COMPUTER AIDED DESIGN AND FABRICATION OF SYNCHRONOUS-INDUCTION MOTOR

PROJECT REPORT 1996-2000
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SYNOPSIS

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An innovative work on SYNCHRONOUS INDUCTION MOTOR has beencarried out in this project.SYNCHRONOUS INDUCTION MOTOR is a single phase induction motor specially design to run at synchronous speed irrespective of the load.This motor has both induction motor and synchronous motor characteristics.

The design of this SYNCHRONOUS INDUCTION MOTOR has been carried of using an user friendly software developed in C language.

The details of constructional features , design and the test results are presented in this project.

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dsc = Depth of stator core(metre)

dss = Depth of stator slot(metre)

deri = Inner diameter of stator core(metre)

dero = Outer diameter of end ring(metre)

dors = Depth of rotor slot(metre)

E = Induced Emf in the machine(volts)

eff = Required efficiency(%)

Fp = Flux per pole(Wb)

hp = Horse of the machine(hp)

i = Rated current of the machine(Amps)

ib = Rotor bar current(Amps)

id = Current density (Amps/sq. mm)

ie = End ring current(Amps)

kwa = Winding factor of auxillary winding

kwm = Winding factor of main winding

L = Length of stator core(metre)

lg = Length of air gap(metre)

lip = Slot opening of stator slot(metre)

lmtm = Length of mean turn of main winding(metre)

lmts = Length of mean turn of starting winding(metre)

ns = Synchronous speed (rps)

neckr= Neck of rotor slots(metre)

rsw = Rotor slot width(metre)

sr = Number of rotor slots

ss = Number of stator slots

ssp = Stator slot pitch

spp = Stator ploe pitch

tcsm = Total copper section in main winding

tcsr = Total conductor section in rotor bar

wtr = Width of rotor teeth(metre)

worb = Width of rotor bar(metre)

wors = Width of rotor slot(metre)

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Conservation of energy is a vital area which is being regarded as one of the global objectives.In today's energy scenario, industries are the major consumers of Electrical energy produced in any country. Electrical motors, being the most widely used energy converters in any industry, even a small percentage of energy saving is considered to be a big deal in existing industrial drive applications. In recent years, the demand for higher efficiency motors, running at constant speed, has increased. To meet this demand, various designs of ac motors are being tried out. The trend, nowadays, is towards the design of Energy Efficient Motors. The essential requirements of industrial drives are high starting torque, constant speed of operation, higher efficiency and high power factor. To meet these requirement, various designs of ac motors fed from inverters were tried out. Induction motor drives are standard technology with existing manufacturing Infrastructure. They are preferred for their high reliability and maintenance free operation. However, they have the

- The slip of the motor is zero for all loads so it has a higher efficiency than induction motors..
- The annual running cost of the motor is reduced..
- They are as reliable as induction motor.

Synchronous induction motor can be fabricated for single phase as well as three phase.In our project single phase induction motor is dealt with.

1.3 SINGLE PHASE SYNCHRONOUS INDUCTION MOTOR

The Synchronous Induction Motor has a conventional induction motor stator and a cage rotor with permanent magnets buried inside the rotor .Fig 1.0 shows the cut away section of a Synchronous Induction Motor.

The stator consists of single phase winding. It is wound for definite number of poles. The stator winding when excited by a single phase ac supply produces revolving flux.

The rotor is Squirrel Cage type with permanent magnets buried inside the rotor core. Because of this geometry the Synchronous Induction Motor has a mechanically robust rotor construction and a low effective air gap. These features permit this motor to be operated even at high speeds. The Squirrel Cage rotor

Thus the synchronous induction motor starts with dominant induction motor characteristics . When rotor speed approaches synchronous speed , ,the field set up by the permanent magnet gets locked with the stator field,making the rotor to run at synchronous speed. As the load increases the rotor still locks to synchronous speed

1.5 PROMINENT FEATURES

- Simple rotor construction .
- Zero slip.
- Absence of rotor copper loss.
- High efficiency.
- Relatively higher stability.
- Relatively lower maintenance.

PERMANENT MAGNETS

CHAPTER 2

PERMANENT MAGNETS

2.1 INTRODUCTION

Almost all permanent magnet can be made to suit the requirements of the customer. To select the type of the magnet the following Considerations should be followed.

- Magnetic property
- Shape and size
- Temperature

2.2 MAGNETIC MATERIALS

2.2.1 Ferrite (Ba OR Sr) Permanent magnets

Ferrite permanent magnets are fabricated by powder metallurgy method, their remanence and reversibility are low. Coercivity is high, so they have less action of demagnetizing field and are suitable to dynamic applications. Because of their low density, these magnets have a light weight, these magnets cost is low compared to ALNICO, Fe-Cr-Co and Re-Co. They are suitable used in instrument,Meter, electro acoustic device, micro meter, duplicator,following machine, magnet-Medieval apparatue.

2.2.2 CAST ALNICO MAGNETS

Cast ALNICO magnets are one of the most widely used permanent magnets.These are a series of alloys consisting of basic raw materials like aluminium, nickel, cobalt, iron, etc. they are characterized by excellent temperature Stability and high resistance to demagnetizing from vibration and shock. Being hard and brittle, the only possible way of machining is grinding.

Cast Al-Ni-Co magnets poesses a higher remanence and excellent stability.the lower remanence temperature coefficient make these magnets to be demagneted less in the conditions of wider range temperature.

2.2.3 ALNICO III

They are isotropic magnets ie, they exhibit equal magnetic properties irrespective of the directions in which they are magnetised. They are useful when multipolar configurations are desired.

2.2.4 ALNICO V

These are anisotropic magnet ie, they exhibit stronger magnetization properties in the direction of magnetization. Simple configurations such as straight, horse shoe of circular shape of common applications like loud speakers,energy meters,measuring instruments, magnetic chucks,V-blocks,seperators,holding devices etc are manufactured in ALNICO V because of the high energy product of these magnets.

CONSTRUCTIONAL DETAILS

CHAPTER 3

CONSTRUCTIONAL DETAILS:

3.1 STATOR:

Stator construction is almost similar to that of ordinary Induction motor. Stator is a cylindrical structure made up of large number of silicon steel laminations, which are slotted to house the windings. The stampings are made up of silicon steel, which is 0.5 mm thick. The stator carries single-phase winding. The stator is wound for a definite number of poles. The stator is fed from a single-phase supply.

3.2 STATOR FRAMES:

The stator frame supports stator core and forms a covering for the internal parts of the motor. They are made up of cast iron. Two end covers also made up of cast iron are fitted to the frame. They are used to house the ball bearings, which provide trouble free running and enhanced service life.

- The frames serve the following purposes.
- They enclose the core and winding.
- They shield the live and moving machine parts from human contact and injury caused by intruding objects or weather exposure.

the main winding than the auxillary winding. The most popular kinds of single phase windings are the:

- Concentric
- Progressive
- Skein

Concentric windings are so named because all the coils for a single pole have a common center and different pitches for individual coils. That is the individual coils in a pole group are concentric coils of varying sizes.

3.4 ROTOR:

Squirrel cage rotor has been used for fabrication of synchronous induction motor. The rotor consists of cylindrical laminated core with parallel slots for carrying rotor conductors, which are bars of aluminum. The stampings used for rotor construction are made up of silicon steel, 0.5 mm thick.

The rotor bar is die-casted. Two permanent magnet poles are placed in side the rotor.

3.5 SHAFTS AND BEARINGS:

aluminium foil separated by two layers of insulated paper into a cylindrical shape. The unit is impregnated with an electrolyte usually ethylene glycol. An anodic film is later produced on each foil by electro chemical means.

The voltage rating of a capacitor is not necessarily same as that of the motor, it may less, the same , or more depending upon how it is used. The power factor of the electrolytic capacitor is of the order of 6 to 8%.

DESIGN ASPECTS

CHAPTER 4

DESIGN ASPECTS

4.1 STATOR

4.1.1 OUTPUT EQUATIONS:

The output Equation for Single Phase Machine is

KVA Input Q = $Co * D^2 * L * N_s$

Output Coefficient = $Co = 11 \times KW \times B_{av} \times AC \times 10^{-3}$

KVA Input = $KW / (\cos\phi * \eta)$

$D^2 * L$ = $Q / (Co * N_S)$

But normally the rating of the induction motor is given by the HORSE POWER. Then the KVA input is

Q = HP rating $\times 0.746 / (\eta * COS\phi)$

The Horse Power , Efficiency , Powerfactor & Speed of the machine are specified. Therefore in order to calculate the value of $D^2 * L$, we must evaluate output coefficient. But the output coefficient depends on the choice of electric and magnetic loadings (i.e) values of ac and Bav.

4.1.2 CHOICE OF AVERAGE FLUX DENSITY IN THE AIRGAP:

The choice of average flux density depends upon the following factors.

- **Power Factor:** The value of flux density in the airgap should be small as otherwise the machine will draw a large magnetsing current giving a poor powerfactor.
- **Iron loss:** An increased value of B_{av} results in increased iron loss and decreased efficiency.
- **OverLoad Capacity:** An increased Bav value means that flux per is large . If the number of turns is less, the leakage reactance become small. So the diameter of the conductor is large which means that the maxium output or in otherwords the machine has a large OverLoad Capacity.

For 50 Hz single phase machines , the value of B_{av} normal lies between 0.35 to 0.6 Wb / m^2

4.1.3 CHOICE OF AMPERE CONDUCTOR PER METRE :

- **Copper loss :** A large value of ac means that a greater value of copper employed in the machine results in higher copper and large temperature rise.

- **VOLTAGE :** A small value of ac should be taken for high voltage machines as in this case the space for insulation is large.

- **OVERLOAD CAPACITY :** A large value of ac would result in large number of turns. This would mean the leakage reactance of the machine would become high and will result in reduced value of overload capacity.

For single phase induction motors the value of ampere conductors normally lies between 5000 to 12000 ac/metre.

4.1.4 MAIN DIMENSION:

The main dimensions D and L are separated by selecting proper value of the ratio of core length to pole pitch (L/τ).

Where $\tau = \pi * D/P$

The ratio of core length to pole pitch (L/τ) for various design feature is :

- Minimum Cost - 1.5 to 2.0
- Good Power Factor - 1.0 to 1.25
- Good Efficiency - 1.5
- Overall Design - 1.0

4.1.5 STATOR WINDINGS:

Single layer concentric windings are generally used for stator. In the concentric windings all coils have a common centre and different pole pitch.

4.1.6 MAIN WINDING TURNS:

The number turns is calculated by using the following formulae

Flux per pole (ϕ) = $Bav \times \pi \times D \times L / P$

Total Turns T_m = $E / (4.44 \times f \times \phi \times Kwm)$

4.1.7 NUMBER OF STATOR SLOTS :

The following factors are considered for selecting the number of stator slots.

- **TOOTH PULSATION LOSS:** Tooth pulsation losses and noise can be minimised by using a large number of narrow slots.
- **LEAKAGE REACTANCE**: With a large number of slots, the machine has a higher overload capacity.
- **MAGNETISING CURRENT AND IRON LOSS**: The use of large number of slots may result in excessive flux density in teeth giving rise to higher magnetising current and higher iron losses. The stator slot pitch,

The number of slots per pole lies between 9 to 12.

Total number of stator conductors = 2*Tm

4.1.8 SIZE OF STATOR SLOTS:

All the stator slots do not have the same number of conductors and some contain both the running and starting winding conductors. Starting winding conductors have small cross sectional area and it's effect upon the size is small.

Generally the running winding coil with a large number of turns will determine the size of the slot. The slot liner is usually 0.3 to 0.4 mm thick. The ratio of insulated conductor area to the slot area should never exceed 0.5. Actually this ratio should not exceed 0.35 if the winding process is made easy. The area required for insulated conductors = $Zs * (\Pi/4) * d1^2$ where Zs is the total number of conductors and d1 is the diameter of the insulated conductor in mm.

The slot area provided in the stamping is calculated by multiplying the mean width by the depth of the slot.

The average slot width

$$Ws(av) = \pi * (D + dss)/Ss - Wts$$

Where

dss is the depth of the stator slots.

Wts is the width of the stator tooth and

Ss is the number of stator slots.

Area of each slot = Ws (av) * dss.

4.1.9 STATOR TEETH:

We should check the flux density in the stator teeth in order to see that it is not excessive. The stator tooth density Bts can generally be from 1.4 to 1.7 Wb/m^2. If the low losses and noise are important or if the motor is totally enclosed the lower density should be used. For general purpose machines a flux density of 1.45 Wb/m^2. is taken while for high torque it may go up to1.8 Wb/m^2

As stacking factor of 0.95 is taken the net iron length

Li = 0.95 * L.

The flux density in stator teeth Bts = ϕ_m/(Ss/p * Li * Wts).

4.1.10 STATOR CORE:

The flux density in the stator core should not exceed 1.5 Wb/m^2. Generally it lies between 0.9 to 1.4 Wb/m^2. Flux in the stator core $\phi_c = \phi_m/2$

The flux density in the stator core

$Bcs = \phi_m /(2 * Li * dcs)$

where

dcs is the depth of the stator core.

Area of the stator core = Li * dcs.

Outer diameter of stator laminations

$Do = D + 2 * dcs + 2 * dss.$

4.1.11 LENGTH OF MEAN TURN :

The length of the mean turn for each of the coils per pole of a concentric winding

$Lmt = 8.4 * (D + dss)/Ss * \text{slot span} +2 * L.$

4.2DESIGN OF AIR GAP:

The following factors should be considered while estimating the length of the air gap.

- **POWER FACTOR**: If the length of the air gap increases the power factor decreases.
- **OVERLOAD CAPACITY:** If the length of the air gap affects the value of zig zag leakage reactance which forms a large part of total leakage reactance in the case of induction motors. If the length of the air gap is large,

the zig zag leakage flux is reduced resulting in reduced value of leakage reactance. So the overload capacity will increase.

- **PULSATION LOSS:** The pulsation loss is less with larger air gaps.
- **UNBALANCED MAGNETIC PULL**: If the length of the air gap is small even a small deflection or eccentricity of the shaft would produce a larger irregularity in the length of the air gap and is responsible for the production of larger unbalanced magnetic pull.

- **COOLING:** If the length of the air gap is large, the distance between the stator and rotor is large. This would provide better cooling.

- **NOISE:** The noise of the motor is reduced by increasing the air gap length.

The following empirical relation gives the value of length of air gap in mm.

- $lg = 0.007 * \text{rotor diameter} / \sqrt{p}$
- $lg = 0.2 + 2\,\overline{*\,\sqrt{D}\,*}\,L$
- $lg = 0.125 + 0.35 * D + L + 0.015 * Va$
- $lg = 0.2 + D$

4.3 DESIGN OF SQUIRREL CAGE ROTOR

4.3.1 NUMBER OF ROTOR SLOTS:

The selection of the number of rotor slots in squirrel cage motors is very important and a considerable attention should be paid to select a suitable value of rotor slots. This is because a certain combination of stator and rotor slots the machine may refuse to start or may crawl at some synchronous speed. In some cases severe vibrations may be setup generating excessive noise. The effects are produced by harmonic fields. The harmonic fields are due to:

- Windings
- Slottings
- Saturation
- Irregularities in the air gap.

The difference between the stator and rotor slots should not be equal to:

- 0,+p,-p,+2p,-2p,+3p,-3p,+5p,-5p to avoid synchronous cusps
- +1,-1,+2,-2,+(p+1),+(p-1),-(p+1),-(p-1),+(p+2),-(p+2),+(p-2),-(p-2) to avoid noise and vibration

4.3.2 AREA OF ROTOR BARS:

The cage rotor winding may be either of copper bars and end rings or of cast aluminium. Also technical advantages lie with copper but manufacturing is cheaper with cast aluminium. Also with cast rotors, the joints between bars and end rings are eliminated.

A high rotor resistance is desirable from the standpoint of startting torque and current but leads to high slip and poor efficiency. The total rotor copper section is generally 0.5 to 0.8 of total stator copper section.

Total cross section of rotor bars Ar = Sr * ab

where ab = Area of each bar in mm.

Ratio Ar/Am = 0.5 to 0.8 for copper rotors. Since aluminium is generally used for this purpose has a resistivity of approximately twice as that of copper, total bar area must be two times the area required for copper.

Ratio Ar/Am = 1 to 1.6 for aluminium rotors.

4.3.3 SHAPE AND SIZE OF ROTOR SLOTS:

The rotor slots for squirrel cage rotor may either closed or semi closed types. Closed slots are preffered for small size machines because the reluctance of air gap is not large owing to absence of slot opening. It reduces magnetizing current. As surface of the rotor is smooth, the operation of the machine is quieter. The advantage is that leakage reactance is large Therefore the current at starting can be limited, so we can use it to start with direct online starters. But it results in reduced overload capacity. By semi closed slots give a better overload capacity.

4.3.4 ROTOR BARS:

The rectangular shaped bars and slots are generally preferred to circular bars and slots as the high leakage reactance of the lower part of the rectangular bars, during starting forces most of the through the top of the bar. It gives increased rotor resistance at starting,so improves the starting torque. The value of the resistance depends upon current density used for rotor conductors. Current density of the rotor taken as 4 to 7 A/mm^2.

4.3.5 END RING:

The stator field produces EMF of fundamental frequency in the bar. The magnitude of the EMF in the bar are assumed to be infinitely distributed, the distribution of EMF can be considered as sinusoidal in the bars over a pole pitch. This EMF produced in the bars would circulate currents. The resistance of end rings is negligible when compared with that of the bars, the resistance coming in each current path is the resistance of two bars. Thus the current which the bars carry would be proportional to the instantaneous EMF which in turn depends upon the position of the bar in magnetic field.

The maximum value of current in the end ring

Ie(max) = bars per pole/2 * current/bar = Sr/2 * Ib(max)

4.3.6 ROTOR TEETH:

The width of the rotor slots should be such that the flux density in the rotor teeth does not exceed about 1.7 Wb/m^2. The maximum flux density occurs at their roots as their section is minimum.

Minimum width of the rotor teeth,

Wtr(min) = mm/(1.7 * Sr/p * Li)

Minimum width of tooth actually provided,

Wtr = Rotor slot pitch at the root – Rotor slot width

$= \pi * (dr - 2 * dsr)/Sr - Wsr$

where dsr = depth of the rotor slot

Wsr = width of the stator slot

4.3.7 ROTOR CORE:

The flux density in the rotor core is generally equal to the stator core density.

Depth of the rotor core = ϕ_m /(2 * Bcr * Li)

where Bcr = flux density in the rotor core

Inner diameter of rotor lamination

$$Di = Dr - 2 * (dsr + dcr)$$

The flux density in the rotor teeth and core can be taken slightly higher than those in the stator teeth and core.

COMPUTER AIDED DESIGN

CHAPTER 5

COMPUTER AIDED DESIGN

5.1 ADVANTAGES OF COMPUTER AIDED DESIGN

The use of computer makes possible more trial designs and enables sophisticated calculations to be made without intolerable tedium and excessive time.
The advantages of use of a digital computer for the design of electrical machines are:-

- It has capabilities to store amount of data, count integers, round off results down to integers and refer to tables, graphs and other data in advance.
- It makes it possible to select an optimized design with a reduction in cost and improvement in performance.

- A large number of loops can be incorporated in the design program and therefore makes it easier to compare different designs out of which the best suited can be selected.

- It performs all simple arithmetic operations at a high speed and makes it possible to produce designs in a short time.

- It is capable of automatic operation, going from one step to another without the attention of the operator.

- It reduces the probability of error with the result highly accurate and reliable results are obtained.

- Larger manufacturing savings can be obtained by optimization of design. This optimization is economically feasible only through the use of digital computers.

- It is capable of taking logical decisions by itself if programmed into thereby saving the man hour of the design engineers which can be utilized for other gainful work.

5.2 ALGORITHM

STEP 1: For the design of the single phase induction motor the input requirements are rated voltage,horse power,speed,efficiency,power factor,specific magnetic loading and specific electric loadings.

STEP 2: Winding factor of the main winding is calculated by the following equation.

Pitch factor of coils = sin(coil span/slots per pole)

winding factor of concentric winding kw = Sum of product of pitch factor of each coil to turns in each coil divided by total turns per pole.

STEP 3: The main dimensions are obtained by the following equations

- $n_s = n/60$
- $c_0 = 11*bav*ac*kwm/1000$
- $q = (output/1000)/(t*\cos(\phi))$
- $d^2*l = q/(c0*ns)$

Core diameter can be obtained upon the length to pole pitch ratio.

STEP 4: The flux per pole in stator

$\phi_m = b_{av}*\pi*D*L/P$

STEP 5: Main winding parameters are designed by the following equations

- Induced voltage, E = 0.95*v
- Total series turns in main winding is: Ts = E/(4.44*kwm*f*mm)
- Total turns per pole, Tp = Ts/P
- Stator rated current,Is = op/(v*cos(ϕ)*t)
- Area of main winding,$A_m = I_s/I_{ds}$

  where

  I_{ds} = Current density in main winding

  I_{ds} lies between 7 to 9 A/mm sq.

- Diameter of the main winding is $d_m = \sqrt{(A_m*4/t)}$
- Length of mean turn of main winding is

  L_{mt} = 8.4*(D+dss)/Ss*slots spanned +2*l

STEP 6: Winding factor of auxillary winding

Pitch factor of auxillary winding for coils

sin((coil span+1)/slots per pole)

Kwa = (sum of product of pitch factor of each coil to turns in each coil)/

(total turns per pole in auxillary winding)

STEP 7: Starting winding design

Starting winding parameters are found by the following equations

- Total number of turns,Ta = k*Ts*Kwm/Kwa
- Total turns per pole,Tpa = Ta/P
- Area of auxillary winding,

  As = Area of main winding/2 to 2.4
- Diameter of auxillary winding = da = $(As*4/\pi)$
- Length of mean turn of auxillary winding

  Lmts = 8.4*(D+dss)/Sr*slots spanned+(2*L)

STEP 8: Stator slot design

The stator slot parameters are obtained by the following steps

- Stator slot pitch,Ssp = π * T/Ss
- Depth of stator core,dsc = $\phi_m/(2*Li*bcs)$

  where bcs is the flux density in the sator core (0.92 to 1.4 Wb/m^2)
- Width of stator teeth,Wst = ϕ_m /((Ss/p)*Li*bst

  b_{st} = flux density in stator (1.4 to 1.7 Wb/m sq.)
- Slot area = conductor area/space factor

  normally space factor=0.5
- Conductor area = 2*Tm*A_m

STEP 9: Length of air gap, $lg = 0.2+2*\sqrt{(D*L)}$ mm

where D and L are in metres

STEP 10: Design of squirrel cage rotor

Normally squirrel cage rotors are used in the single phase induction motors

The values are calculated by the following steps

- Rotor outer diameter, Dr = stator inner diameter - 2*length of air gap

  $Dr = D-2*lg$

- Total conductor section in stator

  $Tcu = 2*Tm*A_m$

- Copper rotor:

  Total conductor section in the rotor = 0.55*Tcu

- Aluminium rotor:

  Total conductor section in the rotor = 1.1*Tcu

STEP 11: Rotor slot and bar design

The rotor slot parameters are obtained from the following equations

- Rotor slot pitch = $\pi*dr/Sr$

- Width of the rotor teeth, $Wtr = \phi_m/(Sr/p)*Li*b_{tr})$

  where b_{tr}=flux density in the rotor teeth.It's value is slightly more than the flux density in the stator teeth(b_{ts})

- Depth of the stator core,dsc = ϕ_m /(2*Li*bcr)
- Bar current,Ib = 2*i*cos(ϕ)*ts*kwm/Sr
- The bar width and depth are equal to the slot dimensions excluding(neckr)

The rotor bars are skewed by one slot pitch in the rotor slots

STEP 12: End ring design

The end ring design are obtained by the following formulae

- Area of end ring = 0.32*tscr/p

  where tscr is the total conductor section in the rotor

In this case the current density in the bars is assumed to be equal to the current density in the end ring. The thickness and depth are selected depending upon the areaof the end ring. (Assign the value of depth in order to find the thickness of the end ring)

- End ring current,Ie = Sr*Ib/(π*p)

STEP 13: Capacitor design

- Capacitive reactance required for maximum starting torque,

  Xc = Xla + (Ra+Rm)/(Zm+Xlm)

  where Xla = Total leakage reactance in terms of auxillary winding

  Ra = Total resistance in terms of auxillary winding

  Rm = Total resistance in terms of main winding

Zm = Locked impedance of main winding

Xlm = Total leakage reactance referred to main winding

- Capacitance,C = 1000000/(2*π*f*Xc)

5.3 PROGRAM

A Computer program is written in'C' language for the design of synchronous induction motor. The program is given below.

```
#include<stdio.h>
#include<ctype.h>
#include<math.h>
#include <conio.h>
void main()
{
int E,f,N,ac,Ss,p,ch,a,Tm,x3,x4,Tpm,Ttm,c3,Ta;
int j,rx,Tppax,Tta,c6[10],j1,vc,idr,Tf;

float Q,pi=3.142,Bav,QHP,Co,Dia,D,L,x,y,b,FP,Bts,Wts,Bcs,Dcs,tempvc;
float
lg,D0,asw,ab,slht,ttx,tty,x5,x6,kwm,c1[10],c[10],c4[10],c2[10],c5[10],k2;
float dss=.012,i,z1,z2,lmt[10],lmtn,lmtm,kwa,a1,tou;
float If,Xn,dfw,xm,va,kvar,Ic,Xc,Ab,Im,eff,powfac;
float lmty,lmta[10],lmts,li,tta,tts;
float id=7.5,k=0.6,sa,cd,nwa,sf,swa,uw=0.01042,bw=0.00754,av,cf,upw,pl;
double ar,C;

/* Rotor design variables */

float dr,d,sr,tcsm,neckr,lipr,rsp,ib,wors,wtr,aer,worb,dob;
float tcsb,dors,ab1,lb,ie,doe,toe,dero,deri,dem,l1,bcr=1.4;
float ssp,sd,tcsr,dcr;

clrscr();
printf("\n\n\n\n\n\n\n\n\n\t\t COMPUTER AIDED DESIGN AND
FABRICATION OF");
```

```
printf("\n\n\t\t\tSynchronous induction motor");
sleep(2);
clrscr();
printf("\n\n\n\n\n\n\nGUIDED BY");
printf("\n\n\tMr.R.K.Pongiannan");
sleep(2);
clrscr();
printf("\n\n\n\n\n\nDONE BY");
printf("\n\tR.Sreevatsan ");
printf("\n\t\tN.Prakash");
printf("\n\t\t\tG.Senthamaraikannan");
printf("\n\t\t\t\tV.Krishnan");
sleep(2);
clrscr();
sleep(2);
clrscr();
printf("\n          -------------------   ");
printf("\n          I N P U T   D A T A           ");
printf("\n          ---------------------   ");
printf("\n \t RATING (h.p ) Q  : ");
scanf("%f",&QHP);
printf("\n\t ENTER THE EFFICIENCY: ");
scanf("%f",&eff);
printf("\n\tENTER THE POWER FACTOR: ");
scanf("%f",&powfac);
Q=QHP/(eff*powfac);
printf("\n \t  VOLTAGE RATING (VOLTS) : ");
scanf("%d",&E);
printf("\n \t FREQUENCY (HERTZ)          : ");
scanf("%d",&f);
printf("\n \t SPEED (RPM)               : ");
scanf("%d",&N);
printf("\n \t AVERAGE FLUX DENSITY (Bav), unit=(Wb/sq.m) : ");
scanf("%f",&Bav);
printf("\n \t AMPERE CONDUCTORS (ac)      : ");
scanf("%d",&ac);
printf("\n \t NUMBER OF STATOR SLOTS (Ss) : ");
scanf("%d",&Ss);
//  clrscr();
p=(120*f)/N;
```

```
// printf("WINDING FACTOR(main)");
k2=Ss/(3*p);
x4=1;
x3=3*k2;
x5=0;
for(j=0;j<(int)k2;j++)
{
tty=(((x3-x4)/(3*k2))*90*(3.14/180));
c[j]=sin(tty);
x5+=c[j];
x3--;x4++;
}
kwm=0;
for(j=0;j<(int)k2;j++)
{
c1[j]=c[j]/x5;
kwm+=c[j]*c1[j];
}


Co=(11*Bav*ac*kwm)/1000;
printf("\n \t OUTPUT CO-EFFICIENT  (Co)       : %f ",Co);
printf("\n \t SELECTION OF L/%c RATIO         : ",231);

printf("\n \t 1.FOR GOOD OVERALL DESIGN L/%c=1 ",231);
printf("\n \t 2.FOR GOOD EFFICIENCY L/%c=1.5   ",231);
printf("\n \t 3.FOR GOOD POWER FACTOR L/%c=1.0 to 1.25",231);
printf("\n \t 4.FOR MINIMUM COST L/%c=1.5 to 2 ",231);
printf("\n");

printf("\n \t ENTER YOUR CHOICE              :");
scanf("%d",&ch);

printf("\n");
switch(ch)
{
case 1:
{
Dia =(Q*p*60)/(1*pi*N*Co);
D=pow(Dia,0.333);
```

```
L=(1*pi*D)/p;
break;
}
case 2:
{
Dia=(Q*p*60)/(1.5*pi*N*Co);
D=pow(Dia,0.333);
L=(1.5*pi*D)/p;
break;
}
case 3:
{
printf("\n \t ENTER A VALUE BETWEEN 1.0 TO 1.25 : ");
scanf("%f",&x);
if ((x<1.25)&&(x>1))
{
Dia=(Q*p*60)/(x*pi*N*Co);
D=pow(Dia,0.333);
L=(x*pi*D)/p;
}
else
printf("\n \t THE VALUE SHOULD LIE BETWEEN 1.0 TO 1.25");
break;
}
case 4:
{
printf("\n \t ENTER THE VALUE BETWEEN 1.5 TO 2  :");
scanf("%f",&y);
if ((y<2)&&(y>1.5))
{
Dia=(Q*p*60)/(y*pi*N*Co);
D=pow(Dia,0.333);
L=(y*pi*D)/p;
}
else
printf("\n \t THE VALUE  SHOULE LIE BETWEEN 1.5 TO 2.0 ");
break;
}
}
tou=(pi*D)/p;
```

```
li=0.95*L;
FP=Bav*pi*D*L/p;
printf("\n \t ENTER THE FLUX DENSITY OF THE STATOR TEETH IN
BETWEEN 1 TO 1.7 Wb/sq.m (Bts) : ");
scanf("%f",&Bts);
Wts=FP*p/(Ss*0.95*L*Bts);
printf("\n \t ENTER THE FLUX DENSITY OF THE STATOR CORE IN
BETWEEN 0.9 TO 1.4 Wb/sq.m (Bcs) :");
scanf("%f",&Bcs);
Dcs = FP/(2*0.95*L*Bcs);

clrscr();
//  getch();
// printf("CONDUCTOR CALCULATIONS");
Tm=.95*E/(4.44*kwm*f*FP);
Tpm=ceil(Tm/p);
Ttm=Tpm*p;
i=(Q*1000)/(E);
ar=i*(1E-6)/id;
z1=sqrt(28*ar/22);
c3=0;
for(j=0;j<(int)k2;j++)
{
c2[j]=ceil(c1[j]*Tpm);
c3+=c2[j];
}
x3=3*k2;
x4=1;
for(j=0;j<(int)k2;j++)
{
lmt[j]=(8.4*(D+dss)/Ss)*(x3-x4)+2*L;
x3--;
x4++;
}
lmtn=0;
for(j=0;j<(int)k2;j++)
lmtn=c2[j]*lmt[j]+lmtn;
lmtm=lmtn/Tpm;
// printf("WINDING FACTOR AUX");
x3=5*k2;
```

```
x4=(int)k2+1;
x6=0;
for(j=0;j<(int)k2;j++)
{
ttx=(x3-x4)/(3*k2)*90*(3.14/180);
c4[j]= sin(ttx);
x6=x6+c4[j];
x3--;
x4++;
}
kwa=0;
for(j=0;j<(int)k2;j++)
{
c5[j]=c4[j]/x6;
kwa=kwa+c4[j]*c5[j];
}
// printf("STARTING WINDING DESIGN");
Ta=ceil(k*Tm*kwm/kwa);
Tppax=ceil(Ta/p);
Tta=Tppax*p;
a1=ar/2.2;
z2=sqrt(28*a1/22);
lmty=0;
x3=5*k2;
x4=k2+1;
for(j=0;j<(int)k2;j++)
{c6[j]=ceil(c5[j]*Tppax);
lmta[j]=8.4*(D+dss)/Ss*(x3-x4)+2*L;
x3--;
x4++;
lmty=lmty+c6[j]+lmta[j];
}
lmts=lmty/Tppax;
D0=D+ 2*dss+2*Dcs;
lg=(.2+2*sqrt(D*L))/1000;
/*  ROTOR DIMENSIONS */
cf=(pi*D);
upw=(cf/4);
pl=D-(2*lg);
/*FIELD WINDING DESIGN*/
```

```
idr=7;
If= 0.25*i;
Xn=If*(1e-6)/idr;
dfw=sqrt((4*Xn)/pi);
/*CAPACITOR DESIGN*/
Im=0.35*i;
xm=E/Im;
kvar=Im*E;
va=0.6*E;
tempvc=pow(E,2)+pow(va,2);
vc = sqrt(tempvc);
Ic=Im*E/vc;
Xc=E/Ic;
C=1/(2*pi*f*Xc);
/*TURNS*/
Tf=i*Tm/If;
Ab=Tf*Xn;
printf("\n        -------");
printf("\n        OUTPUT  ");
printf("\n        --------");
printf("\n  HP RATING   :%f HP",QHP);
printf("\n  THE  NUMBER OF POLES :%d ",p);

printf("\n        ----------------------------------------");
printf("\n        THE STATOR  PARAMETERS");
printf("\n        ----------------------------------------");
printf("\n  DIAMETER (D)       :%f METRES",D);
printf("\n  LENGTH (L)         :%f METRES",L);
printf("\n  POLE PITCH(%c)     :%f METRES",231,tou);
printf("\n  NET IRON LENGTH(Li):%f METRES ",li);
printf(" \n THE FLUX PER POLE  (FP):%f WEBER ",FP);
printf("\n  THE  OUTER  DIAMETER  OF  THE  STATOR  CORE  (D0):%f
METRES",D0);
printf("\n  ------------------------------------------");
printf("\n  STATOR SLOT PARAMETERS");
printf("\n  ------------------------------------------");
printf("\n  THE DEPTH OF THE STATOR CORE              :%f METRES
",Dcs);
printf("\n  THE DEPTH OF THE STATOR SLOT              :%f METRES
",dss);
```

```
printf("\n  TOP WIDTH OF THE STATOR SLOT                    :%f
METRES",uw);
printf("\n  BOTTOM WIDTH OF THE STATOR SLOT                  :%f
METRES",bw);
printf("\npress any key to continue");
getch();
printf("\n  --------------------------------------------------");
printf("\n  THE MAIN WINDING PARAMETERS ");
printf("\n  --------------------------------------------------");
printf("\n THE WINDING FACTOR OF MAIN WINDING :%f ",kwm);
printf("\n THE NUMBER OF TURNS IN SERIES PER POLE :%d",Tpm);
printf("\n THE TOTAL TURNS IN SERIES FOR THE MAIN WINDING
:%d",Tm);
printf("\n THE RATED CURRENT OF THE MACHINE :%fAMPS",i);
printf("\n THE AREA OF THE MAIN WINDING IS :%e SQUARE
METRES",ar);
printf("\n THE DIAMETER OF THE CONDUCTOR :%f METRES",z1);
printf("\n THIS DIAMETER IS NOT CONSIDERING THE ENAMEL
THICKNESS");
getch();
x3=3*k2;
x4=1;
for(j=0;j<(int)k2;j++)
{
rx=ceil(c2[j]);
printf("\n THE TURNS OF THE COIL (%d,%d)=%d",x3,x4,rx);
x3--;
x4++;
}
x3=3*k2;
x4=1;
for(j=0;j<(int)k2;j++)
{
printf("\n THE LENGTH OF MEAN TURN OF COIL
(%d,%d)=%f",x3,x4,lmt[j]);
x3--;
x4++;
}
printf("\n THE LENGTH OF THE MEAN TURN OF THE MAIN
WINDING =%f",lmtm);
```

```
getch();
clrscr();
printf("\n ------------------------------------------------------------     ");
printf("\n T H E  S T A R T I N G  W I N D I N G  P A R A M E T E R S
");
printf("\n ------------------------------------------------------------");
printf("\n THE AREA OF THE STARTING WINDING :%e SQUARE
METRES ",a1);
printf("\n THE DIAMETER OF THE STARTING WINDING :%f
METRES",z2);
printf("\n THIS DIAMETER IS NOT CONSIDERING THE ENAMEL
THICKNESS");
printf("\n THE WINDING FACTOR OF STARTING WINDING :%f
",kwa);
printf("\n THE TURNS PER POLE IN STARTING WINDING
:%d",Tppax);
printf("\n THE TOTAL TURNS IN STARTING WINDING :%d",Tta);
x3=5*k2;
x4=(int)k2+1;
for(j=0;j<(int)k2;j++)
{
printf("\n THE TURNS OF THE COIL (%d,%d)=%d",x3,x4,c6[j]);
x3--;
x4++;
}
x3=5*k2;
x4=(int)k2+1;
for(j=0;j<(int)k2;j++)
{
printf("\n THE LENGTH OF MEAN TURN OF
COIL(%d,%d)=%f",x3,x4,lmta[j]);
x3--;
x4++;
}
printf("\n THE LENGTH OF MEAN TURN OF STARTING WINDING
:%f",lmts);
printf("\n THE LENGTH OF AIR GAP OF THE MACHINE :%f
METRES",lg);
getch();
printf("\n\t\tROTOR DESIGN");
```

```
dr = D-(2*lg*1e-3);
sr = Ss-2*p;
tcsm = 2*Ttm*ar;
tcsr = 0.5*tcsm;
neckr = 1.0668;
lipr = 1;
rsp = (3.141592654*dr)/sr;
ib = (2*i*powfac*Ttm*kwm)/sr;
l1 = 0.95*L;
wtr = FP/((sr/p)*l1*1.5);
wors = rsp-wtr;
aer = 0.32*tcsr/p;
aer = aer+0.0001;
tcsb = tcsr-2*aer;
worb = wors-0.001;
dob = tcsb/worb;
dors = (neckr/1000)+(dob+0.002);
dcr = FP/(2*l1*bcr);
idr = dr - dors - dcr;
ab1 = dob*worb;
ssp = 3.142857*D/Ss;
lb = sqrt(L*L+ssp*ssp);
sd = idr;

/*  END RING DESIGN */

ie = sr*ib/(3.141592654*p);
doe = 10e-3;
toe = aer/doe;
dero = dr-3*1e-3;
deri = dero - 2*doe;
dem = (dero+deri)/2.0;
printf("\n-----------------------------------------");
printf("\n\t\tROTOR DESIGN");
printf("\n-----------------------------------------");
printf("\nThe number of rotor slots : %f",sr);
printf("\nThe outer diameter of rotor : %f metres",dr);
printf("\nThe width of rotor slot is : %f metres",wors);
//printf("\nThe depth of rotor slots is %f metres",dors);
printf("\nThe width of the bar is %f metres",worb);
```

```
//printf("\nThe depth of the bar is %f metres",dob);
//printf("\nThe area of the bar is %f sq. metres",ab1);
printf("\nThe length of each bar is %f metres",lb);
printf("\nThe width of rotor tooth is %f metres",wtr);
printf("\nThe depth of rotor core is %f metres",dcr);
printf("\nThe neck of the rotor slot is %f mm",neckr);
printf("\nThe lip of the rotor slot is %f mm",lipr);
//printf("\nThe inner diameter of the rotor is %f metres",idr);
printf("\nThe bar current is %f Amps",ib);
getch();
clrscr();

printf("\n------------------------------------------");
printf("\n\t\tEND RING DESIGN");
printf("\n------------------------------------------");
printf("\nThe depth of the end ring is %f metres",doe);
printf("\nThe thickness of the end ring is %f metres",toe);
printf("\nThe outer diameter of the end ring is %f metres",dero);
printf("\nThe inner diameter of the end ring is %f metres",deri);
printf("\nThe mean diameter of the end ring is %f metres",dem);
printf("\nThe area of the end ring is %f sq. metres",aer);
printf("\nThe end ring current is %f Amps",ie);
getch();
clrscr();



clrscr();
printf("\n--------------------------------");
printf("\n C A P A C I T O R   D E S I G N ");
printf("\n---------------------------------");
printf("\nMAGNETISING CURRENT(Im):%f AMPS",Im);
printf("\n VOLTAGE ACROSS THE CAPACITOR (Vc):%d VOLTS ",vc);
printf("\n CAPACTIVE REACTANCE(Xc): %f OHMS ",Xc);
printf("\n THE VALUE OF CAPACITANCE(C);%e FARADS",C);
printf("\n AREA TO BE PROVIDED IN THE BOBBIN FOR THE
WINDINGS TO BE WOUND(Ab):%f SQUARE METRES",Ab);
printf("\n NUMBER OF TURNS IN THE FIELD WINDING(Tf): %d ",Tf);
getch();
}
```

FABRICATION AND TESTING

CHAPTER 6

FABRICATION AND TESTING

6.1 FABRICATION

The motor is fabricated for 0.25 hp,3000 rpm. The details of fabrication is given below.

6.1.1 SELECTION OF FRAMES AND STATOR ASSEMLY

The main dimensions D and L are obtained from the software written in 'C' language and the stator frame size is selected based on these values . The various machine parts such as end covers, shafts and bearings are chosen .They are machined according to the standards .

The stator core is placed in the frame and winding is housed in the slots .

6.1.2 ROTOR DIECASTING

The rotor is diecasted to provide the end rings and rotor windings . The magnetic poles are placed in the cage rotor.

6.1.3 INSPECTION AND ASSEMBLY

The stator frame, rotor assembly, dimensions of the shaft, end covers, are inspected .After successful inspection the machine is assembled and tested.

6.2 TESTING

The tests that are performed on the synchronous induction motor are:

- Measurement of stator resistance.
- No load test
- Load test

6.2.1 MEASUREMENT OF STATOR RESISTANCE

The resistance of the stator is measured by using an ohmmeter. The stator resistance at 32°is found to be 5.08 ohms.

6.2.2 NO LOAD TEST

The no load test is conducted and the following results are obtained.

Voltage (Volts)	Current (Amps)	Input (Watts)	Speed (rpm)	Frequency (Hz)
230	3.1	250	2900	48.33

6.2.3 LOAD TEST

Load test is conducted on the motor by using brake drum arrangement. The following results are obtained.

Voltage (volts)	Current (Amps)	Input (Watts)	Speed (rpm)	Frequency (Hz)
230	3.5	280	2900	48.33
230	3.6	300	2900	48.33
230	3.8	328	2900	48.33
230	4.0	340	2900	48.33
230	4.1	348	2900	48.33
230	4.2	360	2900	48.33
230	4.3	400	2900	48.33
230	4.4	440	2900	48.33
230	4.5	496	2900	48.33

6.2.4 CALCULATIONS

Resistance of the stator at 75° C $R_{75} = 5.77\Omega$

Constant loss, W_k = No load input – No load copper loss

= $180 - 5.77 * 3.1^2$

= 194.55 Watts

The calculation is done only for the last value.

Total loss = Constant loss + Copper loss

Input = 496 Watts

Stator copper loss = $5.77 * 4.5^2$ = 116.68 Watts

Total loss = 116.68 + 194.55 = 311.39 Watts

Rotor input = Input – Total loss =496 –311.39 = 184.60 Watts

Rotor output = 0.995 * rotor input (Considering friction and windage loss)

= 183.68 Watts

Efficiency = Rotor output/Input = 183.68/496 = 37.03 %

The variation of output with speed is given by the following tabular column.

Output (Watts)	Speed(rpm)
14.69	2900
30.67	2900
50.13	2900
53.13	2900
56.45	2900
63.66	2900
98.76	2900
133.74	2900
184.60	2900

CONCLUSION

CHAPTER 7

CONCLUSION

In this project, a synchronous induction motor of 0.25 hp, 3000 rpm has been designed, fabricated and tested successfully.

A user friendly computer program has been developed for the design of the motor.

The motor runs at a constant speed irrespective of the load. Thus the desired feature has been achieved.These motors can be made cheaper if fabricated on a large scale.

These motors can be used in appliances like

- Wet grinders
- Small Pumps
- Fans
- Tool grinders etc.

REFERENCES

REFERENCES

(1) Ram Kumar & Rakesh Aggarwal – "Programming in ANSI C ", 4th edition ,Tata McGrawHill Publishing Company Ltd. , New Delhi –1996.

(2) A.K Sawhney - "Electrical Machine Design ", 3rd edition, Dhanpat Rai & Sons, New Delhi – 1995

(3) B.L Theraja – "Electrical Technology ", 10th edition, Niraj Construction & Development Company(P) Ltd. ,New Delhi, 1989.

(4) A. Shanmugasudaram , G. Gangadharan , R.Palani – "Electrical Machine Design Data Book",1st edition, Wiley Eastern Ltd. ,New Delhi, 1972

(5) M.V Deshpande – "Design & Testing of Electrical Machines ", 2nd edition, Wheeler Publishing, New Delhi, 1985.