated 400 v on no load. The flux per pole is 0.05 web. Determine the speed of the motor.***
- **14. When driven a 1000 RPM with a flux per pole of 0.02 Wb, a d.c. generator has an e.m.f. of 200 V. If speed is increased to 1100 RPM and at the same time the flux per pole is reduced to 0.019 Wb per pole, What is then the induced emf.**

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D.C. GENERATORS PROBLEMS

- 15. Calculate the flux in a 4-pole dynamo with 722 armature conductors generating 500 V when running at 1000 r.p.m. when the armature is (a) lap connected (b) wave connected.
- 16. A 4-pole machine running at 1500 r.p.m. has an armature with 90 slots and 6 conductors per slot. The flux per pole is 10 mWb. Determine the terminal e.m.f. as d.c. Generator if the coils are lap connected.If the current per conductor is 100 A, determine the electrical power.
- 17. A long-shunt, compound generator delivers a load current of 50 A at 500 V and the resistances armature, series field and shunt field are 0.025 ohm, 0.025 ohm and 250 ohm respectively. Calculate the generated emf and the armature current. Allow 1.0 V per brush for contact drop.

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D.C. GENERATORS PROBLEMS

- 18. A shunt generator produces 450 A at 230 V. The resistance of the shunt field and armature are 50 ohm and 0.025 ohm respectively. Find out the armature voltage drop.
- 19. A 2-pole generator with wave wound armature has 51 slots each having 24 conductors.The flux per pole is 0.01 Wb. find speed at which the generator should run. If generated emf is 500 V.
- 20. In a 10-pole, lap wound d.c. generator, the number of active armature conductors per slot is 50 each having 24 slots . The flux per pole is 0.01 Wb. Find generated emf if speed at which the generator should run is 1000 RPM.

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D.C. GENERATORS PROBLEMS

- 21. A 100 kW, 250 rpm, d.c. generator has 6 poles. The armature has 83 slots each holding 8 conductors, and the winding is wave wound. Find out the no-load flux per pole at which and e.m.f. of 500 volts is induced.
- 22. A 4-pole, 1200 rpm generator with a lap wound armature has 65 slots and 12 conductors per slot. The flux per pole is 0.02 Wb. Calculate the e.m.f. induced in the armature.
- 23. A 4-Pole, 1200 rpm, lap wound dc generator has 760 conductors. If the flux per pole is 0.02 wb. Calculate the e.m.f generated.

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D.C. GENERATORS PROBLEMS

- 24. In a dc generator running at 1600 rpm gives 240 V d.c. If the speed is propped to 1400 rpm without change in flux. Calculate the new e.m.f.
- 25 A shunt generator running at 600 rpm has an induced e.m.f. of 200 Volts. If the speed increases to 750 rpm. Calculate the induced e.m.f.

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D.C. MOTORS PROBLEMS

1. *A 140 V d.c. shunt motor has an armature resistance of 0.2 ohm and a field resistance of 70 ohm. The full load line current is 40A and the full load speed is 1800 rpm. If the brush contact drop is 3 V. Find the speed of the motor at half load.*
2. *A 220 V shunt motor has an armature resistance of 0.5 ohm and takes a current of 40 A on full load. By has much the main flux be reduced to raise the speed by 50% if the developed torque is constant?*
3. 230 V d.c. motor takes a no-load current of 2 A and runs at 1200 rpm. In case the full load current is 40 A then calculate the speed at full load

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D.C. MOTORS PROBLEMS

4. A 4-pole wave wound dc armature has 294 conductors. Find out : (a) flux per pole to generate 230 V at 1400 rpm. (b) electromagnetic torque at this flux when the armature current is 120 A.
5. A d.c. motor develops a torque of 140 Nm at 1400 rpm. If the motor now runs at 1000 rpm, then obtain the new developed torque.
6. A d.c. series motor develops a torque of 20 Nm at 34 of load current. If the current increased to 6 A, the calculate the new torque developed

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Three-phase Induction Motors

Problems

- 1. The frequency of the e.m.f. in the stator of a 4 pole induction motor is 50 Hz, and that in the rotor is 1.5 Hz. What is the slip, and at what speed is the motor running ?
- 2. A 3-phase, 6-pole, 50 Hz induction motor has a slip of 1% at no load, and 3% at full load. Determine :

  (a) synchronous speed *(b)* no-load speed c) full-load speed *(d)* frequency of rotor current at stand-still

  (e) frequency of rotor current at full load.
- *3. A 4-pole, 3-phase induction motor operates from a supply whose frequency is 50 Hz what is the speed at which the magnetic field of the stator is rotating. the speed of the rotor when the slip is 0.04. the frequency of the rotor currents when the slip is 0.03.the frequency of the rotor currents at standstill*

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Three-phase Induction Motors

Problems

- *4. A 3 phase 6 pole 50 Hz induction motor has a slip of 2% at no-load and 4% at full : load. Calculate*

  (a) synchronous speed (b) no-load speed

  (c) full-load speed (d) frequency of rotor current at stand still

  (e) frequency of rotor current at full load .

- *5. A 3-Phase induction motor is wound for 4 poles and is supplied from 50-Hz system. Find (i) the synchronous speed (ii) the rotor speed, when slip is 4% and (iii) rotor frequency when rotor runs at 600 rpm.*

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TOTAL HOME WORK OF UNIT - 4

1.	THEORY QUESTION OF DC GENERATOR	- 04.
2.	PROBLEMS OF DG GENERATORS	- 25
3.	THEORY QUESTION OF DC MOTORS	- 09.
4.	PROBLEMS OF DG MOTORS	- 06
5.	THEORY QUESTION OF 3- ϕ INDUCTION MOTOR	- 09.
6.	PROBLEMS OF 3-ϕ INDUCTION MOTOR	-05
7.	THEORY QUESTION OF 1-ϕ INDUCTION MOTOR	-02

TOTAL THEORY QUESTION - 24

TOTAL PROBLEMS - 36

TOTAL - 60

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