SRI MANAKULA VINAYAGAR ENGINEERING COLLEGE
(Approved by AICTE, New Delhi & Affiliated to Pondicherry University)
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Madagadipet, Puducherry - 605 107

DEPARTMENT OF MECHANICAL ENGINEERING

Subject Name: Electrical and Electronics Engineering **Subject Code:**MET35

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2. AC MACHINES

Theory and operation of 3 phase Induction motor - constructional details – starting methods – speed control methods – principle of operation of single phase Induction motor – stepper motor – AC series motor – Applications

Part-A (2 Marks)

1. What is the function of capacitor in a single phase induction motor (NOV/2014)
   - Developing high starting torque
   - To improve the power factor
2. What are the classifications of three phase induction motor based on the method of construction (NOV/2014)

   The three phase induction motor are classified based on their constructions are
   - Squirrel cage induction motor
   - Slip ring (or) wound rotor induction motor
3. What is Slip?(APRIL/2014)

   (or)

   Define slip of an induction motor. (APRIL/2012)

   Slipoftheinductionmotorisdefinedasthe***"Differencebetweenthesynchronousspeed(Ns) andactualspeedof rotori.e. motor (N) expressed asa frictionof the synchronousspeed(Ns)"***. Thisis also called **absolute slipor fractional slip** and is denoted as's'

   Thus $s = \frac{Ns-N}{Ns}$-- Absolute slip

   Thepercentageslip is expressed as,

   $\% s = \frac{Ns-N}{Ns} * 100$----------------------------------- Percentage slip
4. Mention the methods available to make single phase induction motors self-starting (APRIL/2014)

   (or)

   What are the classifications of single phase induction motor based on the method of starting(NOV/2012)

   (Or)

   What are the different types of single phase induction motor? (APRIL/2012)

- Split phase induction motor
- Capacitor start induction motor
- Capacitor start and capacitor run induction motor
- Shaded pole induction motor

5. A 6 pole, 50 Hz, three phase induction motor runs at 800 rpm at full load. Determine the value of slip at this load condition. (NOV/2013)

P= 6
F= 50 Hz
N= 800 rpm

$$N_S = \frac{120\,f}{\text{P}}$$

$$N_S = \frac{120 * 50}{6} = 1000\,rpm$$

$$\%\,s = \frac{Ns - N}{Ns} * 100$$

$$\%\,s = \frac{1000 - 800}{1000} * 100$$

$$\%\,s = 20\,\%$$

6. Mention some applications of AC series motor (NOV/2013)
   - Electric traction
   - Hoists
   - Locomotives
7. What are the advantages of three phase induction motor? (APRIL/2013)
   - Simple and Rugged construction
   - High efficiency
   - Self-starting motor
   - Good power factor
   - High reliable
   - Requires less maintenance
   - Low cost
   - Can be operated in explosive and in dirty environment
8. Mention the types of stepper motor. (APRIL/2013)
   - Variable reluctance stepper motor
   - Permanent magnet stepper motor
   - Hybrid stepper motor
9. Compare squirrel cage rotor and slip ring rotor. (NOV/2012)

S. NO.	SLIP RING INDUCTION ROTOR	SQUIRREL CAGE ROTOR
1	Rotor consists of three windings similar to stator winding	Rotor consists of bars which are shorted at the ends with the help of end rings
2	Construction is complicated	Construction is simple
3	Resistance can be added externally	Resistance cannot be added externally
4	Slip rings and brushes are present to add external resistance	Slip rings and brushes are absent
5	The construction is delicate and due to brushes, frequent maintenance is necessary	The construction is robust and maintenance free

6	The rotors are very costly	Rotor is cheap
7	Only 5% of induction motors in industry use slip ring rotor	Very commonly used motor in industry
8	High starting torque can be obtained	Moderate starting torque can be obtained
9	Speed control is possible	Speed control is not possible as it has short circuit rotor
10	Less efficiency	High efficiency

10. What are the main parts of an induction motor
   - Stator (Stationary parts)
   - Rotor (Rotating parts)

(Part- B) 11 Marks

1. With neat sketches explain the constructional details and operation of three phase induction motor. (APRIL/2013)

(or)

Explain the construction of anthree phase induction motor with neat sketch**.**

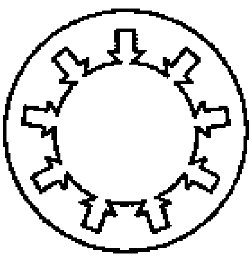
CONSTRUCTION OF THREE PHASE INDUCTION MOTOR

Basicallythe induction motor (all motors) consistsof two main parts, namely
   - STATOR
   - ROTOR

The conversion of electricalpower to mechanical power takes placein arotor. Hencerotor develops a drivingtorqueand rotates.

STATOR:

The statorhasalaminatedtype ofconstructionmade upofstampingswhichare0.4to0.5mm thick.Thestampingsareslottedininner peripherytocarrythestatorwinding.Thestampingsare insulatedfromeachother.Suchaconstructionessentially keepstheironlossestoaminimumvalue. Thenumberofstampingsare stampedtogethertobuildthestatorcore.Thebuiltupcore isthenfitted inacasted orfabricatedsteelframe.Thechoiceofmaterialforthestampingsisgenerallysiliconsteel, whichminimizesthehysteresisloss.Theslotsintheperiphery ofthestatorcorecarriesathreephases winding,connectedeitherinstarordelta.Thisthreephasewindingiscalledstatorwinding.Itis woundfordefinitenumberofpoles.Thiswindingwhenexcitedby athreephasesupplyproducesa magneticrotating fieldasdiscussedearlier.Thechoiceofnumberofpolesdependsonthespeedofthe rotating magneticfieldrequired.Theradialductsare providedforthecooling purpose.Insome cases, allthesixterminalsofthreephasestatorwindingarebroughtoutwhichgivesflexibility totheuserto connect them either in staror delta.



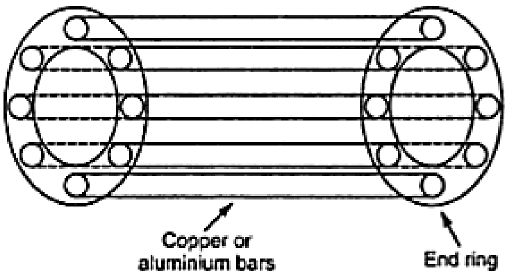
Stator core

ROTOR:

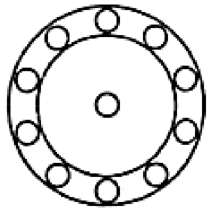
Therotorisplacedinsidethestator.Therotorcore isalsolaminatedinconstructionandusescast iron.Itiscylindrical,withslotsonits outer periphery.Therotorconductorsorwinding isplacedinthe rotor slots. Thetwo type of rotor constructions whichareusedforinduction motors are,
   - Squirrel cagerotor and
   - Slip ringwound rotor

Squirrel CageRotor

Therotorcoreiscylindricalandslottedonitsperiphery.Therotorconsistsofun-insulatedcopper or aluminumbars called**rotor conductors**. Thebars are placedin theslots.Thesebars arepermanently shortedateachendwiththehelpofconductingcopperringcalled**endring**.Thebarsareusually brazedtotheendringstoprovidegoodmechanicalstrength.Theentirestructure lookslike a cage, forming aclosedelectricalcircuit.Sotherotoris calledsquirrelcagerotor.Theconstructionisshown in the below figures.



(a) Cage type structure of rotor

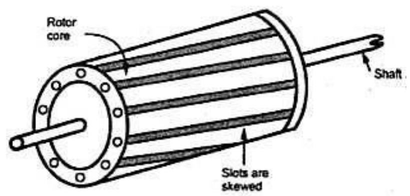


(b) Symbolic representation

Squirrel cagerotor

Asthebarsarepermanently shortedtoeachotherthroughendring,theentirerotorresistanceis verysmall. Hencethis rotoris also called **short circuited rotor**.As rotor itselfis short circuited, no externalresistancecanhaveany effectontherotorresistance.Hencenoexternalresistancecanbe introducedintherotorcircuit.Soslipringandbrushassembly isnotrequiredforthisrotor.Hencethe construction ofthis rotoris verysimple. Theairgapbetweenstatorandrotoriskept uniform and as smallaspossible.

Inthistypeofrotor,theslotsare notarrangedparalleltotheshaftaxis butare skewedasshownin the below figure.



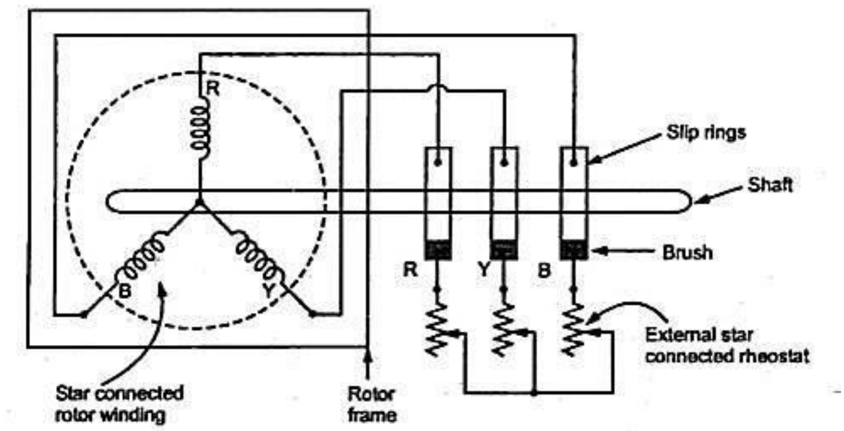
Skewing inrotorconstruction

The skewing is done in the squirrel cage rotor to

- Reduce humming noisehenceskewingmakesthemotor operation quite.
- Make the rotor operation smooth.
- Avoid magnetic locking between statorandrotorteeth
- Increases the effectivetransformation ratio between stator androtor.

<u>SlipRing RotororWoundRotor</u>

Inthis typeofconstruction,rotorwindingisexactly similartothestator.Therotorcarriesathree phasestarordeltaconnected,distributedwinding,woundfor samenumber ofpolesasthatofstator. The rotor constructionislaminatedandslotted.The slotscontaintherotor winding.The three endsof threephasewinding,availableafterconnecting thewinding instarordelta,are permanentlyconnected totthesliprings.Theslipringsare mountedonthe sameshaft. Wehaveseenthatslipringsareusedto connectexternalstationary circuittotheinternalrotatingcircuit.Sointhistypeofrotor,theexternal resistancescanbeaddedwiththehelpofbrushesandslipringarrangement,inserieswitheachphase of therotorwinding.



Sliprings orwoundrotor construction

Intherunningcondition,theslipringsareshorted.Thisispossibleby connecting ametalcollar whichgetspushedandconnectsalltheslipringstogether,shorting them.Atthesametimebrushesare alsoliftedfromthesliprings.Thisavoidswearandtearofthebrushesduetofriction.Thepossibility ofadditionofanexternalresistanceinserieswiththerotor,withthehelpofslipsingsisthemain featureof this typeof rotor.

WORKING PRINCIPLEOFTHREE PHASE INDUCTION MOTOR

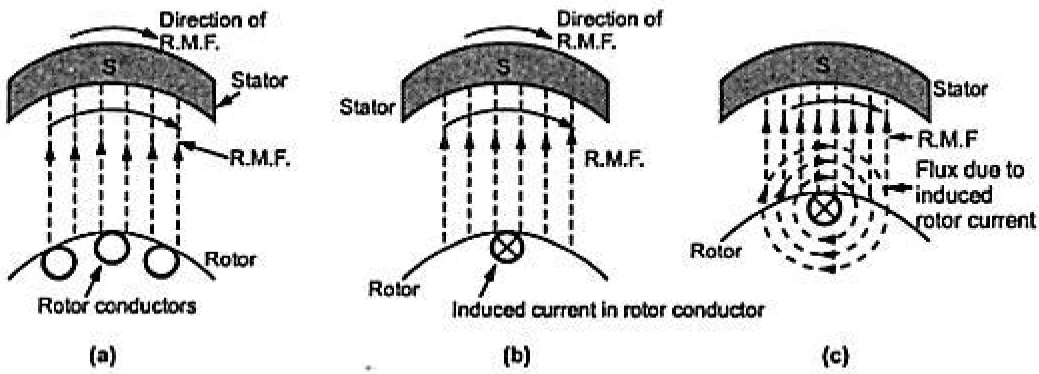
Induction motor works on the principle of Faradays Law of Electromagnetic induction. Whenathreephasesupply isgiventothethreephasestatorwinding,arotatingmagneticfieldof constantmagnitude will beproduced. The speedofthisrotationmagnetic fieldis synchronous speed N_Sr.p.m.

$$N_s=120f/P$$

Where, f =supplyfrequency.

P =Number ofpoles for which stator windingis wound.

Thisrotating fieldproducesaneffectofrotatingpolesarounda rotor.Letdirectionofrotationof this rotatingmagneticfield is clockwise as shownin the below figure (a).



Nowatthisinstantrotorisstationary andstatorfluxR.M.F.isrotating.Soit'sobviousthatthere existsarelativemotionbetweentheR.M.F.androtorconductors.NowtheR.M.F.getscutby rotor conductorsasR.M.F.sweepsover rotorconductors. Whenever conductor cutsthe flux,e.m.f. gets inducedinit. Soe.m.f.getsinducedinthe rotor conductorscalledrotor inducede.m.f.Thisiselectro-magneticinduction.Asrotorformsclosedcircuit,inducede.m.f.circulatescurrentthroughrotor calledrotorcurrentasshownintheabove figure (b).

Any currentcarryingconductorproducesitsownflux.Sorotorproducesitsfluxcalledrotorflux. Forassumeddirectionofrotorcurrent,thedirectionofrotorfluxisclockwiseasshowninthe above figure (c).Thisdirectioncanbeeasily determinedusingrighthandthumbrule.Nowtherearetwofluxes, oneR.M.F.andotherrotorflux.Boththefluxesinteractwitheachasshowninthe below figure (d).Onleft of rotor conductor,twofluxescanceleachother toproduce lowfluxarea.Asfluxlinesactasstretched rubberband,highfluxdensityareaexertsapushonrotorconductortowardslowfluxdensity area.So rotor conductorexperiences aforce fromlefttorightinthiscase,asshowninthe below figure (d), dueto interaction ofthe two fluxes.

Asallthe rotor conductorsexperience a force,the overallrotor experiencesa torque andstarts rotating.Sointeractionofthetwofluxesisveryessentialforamotoringaction.Hencerotorstarts rotatingin thesamedirection as that of rotatingmagneticfield.

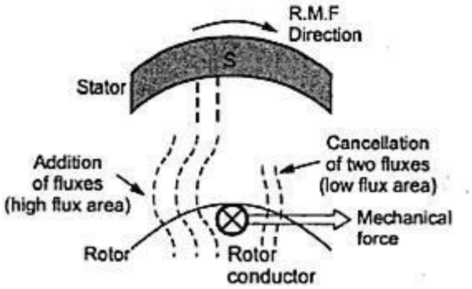


Figure (d)

SLIPOFINDUCTION MOTOR

Whenthe rotorrotatesinthesamedirectionasthatofR.M.F.butinsteady state attains a speed lessthanthe synchronous speed. The difference betweenthe two speeds i.e. synchronousspeedofR.M.F.(Ns)androtorspeed(N)iscalled**slipspeed**.Thisslipspeedis generallyexpressedas the percentageof thesynchronous speed.

Soslipoftheinductionmotorisdefinedasthe***"Differencebetweenthesynchronousspeed(Ns) andactualspeedof rotori.e. motor (N) expressed asa frictionof the synchronousspeed(Ns)"***. Thisis also called **absolute slipor fractional slip** and is denoted as's'

Thus

$$s = \frac{Ns-N}{Ns}$$ -- Absolute slip

Thepercentageslip is expressed as,

$$\% s = \frac{Ns-N}{Ns} * 100$$ ---------------------------------- Percentage slip

In terms ofslip, the actual speed of motor (N) can beexpressed as, At

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

$$s = 1$$ ---------------------------------- At start

At start, motor is at rest and henceits speedN is zero.

Thisismaximumvalue ofslipspossiblefor inductionmotorwhichoccurs atstart. While s= 0 givenusN=Nswhichisnotpossibleforaninductionmotor.Soslipofinductionmotorcannotbe zero under anycircumstances. Practically motoroperatesinthesliprangeof0.01to0.05i.e.1%to5%.Theslipcorresponding to full load speed of themotor is called full load slip.

2. Derive the equation for torque developed by three phase induction motor. Draw the torque slip curve and deduce the condition for maximum torque (11)(NOV/2014)

TORQUE EQUATION:

"Torque is the turning force through a radius and the units is rated in Nm"

Thetorqueproduced in theinduction motor depends on thefollowingfactors:

- Thepartofrotating magneticfieldwhichreactswithrotorandisresponsibletoproduceinduced e.m.f. in rotor.
- Themagnitudeof rotor current in running condition.
- Thepowerfactor oftherotor circuitin running condition.

Mathematicallythe relationship can be expressed as

$$T \alpha \Phi I_{2r} Cos\ \Phi_{2r}$$ ----------- (1)

Where, Φ= Fluxresponsible to produceinduced e.m.f.

I_{2r} =Rotorrunning condition
Cos Φ_{2r} =Runningp.f. of motor

ThefluxΦ produced bystator is proportional to stator voltage.

$$\Phi \alpha E_1 \qquad \text{----------- (2)}$$

While $E_1$and E_2arerelated to each otherthrough ratio of stator turns torotorturns i.e. K

$$\frac{E_2}{E_1} = K \text{------------(3)}$$

Using equation (3) in (2) we can write,

$$E_2 \alpha \Phi \qquad \text{------------- (4)}$$

Thus in equation (1), ϕ can be replaced by E_2

While $$I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{s\,E_{2r}}{\sqrt{R_2^2+(sX_2)^2}} \qquad \text{-----------(5)}$$

And $$\cos\phi_{2r} = \frac{R_2}{Z_{2r}} = \frac{R_2}{\sqrt{R_2^2+(sX_2)^2}} \qquad \text{---------- (6)}$$

Using(4), (5), (6) inequation (1),

$$T \propto E_2 \frac{s\,E_{2r}}{\sqrt{R_2^2+(sX_2)^2}} \frac{R_2}{\sqrt{R_2^2+(sX_2)^2}}$$

$$\boxed{T \propto \frac{s\,E_2^2 R_2}{R_2^2+(sX_2)^2}} \text{ N-m}$$

$$T = \frac{k\,s\,E_2^2 R_2}{R_2^2+(sX_2)^2} \qquad \text{------------ (7)}$$

Where, k=*Constant of proportionality*

The constant k is proved to be $3/2\pi n_s$ for the three phase induction motor

$$k = \frac{3}{2\pi n_s} \qquad \text{---------------- (8)}$$

n_S = synchronous speed in r.p.s. = $\frac{N_s}{60}$

Using (8) in (7) we get the torque equation as,

$$\boxed{T = \frac{3}{2\pi n_s} \frac{s\,E_2^2 R_2}{R_2^2+(sX_2)^2}} \text{ N-m}$$

Sotorquedevelopedatany loadconditioncanbeobtainedifslipatthatloadisknownandall standstillrotorparameters areknown.

STARTING TORQUE

Starting torqueisnothing butthetorqueproducedby aninductionmotorasstart.Atstart,N=0 andslips=1.Soputtings=1inthetorqueequationwecanwriteexpressionforthestartingtorque T_{st}as,

$$T_{st} = \frac{3}{2\pi n_s} * \frac{E_2^2 R_2}{R_2^2 + X_2^2}\ N - m$$

ThechangeinR$_2$atstartispossibleincaseofslipring inductionmotoronly.Thisistheprinciple used in caseof slip induction motor to control thestartingtorqueT_{st}.

CONDITIONOFMAXIMUMTORQUE

Itisclearthattorquedependsonslipatwhichmotorisrunning.Thesupplyvoltagetothe motorisusually ratedandconstantandthereexistsafixedratio betweenE_1andE_2.HenceE_2isalso constant.SimilarlyR_2,X_2andn_s areconstantsfortheinductionmotor.Hencewhilefindingthe condition formaximum torque, rememberthat theonlyparameter which controls thetorqueis slip s.

$$\frac{dT}{ds} = 0$$

where $$T = \frac{k s E_2^2 R_2}{R_2^2 + (sX_2)^2}$$

While carrying out differentiation remember that E_2, R_2, X_2 and k are constants. The only variable is slip s. As load on motor changes, its speed changes and hence slip changes. This slip decides the torque produced corresponding to the load demand.

$$T = \frac{k s E_2^2 R_2}{R_2^2 + s^2 X_2^2} \qquad \text{... writing } (s X_2)^2 = s^2 X_2^2$$

As both numerator and denominator contains s terms, differentiate T with respect to s using the rule of differentiation for u/v.

$$\therefore \frac{dT}{ds} = \frac{(k s E_2^2 R_2) \frac{d}{ds}(R_2^2 + s^2 X_2^2) - (R_2^2 + s^2 X_2^2) \frac{d}{ds}(k s E_2^2 R_2)}{(R_2^2 + s^2 X_2^2)^2} = 0$$

$$\therefore \quad k s E_2^2 R_2 [2s X_2^2] - (R_2^2 + s^2 X_2^2)(k E_2^2 R_2) = 0$$

$$\therefore 2 s^2 k X_2^2 E_2^2 R_2 - R_2^2 k E_2^2 R_2 - k s^2 X_2^2 E_2^2 R_2 = 0$$

$$\therefore \quad k s^2 X_2^2 E_2^2 R_2 - R_2^2 k X_2^2 R_2 = 0$$

$$s^2 X_2^2 - R_2^2 = 0 \qquad \text{Taking } k E_2^2 R_2 \text{ common.}$$

$$s^2 = \frac{R_2^2}{X_2^2}$$

$$s = \frac{R_2}{X_2} \qquad \text{Neglecting negative slip}$$

This is the slip at which the torque is maximum and is denoted as s_m.

$$s_m = \frac{R_2}{X_2}$$

Itistheratioofstandstillpervaluesofresistanceandreactanceofrotor,whenthetorque produced bythe induction motor is at its maximum.

MAXIMUMTORQUE:

This can beobtained bysubstitutings$_m$ =R_2/X_2 in thetorque equation.It is denoted byT_m.

$$T_m = \frac{k s_m E_2^2 R_2}{R_2^2 + (s_m X_2)^2}$$

$$T_m = \frac{k\left(\frac{R_2}{X_2}\right) E_2^2 R_2}{R_2^2 + \left(\frac{R_2}{X_2} X_2\right)^2}$$

$$T_m = \frac{k E_2^2}{2X_2} \text{ N-m}$$

From the expressionof T_m, itcan beobservedthat

- It is inverselyproportional to the rotor reactance.
- It is directlyproportionalto thesquareof therotorinduced e.m.f. at standstill.

Themost interesting observation is, themaximum torqueis not dependent on therotor resistanceR_2.Buttheslipatwhichitoccursi.e.speedatwhichitoccursdependsonthevalue of rotor resistanceR_2.

3. *Problem 1:*A3phase,400V,50Hz,4poleinductionmotorhasstar connectedstatorwinding.The rotorresistanceandreactanceare 0.1Ωand1Ωrespectively.Thefullloadspeedis1440r.p.m. Calculate thetorquedeveloped on fullload bythemotor. Assume stator to rotorratio as 2:1.

Solution:

Thegiven values are,

P=4, f =50 Hz, R_2=0.1 Ω, X_2=1 Ω, N =1440 r.p.m. Statorturns/Rotor turns =2/1

K =E_2/E_1=Rotor turns/Statorturns =1/2 = 0.5

N_s=120f/P=120x50 / 4 = 1500r.p.m.

E_{1line} =400 V

E_{1ph} =E_{1line} /√3 =400/√3 =230.94V

But, E_{2ph}/E_{1ph}=0.5 =K

E_{2ph} =0.5 x230.94 =115.47 V

Fullload slip, s =(N_s-N)/N_s=(1500-1400)/1500 =0.04

n_s=Synchronous speed in r.p.s.

=N_s/60 = 1500/60 =25 r.p.s.

$$T = \frac{3}{2\pi n_s}\frac{sE_2^2R_2}{R_2^2 + (sX_2)^2}$$

$$T = \frac{3}{2\pi * 25} * \frac{0.04 * (115.47)^2 * 0.1}{(0.1)^2 + (0.04 * 1)^2}$$

T =87.81 N-m

4. *Problem 2:*A 400V, 4pole, 3 phases, and 50 Hzstarconnectedinduction motor hasarotorresistance and reactanceperphaseequalto0.01Ωand0.1Ωrespectively.Determinei)Starting torqueii)slipat whichmaximumtorquewilloccuriii)speedatwhichmaximumtorquewilloccur.Assumeratio of stator to rotor turns as 4.

Solution:

Thegiven values are,

P=4, f =50 Hz, stator turns/ rotor turns =4, R_2=0.01 Ω, X_2=0.1 Ω

E_{1line}=stator line voltage=400 V

E_{1ph}=E_{1line}/√3 =400/√3 =230.94 V ....starconnection

K =E_{2ph}/E_{1ph}=Rotor turns/Statorturns =1/4

E_2=(1/4)xE_{1ph}=230.94/4 = 57.735 V

N_s =120f/P=120x50 / 4 = 1500 r.p.m.

i) At start, s =1

T_{st}=(k $E_2^2$$R_2$)/ ($R_2^2$+$(X_2)^2$) wherek =3/ (2 π$n_s$)

n_s=N_s/60 = 1500/60 =25 r.p.s.

k =3/ (2πx25) =0.01909

T_{st}=(0.01909 x57.735^2 x0.01)/ (0.01^2+0.1^2) =**63.031 N-m**

ii) Slip at which maximum torqueoccurs is,

$S_m = R_2/X_2 = 0.01/0.1 = 0.1$

$\% S_m = 0.1 \times 100 =$ **10%**

iii) Speed at which maximum torqueoccurs is speed correspondingto,

$N = N_s(1 - s_m) = 1500\ (1 - 0.1) =$ **1350 r.p.m.**

5. Draw torque slip characteristics curve and explain

TORQUE-SLIPCHARACTERISTICS

Astheinductionmotor islocatedfromnoloadtofullload,itsspeeddecreaseshence slip increases.Duetotheincreasedload,motorhastoproducemoretorquetosatisfy loaddemand.The torqueultimately dependsonslip.Thebehaviourofmotorcanbeeasilyjudgedby sketchingacurveobtained by plottingtorqueproducedagainstslipofinductionmotor.

"Thecurve obtainedby plottingtorqueagainstslipfroms=1(atstart)tos=0(atsynchronousspeed)iscalled torque-slipcharacteristicsoftheinductionmotor." Wehaveseenthatforaconstantsupplyvoltage, E_2 isalsoconstant.Sowecanwritetorque equations as,

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

Tojudgethenatureoftorque-slipcharacteristicsletusdividetheslip range(s=0tos=1) into two regions and analysethem independently.

Lowslipregion:

Inlowslipregion, 's'isveryverysmall.Duetothis,theterm$(sX2)^2$issosmallascomparedto R_2^2 that itcan beneglected.

$$T \propto \frac{s R_2}{R_2^2} \propto s \qquad \text{... As } R_2 \text{ is constant.}$$

Henceinlowslipregiontorqueisdirectlyproportionaltoslip.Soasloadincreases,speed decreases, increasingtheslip. This increases the torquewhich satisfies the load demand. Hencethegraph is straight line in nature. At$N=N_s$,s=0henceT=0.Asnotorqueisgeneratedat$N=N_s$,motorstopsifittriesto achievethesynchronousspeed. Torqueincreases linearlyin this region, of low slip values.

Highslipregion:

Inthisregion,slipishighi.e.slipvalueisapproachingto1.Hereitcanbeassumedthattheterm R_2^2 is veryverysmallas compared to $(sX2)^2$. Henceneglecting from thedenominator, weget

$$T \propto \frac{s R_2}{(sX_2)^2} \propto \frac{1}{s} \qquad \text{where } R_2 \text{ and } X_2 \text{ are constants.}$$

So in high slip region torqueis inverselyproportional to theslip. Henceits natureis like rectangular hyperbola. Now whenload increases,loaddemand increasesbutspeeddecreases.Asspeeddecreases,slip increases.In high slip region as $T \alpha 1/s$, torquedecreases as slip increases.

Buttorquemustincreasestosatisfy theloaddemand.Astorquedecreases,duetoextraloading effect, speedfurther decreasesand slip furtherincreases. Again torquedecreasesas$T \alpha 1/s$ hencesame load actsasanextra loaddue toreductionintorque produced.Hence speedfurther drops. Eventually motorcomestostandstillcondition.Themotorcannotcontinuetorotateatany pointinthishighslip region. Hencethis regionis called unstable regionof operation.

So torque-slip characteristics has two parts,

- Straight line called stable region of operation
- Rectangularhyperbolacalled unstableregion ofoperation.

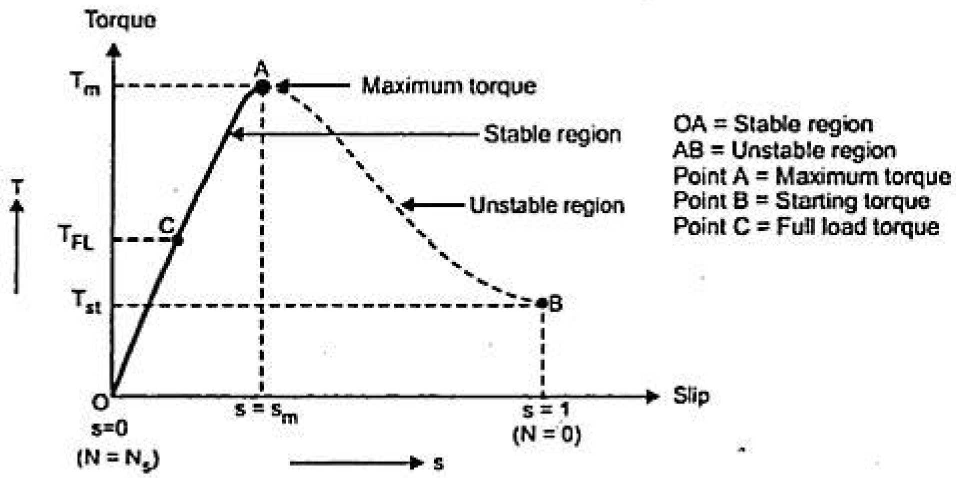
Stable operation:

Inlowslipregion,asloadincreases,slipincreasesandtorquealsoincreaseslinearly.Every motor hasitsownlimittoproduceatorque.Themaximumtorque,themotorcanproducesasloadincreases is T_m which occurs at s $=s_m$. So linear behaviorcontinues tills $=s_m$. So ranges=0tos=s_m is called**lowslipregion**,knownasstableregionofoperation.Motoralways operatesatapointinthisregion.

Unstable operation:

Ifloadisincreasedbeyondthislimit,motorslipactsdominantlypushingmotorintohighslip region.Due tounstable conditions,motor comestostandstill conditionatsucha load. Hencei.e. maximumtorquewhichmotorcanproduceisalsocalled***breakdowntorqueorpullouttorque***.Andranges=s m tos=1iscalledhighslipregionwhichis rectangularhyperbola,calledunstable**regionofoperation**.Motorcannotcontinuetorotateatany pointin this region. At s =1, N =0 i.e. start, motor producesatorque called **startingtorque**denoted as T_{st}.

<u>TORQUE -SLIP CHARACTERISTICS CURVE:</u>



Torque-slip characteristics

Whentheloadonthemotorincreases,thetorque producedincreasesasspeed decreasesand slip increases. Theincreases torquedemand is satisfied bydrawingmotor current from thesupply. Theloadwhichmotorcandrivesafely whileoperatingcontinuouslyandduetosuchload,the current drawnisalsowithinsafe limitsiscalled fullloadconditionofmotor. Whencurrentincreases, duetoheatproducedthetemperaturerise.Thesafe limitofcurrentisthatwhichwhendrawnfor continuousoperationofmotor,producesatemperaturerisewellwithinthelimits.Suchafullload pointis shown on thetorque-slip characteristics torque as $T_{F.L}$.

TheinterestingthingisthattheloadonthemotorcanbeincreasedbeyondpointC tillmaximum torquecondition.Butduetohighcurrentandhencehightemperaturerisethereispossibilityof damageofwindinginsulation,ifmotorisoperatedforlongertimedurationinthisregioni.e.from pointC toB.Butmotorcanbeusedtodriveloadsmorethanfull load,producing torqueupto maximumtorqueforshortdurationoftime.Generallyfullloadtorqueislessthanthemaximum torque.

SoregionOC uptofullloadconditionallowsmotoroperationcontinuously andsafely fromthe temperaturepointofview.WhileregionCB ispossibletoachieveinpracticebutonlyforshort durationoftimeandnotfor continuousoperationofmotor.Thisisthedifferencebetweenfullload torque and the maximum or breakdown torque. Thebreakdown torqueis also called **stallingtorque**.

6. Explain in detail about the losses and efficiency of an three phase induction motor

<u>LOSSES ININDUCTION MOTOR:</u>

Thevarious power lossesin an induction motor can be classified as,

- ***Constant losses***
- ***Variable losses***

<u>Constant losses:</u>

Constant losses in three phase induction motor can befurtherclassified as

- Corelosses

- Mechanical losses.

Core losses:

Core lossesoccurinstatorcore androtor core.Thesearealsocalled**ironlosses** as the stator and rotor core are made up of iron material (Silicon steel).Theselosses sub divided into

- Eddycurrentlosses
- Hysteresislosses

Theeddycurrentlossesareminimizedby using laminatedconstructionwhilehysteresislossesareminimizedbyselectinghighgradesiliconsteelas the material for stator and rotor. Theironlossesdependonthefrequency.Thestatorfrequency isalwayssupply frequency hence stator iron losses aredominate. As againstthis in rotor circuit, thefrequencyis verysmall whichis slip timesthesupplyfrequency.Hencerotorironlossesareverysmallandhencegenerallyneglected,in the running condition.

Mechanical losses:

The mechanicallossesinclude frictionallossesatthe bearingsandwindingslosses.Thefriction changeswithspeedbutpracticallythedropinspeedisverysmallhencetheselossesare assumedtobe the part of constant losses.

Variable losses:

Variable lossesincludethecopperlossesinstatorandrotorwindingduetocurrentflowinginthewinding. As current changesas load changes as load changes, theselosses aresaid to bevariable losses. Generally statorironlossesarecombinedwithstatorcopperlossesataparticularloadtospecify total stator losses at particularload condition.

Rotor copper loss =$\boldsymbol{Pcu = 3\, I_{2r}^2 R_2}$-------------------------------------analysed separately

Where, I_{2r}=Rotor current per phase at a particularload

R_2 =Rotor resistanceper phase

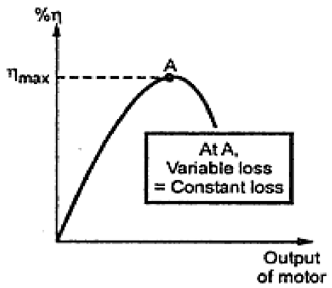
EFFICIENCY OFANINDUCTION MOTOR:

"Theratioofoutputpoweravailableattheshaft(P_{out})andthenetelectricalpowerinput(P_{in})tothe motor is called as overallefficiencyof an induction motor."

$$Efficiency = \frac{Output\ Power\ (Pout)}{Input\ Power\ (Pin)}$$

$$\%\ Efficiency = \frac{Output\ Power\ (Pout)}{Input\ Power\ (Pin)} * 100$$

MAXIMUM EFFICIENCY:



Themaximum efficiencyoccurswhen variablelosses become equal to constant losses. When motor is on no load, current drawn bythe motor is small. Henceefficiencyis low. As load increases, current increases so copper losses also increases.When such variable losses achievethe same valueas that of constant losses, efficiencyattains its maximum value.If load is increasedfurther, variable losses becomesgreaterthan constant losses hencedeviatingfrom condition formaximum, efficiency starts decreasing.

7. What is meant by starter? Why starter is necessary for an induction motor to start and give its

types

STARTER:

Starter is a device which is used to start the three phase induction motor

NECESSITY OF STARTER:

Ina three phase inductionmotor, the magnitudeof aninducede.m.f. inthe rotorcircuit dependsontheslipoftheinductionmotor.Thisinducede.m.f.effectively decidesthemagnitude of therotor current. Therotor current in therunningcondition is given by,

$$I_{2r} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Butatstart,thespeedofthemotoriszeroandslipisatitsmaximumi.e.unity.So magnitudeofrotorinducede.m.f.isverylargeatstart.Asrotorconductorsareshortcircuited, the largeinduced e.m.f.circulates veryhighcurrent through rotorat start.

Theconditionisexactly similartoatransformerwithshortcircuitedsecondary.Sucha transformerwhenexcited by aratedvoltagecirculatesvery highcurrent throughshortcircuited secondary.Assecondarycurrentislarge,theprimary alsodrawsveryhighcurrentfromthe supply.

Similarly inathreephaseinductionmotor,whenrotorcurrentishigh,consequentlythe stator draws averyhighcurrent from the supply. Similarly inathreephaseinductionmotor,whenrotorcurrentishigh,consequentlythe statordrawsavery highcurrentfromthesupply.Thiscurrentcanbeoftheorderof5to8times the fullload current, at start.

Duetosuch heavyinrush currentat start there is possibilityof damageof themotorwinding. Similarly suchsuddeninrushofcurrentcauseslargelinevoltagedrop.Thusotherappliances connectedtothesamelinemaybesubjectedtovoltagespikeswhichmayaffecttheirworking. Toavoidsucheffects,itisnecessarytolimitthecurrentdrawnbythemotoratstart.

“***Thestarter isadevicewhichisbasicallyusedtolimithighstartingcurrent by supplyingreducedvoltageto themotoratthe timeofstarting”.***

Suchareducedvoltageisappliedonlyforshortperiodandonce rotorgets accelerated, full normal rated voltageisapplied.

In three phases induction motors the starters operations are

- *To limitsthestartingcurrent*
- *To protectagainstoverloading loading*
- *To protect against lowvoltagesituations*
- *To protect against singlephasing*

Theinductionmotorhaving rating below5h.p.can withstandstartingcurrentshencesuchmotorscanbestarteddirectlyonline.Butsuchmotors also need overload, singlephasing and low voltageprotection which is provided byastarter. Thus allthe threephaseinduction motors need someor theothertypeof starter.

TYPES OFSTARTERS:

Thevarious types of starters for three phase induction motor is given by

- Statorresistancestarter
- Autotransformer starter
- Star-deltastarter
- Rotor resistancestarter
- Direct on line starter

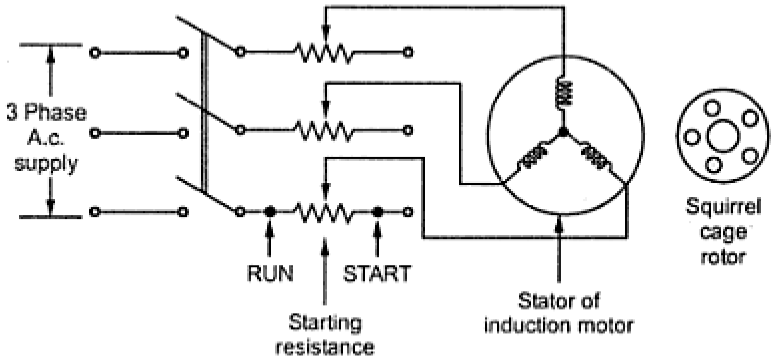
8. Explain the starting method of cage induction motors (APRIL/2014)

(or)

Explain any two starting methods of three phase induction motor. (NOV/2013)

1. **STATORRESISTANCESTARTER:**

Inordertoapplythereducedvoltagetothestatoroftheinductionmotor,threeresistances areaddedinserieswitheachphaseofthestatorwinding.Initially theresistancesarekept in maximuminthe circuit.Duetoitslarge voltagegetsdroppedacrosstheresistances.Hence a reducedvoltagegetsappliedtothe stator whichreducesthe highstartingcurrent.Theschematic diagram showingstator resistances isshown below figure.



StatorResistancestarter

Whenthemotorstartsrunning,theresistancesaregradually cut-offfromthestatorcircuit. Whentheresistancesareentirely removedfromthestatorcircuiti.e.rheostatsinRUNposition then rated voltagegets applied to thestator. Motor runs with normal speed.

Advantage:

- Simpleinconstruction
- Cheap
- Can be used for both star and delta connected stator

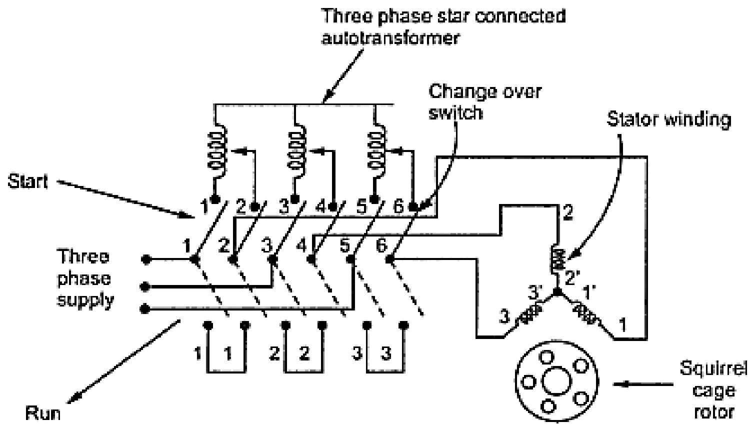
Disadvantage:

- Largepowerlossesduetoresistances.
- Thestartingtorqueof the motor reduces duetoreduced voltage applied tothe stator.

9. Explain the operation of star delta starter and auto transformer starter used for three phase induction motor. (NOV/2012)

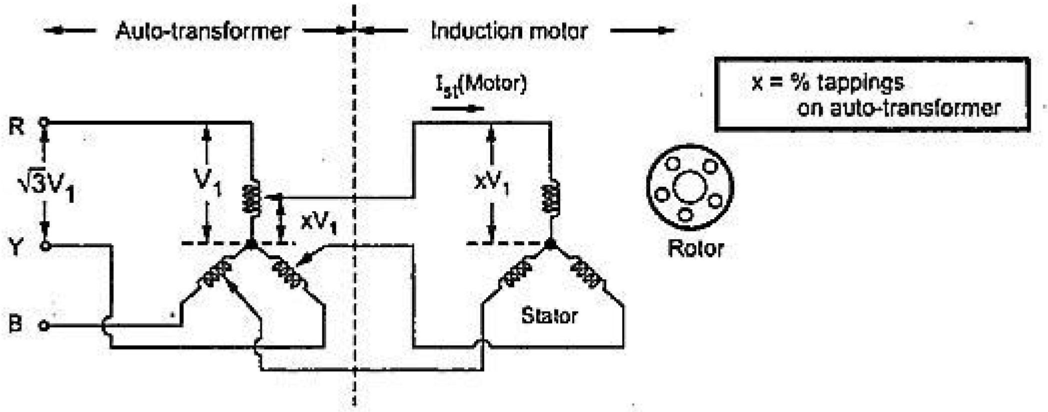
2. **AUTOTRANSFORMERSTARTER:**

Athree phase starconnectedautotransformercanbe usedtoreduce thevoltage appliedtothe stator. Sucha starteriscalledanautotransformer starter.The schematic diagram of autotransformer starter is showninthe below figure.



Autotransformerstarter

It consists of asuitable changeover switch. Whenthe switchisinthe startposition,the stator windingissuppliedwithreducedvoltage. This can be controlled bytappings providedwith autotransformer.Thereduction in applied voltagebythe fractional percentagetapping’s x, used foran autotransformer is shownin the below figure.



Useofautotransformer to reducevoltageat start

When motor gathers 80%of thenormal speed, the changeover switch is thrown into run position. Duetothis, ratedvoltagegetsappliedtostatorwinding.Themotorstartsrotating with normalspeed.Changingofswitchisdoneautomaticallyby usingrelays.

Advantages:

- Thepowerlossismuch lessinthistypeofstarting.
- Canbeusedforbothstaranddeltaconnectedmotors.

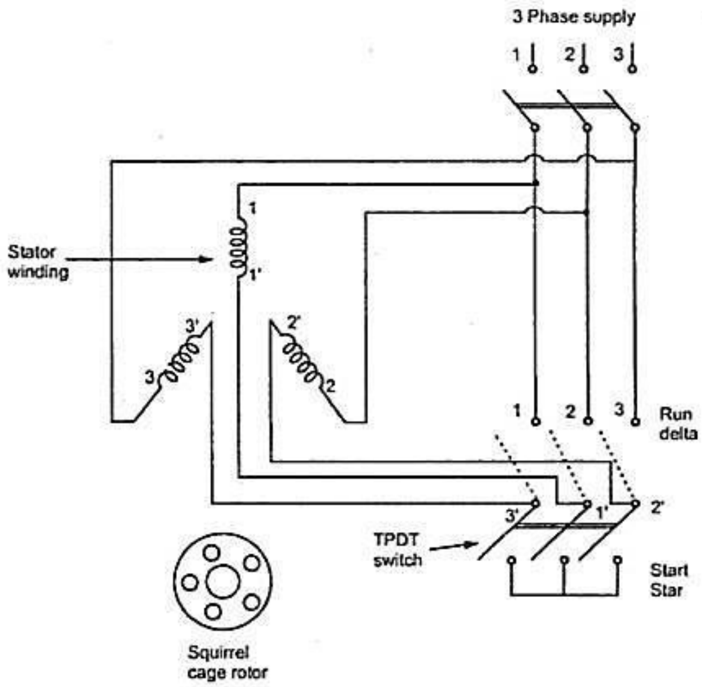
Disadvantage:

- Itis expensive than stator resistancestarter.

3. **STAR-DELTA STARTER:**

It is commonly used starter in three phase induction motor. Ituses triplepoledoublethrow(TPDT)switch.The switchconnectsthestatorwinding instaratstart. Henceper phasevoltagegetsreducedbythefactor $1/\sqrt{3}$. Dueto thisreduced voltage,the starting current is limited.

Whentheswitchis thrownonotherside, thewinding getsconnectedindelta,acrossthe supply. Soitgetsnormalrated voltage.The windingsare connected indelta whenmotor gathers sufficient speed. The arrangement ofstar-deltastarter is shown in the below figure.



Star-delta starter

Theoperationoftheswitchcanbeautomaticby usingrelayswhichensuresthatmotorwill notstartwiththeswitch inRunposition.

Advantages:

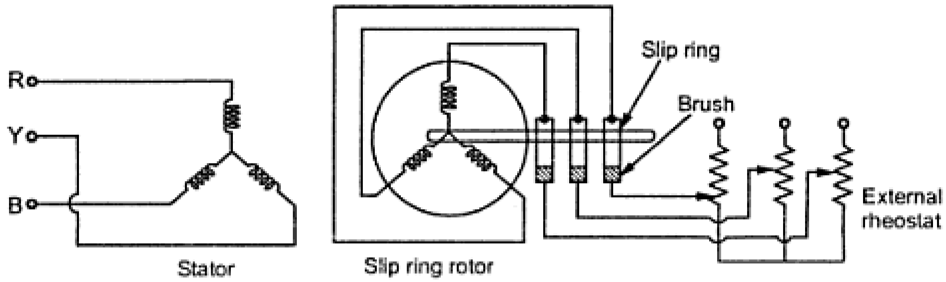
- Thecheapest starter
- Maintenancefreeoperation

Disadvantages:

- Itissuitablefor normal deltaconnectedmotorsandthefactorby whichvoltagechangesis1/√3whichcannotbe changed.

4. **ROTORRESISTANCESTARTER:**

Tolimittherotorcurrentwhichconsequently reducesthecurrentdrawnbythemotorfromthe supply,theresistance canbeinsertedintherotorcircuitatstart.Thisadditionoftheresistancein rotorin theform of three phasestar connected rheostat.



Rotorresistancestarter

Theexternalresistanceisinsertedineachphaseoftherotorwinding throughslipringand brushassembly. Initiallymaximumresistanceisinthecircuit.Asmotor gatherspeed,the resistanceisgraduallycut-off. Theoperation maybemanual or automatic. Wehaveseenthatthestarting torqueisproportionaltotherotorresistance.

Advantages:

- Improved startingtorque for the motor

Disadvantages:

- Can beusedonlyforslipringinduction motors

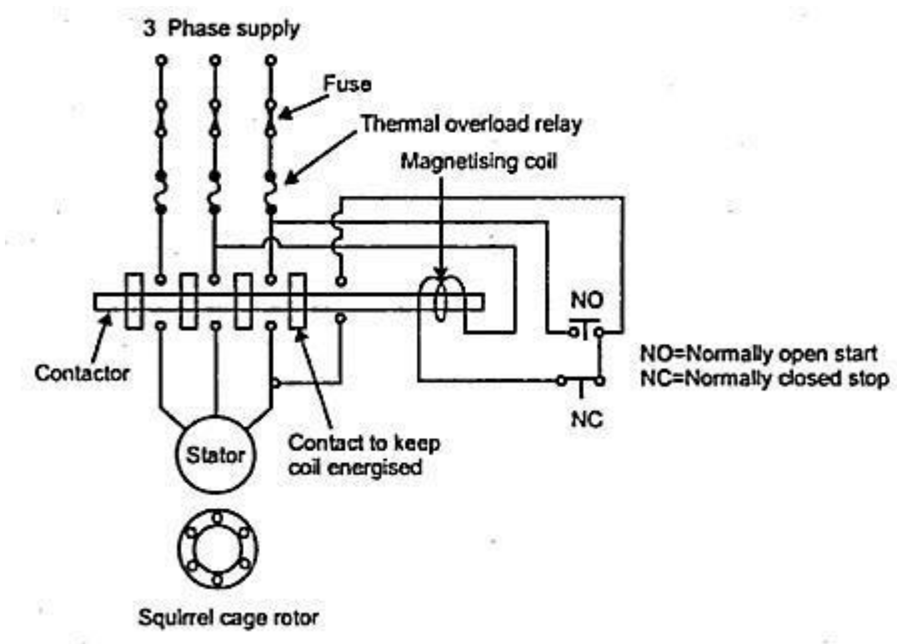
5. **DIRECT ON LOADLINESTARTER(D.O.L.):**

Incaseofsmallcapacitymotorshavingratinglessthan5h.p.,thestartingcurrentisnotvery highandsuchmotorscanwithstandsuchstartingcurrentwithoutany starter.Thusthereisno needtoreduceappliedvoltage,tocontrolthestarting current.Suchmotorsusea typeofstarter whichisusedtoconnectstatordirectlytothesupplylineswithoutanyreductioninvoltage. Hencethestarteris known as direct on line starter.

Though this starterdoes not reducetheapplied voltage, itisused becauseitprotectsthe motor from various severe abnormal conditions like over loading,low voltage, single phasing.

The**NO**contactisnormally openandNCisnormallyclosed.Atstart,NOispushedfor fractionof seconddue towhichcoilgetsenergizedandattractsthe contactor. Sostator directly getssupply.Theadditionalcontactprovided,ensuresthataslongassupply isON,thecoilgets supply andkeepscontactorinONposition.WhenNCispressed,thecoilcircuitgetsopeneddue to which coilgets de-energized and motorgets switched OFFfrom thesupply.

Under over load condition, current drawn bythe motor increases due to which is an excessiveheatproduced,whichincreasestemperaturebeyondlimit.Thermalrelaysgetopened dueto high temperature,protectingthemotor from overload conditions.



Direct Online starter

10. Discuss the various schemes used for speed control of 3 phase induction motor. (APRIL/2012)

SPEEDCONTROL OFTHREE PHASE INDUCTIONMOTOR

Athreephaseinductionmotorispractically aconstantspeedmotorlikeaD.Cshuntmotor. ButthespeedofD.Cshuntmotorcanbevariedsmoothly justby usingsimplerheostats.This maintainsthespeedregulationandefficiency ofD.Cshunt motor.Butincaseofthreephase inductionmotorsitisvery difficulttoachievesmoothspeedcontrol.Andifthespeedcontrolis achievedby somemeans,theperformanceoftheinductionmotorintermsofitspowerfactor, efficiencyetc.gets adverselyaffected.

For theinduction motor weknow that,

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

Fromthisexpression itcanbeseenthat thespeed ofinductionmotorcanbechangedeither bychangingits synchronous speed or bychanging the slip s. Similarlytorqueproducedin caseof threephaseinduction motor is given by,

$$T \alpha \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

SoastheparameterslikeR$_2$,E$_2$arechangedthentokeepthetorqueconstantforconstant load condition, motor reacts bychangein its slip. Effectivelyits speedchanges.

METHODS OF SPEED CONTROL:

The speed of theinduction motor can be controlled bybasicallytwomethods:

- *From statorside*
- *From rotor side*

From statorside:

- Supplyfrequencycontrol to control N_S, calledV / f control.
- Supplyvoltage control.
- Controllingnumberofstator poles to control N_S.
- Addingrheostats in stator circuit.

From rotorside:

- Adding external resistancein therotorcircuit.
- Cascadecontrol.
- Injectingslip frequencyvoltageinto the rotor circuit.

STATORSIDE CONTROL:

1. ***Supply Frequency Control or V/ fControl***

Thesynchronous speed is given by,

$$N_S=120f/P$$

Thus bycontrolling thesupplyfrequencysmoothly, thesynchronous speedcanbecontrolled over awiderange. This gives smooth speed control of an induction motor.

But the expression for the airgapfluxis given by,

$$\Phi_g = \frac{1}{4.44K_1T_{ph1}}\left\{\frac{V}{f}\right\}$$

This is accordingto thee.m.f. equation ofatransformerwhere,

K_1=Statorwinding constant

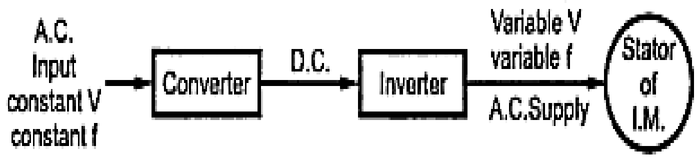
T_{ph1}=Statorturns per phase

V =Supplyvoltage

f =Supplyfrequency

Fromthisexpressionthatifthesupply frequency fischanged,thevalueofair gapfluxesalsogetsaffected.Thismay resultintosaturationofstatorandrotorcores.Suchsaturationleadstothesharpincreaseinthe(magnetization)noloadcurrentofthemotor.Hence itis necessaryto maintain air gap fluxconstant when supplyfrequencyf ischanged.

To achievethis,itcanbeseenfromtheabove expressionthatalongwithf,Valsomust be changedsoastokeep(V/f)ratioconstant.Thisensuresconstantairgapfluxgivingspeed control without affecting the performanceof themotor. Hencethis method is called ***V / f control.***

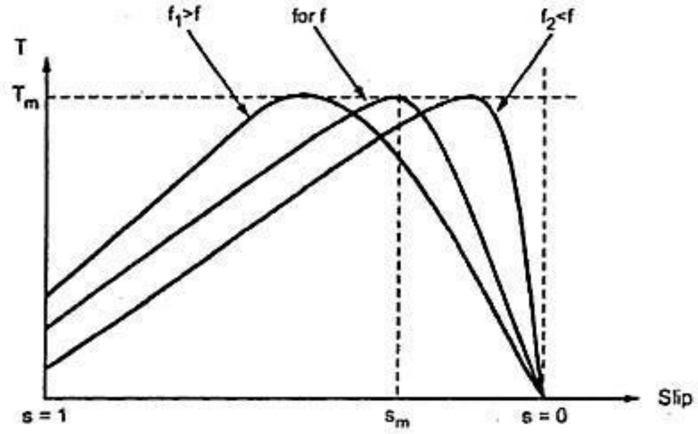


Electronic schemeforV/fcontrol

Hencein this method, the supplytothe induction motor required is variablevoltagevariable frequency supply andcanbeachieved byanelectronicschemeusingconverterandinverter circuitry.

Thenormalsupply availableisconstantvoltageconstantfrequency A.Csupply.The converterconvertsthissupplyintoaD.Csupply.ThisD.Csupplyisthengiventotheinverter. TheinverterisadevicewhichconvertsD.Csupply,tovariablevoltagevariablefrequency A.C supply whichisrequiredtokeepV/fratioconstant.Byselectingtheproperfrequencyand maintainingV / f constant, smooth speed control of theinduction motor is possible.

Iffisthenormalworkingfrequency thenthe below figureshowsthetorque-slipcharacteristicsfor the frequencyf_1>f andf_2<f i.e. forfrequenciesabove and below the normal frequency.



Torque-slipcharacteristics with variablefandconstant (V/f)

Disadvantages:

- Thesupply obtainedcannotbeusedtosupply other deviceswhich require constantvoltage.Hence anindividualschemefor a separatemotor is required
- This method is costly

2. Supply (or) StatorVoltageControl

We know that,

$$T\alpha \ \frac{s\ E_2^2 R_2}{R_2 + \ (s\ X_2)}$$

Now E_2, the rotor induced e.m.f. at standstill depends on the supply voltage V.

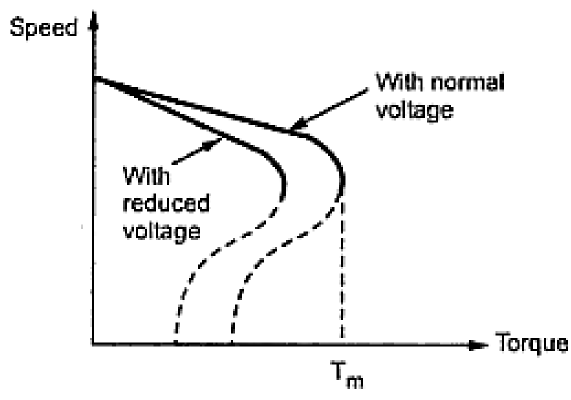
$$\mathbf{E_2 \ \ \alpha\ V}$$

Alsoforlowslipregion,whichisoperatingregionoftheinductionmotor,$(sX_2)^2$<<$R_2$and hencecan beneglected.

$$T\ \alpha\ S\ V^2\ R_2/R_2^2 + S\ V^2 \quad \text{for constant } R_2^2$$

Nowifsupply voltageisreducedbelowratedvalue,asperaboveequationtorqueproduced alsodecreases.Buttosupplythesameloaditisnecessarytodevelopsametorquehencevalue of slipincreasessothattorque producedremainssame. Slipincreasesmeansmotor reactsby runningatlowerspeed,todecreaseinsupplyvoltage.Somotorproducestherequiredload torqueatalowerspeed.Thespeed-torquecharacteristicsforthemotorusingsupply voltage control areshown in the below figure.

Butinthismethod,duetoreductioninvoltage,currentdrawnby themotorincreases.Large change involtage for smallchange inspeedisrequiredisthebiggestdisadvantage.



Speed-torquecurves formotorwith voltage control

Disadvantage:

Due to increasedcurrent,themotormay getoverheated.Additionalvoltagechanging equipmentis necessary.Hencethismethodisrarely usedinpractice.

Dueto reduced voltage, E_2decreases, decreasingthe value ofmaximum torquetoo.

Application:

Motorsdrivingfantypeofloadsusethis method ofspeedcontrol.

3. Controlling NumberofPoles

In this methodpoles are changed to control thespeed of three phase induction motors.Inthismethod, itis possibletohaveone,twoorfourspeedsinsteps,by thechangingthenumberofstatorpoles.A continuous smooth speed control is not possible bythis method.

Thestator poles canbe changed byfollowing methods:

(i).Consequent poles method

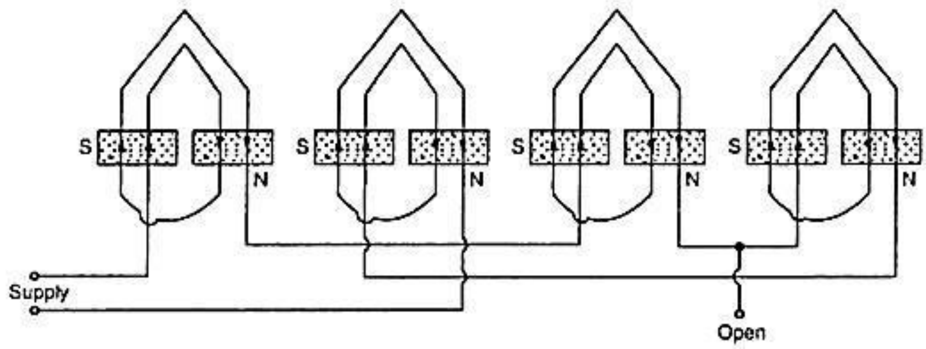
(ii).Multiplestator windingmethod

(iii).Pole amplitudemodulation method.

(i). Consequent PolesMethod

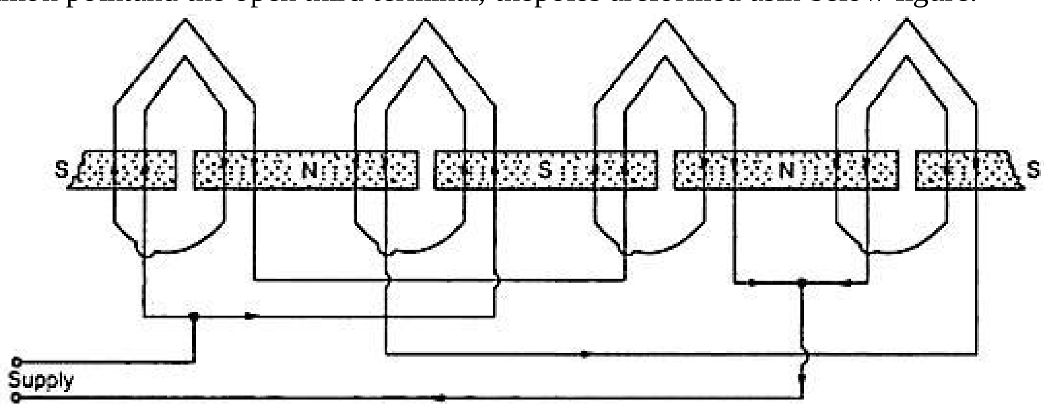
Inthismethod,connectionsofthestator windingarechangeswiththehelpofsimple switching.Due tothis,the number of stator polesgetschangedintheratio2:1.Henceeither of the two synchronous speeds can beselected. Consider the pole formationdue tosingle phase of a three phase winding,asshowninthe below figure.Therearethreetappingpointstothestatorwinding.Thesupplyisgiventotwoofthem and third is kept open.

Itcanbeseenthatcurrentinallthepartsofstatorcoilisflowinginonedirectiononly.Due tothis,8poles getformed asshown inthe below figure. Sosynchronousspeedpossible withthis arrangement with 50 Hzfrequencyis N_s=750 r.p.m.



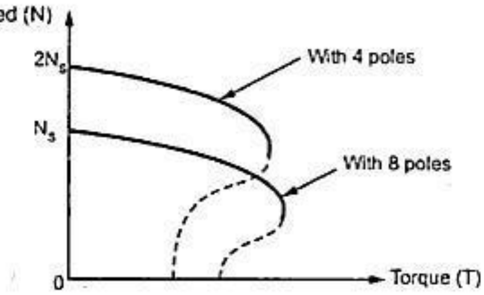
Pole winding

Ifthetwoterminals towhichsupplywasgiveneither are joinedtogetherandsupplyisgiven between this common pointand the open third terminal, thepoles areformed asin below figure.



Pole Winding

Itcanbe seenthatthe directionofcurrentthroughremainingtwo.Thusupwarddirectionis formingsay SpoleanddownwardsayN.itcanbeobservedthatinthiscaseonly 4polesare formed. So thesynchronous speed possible is 1500 r.p.m. for 50Hzfrequency.

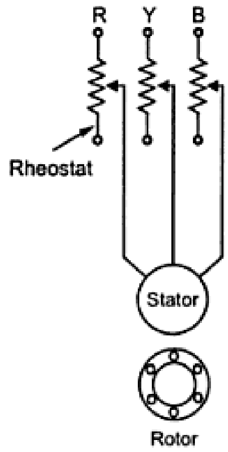


Thusseries/parallelarrangementsofcoils canproduce the polesinthe ratio2:1.Butthe speedchangeisinstepandsmoothspeedcontrolisnotpossible.Similarly themethodcanbe usedonlyforthesquirrelcagetypemotorsassquirrelrotoradjustsitselftosamenumberof poles as stator which is not the casein slip ringinduction motor.

(ii). Multiple StatorWinding Method

Inthismethodinsteadofonewinding,twoseparatestatorwindingare placedinthestator core. The windingsareplacedinthestatorslotsonlybutareelectrically isolatedfromeachother. Eachwindingisdividedintocoilstowhich,polechangingwithconsequentpoles,facility is provided. Thusgiving supplytooneofthetwowindingsandusing switchingarrangement,twospeeds canbeachieved. Same istrue for otherstator winding. Soinallfour differentspeedscanbe obtained.

4. Adding Rheostats in StatorCircuit



Thereducedvoltagecanbeappliedtothestatorby addingtherheostatsin the stator circuit.The partof thevoltagegetsdropped across the resistancesand reduced voltagegets applied across the stator. The reductioninstator voltagecauses reductioninthe speed.Therheostatscanbe variedas pertherequiredchangeinspeed.Buttheentirelinecurrentflowsthroughtherheostatsand hence there are large powerlosses.The methodisnotefficientfromspeedcontrolpointofview henceusedas astarter ratherthan as aspeed control method.

ROTORSIDE CONTROL:

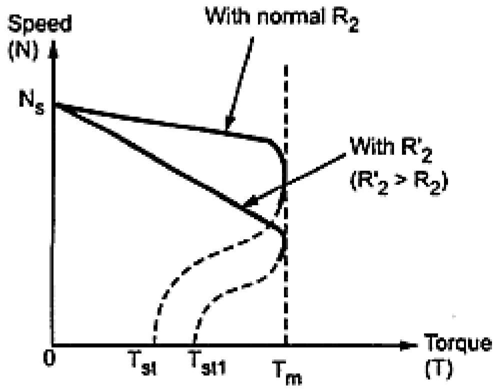
1. Adding External ResistanceinRotorCircuit

$$T\alpha \, \frac{s\, E_2^2 R_2}{R_2 + \, (s\, X_2)}$$

For low slip region (s $(sX_2)^2 \ll R_2$ and can be neglected and for constant supply voltage is also constant

$$T \infty \frac{sR_2}{R_2} \infty \frac{s}{R_2}$$

Thusiftherotorresistanceisincreased,thetorqueproduceddecreases.Butwhentheload onthemotorissame,motorhastosupply sametorqueasloaddemands.Somotorreactsby increasing itssliptocompensate decreasesinTduetoR2andmaintainstheloadtorqueconstant. Sodue tothatadditionalrotor resistance R_2,motorslipincreasesi.e. the speedof the motor decreases. Thus by increasing the rotor resistance R_2, speeds below normal value can be achieved.Anotheradvantageofthismethod isthatthestarting torqueofthemotorincreases proportional to rotorresistance. This method is rarelyused in thepractice due to the following disadvantages.



Torque-speedcurves for rotorresistance control

<u>Disadvantages:</u>

- Thelargespeedchangesarenotpossible.Thisisbecauseforlargespeedchange,large resistance isrequiredtobe introducedinrotor whichcauseslarge rotor copper lossdue to reducethe efficiency.
- Themethod cannot be used forthe squirrel cageinduction motors.
- Thespeeds abovethe normal valuescannotbeobtained.
- Largepower losses occurdueto largeloss.
- Sufficientcoolingarrangementsarerequiredwhichmaketheexternalrheostatsbulkybe expensive.
- Dueto largepower losses, efficiencyis low.

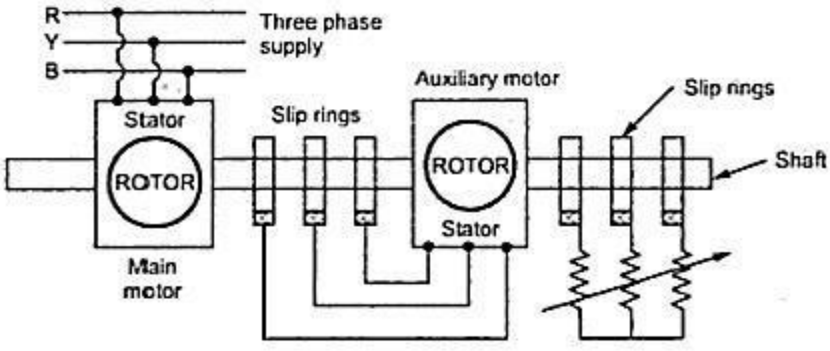
11. Explain about the concatenation connection of three phase induction motor with neat diagram

2. *<u>CascadeControl:</u>*

Cascade control isalsocalled***Concatenation***or ***Tandomoperation***of theinductionmotors.Here,twoinductionmotorsaremountedonthesameshaft.Oneofthetwomotorsmust beofslipringtypewhichiscalledmainmotor.Thesecondmotoriscalledauxiliary motor.The arrangement of this cascade method is shown below.

The auxiliarymotor can beslip ring orsquirrel cagetype. Thestatorofthemainmotorisconnectedtothethreephasesupply.Whilethesupply ofthe auxiliarymotorisderivedataslipfrequencyfromthesliprings ofthemainmotor.Thisiscalled **cascading**ofthemotors.Ifthetorqueproducedby bothactinthesamedirection,cascadingis called**cumulativecascading**.Iftorquesproducedis inoppositedirection,cascading iscalled **differential cascading**.

Let, P_A=Numberof poles ofmain motor
P_B=Number ofpoles ofauxiliarymotor
f =Supplyfrequency



Cascadecontroloftwo induction motor

$$N_{sA} = \frac{120 f}{P_A}$$

$$N = \text{Speed of the set}$$

The speed N is same for both the motors as motors are mounted on the same shaft.

$$s_A = \frac{N_{sA} - N}{N_{sA}}$$

Now $\quad f_A$ = Frequency of rotor induced e.m.f. of motor A

$\therefore \quad f_A = s_A f \ldots$ as $f_r = s f$

Now on no load, the speed of the rotor B i.e. N is almost equal to its synchronous speed N_{sB}.

$$\therefore \quad N_{sB} = N$$

$$\therefore \quad N = 120\left(\frac{N_{sA} - N}{N_{sA}}\right) \times \frac{f}{P_B}$$

$$\therefore \quad N = \frac{120 f}{P_B} \times \left[1 - \frac{N}{N_{sA}}\right]$$

$$\therefore \quad N = \frac{120 f}{P_B} \times \left[1 - \frac{N}{\left(\frac{120 f}{P_A}\right)}\right]$$

$$\therefore \quad N = \frac{120 f}{P_B}\left[1 - \frac{N P_A}{120 f}\right]$$

$$\therefore \quad N\left[1 + \frac{P_A}{P_B}\right] = \frac{120 f}{P_B}$$

$$\therefore \quad \boxed{N = \frac{120 f}{P_A + P_B}}$$

If byinterchanging anytwo terminals of motor B, thereversal of direction ofrotating magneticfield ofBis achieved then theset runsas differentiallycascadedset. And in such a caseeffectivenumberofpoles isP_A-P_B.

Thus in cascade control,fourdifferent speeds arepossible as,

- With respect to synchronous speed of Aindependently,

$$N_{sA} = \frac{120 f}{P_A}$$

- With respect to synchronous speed of B independently with main motor is disconnected and B is directly connected to supply,

$$N_{sB} = \frac{120f}{P_B}$$

- Runningsetascumulativelycascaded with,

$$N = \frac{120f}{P_A + P_B}$$

- Runningset as differentiallycascadedwith,

$$N = \frac{120f}{P_A - P_B}$$

Disadvantages:

- It requires two motorswhich makes the setexpensive.
- Smooth speed control is not possible.
- Operation is complicated.
- Thestartingtorqueisnot sufficient to start theset.
- Setcannot beoperatedif $P_A = P_B$.

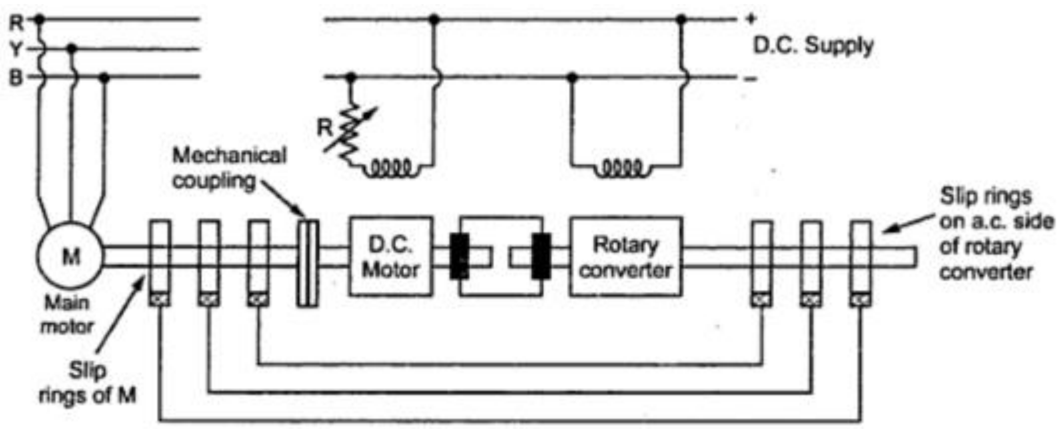
3. **Injecting Slip-Frequency E.M.F. into RotorCircuit:**

Inthis method, avoltageis injected in therotorcircuit. Thefrequencyof rotor circuitisaslip frequencyand hencethevoltageto beinjected must be at a slip frequency. Itispossiblethattheinjectedvoltagemay opposetherotorinducede.m.f.ormay assistthe rotor inducede.m.f.Ifitisinthephaseopposition,effectiverotor resistance increases.Ifitisin thephaseofrotorinducede.m.f.,effectiverotorresistancedecreases.Thusby controllingthe magnitudeof theinjectede.m.f., rotor resistance and effectivelyspeedcanbe controlled.

Practicallytwo methods areavailable which usethis principle. Thesemethods are,

- ***Kramersystem***
- ***Scherbiussystem***

KRAMER SYSTEM:



Kramer system

This system consists of main induction motor M, speed of which is to be controlled. A DC motor & rotary converter is used. The slip rings of main motor are connected to AC side of rotary converter.

The D.C side of rotary converter feeds a D.C shunt motor commutator, which is directly connected to the shaft of the main motor. Rotary converter converts the low-slip frequency A.C power into D.C power supplied from main line so that its speed derivates from a fixed value only to the extent of the slip of auxiliary induction motor. Both dc motor & rotary converter are excited from a separate DC supply. The variable resistance introduces the field circuit of a DC motor, which act as a field regulator. The speed of the set is controlled by varying the field of DC motor with rheostat R when the field rheostat is changed, the back E.M.F of motor change. Thus D.C voltage at the commutator changes, this changes D.C voltage on the D.C side of rotary converter. Now Rotary converter has a fixed ratio between its A.C & D.C side voltages. Thus Voltage on its A.C side also changes. This A.C voltage is given to the slip ring of that main motor. So the voltage injected in the rotor of main motor which produces the required speed control.

Application:

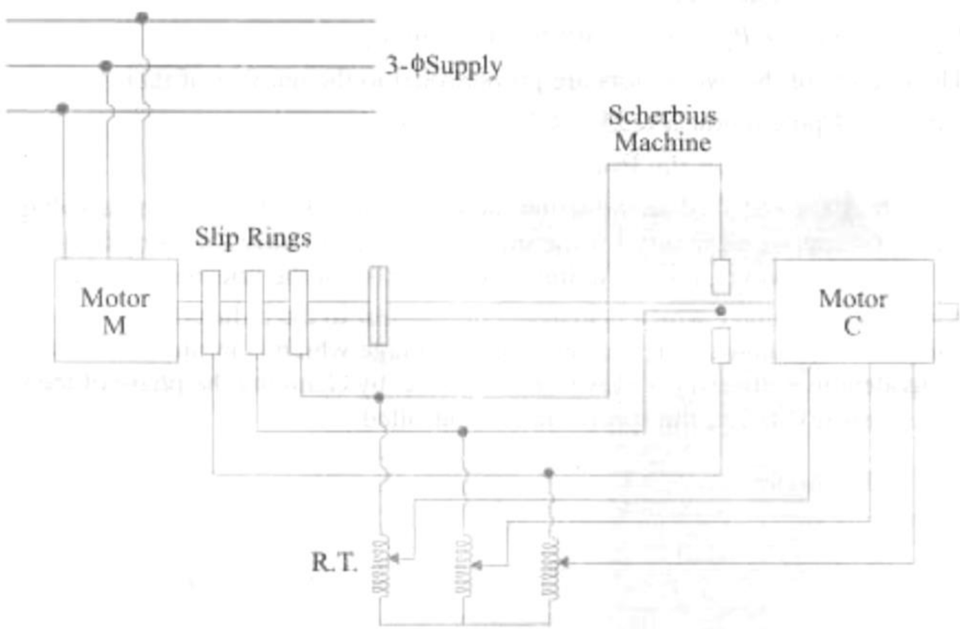
- Very large motors (above 4000kw) such a steel rolling mills use this type.

Advantages:

- Smooth speed control is possible.
- Wide range of speed control is possible.
- Design of rotary converter is independent of speed control required.
- If rotary converter is excited, it draws leading current & hence power factor can be improved.

SCHERBIUS SYSTEM:

This is another method for controlling a large size induction motors. The slip energy is not converted into DC and then fed to a DC motor; rather it is fed directly to a special three phase (or) six phase AC commutator motor called a Scherbius machine. The poly phase winding of machine C is supplied with the low-frequency output of machine M through a regulating transformer RT. The commutator motor C is a variable-speed motor and its speed is controlled by either varying the tappings on RT or by adjusting the position of brushes on C.



Scherbius system

12. Explain about the construction and working operation of an single phase induction motor

SINGLE PHASE INDUCTION MOTOR

Singlephasemotors are themostfamiliarofallelectricmotors becausethey areextensivelyusedinhomeappliances, shops,offices due to availability for single phase supply worldwide very easy.TheseACmotorsarecalledsinglephaseinductionmotors. Thepower ratingof such motors is verysmall.Someofthemareevenfractionalhorsepowermotors,whichare usedinapplications likesmalltoys,smallfans,hairdryersetc.

CONSTRUCTION OF SINGLE PHASEINDUCTION MOTORS

Singlephaseinductionmotorhasbasically twomainparts.

- **Stator***(stationary parts in motor)*
- **Rotor** *(rotating parts in motor)*

STATOR:

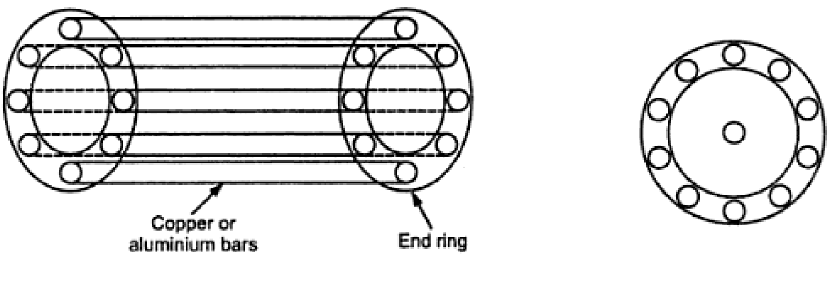
Thestatorhaslaminatedconstruction,madeupofstampings.Thestampingsareslottedon its inner peripherytocarrythewindingcalledstatorwindingormainwinding.Thisisexcitedby a single phase A.C supply. The laminatedconstructionkeepsiron losses (or) core lossto minimum. The stampingsare madeupof high graded siliconsteelwhichminimizesthe*hysteresisloss*.The statorwinding iswoundforcertaindefinitenumberofpolesmeanswhenexcited bysinglephase ACsupply,statorproducesthe magnetic fieldwhichcreates the effectof certaindefinite number ofpoles.Thenumberofpolesforwhichstatorwinding iswound,decidesthe synchronousspeed ofthemotor.ThesynchronousspeedisdenotedasNs andithasafixedrelationwithsupply frequencyf and numberof poles P. The relation is given by,

$$N_S = \frac{120\,f}{P}$$

Theinduction motorneverrotates with thesynchronous speed butrotates at aspeed whichis slightlyless than thesynchronous speed.

ROTOR:

The rotorconstructionisofsquirrelcage type as that of in three phase motor.Rotorconsistsofuninsulated copperoraluminiumbars,placedintheslots.The bars are permanently shortedatboththeends withthehelp ofconducting ringscalled***endrings***.Theentire structurelookslikecagehence called squirrelcagerotor.The constructionand symbolis shown in the below figure.

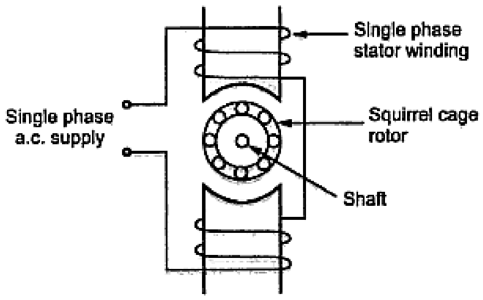


(a) Cage type structure (b) Symbolic representation

Asthebarsarepermanently shortedtoeachother,theresistanceoftheentirerotorisvery very small.Theairgapbetweenstatorandrotoriskeptuniformandassmallaspossible.The mainfeatureofthisrotoristhatitautomaticallyadjustsitselfforsamenumberofpolesasthatof the stator winding.

WORKING PRINCIPLE OFSINGLE PHASEINDUCTION MOTOR

Theschematicrepresentation of single phaseinduction motor is shown in the below figure.For themotoring action,theremustexisttwofluxeswhichinteractwitheachotherto producethetorque.Inthesinglephaseinductionmotor,singlephaseACsupply isgiventothestatorwinding. The stator winding carries an alternating current which produces the flux which is also alternating innature.Thisfluxiscalled***mainflux.***



Thisfluxlinkswiththe rotorconductorsand due totransformer actione.m.f.getsinducedintherotor.The inducede.m.f.drivescurrent throughtherotor asrotorcircuitisclosedcircuit.Thisrotor currentproducesanotherfluxcalled ***rotor flux***requiredfor the motoringaction.Thussecondfluxisproducedaccordingtoinduction principleduetoinducede.m.f.hencethemotoriscalled***inductionmotor***.

AsagainstthisinDC motoraseparatesupply isrequiredtoarmaturetoproducearmatureflux.Thisisanimportant differencebetween DCmotor and an induction motor. Anotherimportantdifferencebetweenthetwoisthatthe DC motorsareself-starting while ***single phaseinduction motors arenotself-starting***.

13. Explain the operation of single phase induction motor on the basic of double field revolving theory with neat sketch. (11) (NOV/2014)

DOUBLE REVOLVINGFIELD THEORY

Accordingto double revolving field theory,any alternatingquantity canberesolvedintotworotating componentswhichrotateinoppositedirectionsandeachhaving magnitudeashalfofthe maximummagnitudeof the alternatingquantity. In case of single phase induction motors, the stator winding produces an alternating magneticfield havingmaximum magnitudeof Φ_{1m}.

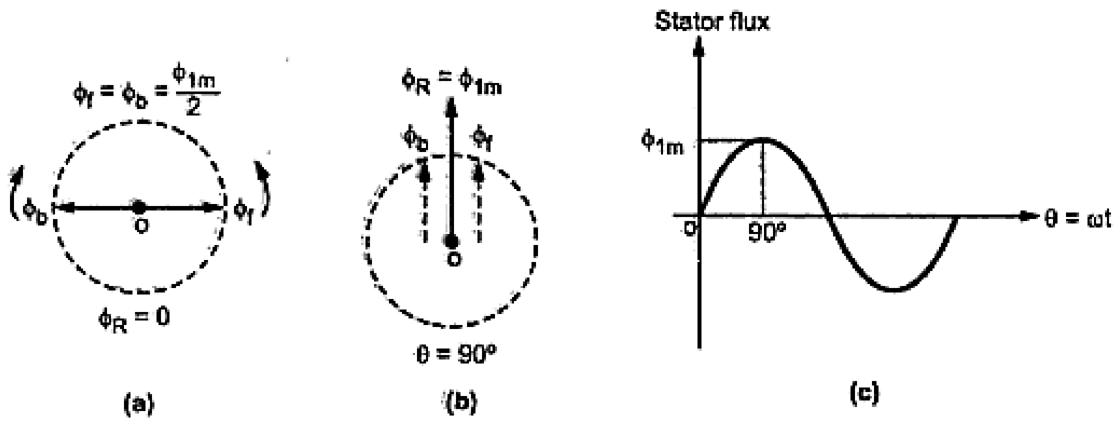
According todouble revolving fieldtheory,considerthetwocomponentsofthestator flux,eachhavingmagnitude halfof maximummagnitudeof stator fluxi.e. ($\Phi_{1m}/2$).Boththese componentsarerotatinginoppositedirectionsatthesynchronousspeed$N_S$whichisdependent on frequencyand stator poles.

Let

Φ_f isforwardcomponentrotatinginanticlockwisedirection

$\Phi_b$isthebackward componentrotatinginclockwisedirection.

Theresultantofthesetwocomponentsatany instant givesthe instantaneousvalue ofthe stator fluxatthe instant. Soresultantofthesetwoisthe original statorflux.



Statorflux andits two components

The above figure showsthestatorfluxanditstwocomponents**Φ_f**and**Φ_b**.Atstartboththe components areshown opposite to each other in the above figure(a). Thus the resultant Φ_R=0. Thisis nothing buttheinstantaneousvalueofthestator fluxatstart.After90^0asshowninthe above figure (b),thetwocomponentsarerotatedinsuchawaythatbotharepointinginthesamedirection. Hence the resultant $\Phi_R$isthe algebraic sumof the magnitudesof the twocomponents.

So $\Phi_R = (\Phi_{1m}/2)+(\Phi_{1m}/2)=\Phi_{1m}$.

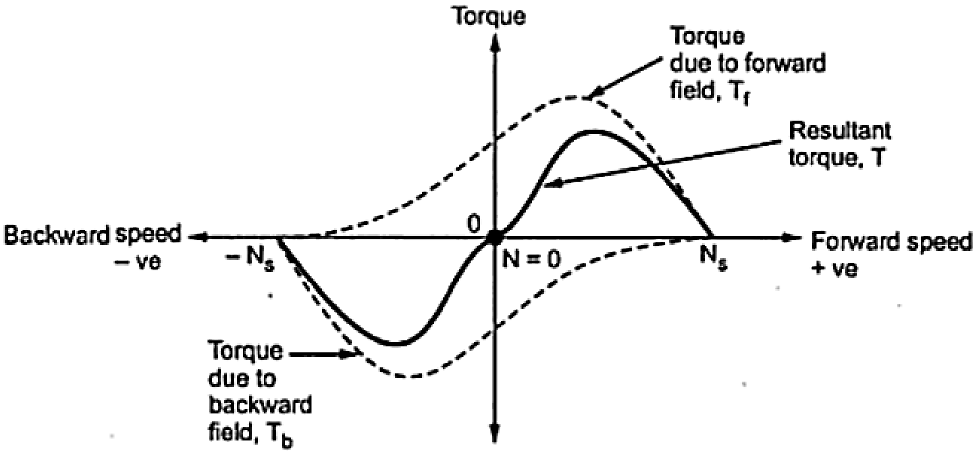
Thisisnothingbuttheinstantaneousvalueofthestatorfluxat$\theta=90^{O}$ asshowninthe above figure(c).Thuscontinuousrotationofthetwocomponentsgivestheoriginal alternatingstator flux.

Boththecomponentsarerotatingandhencegetcutby themotorconductors.Duetocutting offlux,e.m.f.getsinducedinrotorwhichcirculatesrotorcurrent.Therotorcurrentproduces rotorflux.ThisfluxinteractswithforwardcomponentΦ$_f$toproduceatorque inoneparticular directionsay anticlockwisedirection.WhilerotorfluxinteractswithbackwardcomponentΦ$_b$to produceatorque intheclockwisedirection.Soifanticlockwisetorqueispositivethenclockwise torqueis negative.

Atstart, thesetwotorquesareequalinmagnitudebutoppositeindirection.Eachtorquetries torotatetherotorinitsowndirection.Thus***nettorqueexperiencedby therotoriszeroatstart***. And hencethesingle phaseinduction motors arenot self-starting.

TORQUESPEED CHARACTERISTICS

Thetwo oppositelydirected torques and the resultant torquecan beshown effectivelywith the help of torque-speedcharacteristics.It is shown in the below figure.



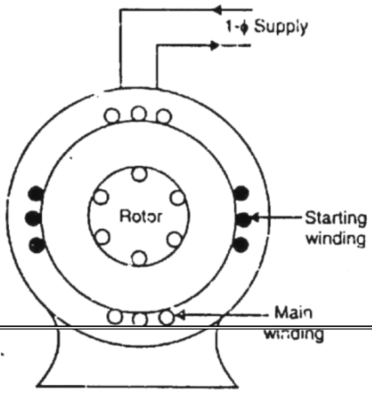
Torque-speedcharacteristics

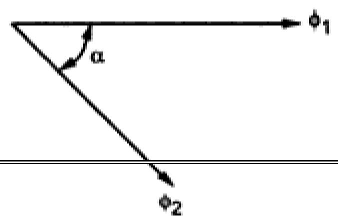
It can beseen that atstart N =0andat that point resultant torqueis zero. So single phase motors arenot self-starting. However ifthe rotoris given an initial rotation in anydirection, the resultant averagetorque increasein thedirection in which rotorinitiallyrotated. And motor starts rotatingin that direction. But in practiceitis not possible to give initial torqueto rotor externallyhencesome modifications aredoneinthe construction ofsingle phaseinduction motorsto makethem self- starting.

MAKINGSELF-STARTING SINGLE PHASE MOTOR:

Thesingle-phaseinduction motor is not self- startingand it is undesirable to give mechanical spinningof theshaft to start it. To makeasingle-phase induction motor self-starting, arevolvingstator magnetic field is required. This maybe achieved byconvertinga single-phasesupplyintotwo-phasesupply through the use of anadditional winding. When the motor attainssufficient speed, the startingmeans (i.e., additional winding) may beremoved dependingupon the typeof the motor. As amatterof fact, single-phase induction motors are classified and named accordingto themethodemployed to makethemself-starting.

The construction of two phase motor and two fluxeshavingphasedifferenceof between them are shown in the below.

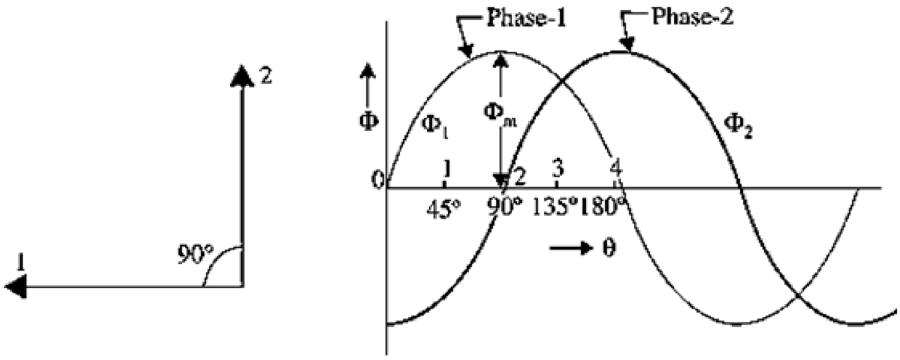




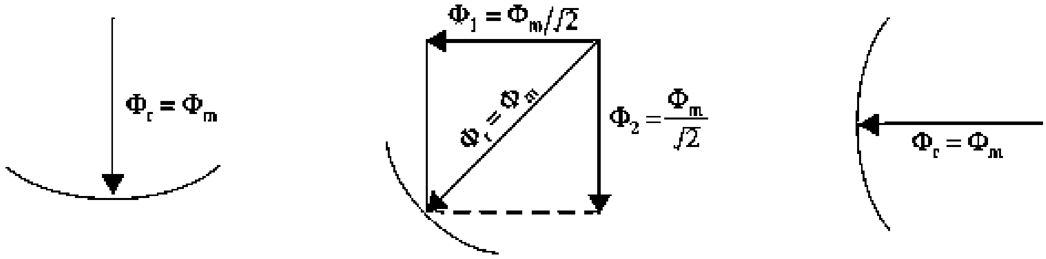
Morethephasedifferenceangle**α**,moreisstartingtorqueproduced.

<u>PRODUCTION OFROTATING FIELD FROMTWO-PHASESUPPLY:</u>

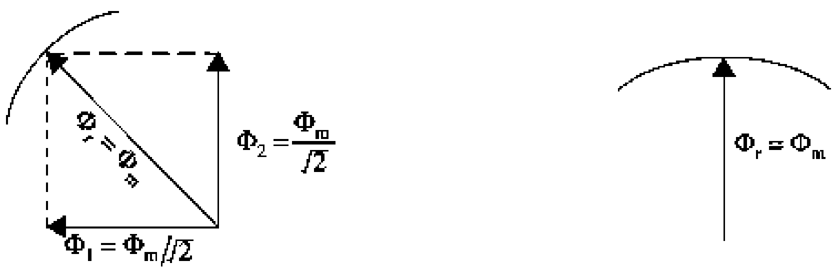
Itwillnowbeshownthatwhenstationarycoils,woundfortwophasesaresuppliedby twophasesupplyrespectively,auniformly-rotating(orrevolving)magneticfluxofconstant value is produced.



Theprincipleofatwo phase, 2 -polestatorhavingtwoidenticalwindings,90^0spaces apart, is illustrated in the above figure. Thefluxduetothecurrentflowing ineachphasewinding isassumedsinusoidalandis represented in the above figure.Theassumed positivedirectionsof fluxes areshown in above figure.



(i) θ = 0° (ii) θ = 45° (iii) θ = 90°



(iv) θ = 135° (i) θ = 180°

Let$\Phi_1$and$\Phi_2$betheinstantaneousvaluesofthefluxessetup by thetwowindings.The resultantflux$\Phi_r$atanytimeisthevectorsumofthesetwofluxes($\Phi_1$andΦ_2)atthattime.We willconsiderconditionsatintervalsof1/8^th^ofa timeperiodi.e.atintervalscorrespondingto anglesof0^0,45^0,90^0,135^0and180^0.ItwillbeshownthatresultantfluxΦ_r isconstantin magnitudei.e.equaltoΦ_m–themaximumfluxduetoeitherphaseandismaking one revolution/cycle.In otherwords, itmeans that theresultant fluxrotates synchronously.

- When $\theta = 0^0$ i.e., corresponding to point 0 in the above figure, $\Phi_1 = 0$, but Φ_2 is maximum i.e. equal to Φ_m and negative. Hence, resultant fluxes $\Phi_R = \Phi_m$ and, being negative, is shown by a vector pointing downwards [Figure (i)].
- When $\theta = 45^0$ i.e. corresponding to point 1 in above figure. At this instant, $\Phi_1 = \Phi_m/\sqrt{2}$ and is positive; $\Phi_2 = \Phi_m/\sqrt{2}$ but is still negative. Their resultant, as shown in figure (ii), is $\varphi_r = \sqrt{[(\frac{\varphi_m}{\sqrt{2}})^2 + (\frac{\varphi_m}{\sqrt{2}})^2]} = \Phi_m$ although this resultant has shifted 45^0 clockwise.
- When $\theta = 90^0$ i.e. corresponding to point 2 in above figure. Here $\Phi_2 = 0$, but $\Phi_1 = \Phi_m$ and is positive. Hence, $\Phi_r = \Phi_m$ and has further shifted by an angle of 45^0 from its position by 90^0 from its original position as shown in figure (iii).
- When $\theta = 135^0$ i.e. corresponding to point 3 in above figure. Here, $\Phi_1 = \Phi_m/\sqrt{2}$ and is positive, $\Phi_2 = \Phi_m/\sqrt{2}$ and is also positive. The resultant $\Phi_r = \Phi_m$ and has further shifted clockwise by another 45^0, as shown in figure (iv).
- When$\theta=180^0$i.e.correspondingtopoint4inabove figureHere,$\Phi_1=0,\Phi_2=\Phi_m$andis positive.Hence,$\Phi_r=\Phi_m$andhasshiftedclockwiseby another45^0orhasrotatedthrough an angle of$180^0$from its position at the beginning as shown in figure (v).

Hence,we conclude

- That themagnitudeof theresultant fluxis constant and is equal to Φ_m, the maximum flux dueto eitherphase.
- That theresultant fluxrotates atsynchronous speed given byN_S=120f/ Prpm.

14. What are the types of single phase induction motor? Explain about any two types of single phase induction motor

TYPESOF SINGLE PHASE INDUCTION MOTOR

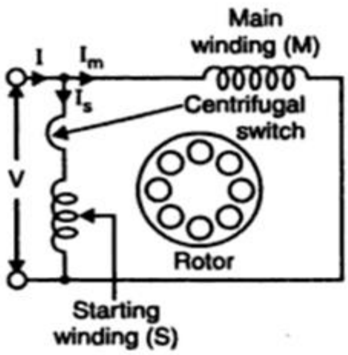
- *Split-phasemotors*
- *Capacitor start motors*
- *Capacitor start Capacitor run motors*
- *Shaded-pole motors*

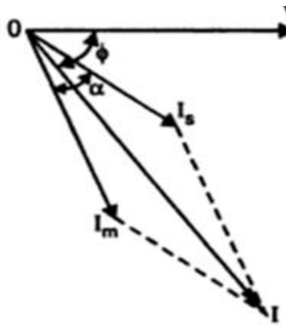
1. SPLIT-PHASEINDUCTIONMOTOR

Construction:

Thestatorofasplit-phaseinductionmotorisprovidedwithan***auxiliary orstarting windingS***inadditiontothe***mainorrunning windingM***.Thestarting winding islocated90° electricalfromthemainwindingandoperatesonly duringtheshortperiod when the motor starts up. A centrifugal switch is connected in series with starting winding.

Thetwo windingsaresodesigned that the ***starting windingS***has a***high resistance*** and ***Low reactance***while the***main winding M*** has relatively***low resistance*** and ***large reactance***as shown in theschematic connections. Consequently, thecurrents flowingin thetwo windings havereasonable phasedifference(25° to 30°) as shown in the phasor diagram.





Operation

Whenthetwostatorwindingsareenergizedfromasingle-phasesupply,themainwinding carries current$I_m$while thestarting winding carries currentI_S. Sincemainwindingismadehighlyinductivewhilethestartingwindinghighlyresistive, thecurrents$I_m$and$I_S$haveareasonablephaseanglea(25°to30°)betweenthemasshown inPhasor diagram.Consequently,aweakrevolvingfieldapproximatingtothatofa2-phase machine is produced which starts the motor.

Thestartingtorqueis given by;

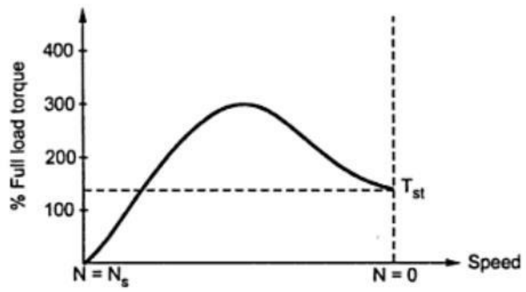
$$T_S = k\, I_m I_S \sin\alpha$$

Where,***k*** *is aconstant whosemagnitudedepends upon the design of themotor.*

Whenthemotorreachesabout75%ofsynchronousspeed,thecentrifugalswitchopensthe circuitofthestartingwinding.The motorthenoperatesasa single-phaseinductionmotor andcontinuestoacceleratetillitreachesthenormalspeed.Thenormalspeedofthemotor is below thesynchronousspeed and depends uponthe load on the motor.

Characteristics

- Thespinningtorqueis1.5to2timesthefull-loadtorquemid(ie.,startingcurrentis6to8 times thefull-load current.)
- Dueto their lowcost, split-phaseinduction motorsare mostpopularsingle-phasemotors in the market.



- Sincethestartingwindingismadeoffinewire,thecurrentdensity ishighandthewinding heatsupquickly.Ifthestarting periodexceeds5seconds,thewindingmay burnoutunless themotorisprotected by built-in-thermalrelay.Thismotoris,therefore,suitablewhere startingperiods is short.
- Animportantcharacteristicofthesemotorsisthattheyareessentiallyconstant-speed motors. Thespeed variation is 2-5%from no-loadto full-load.
- Thepowerratingof suchmotors generallylies between 60 Wand 250 W

Applications:

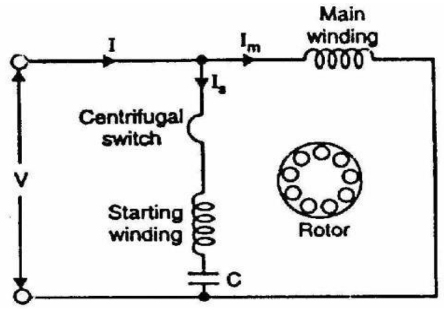
- Fans
- Washingmachines
- Oil burners
- Centrifugal pumps
- Smallmachine tools etc.

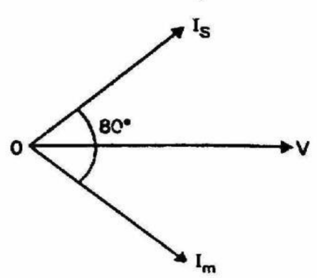
15. Explain why the single phase induction motors are not self-starting? Describe the operation of capacitor start and run motors in detail. (APRIL/2014)

2. **CAPACITOR-START MOTOR**

Construction:

Thecapacitor-start motoris identical to asplit-phasemotorexcept that thestarting winding hasasmany turnsasthemainwinding.Moreover,a***capacitorC***isconnectedinseries withthe starting windingasshown in below figure. Thevalue of capacitor issochosen thatI_S leads$I_m$byabout80°(i.e.,α ~80°)whichisconsiderablygreaterthan25°foundinsplit-phase motor.





Operation:

A single phase supply is given to the two winding of stator. The starting current I_S leads the line voltage due to the presence of a capacitor in series with starting winding. The running current I_m lags the line voltage. The phase displacement between these two currents is approximately equal to 90^0 during starting period. Consequently,startingtorque(T_S=k$I_m$$I_S$sin α)ismuchmorethan thatofasplit-phasemotor.Again,thestartingwindingisopenedby thecentrifugalswitchwhen themotorattainsabout75%ofsynchronousspeed.Themotorthenoperatesasasingle-phase induction motor and continues to accelerate till it reaches the normal speed.

Characteristics:

- Althoughstartingcharacteristicsofacapacitor-startmotorarebetterthanthoseofasplit-phasemotor,bothmachinespossessthesamerunning characteristicsbecausethemain windings areidentical.
- Thephaseanglebetweenthetwocurrentsisabout80°comparedtoabout25°inasplit- phase motor. Consequently,for thesamestartingtorque,thecurrentinthestartingwinding isonly abouthalfthatinasplit-phasemotor.Therefore,thestartingwinding ofacapacitor startmotorheatsuplessquickly andiswellsuitedtoapplicationsinvolvingeitherfrequent orprolonged startingperiods.
- Capacitor-start motors areused where high startingtorqueisrequired and wherethe startingperiod maybelongenough to drive.
- Thepowerratingof suchmotors lies between 120Wand 7500 W

Applications:

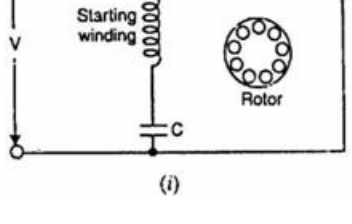
- Compressors
- Largefans
- Pumps
- Refrigerators
- High inertialoads

3. **CAPACITOR-START CAPACITOR-RUNMOTOR**

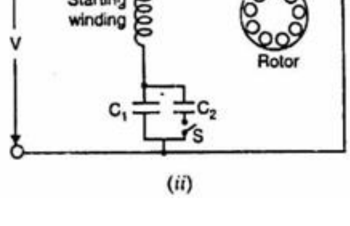
Construction and Operation:

Thismotorisidenticaltoacapacitor-startmotorexceptthatstartingwinding isnotopened afterstartingsothatboththewindingsremainconnectedtothesupplywhenrunningaswellas at starting. Two designs are generallyused.

- Inonedesign,asinglecapacitorCisusedforbothstartingandrunningasshownin figure(i). Thisdesigneliminatesthe needof acentrifugalswitchand atthe same time improves the powerfactor and efficiencyof themotor.
- Intheotherdesign,twocapacitorsC_1andC_2areusedinthestartingwindingasshownin figure (ii).ThesmallercapacitorC_1requiredforoptimumrunning conditionsis permanently connectedinserieswiththestartingwinding.Themuchlargercapacitor$C_2$is connected inparallel with C_1 for optimum starting and remains inthe circuit during starting.ThestartingcapacitorC_1isdisconnectedwhenthemotorapproachesabout75% of synchronous speed. Themotor then runs as asingle-phaseinduction motor.



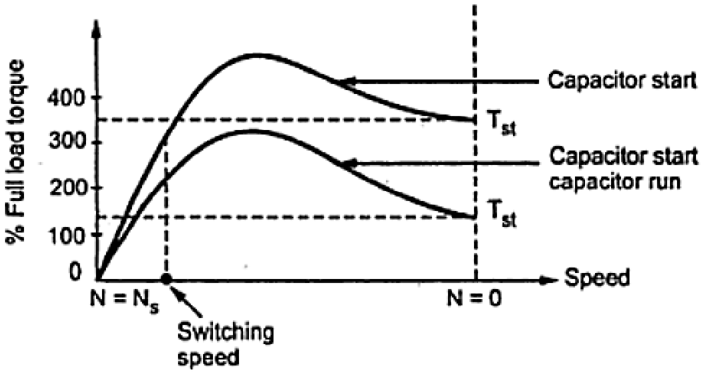
(i)



(ii)

Characteristics:

- Thestarting winding andthecapacitorcanbedesignedforperfect2-phaseoperationatany load.Themotorthenproducesaconstanttorqueandnotapulsating torqueasinother single-phasemotors.
- Becauseofconstant torque, the motor is vibration freeand can beused in placeswheresilenceis important.



Applications:

- Hospitals
- Studios

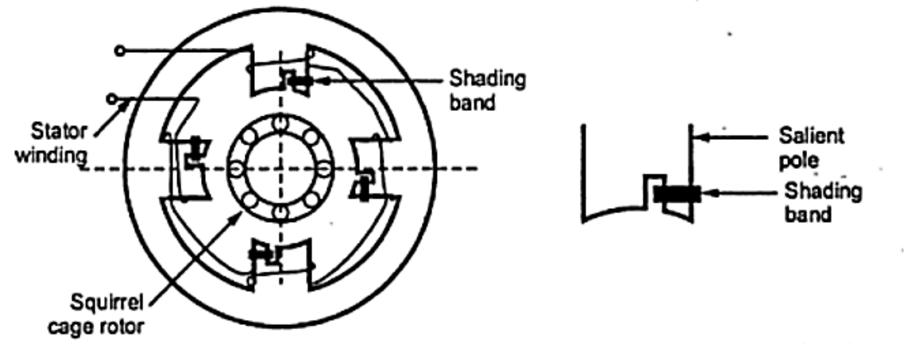
4. **SHADEDPOLE INDUCTION MOTOR**

Construction:

This typeofmotorconsistsofa***squirrelcagerotor***and***stator***consisting of***salientpoles*** i.e. projected poles.Thepolesareshadedi.e. eachpole carriesa copper bandonone of its unequally dividedpartcalled***shadingband.***Figure (a)shows4poleshadedpoleconstructionwhile figure (b)shows asinglepole consistingof coppershadingband.

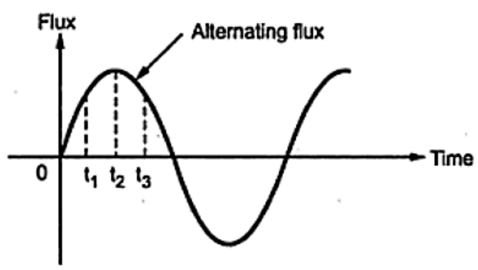
Operation:

WhensinglephaseACsupplyisgiventothestatorwinding,duetoshading provided to thepoles, arotatingmagneticfield isgenerated.



(a) 4 - pole shaded pole construction (b) Salient pole with shading band

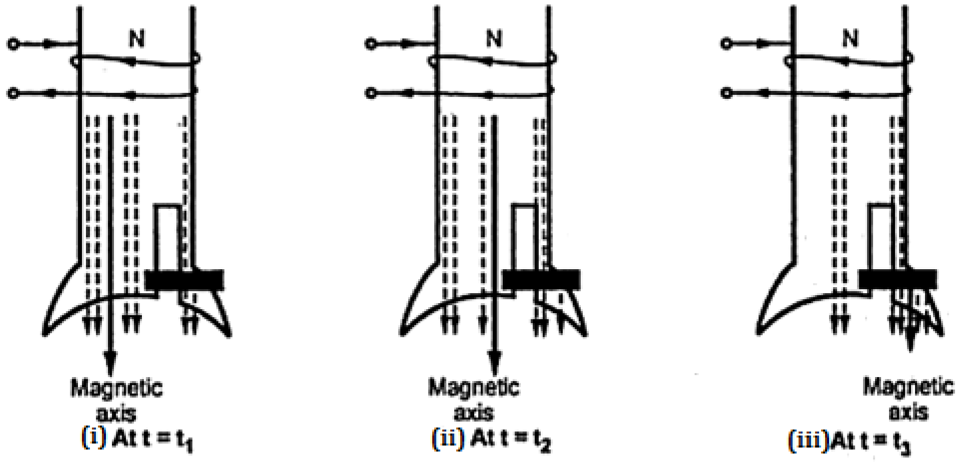
Thecurrentcarriedby thestatorwindingisalternatingandproducesalternatingflux.The waveformofthefluxisshowninthe below figure. Thedistributionofthisfluxin thepoleareais greatlyinfluencedbytheroleofcoppershading band.Considerthethreeinstantssayt_1,$t_2$andt_3 duringfirst half cycleofthe fluxas shown, in the figure.



Waveformofstatorflux

Case (i) $t=t_1$

Atinstantt=t1,rateofriseofcurrentandhencethefluxisvery high.Duetothe transformer action,largee.m.f.getsinducedinthecoppershading band.Thiscirculatescurrent throughshading bandasitisshortcircuited,producingitsownflux.According to***Lenz'slaw,***the direction ofthiscurrent is so as to opposethecausei.e. risein current.Henceshading ringfluxis opposingtothemainflux.Hencethereiscrowdingoffluxinnon-shadedpartwhileweakening of fluxin shaded part. Overallmagneticaxis shifts in non-shaded partas shown in the below figure (i).



Production ofrotating magneticfield

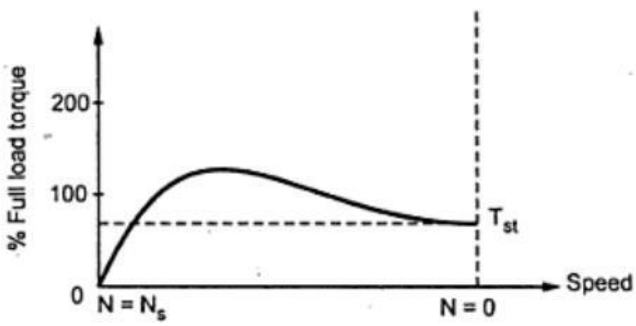
Case (ii) t=t_2

Atinstantt =t2, rateofriseofcurrentandhencetherateofchangeoffluxisalmost zero asfluxalmostreachestoitsmaximumvalue.SodΦ/dt=0.Hencethereisvery littleinduced e.m.f.intheshading ring.Hencetheshadingringfluxisalsonegligible,hardly affecting the distributionofthemainflux.Hencethemainfluxdistributionisuniformandmagneticaxislies at the centreof thepolefaceas shown in the figure (ii).

Case (iii) t=t_3

Attheinstantt= t3,the currentandthefluxisdecreasing.Therateofdecreaseishigh whichagaininducesavery largee.m.f.intheshadingring.Thiscirculatescurrentthroughthe ringwhichproducesitsownflux.Nowdirectionofthefluxproduced by theshadedringcurrent issoastoopposethecausewhichisdecreaseinflux.Soitopposethedecreaseinfluxmeansits directionissameasthatofmainflux,strengthening it.Sothere iscrowding offluxintheshaded partascomparedtonon-shadedpart.Due tothisthemagneticaxisshiftstothemiddleof the shaded part ofthe pole. This is shown in the figure (iii).

Thissequencekeepsonrepeating fornegativehalfcycletoo.Consequently thisproduces aneffectofrotating magneticfield,thedirectionofwhichisfromnon-shadedpartofthepoleto theshadedpartofthepole.Duetothis,motorproducesthestartingtorqueislowwhichisabout 40to50%of thefullloadtorqueforthistypeof motor. The torque speedcharacteristicsare shown in the below figure.



Torque-speedcharacteristics ofshadedpole motor

Duetoabsenceofcentrifugalswitchtheconstructionissimpleandrobustbutthistypeof motor has alotof lamination as:

- Thestartingtorqueis poor.
- Thepowerfactor isverylow.
- DuetoI^2R, copper lossesin theshadingringtheefficiencyare verylow.
- Thespeedreversalisverydifficult.Toachievethespeedreversal,theadditionalsetof

shadingringsisrequired.By openingonesetandclosingother,directioncanbereversed but themethod is complicated andexpensive.

- Thesizeandpowerratingofthesemotorsisverysmall.Thesemotorsareusually available in arangeof1/300 to 1/20 kW.
- Thesemotorsarecheapbuthaveverylowstartingtorque,lowpowerfactorandlow efficiency

Application

- Advertisingdisplays,
- Film projectors,
- Record players,
- Gramophones,
- Hairdryers,
- Photo copyingmachines

16. Explain construction and operation of stepper motor. (NOV/2013)

(or)

Explain in detail about different modes of operation of stepper motor. (NOV/2012)

STEPPER MOTOR

A step orstepping motor converts electronic pulses into proportionate mechanical movement. Each revolution of the stepper motor's shaft is made up of a series of discrete individual steps. A step is defined as the angular rotation produced by the output shaft each time the motor receives a step pulse. These types of motors are very popular in digital control circuits, such as robotics, because they are ideally suited for receiving digital pulses for step control. Each step causes the shaft to rotate a certain number of degrees.

Astep anglerepresents the rotation of the output shaft caused by each step, measured in degrees. The below figure illustrates a simple application for a stepper motor. Each time the controller receives an input signal, the paper is driven a certain incremental distance. In addition to the paper drive mechanism in a printer, stepper motors are also popular in machine tools, process control systems, tape and disk drive systems, and programmable controllers.

Stepper Motors Working

Stepper motors consist of rotating shaft with permanent magnet attached is called rotorand the stationary housing containing the coil-wound poles is called stator (i.e. electromagnets on the stationary portion that surrounds the motor).

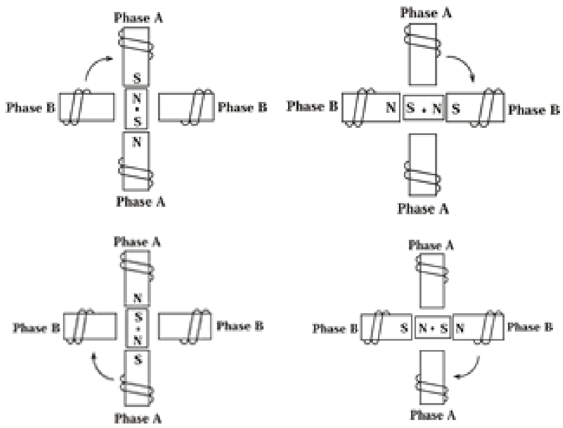
Types of Stepper Motors

There are basically three types of stepping motors;

- Variable reluctance stepper motor
- Permanent magnet stepper motor
- Hybrid stepper motor

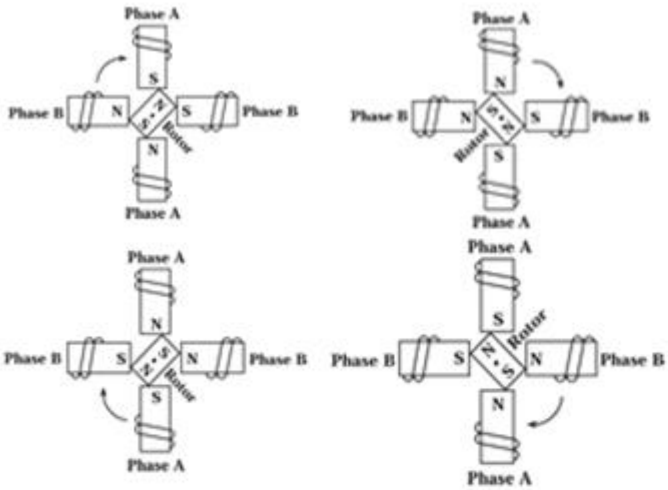
Full Stepping

The below figure illustrates a typical step sequence for a two phase motor. In Step 1 phase A of a two phase stator is energized. This magnetically locks the rotor in the position shown, since unlike poles attract. When phase A is turned off and phase B is turned on, the rotor rotates 90° clockwise. In Step 3, phase B is turned off and phase A is turned on but with the polarity reversed from Step 1. This causes another 90° rotation. In Step 4, phase A is turned off and phase B is turned on, with polarity reversed from Step 2. Repeating this sequence causes the rotor to rotate clockwise in 90° steps.



One Phase ON

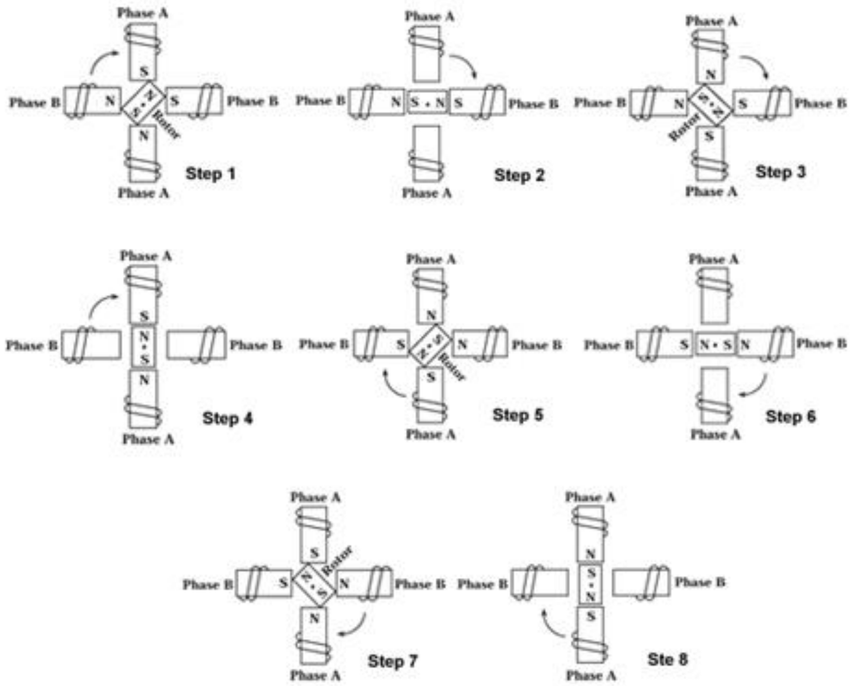
The stepping sequence illustrated in the above figure is called “one phase on” stepping. A more common method of stepping is “two phase on” where both phases of the motor are always energized. However, only the polarity of one phase is switched at a time, as shown in figureWith two phases on stepping the rotor aligns itself between the “average” north and “average” south magnetic poles. Since both phases are always on, this method gives 41.4% more torque than “one phase on” stepping, but with twice the power input.



Two Phase ON

Half Stepping

The motor can also be “half stepped” by inserting an off state between transitioning phases. This cuts a stepper’s full step angle in half. For example, a 90° stepping motor would move 45° on each half step, in the below figure. However, half stepping typically results in a 15% - 30% loss of torque depending on step rate when compared to the two phase on stepping sequence. Since one of the windings is not energized during each alternating half step there is less electromagnetic force exerted on the rotor resulting in a net loss of torque.



Half Stepping

There are several types of stepper motors. 4-wire stepper motors contain only two electromagnets; however the operation is more complicated than those with three or four magnets, because the driving circuit must be able to reverse the current after each step. For our purposes, we will be using a 6-wire motor.

Unlike our example motors which rotated 90 degrees per step, real-world motors employ a series of mini-poles on the stator and rotor to increase resolution. Although this may seem to add more complexity to the process of driving the motors, the operation is identical to the simple 90 degree motor we used in our example. An example of a multi pole motor can be seen in the below figure. In position 1, the north pole of the rotor's permanent magnet is aligned with the south pole of the stator's electromagnet. Note that multiple positions are aligned at once. In position 2, the upper electromagnet is deactivated and the next one to its immediate left is activated, causing the rotor to rotate a precise amount of degrees. After eight steps the sequence repeats

17. Explain the construction and working of AC series motor. (APRIL/2013) (APRIL/2012)

SINGLE PHASE A.C. SERIES MOTOR

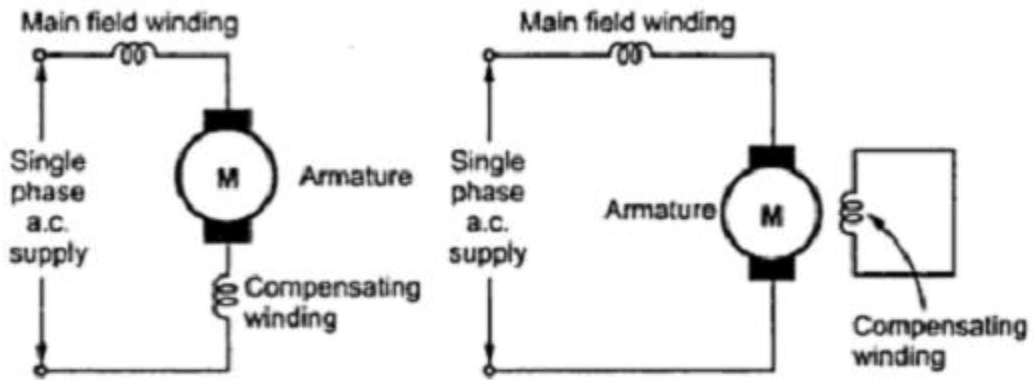
In a normal DC motor if direction of both field and armature current is reversed, the direction of torque remains unchanged. So when normal DC series motor is connected to an AC supply, both field and armature current get reversed and unidirectional torque gets produced in the motor hence motor can work on AC. supply. But performance of such motor is not satisfactory due to the following reasons

- There are tremendous eddy current losses in the yoke and field cores, which causes overheating.
- Armature and field winding offer high reactance to AC due to which operating power factor is very low.
- The sparking at brushes is a major problem because of high voltage and current induced in the short circuited armature coils during the commutation period.

Some modifications are required to have the satisfactory performance of DC series motor on AC supply, when it is called AC series motor. The modification are:

- To reduce the eddy current losses, yoke and pole core construction is laminated.
- The power factor can be improved by reducing the magnitudes of field and armature reactance.

Field reactance can be decreased by reducing the number of turns. But this reduces the field flux. But this reduction in flux (N α 1/Φ), increases the speed and reduce the torque. To keep the torque same it is necessary to increase the armature turns proportionately. This increases the armature inductance. Now to compensate for increased armature flux which produce severe armature reaction, it is necessary to use compensating winding. The flux produced by this winding is opposite to that produced by armature and effectively neutralizes the armature reaction. If such a compensating winding is connected in series with the armature, the motor is said to be 'conductively compensated'. For motors to be operated on AC and DC both, the compensation should be conductive. If compensating winding is short circuited on its self, the motor is said to be 'inductively compensated'. In this compensating winding acts as a secondary of transformer and armature as its primary. The ampere turns produced by compensating winding neutralise the armature ampere turns.



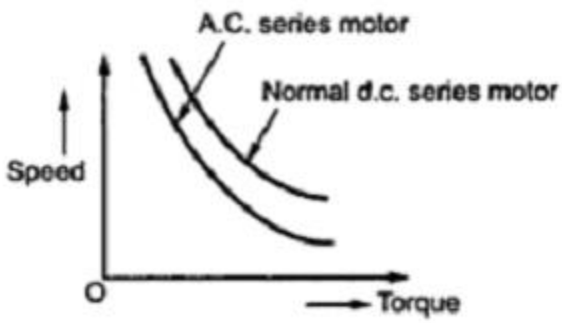
(a) **(b)**

(a)Conductively Compensated motor, (b) Inductively Compensated Motor

To reduce the induced e.m.f. due to transformer action in the armature coils while commutation period, the following measures are taken:

- The flux per pole is reduced and numbers of poles are increased.
- The frequency of supply used is reduced.
- Preferably single turn armature coils are used.

The characteristics of such motor are similar to that of DC series motor. The torque varies as square of the armature current and speed varies inversely as the armature current. The speed of such motor can be dangerously high on no load condition and hence it is always started with some load. Starting torque produced is high which the full load torque is 3 to 4 times. The speed-torque characteristics of such type of motors is as shown in the Figure



Torque Speed Characteristics

Applications

- Because of high starting torque it is used in electric traction
- Hoists
- Locomotives

Reference:

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- *U. A. Bakshi, M. V. Bakshi, Electrical Machines-II, Second Edition, Technical Publications*