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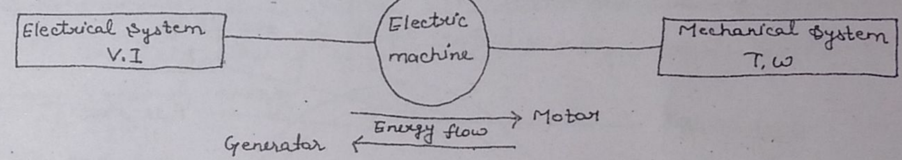
UNIT-IVth

D.C. MACHINES

Quest: Explain the principle of Electromechanical Energy Conversion?

Ans: According the principle of conservation of energy, the energy can neither be created nor be destroyed but it can be transformed from one form to another. We daily use many devices that convert one form of energy into another form. for example, a heater converts electrical energy into heat energy while an electric bulb converts electrical Energy into light energy.

The conversion of electrical energy into mechanical energy or vice-versa is known as Electromechanical Energy Conversion.



Quest: What is D.C Machine? Explain the construction of D.C. Machine.

Ans: An electrical machine which convert mechanical Energy into Electrical Energy is called as Electrical generator.

While an electrical machine which convert electrical Energy into mechanical Energy is called as Electric motor.

Such electrical machines may be related to an Electrical Energy of an alternating type called a.c machines or may be related to an Electrical Energy of direct type called d.c machine.

The first electromagnetic machine to be developed were d.c machine. D.C machine works on the principal of Faradays Law".

Construction of D.C Machine: The construction of d.c machine basically remain same whether it is a generator or a motor. Any d.c generator can be run as a d.c motor and vice-versa.

All d.c. machine have four principle components as shown in the block diagram.

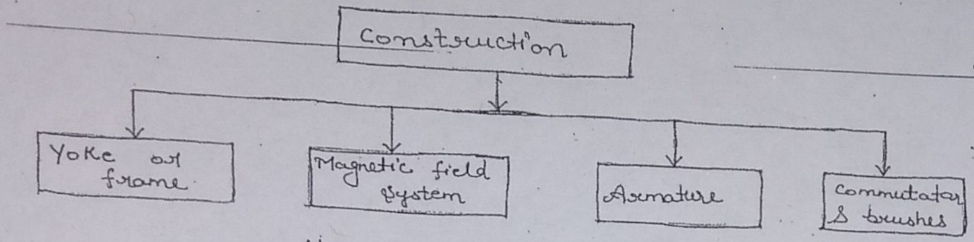
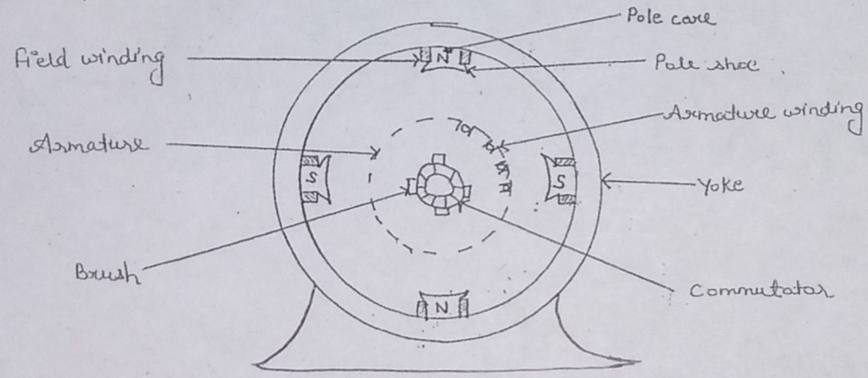


Fig: Block diagram.

1) **Yoke or frame**: It is the outer cover of the d.c. machine in which main poles are fixed. The insulating material get protected from harmful atmospheric element like moisture and dust.

a) It provides mechanical support to the inner parts of the machine.

b) It provide a low reluctance path for the flux.



2) **Magnetic Field System**: The magnetic field system is the stationary part of the machine. It produces the main magnetic flux in which the armature rotate.

The pole shoe serves two purposes:-

a) It support the field coil.

b) It increases the cross section area of the magnetic circuit.

3) **Armature**: The rotating part of d.c. machine is called armature. The purpose of armature is to rotate the conductor in the uniform magnetic field. The armature core has slots on its outer surface. The conductor are placed on slots and known as Armature winding.

a) LAP winding, A=P, where A= No. of parallel path.

b) Wave winding, A= 2, P= No. of poles.

1) LAP winding is employed for high current and low voltage rating machine.

2) Wave winding is employed for low current and high voltage rating machine.

4) **Commutator & Brushes**: The basic nature of emf induced in the armature conductor is alternating. A commutator is a mechanical rectifier which converts the alternating voltage into direct voltage. Brushes are stationary and resting on the surface of the commutator. The current is collected from the armature winding by means of two or more carbon brushes.

Ques: Derive E.M.F. equation of D.C. Generator.

Ans: We shall now derive an expression for the emf generated in a d.c. generator.

Let,

ϕ = Magnetic flux/ pole in weber

P = No. of poles

N = speed of armature in r.p.m.

Z = Total number of armature conductor

A = No. of parallel paths in which Z number of conductor are divid

E_g = Emf of generator = emf/ parallel path.

Now emf gets induced in the conductor according to Faradays Law of electromagnetic induction,

$$e = \text{Rate of cutting the flux} = \frac{d\phi}{dt}$$

Magnetic flux cut by one conductor in one revolution of the armature is
$d\phi = P\phi$ webers.

Time taken to complete one revolution is $dt = 60/N$ second.

$\therefore$ emf generated / ~~conductor~~ $= \frac{d\phi}{dt} = \frac{P\phi}{\frac{60}{N}} = \frac{P\phi N}{60}$ = volts.

Emf of generator, E_g = emf per parallel path.

= (emf/conductor) × no. of conductor in series per parallel path.

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

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

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

Wave winding, $A = 2, E_g = \frac{\phi P N Z}{120}$

Ques: Explain the types of D.C. Generator.

Ans: D.C. generator is classified into two categories as –

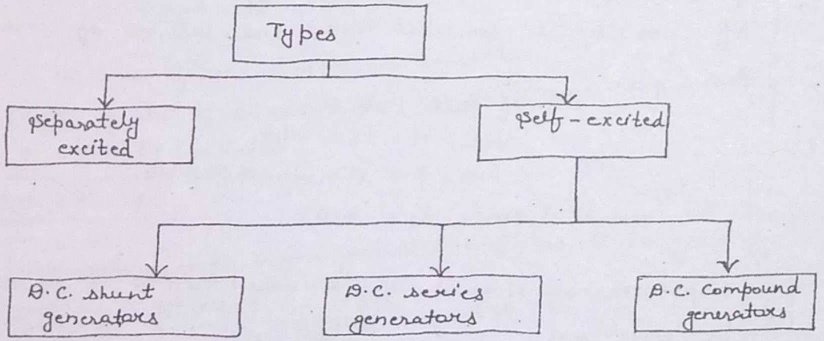
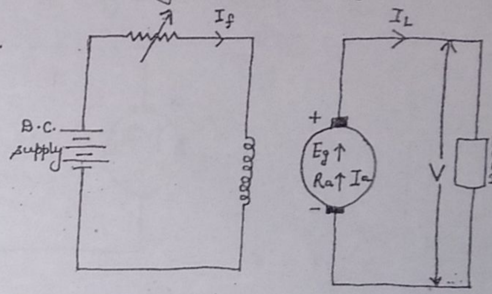


fig: Block diagram.

1. Separately Excited D.C. Generator:

The separately excited d.c. generator are rarely used in practice because they need an additional d.c. source.

A d.c. generator whose field winding is excited from an independent external d.c. source is called separately excited d.c. generator.



current, voltage and power relation.

a) Armature current, $I_a = I_L$

b) Terminal voltage,
$V = E_g - I_a R_a$ – brush drop.

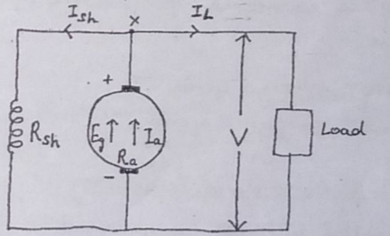
c) Electric power developed $= E_g I_a$

d) Power delivered to load $= V I_a$

2. Self Excited D.C. Generator:

The field winding are excited by the current produced by the generator itself. The field winding of self excited d.c. generator is not excited by any external energy source.

(i) D.C. Shunt Generator: – In d.c. shunt generator, the field winding is connected in parallel with the armature winding. The connection of d.c. shunt generator –



current, voltage and power relation.

a) Armature current, $I_a = I_L + I_{sh}$ (using KCL at point x)

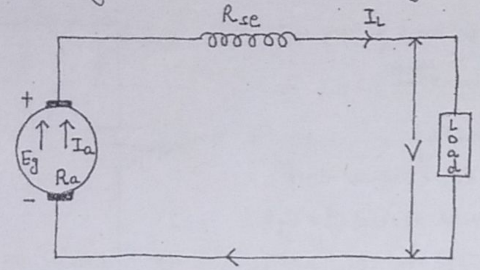
b) Shunt field current, $I_{sh} = V/R_{sh}$ (using KVL)

c) Terminal voltage, $V = E_g - I_a R_a$ – brush drop if exist.

d) Power developed in Armature = $E_g I_a$

e) Power delivered to load = VI_L

(ii) **D.C. Series Generator** :- In series generator, the fixed winding is connected in series with armature winding so that whole armature current flows through the field winding as well as load.



current, voltage and power relation.

(a) Armature current, $I_a = I_{se} = I_L = I$ (say)

(b) Terminal voltage, $V = E_g - I(R_a + R_{se})$

(c) Power developed in armature = $E_g I_a$

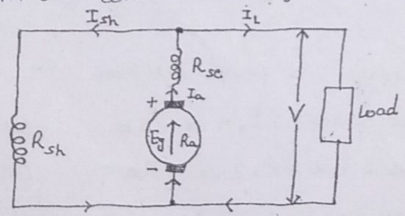
(d) Power delivered to load = VI_a or VI_L $[\because I_a = I_L]$

(iii) **D.C. Compound Generator** :- In d.c. compound generator, the part of field winding is connected in parallel with armature and in series with the armature.

(a) Long shunt compound Generator

(b) Short shunt compound Generator.

(a) **Long Shunt Compound Generator**: The shunt field winding is connected in parallel with the combination of both armature and series field winding.



current, Voltage and Power relation.

a) Series field current $I_{se} = I_a = I_L + I_{sh}$; Shunt field current $I_{sh} = V/R_{sh}$

b) Terminal voltage, $V = E_g - I_a(R_a + R_{se})$

c) Power developed in armature = $E_g I_a$

d) Power delivered to load = VI_L

(b) **Short Shunt Compound Generator**: In this generator, the shunt field winding is connected in parallel with the armature only.

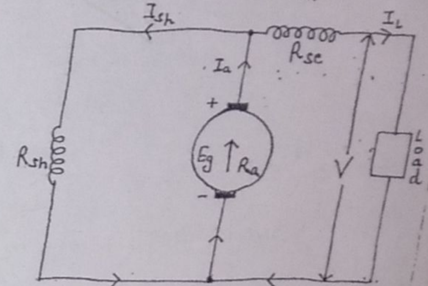
current, voltage and power relation.

a) Series field current, $I_{se} = I_L$; Shunt field current, $I_{sh} = \frac{V + I_{se}R_{se}}{R_{sh}}$

b) Terminal voltage, $V = E_g - I_a R_a - I_{se} R_{se}$

c) Power developed in armature = $E_g I_a$

d) Power delivered to load = VI_L



Solved Examples on d.c Generator

Ques: An 8 pole d.c. Generator running at 1200 rpm and with a flux of 25 mWb/pole generates 440V. Calculate no. of conductors.

Sol: Given,

No. of poles, $P = 8$

Speed, $N = 1200$ rpm

flux, $\phi = 25\,mWb = 0.025\,Wb$

Generated emf, $E_g = 440\,V$

Step 1: When armature is LAP wound then no. of parallel paths, $A = P = 8$

we know that, $E_g = \frac{NP\phi Z}{60A}$

$\therefore$ no of conductor required, $Z = \frac{E_g \times 60 \times A}{\phi N P}$

$= \frac{440 \times 60 \times 8}{0.025 \times 1200 \times 8} = 880$

so, $Z = 880$ conductors.

Step 2: When armature is wave wound then

No. of parallel paths, $A = 2$

$\therefore$ No of conductor required, $Z = \frac{E_g \times 60 \times A}{\phi N P}$

$= \frac{440 \times 60 \times 2}{0.025 \times 1200 \times 8} = 220$

so, $Z = 220$ conductor.

Ques: A 4 pole LAP wound armature has 144 slots with two coils sides per slot, each coil having two turns. If the flux per pole is 20 mWb and armature rotates at 720 rpm. What is the induced voltage?

Sol: Given,

Number of poles, $P = 4$

Flux per pole, $\phi = 20$ mWb $= 20 \times 10^{-3}$ wb

Number of parallel path, $A = 4$ [$\because$ LAP wound $A = P = 4$]

Speed, $N = 720$ rpm

Step 1: The total no of conductor (Z) is given by

Z = No. of slots × no. of coil side per slot × no. of turns in each coil

$= 144 \times 2 \times 2 = 576$.

$Z = 576$.

Step 2: Here induced emf means generated emf, so it is given by

$E = \frac{NP\phi Z}{60A} = \frac{720 \times 4 \times 20 \times 10^{-3} \times 576}{60 \times 4} = 138.24$

$E = 138.24$ Volts

Ques: A D.C. Generator has an armature emf of 100 V when the useful flux per pole is 20 mWb and the speed is 800 rpm. Calculate the generated emf

(i) With the same flux and a speed of 1000 rpm.

(ii) With a flux per pole of 24 mWb and a speed of 900 rpm.

Sol: Given,

$E_{g1} = 100V$

$\phi = 20$ mWb,

$N_1 = 800$ rpm

Step 1: In first case, E_{g2} is calculated as: $E_g \propto \phi N$

We know that $N_2 = 1000$ r.p.m in first case so,

$\therefore \frac{E_{g1}}{E_{g2}} = \frac{\phi_1}{\phi_2} \times \frac{N_1}{N_2}$ but $\phi_1 = \phi_2$

$\therefore \frac{100}{E_{g2}} = \frac{800}{1000}$

$\therefore E_{g2} = 125V$

Step 2: In second case, E_{g2} is calculated as:

$\phi_2 = 24$ mWb, $N_2 = 900$ rpm (given)

$\frac{100}{E_{g2}} = \frac{20 \times 10^{-3}}{24 \times 10^{-3}} \times \frac{800}{900}$

$\therefore E_{g2} = 135V$

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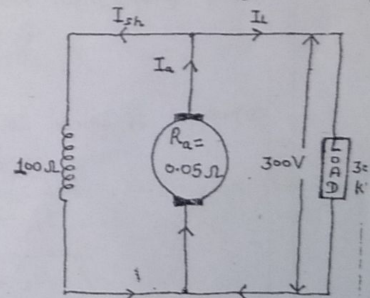
Ques: A 30 kW, 300 V dc shunt generator has armature and field resistance 0.05 Ω and 100 Ω respectively. Calculate the total power developed by the armature when it delivers full load output.



Sol: Given,

$P = 30$ kW $= 30 \times 10^3$ W

$V = 300$ volt

Armature resistance $R_a = 0.05 \Omega$

Field resistance $R_{sh} = 100 \Omega$

Step 1: We know that, $P = VI_L$

or $$I_L = \frac{P}{V}$$

$$\therefore \quad I_L = \frac{30\times10^3}{300} = 100\,A$$

$$I_{sh} = \frac{V}{R_{sh}}$$

$$\therefore \quad I_{sh} = \frac{300}{100} = 3\,A$$

Armature current, $I_a = I_L + I_{sh}$

$= 100 + 3$

$I_a = 103\,A$

Step 2: The emf generated is given by

$E_g = V + I_a R_a$

$E_g = 300 + 103 \times 0.05$

$E_g = 305.15V$

Step 3: The power developed by armature is given by

Power developed by armature $= E_g I_a$

$= 305.15 \times 103$

$= 31.43 \times 10^3\,W$

$= 31.43\,kW.$

Ques: What will be change in emf induced in flux is reduced by 20% and the speed is increased by 20% in case of a d.c. generator.

Sol: Step 1: We know that for a d.c. generator,

$E_g \propto N\phi$

Step 2: If speed is increased by 20% then

$N_2 = N_1 + 20\%$ of N_1

$\therefore \quad N_2 = N_1 + 0.2N_1$

$N_2 = 1.2N_1$

Step 3: If flux is reduced by 20% then

$\phi_2 = \phi_1 - 20\%$ of ϕ_1

$\phi_2 = \phi_1 - 0.2\phi$

$\phi_2 = 0.8\phi_1$

Step 4: The ratio of E_{g1} and E_{g2} find out by

$$\frac{E_{g1}}{E_{g2}} = \frac{N_1}{N_2} \times \frac{\phi_1}{\phi_2} = \frac{1}{1.2} \times \frac{1}{0.8} = 1.041$$

$$\therefore \quad E_{g2} = 0.96\,E_{g1}$$

So the emf will change to 96% of the original value.

D.C. MOTOR

Ques: Explain the principle of operation of a d.c. motor?

Ans: "When a current carrying conductor is placed in a magnetic field, it experiences a mechanical force and hence the conductor moves in the direction of force."

As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductors acts as a twisting or turning force on the armature which is called a torque.

The direction of the force is given by Fleming's left hand rule. The magnitude of force is given by the relation.

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

Where,

B = flux density in wb/m^2

I = current flowing through the conductor in ampere.

L = Length of the conductor in meter.

Ques: Explain the back emf in D.C. Motor?

Ans: When the motor armature rotates, its conductor cut the magnetic flux. Therefore the emf is induced in them. In case of motor, the emf of rotation is known as Back emf or Counter emf. According to Lenz law, the back emf opposes the applied voltage.

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$$E_b = \frac{NP\phi Z}{60A}$$

This emf always opposes the supply voltage, hence it is called back emf.

Ques: Write down the voltage equation of D.C. Motor.

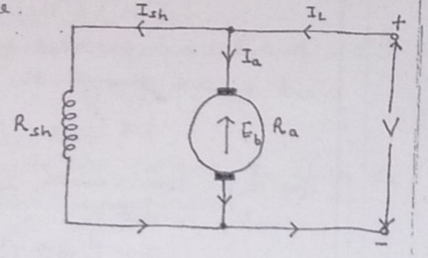
Ans: Let in d.c. motor as shown in figure.

V = applied voltage

E_b = back emf

I_a = Armature current

R_a = Armature resistance.



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

or $\quad V = E_b + I_a R_a$

This is known as voltage equation or fundamental equation of d.c. motor.

Ques: Write down the power equation of D.C. Motor.

Ans: The voltage equation of a d.c. motor is given by:

$$V = E_b + I_a R_a$$

Multiplying both sides of above equation by I_a we get

$$VI_a = E_b I_a + I_a^2 R_a$$

This equation is called power equation of a d.c motor.

VI_a = Electric power supplied to armature (Armature input)

$E_b I_a$ = Power developed (Mechanical power) by armature (Armature output).

$I_a^2 R_a$ = Electric power wasted in armature (armature copper loss).

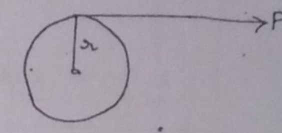
Thus from the armature input, a small portion is wasted as $I_a^2 R_a$ loss and the remaining portion $E_b I_a$ is converted into mechanical power within the armature.

Ques: Derive the Torque equation of D.C. Motor.

Ans: It is measured by the product of the force (F) and the radius (r) at which this force acts i.e;

$$T = F \times r$$

Let the armature is rotating at a speed of N rpm as shown in figure.



The angular speed of the armature is:

$$\omega = \frac{2\pi N}{60} \text{ rad/sec.}$$

So, workdone in one revolution is:

$$W = F \times \text{distance travelled in one revolution}$$

$$W = F \times 2\pi r$$

and P = power developed = $\frac{\text{workdone}}{\text{time}}$

$$\frac{F \times 2\pi r}{\text{time for 1 rev.}} = \frac{F \times 2\pi r}{\frac{60}{N}} = (F \times r) \times \left(\frac{2\pi N}{60}\right)$$

$$\therefore \quad P = T \times \omega \text{ watts}$$

where,

T = torque in N-m

ω = angular speed in rad/sec.

Power in Armature = Armature torque $\times\ \omega$

$$E_b I_a = T_a \times \frac{2\pi N}{60}$$

but E_b in a motor is given by,

$$E_b = \frac{NP\phi Z}{60A}$$

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

$$\therefore \quad T_a = \frac{1}{2\pi}\phi I_a \times \frac{PZ}{A}$$

$$\therefore \quad T_a = 0.159\, \phi I_a \cdot \frac{PZ}{A} \text{ N-m}$$

Since Z, P and A are fixed for a given machine.

$$\therefore \quad T_a \propto \phi I_a$$

Hence torque in a d.c. motor is directly proportional to flux per pole and armature current.

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1. For a shunt motor, flux ϕ is practically constant :

$$T_a \propto I_a$$

2. For a series motor, flux ϕ is directly proportional to armature current.

$$T_a \propto I_a^2$$

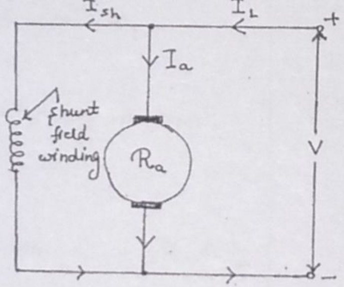
Ques: What is the types of D.C. Motor?

Ans: The different types of D.C. motors are :

1) D.C. shunt Motor
2) D.C. Series Motor
3) D.C. compound Motor.

1) D.C. Shunt Motor :

In this type, the field winding is connected across the armature winding and the combination is connected across the supply voltage as shown in the figure.



Current, Voltage and Power Relation

(a) $I_L = I_a + I_{sh}$

(b) $I_{sh} = \frac{V}{R_{sh}}$

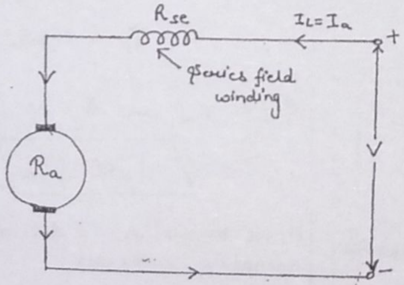
(c) Back emf , $E_b = V - I_a R_a$

(d) Power drawn from supply $= VI_L$

(e) Mechanical power developed $= E_b I_a$

2) D.C. Series Motor :

In this type of motor, the field winding is connected in series with the armature as shown in the figure.



Current, Voltage and Power Relation.

(a) $I_a = I_L = I_{se}$

(b) $E_b = V - I(R_a + R_{se})$

(c) Power drawn from supply $= VI_L$

(d) Mechanical power developed $= E_b I_a$

3) D.C. Compound Motor : The D.C. compound ... field winding connected in series and part of the field winding [illegible] in parallel with armature.

Ques: Explain Torque and Speed equation of D.C. Motor.

Ans: We know that,

$$T \propto \phi I_a \quad \text{from torque equation.}$$

Now flux ϕ is produced by the field winding and is proportional to the current passing through the field winding.

$$\phi \propto I_{field}$$

For a d.c. series motor, I_{se} is same as I_a. Hence flux ϕ is proportional to the armature current I_a

$$T \propto I_a \phi \propto I_a^2 \quad \text{(for series motor)}$$

For a d.c. shunt motor, I_{sh} is constant as long as supply voltage is constant. Hence flux ϕ is also constant.

$$T \propto I_a \quad \text{(for shunt motors)}$$

Similarly as $E_b = \frac{NP\phi Z}{60A}$, we can write the speed equation.

$$E_b \propto \phi N$$

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

Therefore, in a d.c. motor, speed N is directly proportional to back emf E_b and inversely proportional to flux per pole ϕ.

But $V = E_b + I_a R_a$

$\therefore$ $E_b = V - I_a R_a$

$\therefore$ Speed equation becomes,

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

So for shunt motor as flux ϕ is constant.

$\therefore$ $N \propto V - I_a R_a$

While for series motor, flux ϕ is proportional to I_a

$$N \propto \frac{V - I_a R_a - I_a R_{se}}{I_a}$$

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Ques: Draw the characteristics of D.C. Motor.

Ans: There are three types of characteristics of d.c. motor.

1) Torque and Armature current characteristic (T_a/I_a):
It is the curve between armature torque T_a and armature current I_a of a d.c. motor. It is also known as electrical characteristic of the motor.

2) Speed and armature current characteristics (N/I_a):
It is the curve between speed N and armature current I_a of a d.c. motor.

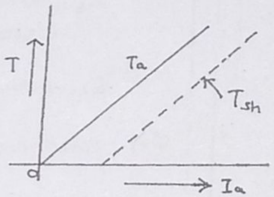
3) Speed and torque characteristics (N/T_a):
It is the curve between speed N and armature torque T_a of a d.c. motor. It is also known as Mechanical Characteristic.

Characteristics Of D.C. Shunt Motor :-

1) Torque – Armature current characteristic: We know that in a d.c. motor. $T_a \propto \phi I_a$

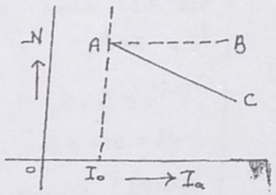
Since the motor is operating from a constant supply voltage, flux ϕ is constant

$\therefore$ $T_a \propto I_a$

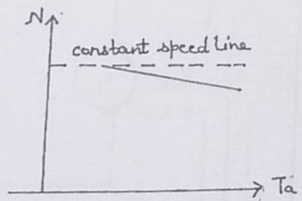


2) Speed-Armature current characteristic: The speed N of a motor is given by $N \propto \frac{E_b}{\phi}$

The flux ϕ and back emf emf in shunt motor are almost constant under normal condition.



3) Speed Torque characteristic:
These characteristic can be derived from the above two characteristics. This curve is similar to speed-armature current characteristics as torque is proportional to the armature current.

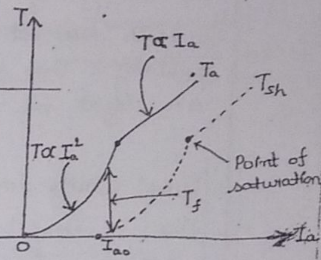


Characteristics Of D.C. Series Motor :

1) Torque – Armature current characteristic:
Flux produced is proportional to the armature current.

$\therefore$ $\phi \propto I_a$

Hence $T_a \propto \phi I_a \propto I_a^2$

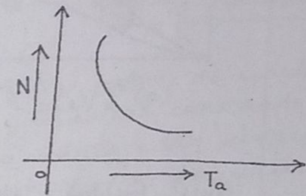


2) Speed and armature current characteristics: The speed N of series motor is given by $N \propto \frac{E_b}{\phi}$ where $E_b = V - I_a(R_a + R_{se})$

or $N \propto \frac{V - I_a(R_a + R_{se})}{\phi}$

when armature current is low then the voltage drop $I_a(R_a + R_{se})$ is very small or almost negligible. The speed of a d.c. motor is

$N \propto \frac{1}{\phi}$ – – – – – (i)



We know that in a d.c. motor, $\phi \propto I_a$. Hence equation (i) is now becomes,

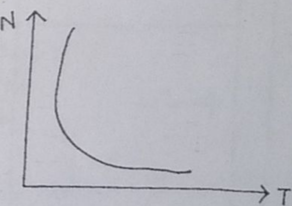
$N \propto \frac{1}{I_a}$

3) Speed – torque characteristics: In case of series motors,

$T \propto I_a^2$ and $N \propto \frac{1}{I_a}$

Hence we can write,

$N \propto \frac{1}{\sqrt{T}}$



Ques: Why series motor is never started on No Load?

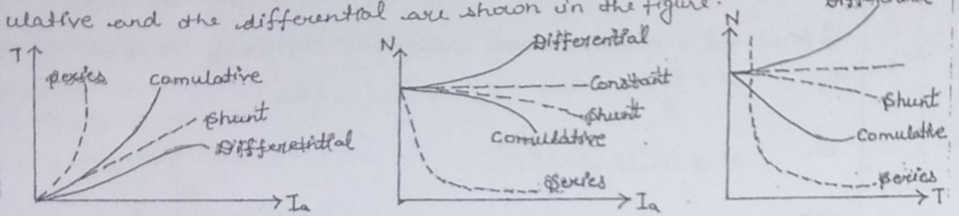
Ans: In case of a d.c. series motor, $\phi \propto I_a$ and no load as I_a is small hence flux produced is also very small. According to speed equations,

$N \propto \frac{1}{\phi}$ as E_b is almost constant.

So on very light load or no-load as flux is very small, the motor tries to run at dangerously high speed which may damage the motor mechanically. This is the reason why series motor should never be started on light or no load.

Ques: Write down the characteristics of D.C Compound Motor.

Ans: The various characteristics of both the types of compound motors cumulative and the differential are shown in the figure.



(a) T Vs Ia (b) N Vs Ia (c) N Vs T

Ques: Explain the Application of D.C. Motors

Ans:

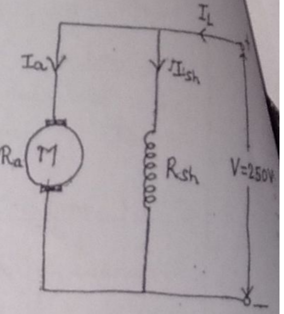
Type of motor	Characteristics	Applcations.
Shunt	Speed is fairly constant and medium starting torque.	1. Blowers and fans 2. Centrifugal and reciprocating pumps 3. Lathe machines 4. Machine tool 5. Milling machine 6. Drilling machine.
Series	High starting torque. No load condition is dangerous Variable speed.	1. Cranes 2. Hoists, Elevators 3. Trolleys 4. Conveyors 5. Electric locomotives.
Cumulative compound	High starting torque. No load condition is allowed	1. Rolling mills 2. Punches 3. Shears 4. Heavy planers 5. Elevators
Differential compound	Speed increases as load increases.	No suitable for any practical application

Ques:- A 250 V, d.c. shunt motor takes a line current of 20 A. Resistance of shunt field winding is 200Ω and resistance of the armature is ... Find the armature current and the back e.m.f.

Sol:- Given,

Voltage, $V = 250V$, $I_L = 20A$, $R_a = 0.3\Omega$, $R_{sh} = 200\Omega$, $I_L = I_a + I_{sh}$

Step 1: Calculate the Armature current (I_a)



$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{200} = 1.25\ A$

$I_a = I_L - I_{sh}$

$= 20 - 1.25$

$I_a = 18.75\ A$

Step 2: Now we can calculate the back emf (E_b)

$E_b = V - I_a R_a$

$= 250 - 18.75 \times 0.3$

$E_b = 244.375\ V$

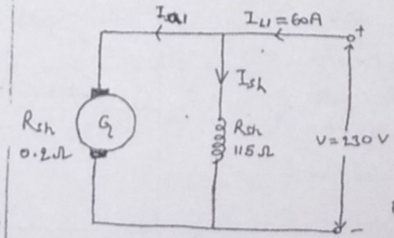
So, Back emf(E_b) = 244.375 V and Armature current = 18.75 A

Ques:- A D.C shunt motor runs at 600 r.p.m. taking 60 A from a 230V supply. Armature resistance is 0.2 ohm and field resistance is 115 ohms. Find the speed when the current through the armature is 30A.

Sol:- Given,

$N_1 = 600$ rpm, $I_L = 60A$, $V = 230$ Volts, $R_{sh} = 115\Omega$, $N_1 = 600$ rpm, $I_{a2} = 30A$

Step 1: Draw the circuit diagram



$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{115} = 2A$

$I_{a_1} = 60 - 2 = 58\ A$

$E_{b1} = V - I_{a1}R_{a1}$ Rsh

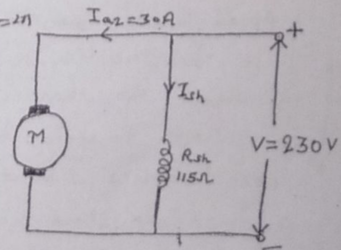
$= 230 - 58 \times 0.2\ 2\Omega$

$E_{b_1} = 218.4\ V$

$E_{b2} = V - I_{a2} R_a$

$= 230 - 30 \times 0.2$

$= 224V$



$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \Rightarrow N_2 = 615.38$ rpm

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Ques: A 6-pole lap wound shunt motor has 500 conductors in the armature. The resistance of armature path is 0.05 Ω. The resistance of shunt field is 25 Ω. Find the speed of the motor when it takes 120 A from d.c. ~~motor~~ mains of 100V supply. Flux per pole is 2×10^{-2} Wb.

Sol: Given,

$P = A = 6,\ Z = 500,\ R_a = 0.05\,\Omega,\ R_{sh} = 25\,\Omega,\ V = 100\,V,\ I_L = 120\,A,\ \phi = 2\times10^{-2}\,Wb.$

Step1: For finding back emf E_b, first we find I_{sh} and I_a

$$I_{sh} = \frac{V}{R_{sh}} = \frac{100}{25} = 4A$$

$$I_a = I_L - I_{sh} = 120 - 4 = 116\,A. \qquad [\because I_L = I_{sh} + I_a]$$

Step2: The back emf is given by.

$$E_b = V - I_a R_a = 100 - 116\times0.05 = 94.2\,V$$

Step3: We know that,

$$E_b = \frac{NP\phi Z}{60A}$$

$$N = \frac{E_b \times 60A}{P\phi Z} = \frac{94.2\times60\times6}{6\times2\times10^{-2}\times500} = 565\ rpm$$

$\therefore$ $N = 565$ rpm.

INDUCTION MOTORS

Ques: Explain the construction of a three phase induction motor?

Ans: A three phase induction motor consist of two main parts as shown in the block diagram.

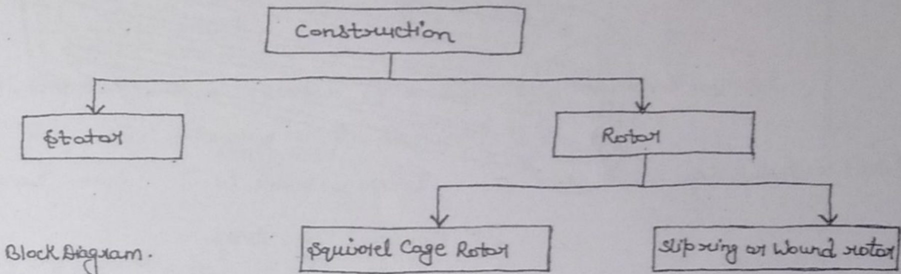
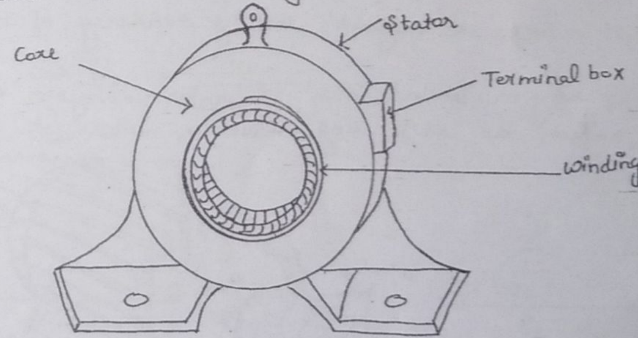


fig: Block Diagram.

1) Stator: Stator is the stationary part of the motor. It consist of a steel frame which enclose a hollow, cylindrical core made up of thin laminations of silicon steel to reduce eddy current and hysteresis losses. The insulated conductors are placed in the stator slots and are suitably connected to three phase a.c. supply.



2) Rotor: Rotor is the rotating part of the motor. The rotor, mounted on a shaft, is hollow laminated core having slots on its outer periphery. There are two types of rotors used in 3-phase induction motor.

a) Squirrel cage Rotor

b) Slip Ring or Wound Rotor.

(a) Squirrel Cage Rotor: The motor whose rotor is squirrel cage type is known as squirrel cage induction motor. Most of the motors have squirrel cage rotor because of simple and rugged construction. Winding, copper or Aluminium bar is placed in each slot.

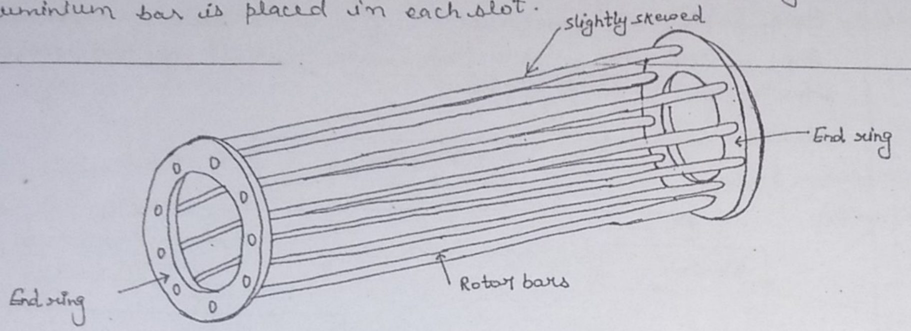


fig: Squirrel Cage Rotor.

The rotor slots are usually not parallel to the shaft but are inclined at some angle, known as skewing. The skewing of the rotor has some advantages like:

(i) It reduces the magnetic humming noise while ~~operating~~ operation.

(ii) To obtain more uniform torque

(iii) It reduces the magnetic locking tendency of the rotor.

(b) Slip ring or Wound rotor: The motor employing this type of motor are known as slip ring induction motor.

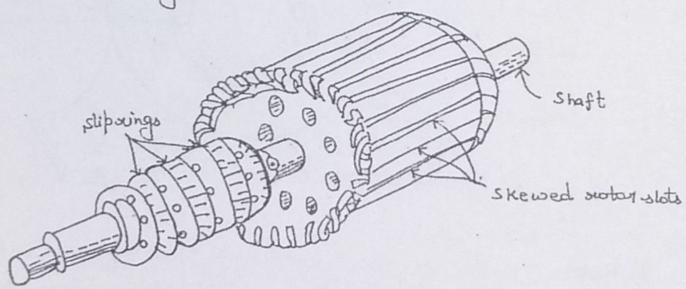


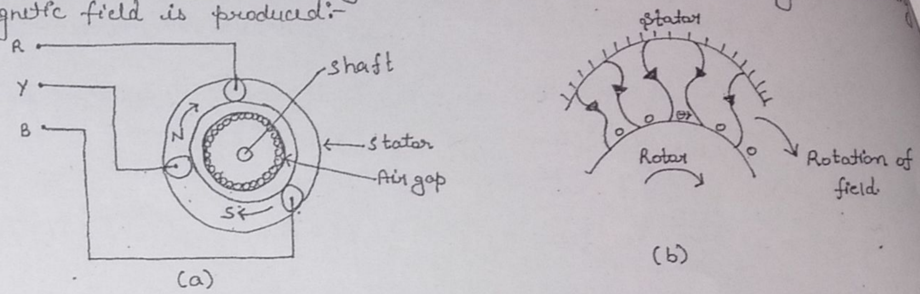
fig: Wound rotor.

The motor having this type of rotor are rarely used. This type of motor are used where high starting torque is required. In this type of rotor, it is possible to add any external resistance to achieve the high starting torque.

Ques: Write down the principle of Operation of three phase induction motor.

Ans: A three phase induction motor works on the principle of Electromagnetic induction. The principle of operation can be understood by the following steps:

Step I: When a 3-phase supply is given to the stator winding, a rotating magnetic field is produced:-



Step II: The rotating magnetic field passes through the air gap and cuts the rotor conductor then an emf is induced in rotor conductor according to Faradays law of electromagnetic induction.

Step (III): This induced emf produces a current in the rotor conductor as rotor conductor are short circuited. This current interacts with rotating magnetic field to developed torque and hence rotor start rotating.

Ques: What is SLIP?

Ans: "The difference between the synchronous speed and the actual rotor speed is called slip". It is denoted by 's'. This is also called absolute slip or fractional slip.

$$s = N_s - N_r$$

where, N_s = Synchronous speed

N_r = Rotor speed.

The percentage slip is expressed as:

$$\% s = \frac{N_s - N_r}{N_s} \times 100$$

$$s = \frac{N_s - N_r}{N_s}$$

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

Case 1: If rotor is stationary then $N=0$ and $s=1$.

Case 2: $N_r = N_s$ then $s=0$.

So, the value of slip varies from $s=0$ to $s=1$

Ques: Explain the effect of slip on Rotor Parameters?

Ans: The effect of slip on the following Rotor Parameters.

1. Rotor frequency
2. Rotor impedance
3. Rotor current
4. Rotor power factor.

1. Effect on Rotor frequency:

In case of induction motor, the speed of rotating magnetic field is given by

$$N_s = \frac{120f}{P} \quad \text{or} \quad f = \frac{PN_s}{120} \quad \text{---(I)}$$

$$f_r = \frac{P(N_s - N)}{120} \quad \text{---(II)}$$

Dividing eq^n (II) by (I), we get

$$\frac{f_r}{f} = \frac{N_s - N}{N_s} \quad \left(s = \frac{N_s - N}{N_s} \right)$$

$$\frac{f_r}{f} = s$$

$$\boxed{f_r = sf}$$

At standstill Condition:

The impedence per phase, $Z_2 = \sqrt{R_2^2 + X_2^2}$

Rotor current per phase, $I_2 = \frac{E_2}{Z_2} = \frac{E_2}{\sqrt{R_2^2 + X_2^2}}$

Rotor power factor, $\cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$

Rotor at slip s:

Impedance per phase, $Z_2' = \sqrt{R_2^2 + (sX_2)^2}$

Rotor current per phase, $I_2' = \frac{E_2'}{Z_2'} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$

Rotor power factor, $\cos\phi_2' = \frac{R_2}{Z_2'} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$

Ques: Explain torque equation of a 3-phase induction motor?

Ans: There are following three factors:

a) Rotor emf b) Rotor current c) Power factor of the rotor circuit

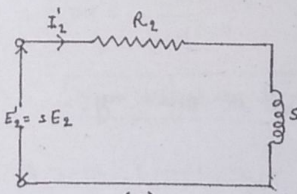
Rotor emf / phase, $E_2' = sE_2$

Rotor reactance/phase, $X_2' = sX_2$

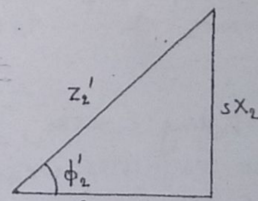
Rotor impedance/ phase $Z_2' = \sqrt{R_2^2 + (sX_2)^2}$

Rotor current/ phase $I_2' = \frac{E_2'}{Z_2'} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$

Rotor p.f., $\cos\phi_2' = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$



(a)



R_2 (b)

$\therefore$ Running torque, $T_r \propto E_2' I_2' \cos\phi_2' \quad \because E_2 \propto \phi$

$$\propto \phi I_2' \cos\phi_2'$$

$$\propto \phi \times \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}} \times \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$\propto \frac{\phi s E_2 R_2}{R_2^2 + (sX_2)^2}$$

$$= \frac{K\phi s E_2 R_2}{R_2^2 + (sX_2)^2}$$

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$$= \frac{K_1 s E_2^2 R_2}{R_2^2 + (sX_2)^2} \qquad (\because E_2 \alpha \phi)$$

If the stator supply voltage V is constant, then stator flux and hence ~~E_2 will be constant~~

$$\therefore \quad T_r = \frac{K_2 s R_2}{R_2^2 + (sX_2)^2} \qquad \text{where } K_2 \text{ is another constant.}$$

Condition for maximum torque

$$T_r = \frac{K_2 s R_2}{R_2^2 + s^2 X_2^2}$$

$$\frac{dT_r}{ds} = \frac{K_2[R_2(R_2^2 + s^2X_2^2) - 2sX_2^2(sR_2)]}{(R_2^2 + s^2X_2^2)^2} = 0$$

or $\quad (R_2^2 + s^2X_2^2) - 2s^2X_2^2 = 0$

or $\quad R_2^2 = s^2 X_2^2$

or $\quad R_2 = sX_2$

Thus for maximum torque (T_m) under running conditions:

Rotor resistance/phase = Fractional slip X standstill rotor reactance/phase

Now, $\quad T_r \propto \frac{sR_2}{R_2^2 + s^2X_2^2}$

Putting $R_2 = sX_2$, the maximum torque is given by:

$$T_m \propto \frac{1}{2X_2}$$

slip corresponding to maximum torque, $s = \frac{R_2}{X_2}$

Ques: Write down the characteristic of Torque slip?

Ans: The curve obtained by plotting torque against slip from s=1 (at start) to s=0 (at synchronous speed) is called torque slip characteristics of 3-phase induction motor.

We know that torque is given by

$$T_r = \frac{sR_2}{R_2^2 + (sX_2)^2}$$

a) Low slip region:-

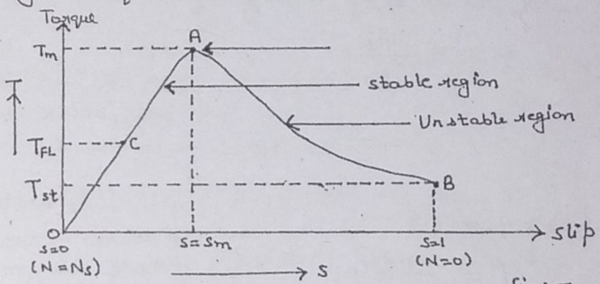
The torque-slip characteristic curve starts from origin shown in figure. When the value of s=0, then T=0.

b) Medium slip region:- (s=0 to s= s_m): At normal working condition, value of slip is small, so term $(sX_2)^2$ is also small and hence negligible.

$$T \alpha \frac{s}{R_2} \qquad (R_2 \text{ is constant})$$

$$T \alpha s$$

So, the torque slip curve is straight line. This is known as stable region of motor.



OA = stable region
AB = Unstable region
Point A = Maximum torque
Point B = Starting torque
Point C = Full load torque.

fig: Torque-slip characteristics.

c) High slip region ($s_m < s < 1$):

$$T \alpha \frac{sR_2}{(sX_2)^2}$$

$$T \alpha \frac{1}{s}$$

High slip region torque is inversely proportional to the slip.

Ques: Explain the Torque-speed curve of Induction Motor?

Ans: They have three operating modes or region:

1) Motoring Mode: $0 \leqslant s \leqslant 1$, slip is positive

2) Generating Mode: $s < 0$, slip is negative

3) Braking Mode: $s > 1$

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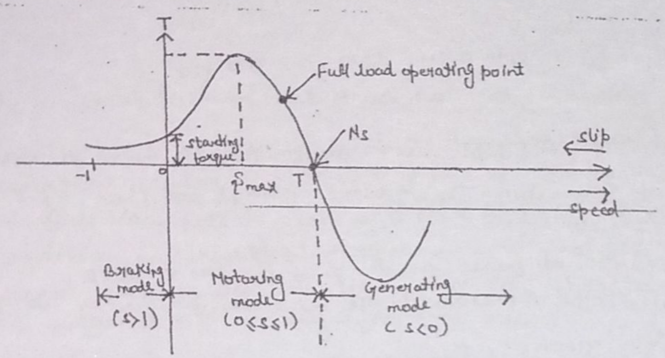

Ques: Write down the Applications of 3-phase induction motor?

Ans: (a) Squirrel Cage Motor

Squirrel cage motor are constant speed motor. So these motor are preferred for the following applications:

(i) fans and blowers
(ii) lathe machine
(iii) printing machine
(iv) grinders
(v) drilling machine
(vi) Water pumps
(vii) textile mills.

(b) Slip Ring Motor:

(i) Cranes
(ii) Lift
(iii) Elevators
(iv) Hoist
(v) compressor
(vi) Large pumps
(vii) cement mill and Rolling mill.

Ques: Comparison of Squirrel cage & Slip Ring Induction Motor.

Ans:

S.No	Squirrel Cage Induction Motor	Slip Ring Induction Motor.
1.	Higher frequency	Lower efficiency
2.	Lower starting torque	High starting torque
3.	low cost and low maintenance	High cost & high maintenance
4.	Simple in construction	complicated in construction.
5.	Slip rings and brushes as absent	Slip rings brushes are present to add external
6.	Lower losses	Higher losses
7.	No speed control	Speed control can be done.

Solved Examples

Exam: A 50 Hz 4-pole, 3-phase induction motor has a rotor current of frequency 2 Hz. Determine (i) slip (ii) speed of the motor.

Sol: Given, $f = 50 Hz$, $P = 4$, $f' = 2 Hz$

Step I) The rotor frequency is given by

$$f' = sf \quad \text{or} \quad s = \frac{f'}{f} = \frac{2}{50} = 0.04 \text{ or } 4\%$$

$\therefore$ $\boxed{s = 4\%}$

Step II) We know that synchronous speed is given by.

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}.$$

Now, $$s = \frac{N_s - N_r}{N_s}$$

$$0.04 = \frac{1500 - N_r}{1500} = 1440 \text{ rpm}.$$

$\therefore$ $\boxed{N_r = 1400 \text{ rmp}}$

Ques: A 3-φ, 6-pole, 50 Hz induction motor has a slip of 1% at no-load and 3% at full load. Find.

(i) Synchronous speed (ii) No-load speed (iii) Full-load speed (iv) Frequency of rotor current at stand still (v) Frequency of rotor current at full-load.

Sol: Given,

$P = 6$, $f = 50 Hz$, No-load slip. $S_{nl} = 1\% = 0.01$

full load slip. $S_{fl} = 3\% = 0.03$

i.e. Synchronous speed of motor

$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000$ rpm $\therefore$ $N_s = 1000$ r.p.m

Step (II): No-load speed

$N_{nl} = N_s(1 - S_{nl}) = 1000(1 - 0.01) = 990$ rpm $\therefore$ $N_{nl} = 990$ rpm

Step (III): Full load speed.

$N_{fl} = (1 - S_{fl}) = 1000(1 - 0.03) = 970$ rpm $\therefore$ $N_{fl} = 970$ r.p.m

Step (IV): Frequency of rotor current at stand still

$S \cdot f = 1 \times 50 = 50$ Hz [∵ s = 1 at standstill]

Step (V): Frequency of rotor current at full load.

$f_r = s_{fl} \times f = 0.03 \times 50 = 1.5$ Hz $\therefore$ $f_r = 1.5$ Hz.

Exam: A 3-phase induction motor is wound for 4 poles and is supplied from 50 Hz system. Calculate -

(i) N_s, (ii) Rotor speed when slip is 4%. (iii) Rotor frequency when rotor runs at 600 rpm:

Sol: Given,

$P = 4$, $S = 4\%$ i.e; 0.04, $f = 50$ Hz

Step I) The synchronous speed is given by

$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$ rpm.

Step II) The rotor speed when slip is 4% is calculate as

$N_r = N_s(1-s) = 1500(1 - 0.04) = 1440$ r.p.m.

Step III) The rotor speed when rotor runs at 600 rpm

$N_1 = 600$ r.p.m

$s_1 = \frac{N_s - N_1}{N_s} \times 100 = \frac{1500 - 600}{1500} \times 100 = 60\%$

$f_r = s_1 f = 0.6 \times 50 = 30$ Hz

Examp: A 5 h.p., 230V, 50 Hz induction motor has a rated full load speed of 950 rpm. The induced voltage per phase of rotor at standstill is 100V. Calculate:

(i) No. of poles and % full load slip

(ii) Rotor induced voltage and its frequency at full load.

Sol: Given,

$V_L = 230$V, $f = 50$ Hz, $N_r = 950$ rpm, $E_2 = 100$ V

Step I) The practical value of full load slip is above 4 to 6%. Hence the nearest synchronous speed to $N_r = 950$ rpm is $N_s = 1000$ r.p.m.

But $N_s = \frac{120f}{P}$ i.e. $1000 = \frac{120 \times 50}{P}$

$\therefore$ $P = 6$ (no. of poles)

$\% s = \frac{N_s - N_r}{N_s} \times 100 = \frac{1000 - 950}{1000} \times 100 = 5\%$ (slip).

Step II) The rotor induced voltage & its frequency at full load is

$E_{2r} = sE_2 = 0.05 \times 100 = 5$V

$f_r = sf = 0.05 \times 50 = 2.5$ Hz

Exam: A 4-pole, 3-phase, 50 Hz, star connected induction motor has a full load slip of 4%. Calculate full load speed of the motor.

Sol: Given, $P = 4$, $f = 50$ Hz, $S_{fl} = 4\%$

Step I) The synchronous speed is given by

$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$ rpm.

Step II) The full load speed is

$S_{fl} = \frac{N_s - N_{fl}}{N_s}$

$\therefore$ $0.04 = \frac{1500 - N_{fl}}{1500}$

$\therefore$ $N_{fl} = 1440$ rpm

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Ques: Why single phase induction motor is not self starting?

Ans: When a single phase supply is connected to the stator winding a Pulsating or Alternating magnetic field is produced. This pulsating field builds up in one direction, fall to zero and then build up in the opposite direction. This condition the resultant torque is zero and pulsating magnetic field can not produce rotation in rotor. Therefore, a single phase induction motor is not a self-starting motor.

Why single phase induction motor are not self starting with the help of a theory called Double Revolving field Theory.

Double Revolving field Theory:

According to double revolving field theory consider the two components of the stator flux, each having magnitude half to of maximum magnitude of stator flux i.e. $(\phi_{1m}/2)$.

Let ϕ_f is forward component rotating in anticlockwise direction which ϕ_b is the backward component rotating in clockwise direction.

The resultant $\phi_R = 0$. This is nothing but the instantaneous value of stator flux at start. After 90°, the two components are rotated in such a way that both are pointing in the same direction. $\phi_R = (\phi_{1m}/2) + (\phi_{1m}/2) = \phi_{1m}$.

At start these two torques are equal in magnitude but opposite in direction. Each torque tries to rotates the rotor in its own direction. Thus net torque experienced by rotor is zero at start hence the single phase induction motor are not self starting.

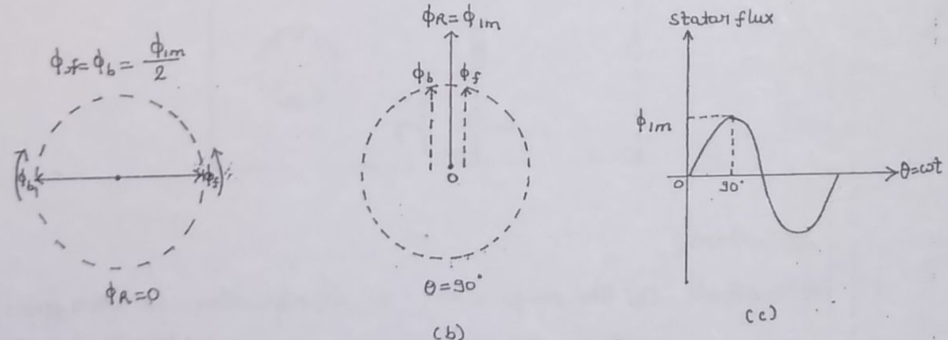
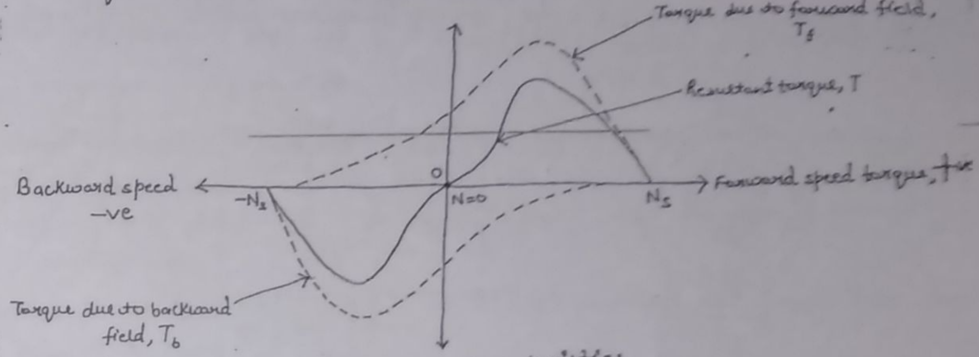


fig: Stator Flux and its two Components.

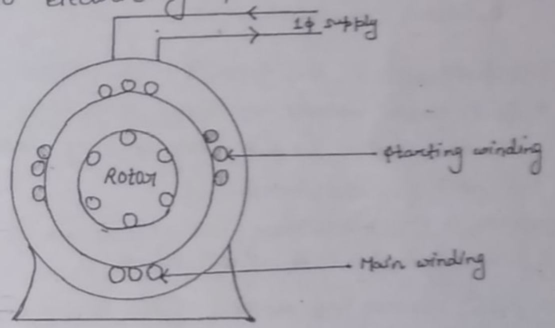
Torque-Speed Characteristics –



Torque speed characteristics

Ques: How to make single phase induction motor self starting?

Ans: The single phase induction motor is not self-starting. To make a single phase induction motor self starting, we should produce a Rotating Magnetic field in stator. The auxiliary winding is connected across the supply voltage and 90° electrically apart with main winding.



Single phase induction motors are usually classified according to the auxiliary means used to start the motor. They are classified as follows:

(1) Split phase motor (Resistance start motor)

(2) Capacitor – start motor

(3) Capacitor start, capacitor run motor

(4) Shadded pole motor.

(1) **Split Phase Induction Motor:** Split phase induction motor is also called resistance start motor.

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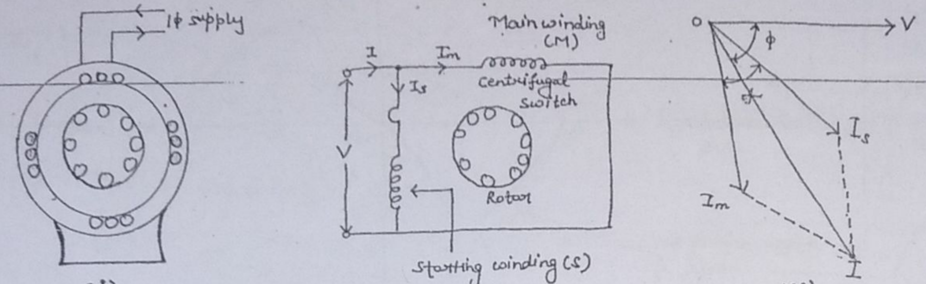
The main field winding and the starting winding are displaced 90° in space like the winding in a two phase induction motor.



(i) (ii) (iii)

Operation:

1) When the two stator windings are energised from a single phase supply, the main winding carries current Im while the starting winding carries current Is.

ii) Im and Is have a reasonable phase difference angle α (25° to 30°) between them.

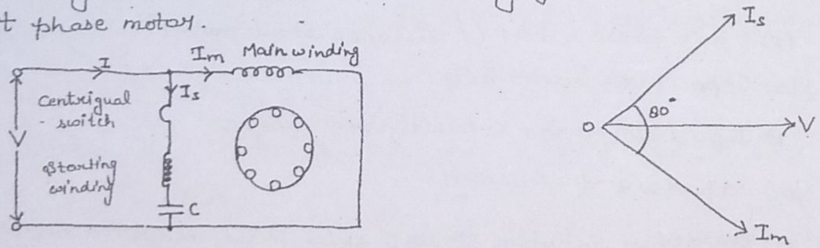
Application:

* Split phase motors are cheap and they are most suitable for easily started loads where frequency of starting is limited.

The common application are –

- fans and blowers
- washing machine & refrigerator.
- Food processing machine, Grinders
- Wood working tools.

(2) Capacitor start Motor: The value of capacitor is so chosen that I_s lead I_m by about 80° which is considerably greater than 25° found in split phase motor.



(i) (ii)

Application:

* Capacitor start motor are used for load of higher inertia where frequenty start are required.

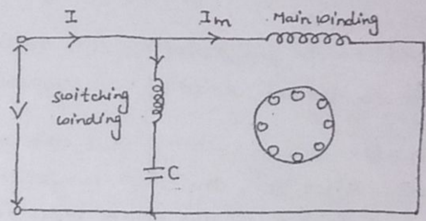
These motors are most suitable for:-

a) Pumps
b) Compressor
c) Air conditioners
d) conveyors.

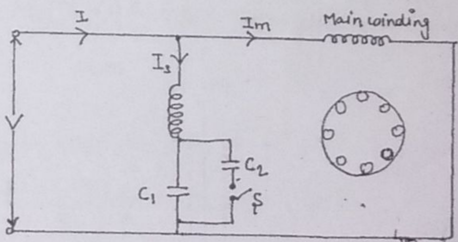
(3) Capacitor start Capacitor Run Motor:

Two designs are generally used - as -

(i) A single capacitor C is used for both starting and running. The design eliminated the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.



(ii) Two capacitors C_1 and C_2 are used in the starting winding. The smaller capacitor C_1 required for optimum running conditions is permanently connected in series with the starting winding.



Application:

(a) Hospitals (b) Air compressor (c) Refrigeration (d) Other places where silence is important.

(4) **Shaded Pole Motor:** A shaded pole motor consist of a stator and a cage type rotor. The stator is made up of salient poles.

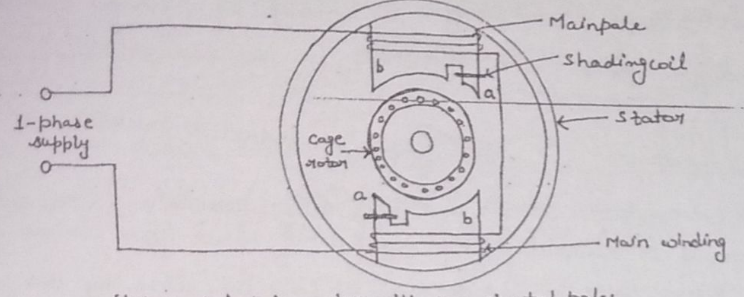


fig: Shaded-pole motor with two started poles.

When the a.c. supply is connected to the main winding the alternatic flux is set up in the core. This alternating flux induces the current in a shading coil which opposes the core flux due to Lenz law. The flux in the shaded portion of the pole lags the flux in the unshaped portion of it.

Application:

Because of low starting torque, the shaded pole motor is generally used for:

(a) Small fans , (b) Toys , (c) Hair dryers & Electric clocks.

THREE PHASE SYNCHRONOUS MACHINES

Ques: Write down the important feature of Synchronous Machine.

Ans: 1) It is always better to protect high voltage winding from centrifugal forces caused due to the rotation. So higher voltage armature is generally keep stationary.

2) It is easier to collect large currents at very high voltages from a stationary members.

3) The problem of sparking at the slip rings can be avoided by keeping field rotating and armature stationary.

4) Rotating field make overall construction very simple.

5) The Ventillation arrangement for high voltage side can be improved if it is kept stationary.

Ques: Explain the construction of Alternator or Generator?

Ans: There are two main parts namely:

(1) Stator (2) Rotor

1) **Stator:** The stator is the stationary part of the machine. It carries the armature winding in which the voltage is generated. The output of the machine is taken from the stator.

2) **Rotor:** The rotor is the rotating part of the machine. The rotor produces the main field flux. Rotor construction is of two types:

a) Salient (projecting) pole type b) Non-salient (cylindrical) pole type.

a) Salient (projecting) pole type: The terms salient means projecting or protruding. The poles are built up of thick steel laminations. The features of salient pole type rotor is:

(i) It is used in low and Medium speed (125-500 rpm) alternator.
(ii) These rotor have large diameters and small axial length.
(iii) The prime movers used to drive such rotor are generally water turbine

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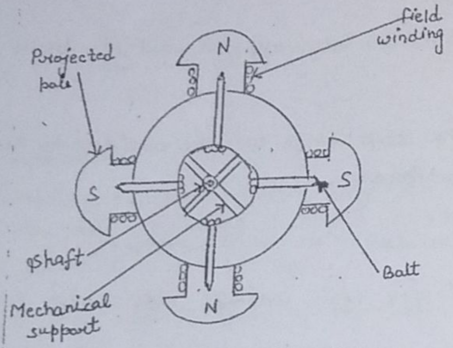
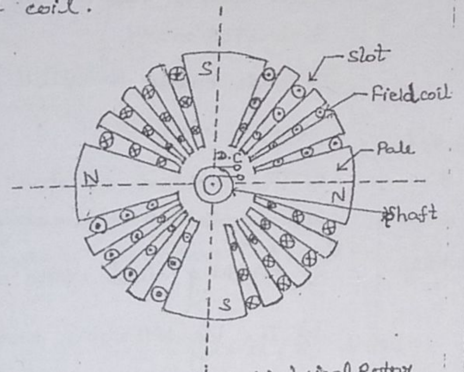
and I.C. engines.

(iv) Salient pole alternator driven by water turbine are called Hydro alternator or hydrogenerators.

(b) Non-salient type Rotor: ~~It is also~~ called smooth cylindrical type rotor. The rotor consist of smooth solid steel cylinder, having number of slots to ~~Gorr~~ accommodate the field coil.



fig(a): Salient Pole Type Rotor



fig(b): Smooth Cylindrical Rotor.

Features of non salient pole type rotor are-

(i) It is used in high speed (750-3000 rpm) alternators.

(ii) These rotors have small diameter and large axial length.

(iii) Prime movers used to drive such type of rotors are generally steam turbine.

(iv) Such high speed alternators are called turbo alternators.

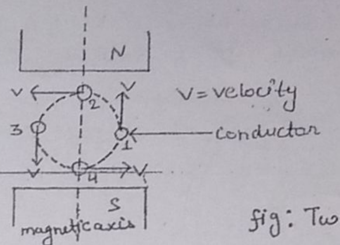
Ques: Explain the principle of operation of Alternator.

Ans: The alternator works on the principle of Electromagnetic induction. When a rotor is ~~rotated by~~ rotated by means of prime mover, the armature conductors cuts the magnetic flux, therefore an emf is induced in the armature conductors, due to electromagnetic induction. The direction of induced emf can be found by Flemings Right hand rule and frequency is given by:

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

where, N = Speed of rotor in rpm

P = Number of poles.



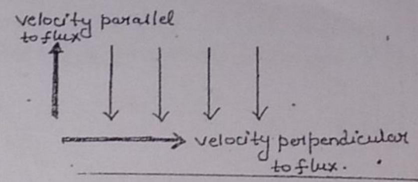


fig: Two pole alternator

Step 1): Let conductor starts rotating from position 1. The entire velocity components is parallel to the flux lines. Hence there is no cutting of flux lines. Hence there is no cutting of flux line by the conductor. So $\frac{d\phi}{dt}$ at this instant is zero and hence induced emf in the conductor is zero

Step 2) Position 1 towards position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that emf gets induced in the conductor.

Step 3) At position 2, the entire velocity component is perpendicular to the flux lines. Hence there exists maximum cutting of the flux lines. The induced emf in the conductor is at its maximum.

Step 4) As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced emf in the conductor is zero.

Step 5) As the conductor moves from position 3 towards 4, the velocity component perpendicular to the flux lines again starts increasing. At position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes perpendicular to the flux lines.

Step 6) from position 4 to 1, induced emf decreases and finally at position 1, again becomes zero,

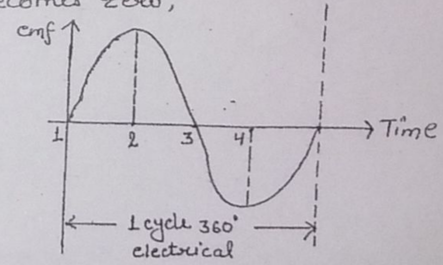


fig: Alternating nature of the induced emf.

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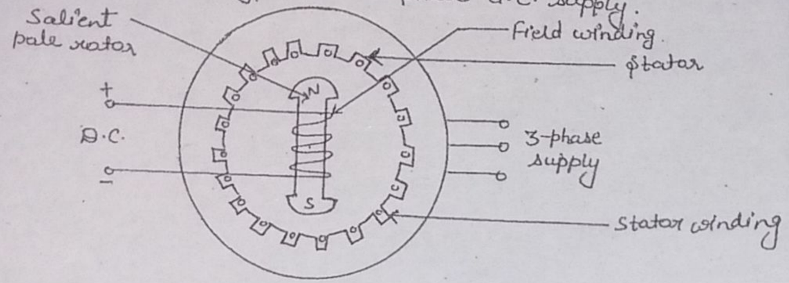
Ques: Explain the principle of Synchronous Motor.

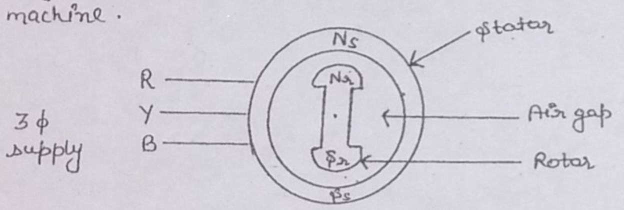
Ans: Stator: Stator is the stationary part of the machine. The three phase armature winding is placed in the slots of stator core and is wound for the same numbers of poles as the rotor as shown in the figure. The stator is excited by a three phase a.c. supply.



Rotor: The rotor of synchronous motor can be of the salient pole or cylindrical pole (non salient) type construction. The field winding is placed on the Rotor. The field winding is excited by a separate d.c. supply.

Ques: Why synchronous motor is not self starting?

Ans: Synchronous motor works on the principle of Magnetic Locking. The operating principle can be explained with the help of 2-pole synchronous ~~motor~~. machine.



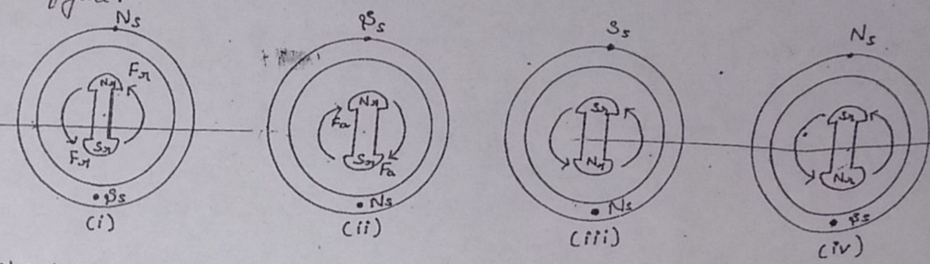
$N_s, S_s \rightarrow$ Stator north and South pole

$N_r, S_r \rightarrow$ Rotor north and South pole

Step I) When a three phase supply is given to the stator winding, a Rotating magnetic field is produced in stator.

Step II) The stator poles N_s and S_s rotate with synchronous speed. Stator pole N_s coincides with N_r and S_s coincides with S_r i.e., like poles of stator and rotor coincide with each other. As we know, like poles experiences as repulsive force.

Assume that the rotor tends to rotate in anticlockwise direction as shown in the figure.



Step 3) After half cycle or half period, stator poles interchange their position. Unlike poles coinciding each other and rotor experiences the attractive force fa and tends to rotate in clockwise direction. The rotation of stator poles the rotor tends to drive in clockwise and anticlockwise direction in every half cycle. As a result, the average torque on rotor is zero. Hence 3-phase synchronous motor is not a self starting motor.

Step 4) The stator and rotor unlike poles will face each other, then due to strong force of attraction, magnetic locking is established, the rotor and stator poles continue to occupy the same relative position.

Step 5) Rotor continuously experiences a unidirection torque in the direction of the rotating magnetic field. Hence 3-phase synchronous motor must run at synchronous speed.

Method of starting a synchronous Motor–

1. Using small Induction motor.
2. Using small d.c. machine.
3. Using damper winding.

Ques: Explain V-curves and Inverted V-curves.

Ans: "The curve plotted between field current (I_f) and armature current (I_a) is called V-curves". Figure (a) shows a typical V-curve at no-load, half-load and full load.

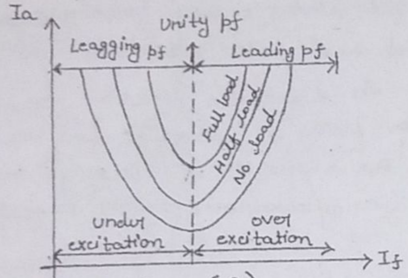
Effects are observed–

1) When the motor is under excited, the armature current and power factor is lagging. In this case, the motor behaves like an inductive load.

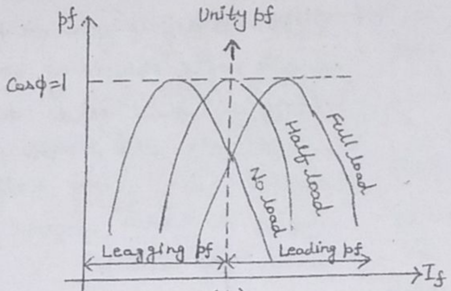
2) When the motor is normally excited, the power factor is unity. The armature current is minimum and is in phase with the terminal voltage.

3) When the motor is over-excited, the power factor is leading. In this case, the motor behaves like a capacitive load.

Curves obtained by plotting power factor against field current (I_f) at various load condition are called Inverted V-curves of synchronous motor. These curves are shown in the figure (b).



(a)



(b)

Ques: Write down the application of three phase Synchronous motor.

Ans: Synchronous motors were mainly used in constant speed applications.

- Over excited synchronous motor can be used to improve the power factor.
- Synchronous motors are used to improve the voltage regulation of transmission lines.
- Synchronous motor only runs at synchronous speed, therefore it is used in textile, paper mill etc.
- Due to constant speed characteristics, it is used in:

a) Machine tools

b) Motor-Generator set

c) Synchronous clocks.

d) Timing devices

e) Fans and blowers

f) Cement industries

Ques: Disadvantages of Synchronous Motor :-

Ans: a) It is not self starting

b) Its cost is higher as comparision to other motors.

c) It needs frequent maintenance.

d) Excitation ...

e) Auxiliary device or additional winding is necessary to make it self starting.

f) The construction of synchronous motor is more complicated than 3-phase Induction motor.

Ques: Comparision of Synchronous and Induction Motor.

Ans:

S.No	Particular	Synchronous Motor	Induction Motor
1.	Speed	Remains constant (i.e., N_s) from no-load to full-load.	Decreases with load.
2.	Power factor	Can be made to operate from Lagging to leading power factor	operates at lagging power factor.
3.	Excitation	Requires d.c. excitation at the rotor.	No excitation for the rotor.
4.	Economy	Economical for speeds below 300 r.p.m.	Economical for speeds above r.p.m.
5.	Self-starting	It is not a self starting motor. Auxiliary means have to be provided for starting.	Self-starting.
6.	Construction	Complicated	Simple.
7.	Starting torque	More	Less
8.	Cost and Maintenance	Motor is costly and required frequent maintenance.	Motor is cheap specially cage motors are maintenance free.
9.	Speed Control	Speed control is not possible	Speed control is possible but difficult.