ENERGY CONSERVATION IN INDUCTION MOTOR

PROJECT REPORT

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CERTIFICATE

This is to certify that the project entitled **"ENERGY CONSERVATION IN INDUCTION MOTOR"** has been submitted by,

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Internal Examiner

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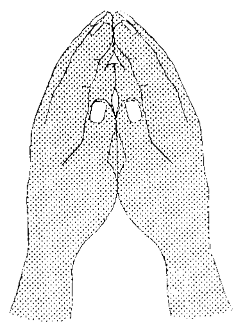
DEDICATED

TO OUR

BELOVED PARENTS

AND

FUTURE ENGINEERS



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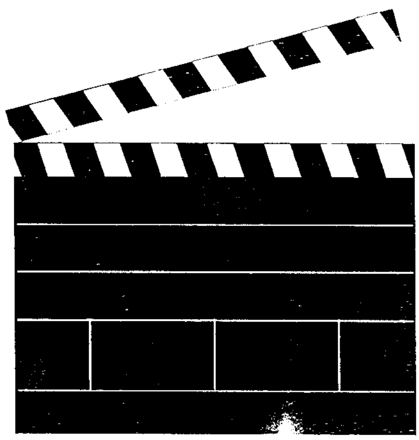


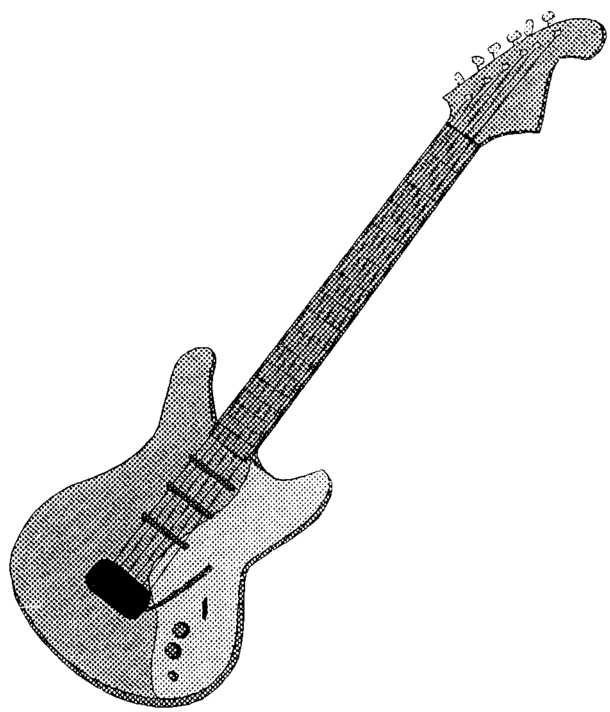
SYNOPSIS

SYNOPSIS

In Agro-Pumping sector, the main problem is wide variation in voltage, frequency and head levels due to which the efficiency of the motor - pumpset is reduced. Due to the above mentioned reasons the cost of pumping the water is increasing. In this project a special type of submersible motor is proposed to be designed which is capable of taking up variable voltage and delivers constant efficiency under these conditions. A suitable solid state circuitry is presented to provide variable frequency to the motor according to the variation in the head level. A software for the design of a submersible motor in C language is developed and the test results are presented.

Since the efficiency in this motor is maintained constant approximately the cost of pumping is considerably reduced. Research is being carried out at national level to conserve the energy.

CONTENTS



NOMENCLATURE

NOMENCLATURE

The following are the symbols used in the design of submersible motor using C software program:

hp	-	Power rating of the machine
eff	-	Efficiency of the motor
pf	-	Powerfactor
E	-	Voltage
J	-	Current density
sa	-	Stator slot area
Iph	-	Current/phase
as	-	Conductor area
di	-	Conductor diameter
di1	-	Conductor diameter (with insulation)
dsi	-	Conductor area (with insulation)
Ss	-	Number of stator slots
D	-	Inner diameter
Z	-	Number of conductors / slot
ac	-	Ampere conductors / m
Bav	-	Average flux density
Kw	-	Winding factor
Co	-	Output co-efficient
Q	-	Power in KVA
Fm	-	Flux/ pole
f	-	Frequency
p	-	Number of poles
polpit	-	Pole pitch

Tph	-	Turns per phase
dcs	-	Depth of stator core
n	-	Speed in rps
ty	-	Thickness of lamination
dcse	-	Effective depth of stator core
wts	-	Width of stator core
dcr	-	depth of rotor core
L	-	Core length
Li	-	Effective core length
Bt	-	Flux density in stator teeth
Bys	-	Flux density in stator core
Btr	-	Flux density in rotor teeth
Byr	-	Flux density in rotor core
dcre	-	Effective depth of rotor core
rsh	-	Shaft radius
wtr	-	Width of rotor teeth
htr	-	Height of rotor teeth
w,a,b,c,d,e	-	Stator slot dimensions
h	-	Height of the stator slot
Vst	-	Volume of the stator teeth
Wst	-	Weight of the stator teeth
Sst	-	Loss factor for stator teeth flux density
ILst	-	Iron loss in stator teeth
Vsy	-	Volume of stator yoke
Do	-	Outer diameter
Wsy	-	Weight of stator yoke
Ssy	-	Loss factor for stator core flux density

ILsy	-	Iron loss in stator yoke
TIL	-	Total Iron loss
TNL	-	Total No load loss
FL	-	Friction and Windage losses
Lmt	-	Length of mean turn
r_s	-	Stator winding resistance
CLs	-	Stator copper loss
Lb	-	Rotor bar length
Ib	-	Rotor bar current
Jb	-	Rotor bar current density
Sr	-	Number of rotor slots
rb	-	Rotor bar resistance
ab	-	Area of rotor bar
CLb	-	Copper loss in rotor bar
Ie	-	End ring current
ae	-	Area of the end ring
de	-	Depth of the end ring
t_e	-	Thickness of the end ring
lg	-	Length of airgap
Dr	-	Rotor diameter
Doe	-	Outer diameter of the end ring
Die	-	Inner diameter of the end ring
De	-	Mean diameter of the end ring
r_e	-	Resistance of the end ring
CLe	-	Copper loss in the end ring
CL	-	Total copper loss
TL	-	Total losses
ef	-	Efficiency of the motor

Kcs	Carter's co-efficient for stator slots
Yss	Stator slot pitch
Kgss	Gap contraction factor for stator slots
Kgsr	Gap contraction factor for rotor slots
Kgs	Gap contraction factor for slots
Kgd	Gap contraction factor for ducts
Kcsr	Carter's co-efficient for rotor slots
Kg	Gap contraction factor
Ag	Area of airgap
Bg60	Maximum flux density in the airgap
lge	Effective length of the airgap
ATg	mmf required for the airgap
At	Area of the stator teeth
atst	AT/m required for stator teeth
ATst	mmf required for stator teeth
Lcs	Length of the stator core
atsc	AT/m required for stator core
Atsc	mmf required for stator core
Lcr	Length of rotor core
atrc	AT/m required for rotor core
Atrc	mmf required for rotor core
AT	Total mmf required
Im	Magnetising current/phase
Il	Loss component of No load current
Io	No load current
atrt	AT/m required for rotor teeth
Atrt	mmf required for rotor teeth
Lss	Stator slot leakage permeance

m_o	-	μ_o (constant)
Lsr	-	Rotor slot leakage permeance
Ls	-	Total slot leakage permeance
Slr	-	Slot leakage reactance
q	-	Stator slots / pole / phase
Cs	-	Coil span
Ks_1, Ks_2, Ks	-	Slot leakage factor
LoLo1, LoLo2, LoLo	-	Loλo
x_o	-	Overhang leakage reactance
X_m	-	Magnetising reactance
q_r	-	Rotor slots / pole / phase
x_s	-	Zigzag leakage reactance
Xs	-	Total leakage reactance
R	-	Radius of the slot curve
pfnl	-	No load powerfactor
pfsc	-	Short circuit powerfactor
Pinl	-	No load power angle
Pisc	-	Short circuit power angle
r35	-	Resistance at 35^0 C
Isc	-	Short circuit current
Zt	-	Total impedance
RCLph	-	Rotor copper loss / phase
Rt, Rr	-	Rotor resistance referred to stator
Pc	-	Copper loss in stator portion
TCL	-	Total loss to be dissipated
OSCA	-	Outer cylindrical surface of stator
CCo	-	Cooling co-efficient

LO	-	Loss dissipated from back of core
Va	-	Peripheral speed
Vvi	-	Velocity of air at end surface
CCs	-	Cooling co-efficient of surface at ends
ISCA	-	Inside cylindrical surface of stator
CCi	-	Cooling co-efficient for inside surface
TLD	-	Total loss dissipated
Temp	-	Stator temperature rise

INTRODUCTION

CHAPTER 1

INTRODUCTION

Electricity (Power/Energy) has become indispensable in everyday life. Electricity is an essential input for the growth of economy of any nation. Agriculture in India uses more energy next to industry. About 35% of electric energy is consumed by pumpsets in agricultural sectors. Electrical energy costing more than Rs.100 billion is annually wasted by agro-pumping. For a developing country like India this is a heavy loss.

1.1 ENERGY CONSUMPTION BY AGRICULTURAL PUMPSETS IN INDIA

The electrical energy consumption for agriculture in India was about 7% in 1965-66 and 17.6% in 1981. Now it is more than 30%. This is mainly to pump the ground water for irrigation purposes. It can be assumed that 25-30 million more agro pumps may be required when all the rechargeable ground water is extracted to irrigate the crops. Each of these agro pumps are consuming on an average about 6000kwh of power per annum whereas only half of this should suffice if suitable pumpsets of presently achievable efficiency are installed and maintained properly.

1.2 MAJOR FACTORS INFLUENCING WASTAGE OF ENERGY

The wastage of energy arises out of

- Mismatch of pump set to water source.
- Large variation in supply voltage.
- Variation in head.

Majority of the centrifugal pumps are operating at very low efficiencies.

The other reasons for low efficiency from mechanics point of view is :

- Use of inferior quality of pipe and wrong pipe fittings.
- Oversized / undersized prime movers.

- Seasonal changes in borewell yields.
- Erosive solid contents in water.

The efficiency of these pumping sets could be increased to a great extent, thereby reducing total electrical energy consumption.

1.3 ENERGY CONSERVATION

It is very difficult to get the required efficiency due to following reasons :

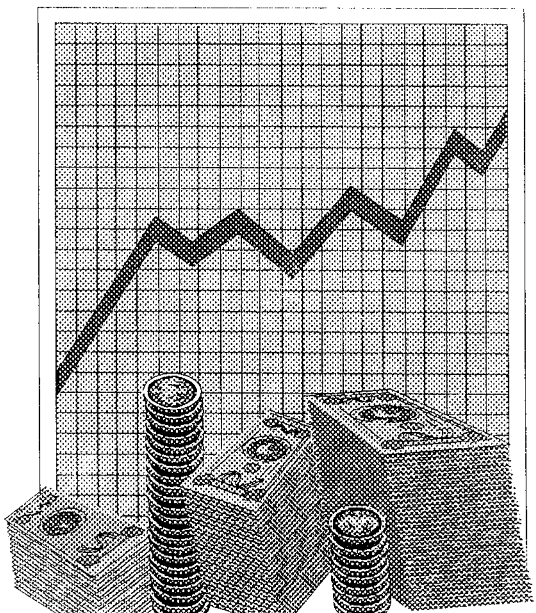
1.3.1 HEAD RANGE

The head variations are too much especially in hard rock area. The head variations may also be due to seasonal variations, drought conditions etc.

1.3.2 SUPPLY VOLTAGE

In view of steady increase in the consumption of Electrical Energy and expansion of electrical power system the voltage in the distribution network, which supplies the Agricultural pumpsets is well below the rated value. The line voltage falls to as low a value as 250. In other words the electricity pumpsets must operate between 250-460 volts and this invariably results in low efficiency.

This project aims at designing an induction motor which is capable of handling variable voltage. Necessary power electronic circuits can be used to match the head variations with frequency.



COST CALCULATIONS

CHAPTER 2

COST CALCULATIONS

2.1 GENERAL

It is a well known fact that pumpsets employed in agriculture and domestic water supply consume more than 30 % of electrical energy annually. It is learnt that efforts are on for increasing the minimum overall efficiency of pumpsets. Before it is decided to raise the minimum overall efficiency of pumpsets, we have to consider the varying operating conditions which these pumpsets are put to and the effect of such field conditions on the pumpsets. In this chapter the performance of a typical 6" submersible pump due to the variation in voltage and frequency is presented.

2.2 WATER LEVEL FLUCTUATIONS

The water level in wells and bore wells vary widely and are affected by seasons, volume of tapping, rainfall etc., A pump selected by the farmer must suit to the local conditions, work at duty point head between summer and monsoon. The pumpset must be operated at 85 % dutypoint during summer and 50% head during monsoon.

Duty point head - Normally submersible pumps are designed for 60m head. The designed head of operation is known as duty point head.

2.3 COST CALCULATIONS

Consider a small village having a tank of capacity 3,00,000 litres. A submersible pump is employed to fill the tank. The cost incurred for filling this tank under voltage and frequency conditions in dealt briefly.

Consider the voltage from the Electricity board in varying from 250 - 460 V, head as variations 30-70m and the frequency from 48.5 to 51 Hz.

The tabular column drawn below illustrates that the cost incurred for these varying conditions.

2.4 MODEL CALCULATIONS

Tank capacity	=	3,00,000 litres
Discharge	=	4 lps
Input power	=	4.43 Kw
Cost/Kwh	=	Rs. 2/-

$$\text{Time taken for filling the tank} = \frac{3 \times 10^5}{4 \times 3600} = 20.83 \text{ hrs}$$

Energy consumed = 4.43 x 20.83

= 92.3 kwh

Total Cost per day= 92.3 x 2 = Rs. 184.6

Total cost per year = 184.6 x 365

= Rs. 67379/-

Duty point head	=	60.8 mtrs
Discharge	=	3.2 lps
Overall efficiency	=	37 %

Voltage (V)	Frequency (Hz)	Head (m)	Q (lps)	Pi (Kw)	Cost (Rs.)
440	51	70	2.68	4.175	94881.84
415			2.35	4.28	110794.33
360			1.90	4.33	138635.97
300			1.03	3.33	199627.84
250			0.55	3.98	440212.09
440	51	60	3.65	4.7	78333.33
415			3.53	4.63	79789.90
360			3.23	4.75	89460.78
300			2.73	4.35	96932.23
250			2.03	4.45	133353.86
440	51	50	4.18	4.6	669450.77
415			4.10	4.6	68252.03
360			3.98	4.8	73366.84
300			3.58	4.7	79864.99
250			2.9	4.9	102787.35
440	51	40	4.5	4.58	61914.81
415			4.4	4.65	62500.61
360			4.45	4.68	63977.53
300			4.05	4.78	71798.36
250			3.58	5.15	87511.64
440	50	60	2.95	4.6	94858.78
415			2.70	4.4	99135.00
360			2.45	4.3	106768.72
300			2.15	4.08	115441.85
250			1.15	4.85	280992.06
440	50	50	3.75	4.44	72026.67
415			3.65	4.44	74000.00
360			3.50	4.52	78561.91
300			3.10	4.29	84185.48
250			2.50	5.16	125560.00
440	50	40	4.15	4.35	63765.06
415			4.10	4.32	64097.57
360			4.0	4.5	68437.50
300			3.7	4.29	70533.78
250			3.08	5.22	104114.75
440	50	30	4.57	4.38	58304.16
415			4.5	4.29	57994.44
360			4.41	4.35	60005.67
300			4.18	4.32	62876.82

250			3.6	5.46	92263.89
440 415 360 300 250	48.5	60	3.15 2.9 2.55 2.25 1.80	4.47 4.33 4.02 3.78 3.81	86325.39 90830.45 95901.95 102200.00 128763.88
440 415 360 300 250	48.5	50	3.725 3.65 3.53 3.10 2.65	4.62 4.5 4.29 4.14 5.22	75348.52 76600.32 79897.56 81241.94 119830.17
440 415 360 300 250	48.5	40	4.18 3.83 3.73 3.68 3.15	4.68 4.53 4.42 4.32 5.46	68110.05 69112.30 70223.45 71413.05 105444.45
440 415 360 300 250	48.5	30	4.63 4.52 4.42 4.18 3.6	4.62 4.53 4.45 4.32 5.46	60701.94 61124.80 62230.45 62870.82 92263.89

2.5 CONCLUSION

It can be noted that for constant frequency and head the cost of pumping the water increases with decreases in voltage from 440 V to 250 V. when f = 50 Hg, and H = 60m., the cost is Rs. 94858.75 for 440 V and Rs. 280992.06 for 250V. Hence, there is a cost difference of Rs. 190000 due to the voltage variation.

It can also be noted that for constant voltage and head the cost of pumping the water changes with the frequency for eg.

For V = 415 H = 60 m

f = 48.5

f = 50

f = 51

T.C.= Rs. 90000

T.C.= Rs. 99000

T.C.= Rs. 79000

Similarly for constant voltage and frequency the cost varies.

For v = 415V, ; f = 50 Hz

60m	Rs. 99000
50m	Rs. 74000
40m	Rs. 64000
30m	Rs. 58000

To prevent the wide variation in the cost for variable working conditions it is necessary to operate the submersible motor under optimum conditions. So in order to bring the cost of pumping water around Rs.60000 the efficiency of the motor is maintained constant approximately for variable voltages. The energy efficiency of motor is highest only for the rated voltage, frequency and power. Since the value of all these parameters namely head, voltage and frequency are varying beyond tolerable level in India. In even the best pumpsets are destined to waste energy and run at lower efficiencies.

INVERTER CONTROLLED INDUCTION MOTOR

CHAPTER 3

INVERTER CONTROLLED INDUCTION MOTOR

3.1 INTRODUCTION

The large variation in ground water level during pumping and over season makes the selection of a suitable pumpset with lowest operating cost (expending least energy) impossible. Indian standards prescribe head ranges to cope with this situation. Only alternating way is to vary the speed of pump to suit the varying water level to work at its best efficiency. This type of variable application has come into vogue in U.S.A. and Europe. This requires variable speed motion.

This could be possible by means of a solid controller which would accept the widely varying frequency and provide the motor with controlled frequency depending upon the head variation so that the pumpset would be made to run at any speed safely.

The block diagram of the project is shown in figure 1.1.

The project is split up into two parts.

i. Design of a submersible motor capable of taking up variable voltage.

ii. Design of a solid state controller capable of supplying variable frequency depending upon the head variation.

3.2 SELECTION OF SUITABLE MOTOR:

The following types of variable speed motors are available:

a) Induction motor

b) Permanent magnet Brushless DC motor (BDCM)

c) Switched Reluctance Motor (SRM)

Switched Reluctance motor (SRM) is attractive due to its simple construction, but the electronic technology required for its control has not reached sufficient maturity to have confidence to adopt it. BDCM technology is more mature and also offers the highest efficiency. However it is likely to be costly owing to the need of permanent magnets and rotor-position sensing. Significant development effort will also be required to produce suitable designs for 'all wet' motors and considerable investments in new materials and techniques by the manufacturers. Thus, the induction motor with inverter is the most appropriate solution.

The technology is well proven in similar application and it offers the lowest cost for a brushless, variable speed drive. Further more, the burden of change on the industry is relatively slight in respect to the motor itself and the manufacturers can devote more of their resources to the implementation of reliable, low cost, electronic control system.

3.3 MERITS OF THE INDUCTION MOTOR WITH INVERTER CONTROL:

1) Of the three motor types considered, the induction motor is the only one that is capable of running independently of an electronic system. It means that the customer could be offered the option of fixed speed or variable speed based on

the same motor. It is also possible that the motor could be operated in fixed speed mode in the even of electronic failure.

2) The inverter can be used to overcome to some degree, the problems of voltage regulation (i.e.) unbalance in 3 phase supply.

3) With inverter control a three-phase motor can be used even when the supply is single phase, with added advantages of **higher** efficiency and lower cost.

3.4 VARIABLE SPEED CONTROL

As mentioned above highly efficient inverter controllers are used to control industrial pump. The same controllers could be redesigned to suit the requirements of agro-pumpsets.

The controller incidentally could be designed to accept variable voltage and frequencies and deliver required frequency thus over coming low frequency problem of the power supply.

The controller could also be designed to keep unity powerfactor, which could solve the low power factor scenario in rural grids.

The required power electronics circuitry for the above mentioned controllers are explained in detail in chapter 7.

3.5 PRINCIPLE OF OPERATION

The block diagram in figure 3.1 gives the general layout of the project. It consists of

i. Special type of submersible motor.

ii. Variable frequency inverter.

iii. Transducers

A water level transducer is employed which is used to detect the head level variations. The output of the transducer is used to trigger the variable frequency inverter. The frequency output of the inverter will be in proportional to the head level variations.(i.e.)

$$\Delta H \,\alpha\, (\Delta f)^2 \qquad (\because\ \Delta f \,\alpha\, \Delta N\ )$$

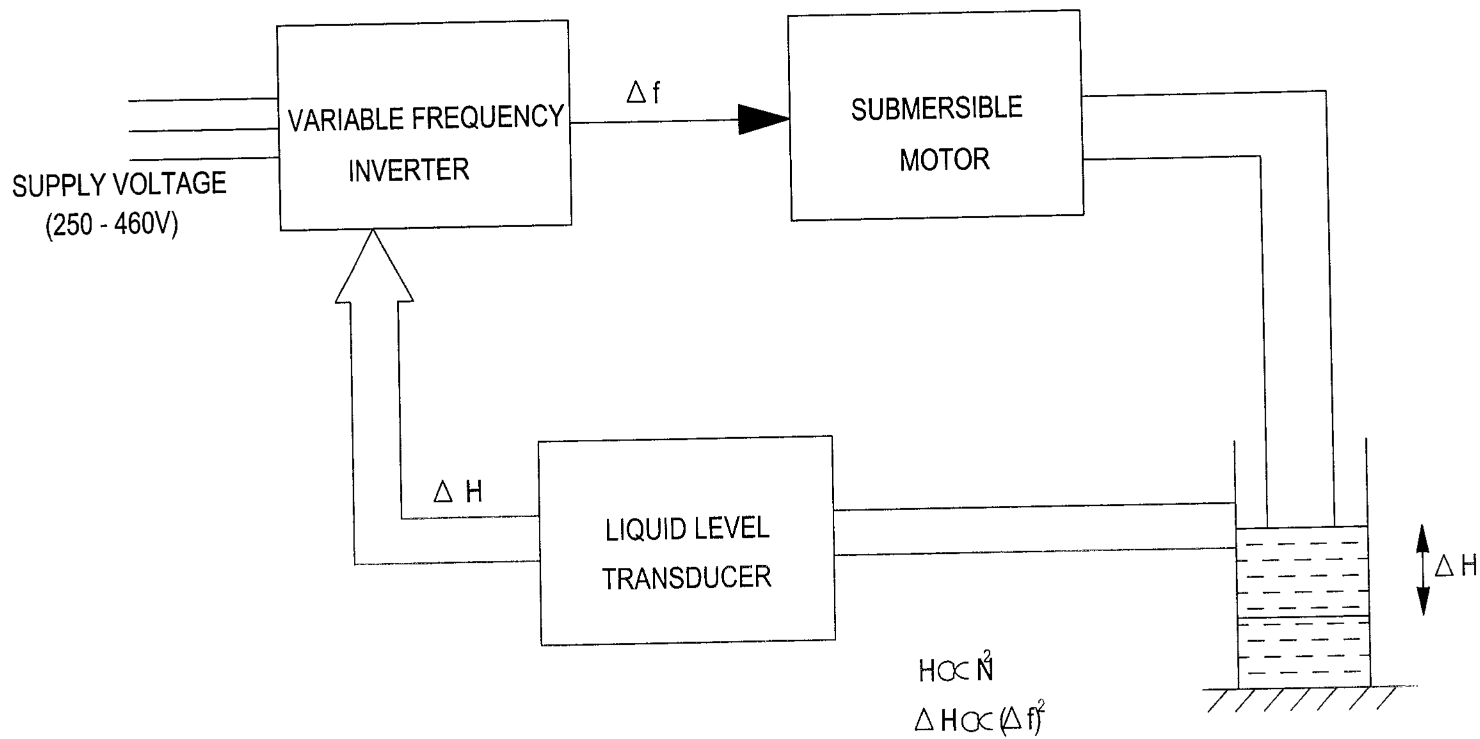
$$\therefore\quad \Delta H \,\alpha\, (\Delta N)^2$$

So by controlling the frequency input to the induction motor the speed of the motor can be controlled and hence the head level variation is compensated.

The induction motor designed is of special type, which is capable of taking up wide variations in voltage from 315V to 440V.

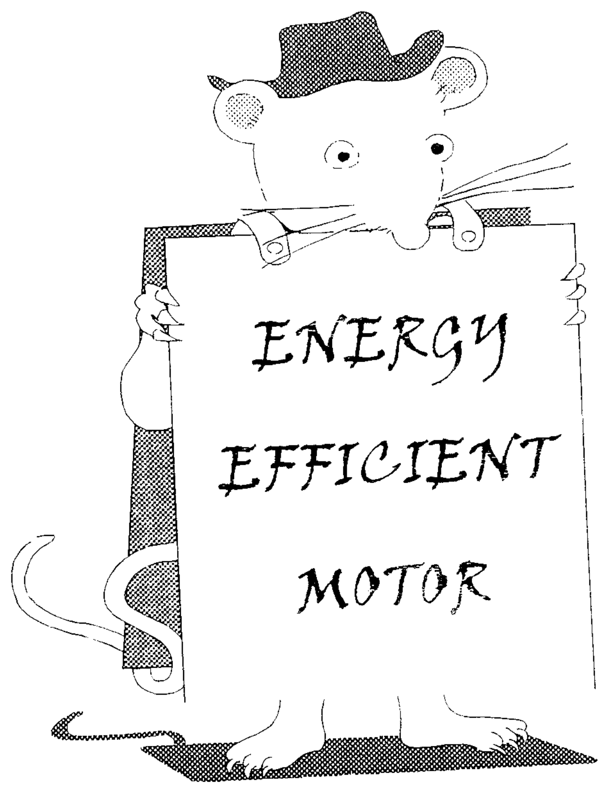
The computer-aided design of induction motor is presented in Chapter 5 and the need for such motor and their design considerations are presented in Chapter 4.

More about the types of transducers* used are presented in Chapter 7.



BLOCK DIAGRAM

FIG 3.1


ENERGY
EFFICIENT
MOTOR

CHAPTER 4

ENERGY EFFICIENT MOTOR

4.1 NEED FOR ENERGY EFFICIENT MOTOR:

The main objective of the manufactures is to reduce the initial cost of the machine by reducing the volume of material and use of low-grade material. But it will result in more overall cost. Using energy efficient motor we can reduce the overall cost since the energy efficient motors have high efficiency and good power factor.

4.2 LOSSES IN AN INDUCTION MOTOR:

4.2.1 STATOR COPPER LOSS:

Due to the current passing through the stator winding the stator copper loss occurs. It can be reduced by reducing the number of turns of the stator coil which reduces the stator resistance. This results in higher magnetic flux density, which may lower the powerfactor and increase the core loss.

4.2.2 STATOR IRON LOSS:

Iron loss consists of hystersis and eddy current loss. Increasing the length of the stator core can reduce iron losses. Thus energy efficient motor uses both more copper and more iron than ordinary motors.

Another efficient means of reducing iron loss is to use a better grade of steel for the laminations and to reduce the thickness. Increasing the silicon content up to some extent reduces the watts/kg loss. However high silicon content may increase the reluctance resulting in lower power factor.

When the thickness of the steel laminations are reduced the eddy current loss decreases but the cost of the motor increases.

4.2.3 ROTOR OHMIC LOSS:

Rotor ohmic loss cannot be changed as the starting torque of a motor is proportional to its rotor resistance. Rotor resistance can be varied only in a limited range, to maintain the value of starting torque. But in case of squirrel cage induction motors rotor resistance can never be varied.

4.2.4 FRICTION AND WINDAGE LOSS

These are associated with the mechanical rotation. Major component of power is taken by fan. Usually energy efficient motor uses smaller fans. Since the submersible motor is water cooled there is no necessity for fan cooling.

4.2.5 STRAY LOSSES

Stray losses are due to the imperfection in the airgap flux density, harmonic rotor currents and iron parts. It can be avoided using magnetic stator slot wedges and stator slot opening.

A comparison between a standard motor and an Energy Efficient motor is shown in table 4.1.

4.3 CONSTRUCTION

4.3.1 STATOR

The stator of a submersible motor has a fixed diameter as the bore hole of the pumpset is fixed. The stator consists of trapezoidal slots generally and the number of slots are fixed. The stator stamping is shown in figure 4.1. The stator laminations are welded at several places. The segments are held together by axial key bars fitting into the dove tailed slots in the outer rim of the core. M_{45} grade stamping is used.

4.3.2 ROTOR

Like stator, the rotor laminations are punched as a single unit. Squirrel cage rotor is used. The same grade of stamping is used as in the case of stator. The rotor dimensions are also fixed.

4.3.3 SHAFTS AND BEARINGS:

The airgap of a submersible motor is made as small as possible. Therefore the shaft is made short and stiff.

Thrust bearing is used, as the whole weight of the frame is going to rest on the bearing.

4.3.4 STATOR WINDINGS

The windings are PVC coated as the motor is going to be placed inside water. Hence the number of conductors/slot is considerably reduced.

4.4 DESIGN

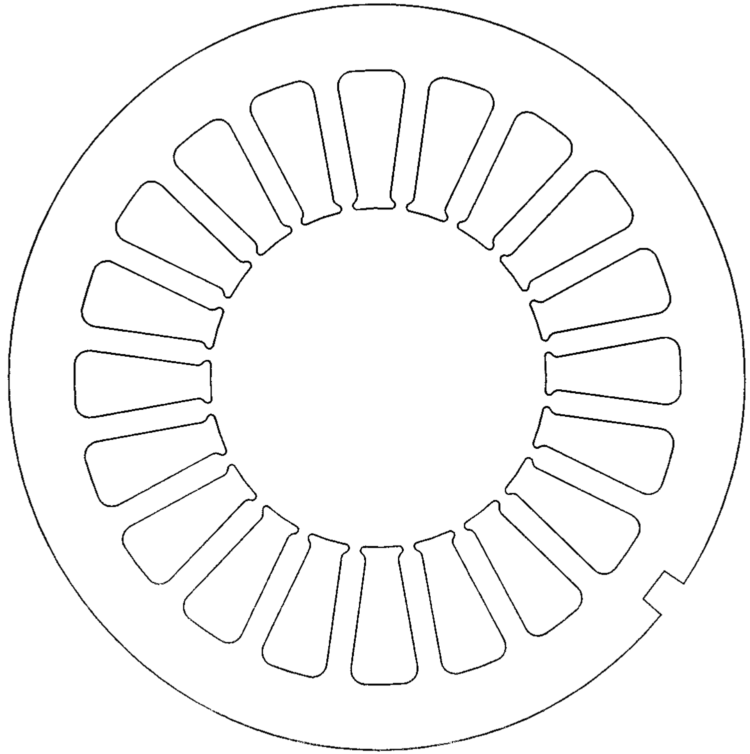
The basic idea behind the design of the Energy Efficient motor is that the extra iron loss at higher voltages is compensated by reduced copper loss and vice versa. Since the outer diameter is fixed varying the rotor length the number of turns required and by choosing various grades of stamping materials the loss compensation is done. By trial and error method an optimum core length, core diameter and grade of stamping are chosen so that the efficiency is approximately maintained constant for voltages varying from 460 – 250V.

The crux of the design is that the core length is chosen for the largest voltage and the wire diameter for the smallest voltage.

COMPARISON OF MOTORS

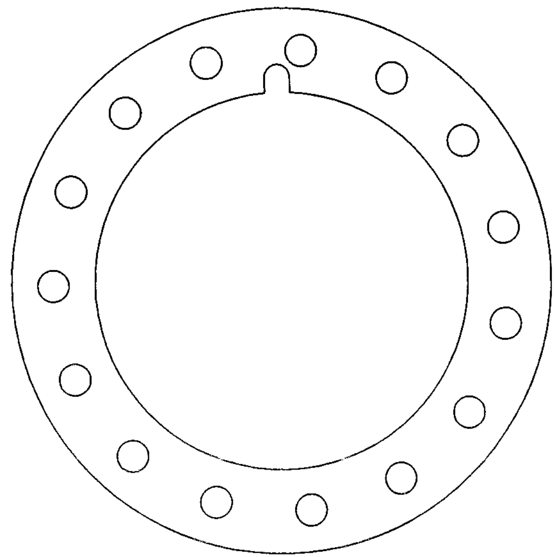
Particulars	Standard motor	Energy efficient motor
Stray loss	4%	3%
Friction & windage loss	10%	9%
Rotor Copper loss	20%	17%
Core loss	24%	17%
Stator Copper loss	42%	30%

TABLE 4.1



STATOR STAMPING

FIG 4 .1



ROTOR STAMPING

FIG 4.2

COMPUTER AIDED DESIGN OF ENERGY EFFICIENT MOTOR

CHAPTER 5

COMPUTER AIDED DESIGN OF ENERGY EFFICIENT MOTOR

In this chapter development of software using C language is presented for the design of submersible motor.

5.1 ALGORITHM:

Step 1 : Start the program

Step 2 : Enter the power rating, powerfactor, efficiency, frequency and number of poles.

Step 3 : Enter the stator and rotor slot dimensions.

Step 4 : Enter the voltage rating.

Step 5 : Enter the core length and number of conductors per slot.

Step 6 : Print the current density, conductor diameter and the average flux density.

Step 7 : Calculate the net iron length and flux per pole.

Step 8 : Calculate the flux density in stator teeth, core, rotor teeth and core.

Step 9 : Check if they are exceeding saturation limits.

If yes, go to step 5.

If no, go to the next step.

Step 10 : Calculate the stator copper loss.

Step 11 : Get the input of the loss factor corresponding to stator teeth flux density.

Step 12 : Calculate the Iron loss in stator teeth.

Step 13 : Get the input of the loss factor corresponding to stator core flux density.

Step 14 : Calculate the Iron loss in stator core.

Step 15 : Calculate the Rotor Bar loss and End ring loss.

Step 16 : Calculate the total losses and hence the efficiency.

Step 17 : Get the input of the at/m for all flux densities.

Step 18 : Calculate the total mmf required and hence the magnetising current.

Step 19 : Calculate the no load current and power factor.

Step 20 : Calculate the leakage reactances and hence the short circuit current and power factor.

Step 21 : Get the input of cooling co-efficient.

Step 22 : Calculate the temperature rise.

Step 23 : Do you want to carry out the calculations for another voltage ?

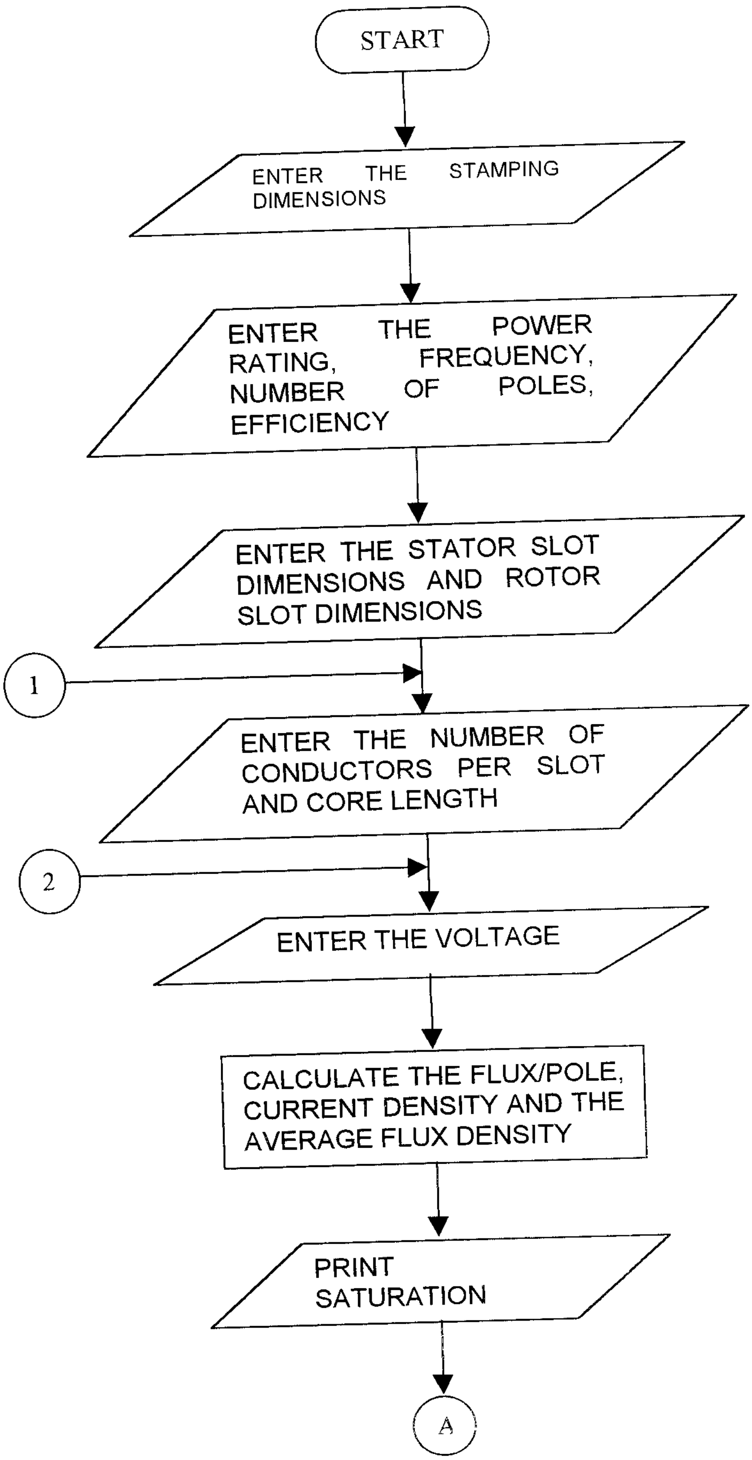
If yes, go to step 4.

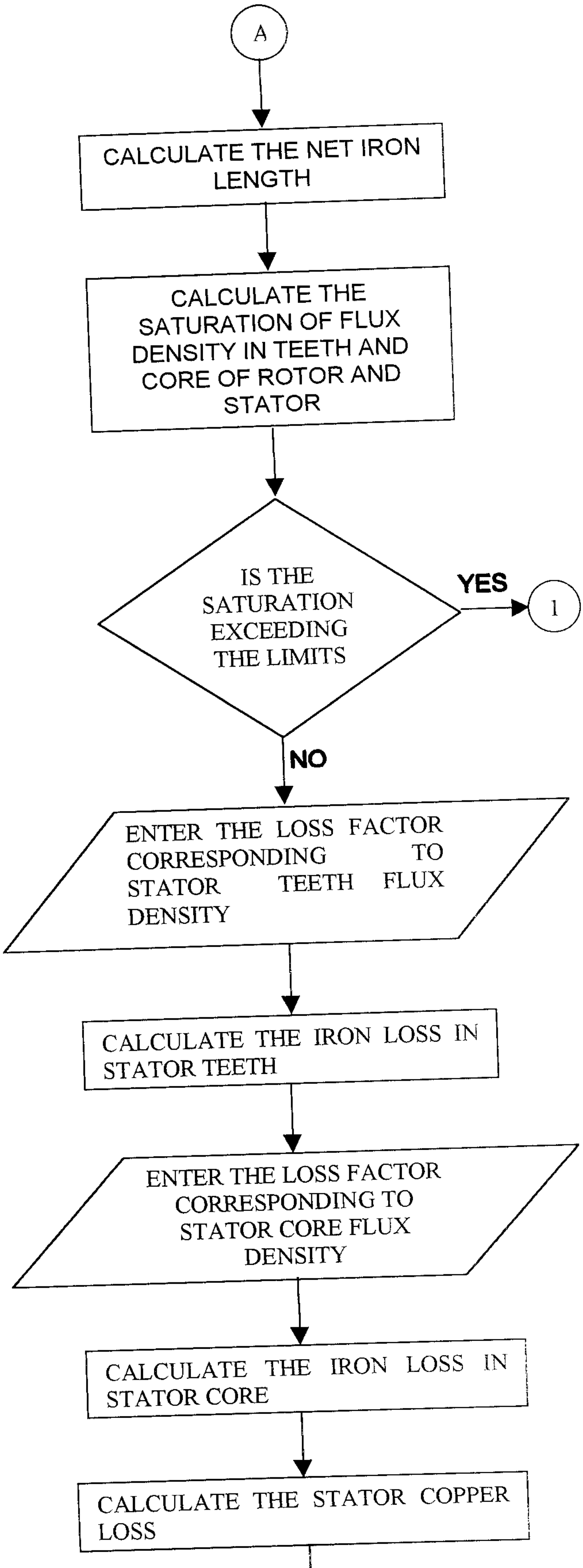
If no, go to next step.

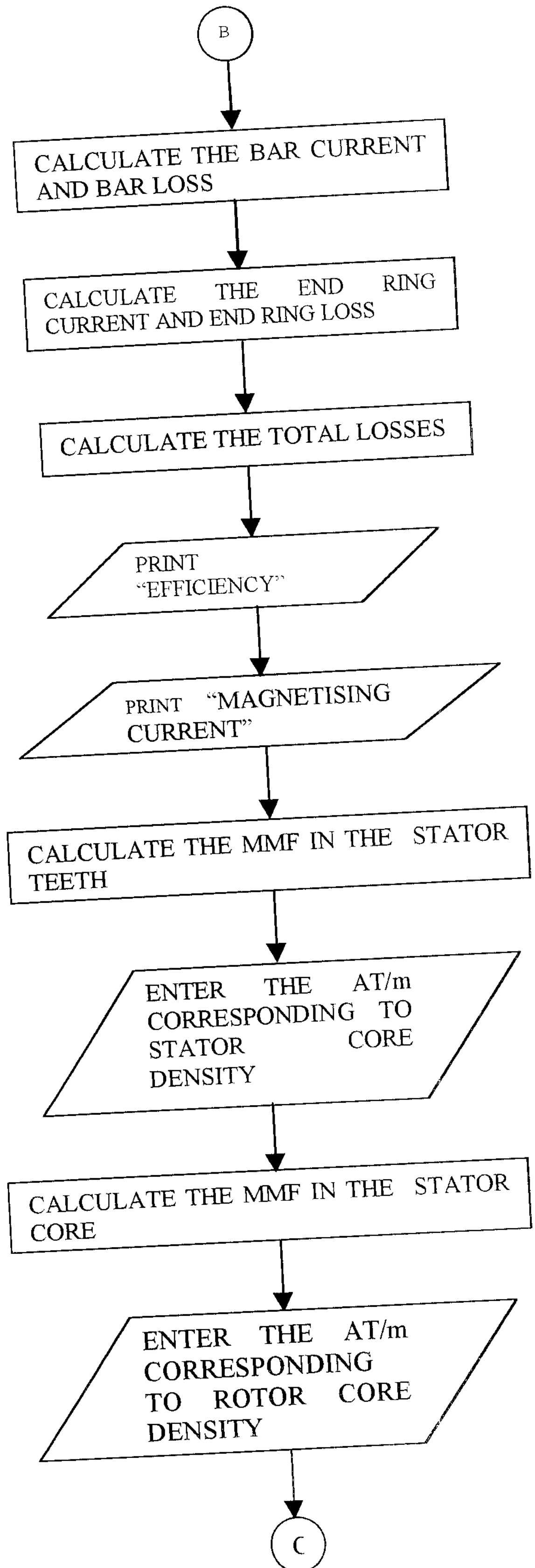
Step 24 : Stop the program.

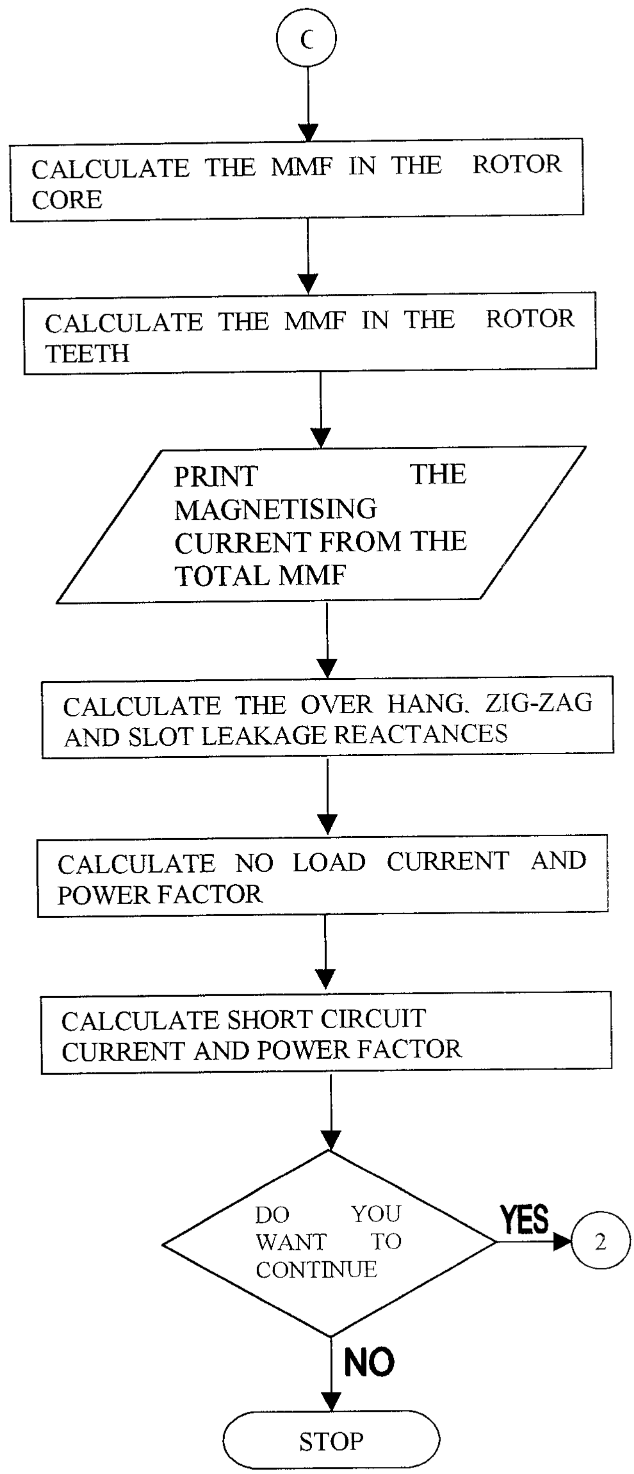
5.2 FLOW CHART

The flow chart for the 'C' software is shown below.




A
CALCULATE THE NET IRON LENGTH
CALCULATE THE SATURATION OF FLUX DENSITY IN TEETH AND CORE OF ROTOR AND STATOR
IS THE SATURATION EXCEEDING THE LIMITS
YES
1
NO
ENTER THE LOSS FACTOR CORRESPONDING TO STATOR TEETH FLUX DENSITY
CALCULATE THE IRON LOSS IN STATOR TEETH
ENTER THE LOSS FACTOR CORRESPONDING TO STATOR CORE FLUX DENSITY
CALCULATE THE IRON LOSS IN STATOR CORE
CALCULATE THE STATOR COPPER LOSS


B
CALCULATE THE BAR CURRENT AND BAR LOSS
CALCULATE THE END RING CURRENT AND END RING LOSS
CALCULATE THE TOTAL LOSSES
PRINT "EFFICIENCY"
PRINT "MAGNETISING CURRENT"
CALCULATE THE MMF IN THE STATOR TEETH
ENTER THE AT/m CORRESPONDING TO STATOR CORE DENSITY
CALCULATE THE MMF IN THE STATOR CORE
ENTER THE AT/m CORRESPONDING TO ROTOR CORE DENSITY
C


C
CALCULATE THE MMF IN THE ROTOR CORE
CALCULATE THE MMF IN THE ROTOR TEETH
PRINT THE MAGNETISING CURRENT FROM THE TOTAL MMF
CALCULATE THE OVER HANG, ZIG-ZAG AND SLOT LEAKAGE REACTANCES
CALCULATE NO LOAD CURRENT AND POWER FACTOR
CALCULATE SHORT CIRCUIT CURRENT AND POWER FACTOR
DO YOU WANT TO CONTINUE
YES
2
NO
STOP

5.3 COMPUTER PROGRAM

THE DESIGN OF THE SUBMERSIBLE MOTOR USING 'C' SOFTWARE IS AS SHOWN BELOW

```
/* SUBMERSIBLE MOTOR DESIGN */

#include<stdio.h>
#include<math.h>
main()
{
 float hp,eff,pf,E,J,sa,count=1;
 float Iph,as,asi,di,di1,D,Ss;
 float Z,ac,Jb;
 /*core length*/
 float Bav,Kw,Co,Q,Fm,f,p,polpit,Tph,L,n,z,dcse,ty;
 /*saturation*/
 float  wts,dcs,dcr,Li,Bt,Bys,Byr,dcre;
 float  rsh=0.021,Btr,wtr=0.00385;
 /*Iron Loss*/
 float w=.0107,a=.0064,b=.016,c=.003,d=.0005;
 float e=0.0029,h,Vst,Wst,Sst;
 float ILst,Vsy,Do=.13,Wsy,ILsy,Ssy,TIL,TNL,FL;
```

```
float ILst,Vsy,Do=.13,Wsy,ILsy,Ssy,TIL,TNL,FL;
/*Copper loss*/
float Lmt,rs,CLs,Lb,Ib,m=4,Sr=16,rb,ab=42;
float CLb,Ie,ae,de,te;
float lg,Dr,Doe,Die,De,re,CLe,CL,TL,ef;
/*mmf*/
float Kcs,Yss,Kgs,Kgss,Kgsr,Kcsr,Kgd,Kg,Ag;
float Bg60,lge,Kgc,ATg,At,atst,ATst,Yst;
float Ysr,lcs,atsc,ATsc,lcr,atrc,ATrc;
float AT,Im,Il,Io,ATrt,atrt,htr=0.00867;
/*Leakage reactance*/
float Lss,mo=4*3.14/10000000;
float Lsr,Ls,Slr,q=4;
float Cs,Ks,LoLo1,LoLo2,LoLo,xo,Xm,qr;
float xs,Xs,pi,R,Ks1,Ks2;
/*Temperature Rise*/
float Cus,Pc,TCL,IL,OSCA,CCo,LO,Va;
float VVi,CCs,ISCA,Ns=3000,LI,CS;
float CCi,LE,TLD,Temp,RCLph,CLr,pfnl,pfsc,Rt;
float Pisc,Pinl,Rr,r35,Isc,Zt;
char choice;

clrscr();
```

```
{
count++;
printf("\nSELECTION OF WIRE SIZE\n");
printf("\nENTER THE POWER RATING, hp=");
scanf("%f",&hp);
printf("\nENTER THE EFFICIENCY, eff=");
scanf("%f",&eff);
printf("\nENTER THE POWERFACTOR, pf=");
scanf("%f",&pf);
printf("\nENTER THE STATOR SLOT AREA(in mm2),
sa=");
scanf("%f",&sa);
printf("\nENTER THE INNER DIAMETER(in m), D=");
scanf("%f",&D);
printf("\nENTER THE NO. OF STATOR SLOTS, Ss=");
scanf("%f",&Ss);
printf("\nENTER THE WIDTH OF STATOR TEETH(in m),
wts=");
scanf("%f",&wts);
printf("\nENTER THE DEPTH OF STATOR CORE(in m),dcs=");
scanf("%f",&dcs);
printf("\nENTER THE DEPTH OF ROTOR CORE(in m), dcr=");
scanf("%f",&dcr);
```

```
printf("\nENTER THE VOLTAGE RATING, E=");
scanf("%f",&E);
printf("\nENTER THE FREQUENCY, f=");
scanf("%f",&f);
getch();
clrscr();
printf("\nENTER THE NO. OF POLES, p=");
scanf("%f",&p);
printf("\nENTER THE WINDING FACTOR, Kw=");
scanf("%f",&Kw);
Iph=hp*736/(sqrt(3)*E*pf*eff);
printf("\nCURRENT, Iph=%f",Iph);
l1: printf("\nENTER THE NO. OF CONDUCTORS/SLOT, Z=");
scanf("%f",&Z);
polpit=3.14*D/p;
asi=sa*0.42/Z;
di1=sqrt(asi*4/3.14);
printf("\nWIRE DIAMETER(WITH INSULATION),  do=%fmm",di1);
printf("do=");
scanf("%f",&di1);
di=di1-0.45;
printf("\nWIRE DIAMETER, di=%fmm",di);
printf("di=");
```

```
scanf("%f",&di1);
di=di1-0.45;
printf("\nWIRE DIAMETER, di=%fmm",di);
printf("di=");
scanf("%f",&di);
as=3.14*pow(di,2)/4;
J=Iph/as;
printf("\nCURRENT DENSITY, J=%fA/mm2",J);
printf("\nENTER THE CORE LENGTH, L=");
scanf("%f",&L);
getch();
clrscr();
Tph=Z*Ss/6;
Fm=E/(4.44*sqrt(3)*f*Tph*Kw);
Bav=Fm/(polpit*L);
printf("\nAVERAGE FLUX DENSITY, Bav=%fWb/m2",Bav);
}
else
{
printf("\nENTER THE VOLTAGE RATING, E=");
scanf("%f",&E);
Iph=hp*736/(sqrt(3)*E*pf*eff);
J=Iph/as;
```

```
printf("\nCURRENT DENSITY, J=%fA/mm2",J);

Fm=E/(4.44*sqrt(3)*f*Tph*Kw);

Bav=Fm/(polpit*L);

printf("\nAVERAGE FLUX DENSITY, Bav=%fWb/m2",Bav);


}
```

```
/*SATURATION*/

/*STATOR teeth*/
printf("\nSATURATION\n");
printf("------------");
Li=L*0.92;
Bt=Fm*1.36/((Ss/p)*wts*Li);

/*STATOR yoke*/
ty=0.005/2;
dcse=dcs+ty;
Bys=Fm/(2*dcse*Li);

/*ROTOR yoke*/
dcre=(dcr/2)+(rsh/2);
Byr=Fm/(2*dcre*Li);

/*ROTOR tooth*/
Btr=1.36*Fm/(Sr*Li*wtr/p);
printf("\nFLUX DENSITY\n");
printf("\nSTATOR TEETH, Bt=%f\nSTATOR YOKE,
Bys=%f\nROTOR YOKE, Byr=%f,\nROTOR TEETH,
Btr=%fWb/m2",Bt,Bys,Byr,Btr);
```

```
printf("\nDO YOU WANT TO CHANGE THE STATOR LENGTH(y/n):");
choice=getch();
if (choice=='y')
goto l1;

/*IRON LOSS*/
/*stator teeth*/
printf("\nLOSSES\n");
printf("--------\n");
h=b+c+d;
Vst=Ss*wts*Li*h;
Wst=Vst*7.85*1000;
printf("\nENTER THE LOSS FACTOR FOR STATOR TEETH(in  W/Kg),
Sst=");
scanf("%f",&Sst);
ILst=Sst*Wst;

/*stator yoke*/
Vsy=3.14*(pow(Do,2)-pow((D+(2*h)),2))*Li/4;
Wsy=Vsy*7.85*1000;
printf("\nENTER THE LOSS FACTOR FOR STATOR YOKE(in W/Kg), Ssy=");
scanf("%f",&Ssy);
getch();
clrscr();
```

```
ILsy=Ssy*Wsy;
TIL=2*(ILst+ILsy);

/*Friction Loss*/
FL=6*hp*736/100;
TNL=TIL+FL;
printf("\nTOTAL NOLOAD LOSS, TNL=%fwatts",TNL);

/*Stator Copper Loss*/
/*Lmt=2*L+(2.3*polpit)+.24;*/
Lmt=0.85;
rs=.021*Lmt*Tph/as;
r35=270*rs/255;
CLs=3*pow(Iph,2)*rs;

/*Rotor Copper Loss*/
/*Bar loss*/
Lb=L+(2*.015)+.01;
Ib=Kw*Ss*Z*Iph*pf/Sr;
Jb=Ib/ab;
printf("\nBAR CURRENT DENSITY, Jb=%f",Jb);
rb=.021*Lb/ab;
/*rb=310*rb/255;*/
```

```
CLb=Sr*pow(Ib,2)*rb;
/*Endring loss*/
Ie=Sr*Ib/(3.14*p);
ae=Ie/7;
printf("\nAREA OF ENDRING, ae=%fmm2",ae);
printf("\nENTER THE DEPTH OF ENDRING(in cm),
de=");
scanf("%f",&de);
printf("\nENTER THE THICKNESS OF ENDRING(in cm),
te=");
scanf("%f",&te);
ae=de*te;
/*lg=.2+(2*sqrt(D*L));*/
lg=0.0006;
Dr=D-(2*lg/1000);
Doe=Dr-(2*.00734);
Die=Doe-(2*de/1000);
De=(Doe+Die)/2;
re=.021*3.14*De/ae;
/*re=re*310/255;*/
CLe=2*pow(Ie,2)*re;
CLr=CLb+CLe;
CL=CLr+CLs;
```

```
printf("\nCOPPER LOSS, CL=%fwatts",CL);


/*Efficiency*/
TL=CL+TNL;
ef=hp*736/((hp*736)+TL);
printf("\nEFFICIENCY, Ef=%.2f%",ef*100);


/*MMF CALCULATIONS*/
printf("\nMMF CALCULATIONS\n");
printf("----------------\n");
printf("\nSLOT OPENING/GAP LENGTH=%f",e/lg);
printf("\nENTER THE CARTER'S CO-EFF, Kcs=");
scanf("%f",&Kcs);
Yss=(3.14*D)/Ss;
Kgss=Yss/(Yss-(Kcs*e));
Kgsr=1;
Kgs=Kgss*Kgsr;
Kgd=1;
Kg=Kgs*Kgd;
/*Ag=3.14*D*L/p;*/
Bg60=Bav;
lg=0.0006;
lge=Kg*lg;
```

```
ATg=800000*Bg60*lge;
printf("\nAIR GAP MMF, ATg=%fAT",ATg);

/*Stator teeth*/
/*At=(Ss/p)*wts*Li;*/
printf("\nBt=%f",Bt);
printf("\nENTER THE AMP.TURNS/M, atst=");
scanf("%f",&atst);
getch();
clrscr();
ATst=atst*h;
printf("\nSTATOR TEETH MMF, ATst=%fAT",ATst);

/*Stator core*/
lcs=3.14*(D+(2*h)+b)/(3*p);
printf("\nBys=%f",Bys);
printf("\nENTER THE AMP.TURNS/M, atsc=");
scanf("%f",&atsc);
ATsc=atsc*lcs;
printf("\nSTATOR CORE MMF, ATsc=%fAT",ATsc);

/*Rotor core*/
dcr=.00764;
```

```
lcr=0.00375;

printf("\nByr=%f",Byr);

printf("\nENTER THE AMP.TURNS/M, atrc=");

scanf("%f",&atrc);

ATrc=atrc*lcr;

printf("\nROTOR CORE MMF, ATrc=%fAT",ATrc);
```

```
/*Rotor teeth*/
printf("\nBtr=%f",Btr);
printf("\nENTER THE AMP.TURNS/M, atrt=");
scanf("%f",&atrt);
ATrt=atrt*htr;
printf("\nROTOR TEETH MMF, ATrt=%fAT",ATrt);
AT=ATg+ATsc+ATrc+ATst+ATrt;
Im=0.427*p*AT/(Kw*Tph);
printf("\nMAGNETISING CURRENT/PHASE, Im=%fA",Im);
Il=TNL/(sqrt(3)*E);
printf("\nLOSS COMPONENT OF NOLOAD CURRENT,
Il=%fA",Il);
Io=sqrt(pow(Im,2)+pow(Il,2));
printf("\nNOLOAD CURRENT, Io=%fA",Io);
pfnl=Il/Im;
printf("\nNOLOAD POWERFACTOR, pfnl=%f",pfnl);
Pinl=acos(pfnl)*180/3.14;
printf("\nNOLOAD POWERANGLE, Pinl=%f",Pinl);


/*Leakage Reactance*/
printf("\nLEAKAGE REACTANCE\n");


/*Stator Slot Leakage*/
```

```
printf("\na1/a2=%f",a/w);
printf("\npi=");
scanf("%f",&pi);
getch();
clrscr();
R=a/2;
Lss=mo*((pi*b/w)+(d/e)+(3.14*acos(e/(2*R))/(4*1.57)));

/*Rotor slot leakage*/
Lsr=mo*0.66*Kw*Kw*Ss/Sr;
Ls=Lss+Lsr;
Slr=8*3.14*f*pow(Tph,2)*L*Ls/(p*q);
printf("\nSTATOR SLOT LEAKAGE REACTANCE, Slr=%fohms",Slr);

/*Overhang leakage*/
Yss=3.14*D/Ss;
Cs=11;
polpit=3.14*D/p;
Ks1=Cs/12;
Cs=9;
Ks2=Cs/12;
printf("\ncoil span/coil pitch=%f",(Ks1+Ks2)/2);
printf("\nKs=");
```

```
scanf("%f",&Ks);

LoLo=mo*Ks*polpit*polpit/(3.14*Yss);

xo=8*3.14*f*Tph*Tph*LoLo/(p*q);

printf("\nOVERHANG LEAKGE REACTANCE,

xo=%fohms",xo);


/*ZigZag Leakage*/

Xm=415/(sqrt(3)*Im);

qr=Sr/(3*p);

xs=5*Xm*((1/pow(q,2))+(1/pow(qr,2)))/(6*3*3);

printf("\nZIGZAG LEAKAGE REACTANCE,

xs=%fohms",xs);

Xs=1.25*(xs+Slr+xo);

printf("\nTOTAL LEAKAGE REACTANCE, Xs=%fohms",Xs);

RCLph=CLr/3;

Rr=RCLph/(pow(Iph,2)*pow(pf,2));

Rt=Rr+r35;

Zt=sqrt(pow(Xs,2)+pow(Rt,2));

Isc=415/(sqrt(3)*Zt);

printf("\nSHORT CIRCUIT CURRENT/PHASE,

Isc=%fA",Isc);

pfsc=Rt/Zt;
```

```
printf("\nSHORT CIRCUIT POWERFACTOR,
pfsc=%f",pfsc);
Pisc=acos(pfsc)*180/3.14;
printf("\nSHORT CIRCUIT POWERANGLE,
Pisc=%f",Pisc);

/*Temperature Rise*/
Cus=2*L*CLs/Lmt;
TCL=Cus+TIL;
OSCA=3.14*Do*L;
printf("\nCOOLING CO-EFF, CCo=");
scanf("%f",&CCo);
LO=OSCA/CCo;
ISCA=3.14*D*L;
Va=3.14*D*Ns/60;
CCi=.04/(1+(.1*Va));
LI=ISCA/CCi;
CS=2*3.14*(pow(Do,2)-pow(D,2))/4;
Va=.1*Va;
LE=CS*Va/0.15;
TLD=LI+LO+LE;
Temp=TCL/TLD;
printf("\nTEMPERATURE RISE, Temp=%f",Temp);
```

```
getch();
clrscr();
printf("DO YOU WANT TO CONTINUE(y/n):");
choice=getch();
if (choice=='y')
{
clrscr();
goto 12;
}
}
```

5.4 OUTPUT

SELECTION OF WIRE SIZE

```
ENTER THE POWER RATING, hp=5
ENTER THE EFFICIENCY, eff=0.8
ENTER THE POWERFACTOR, pf=0.82
ENTER THE STATOR SLOT AREA(in mm2), sa=149.02
ENTER THE INNER DIAMETER(in m), D=0.067
ENTER THE NO. OF STATOR SLOTS, Ss=24
ENTER THE WIDTH OF STATOR TEETH(in m), wts=0.00315
ENTER THE DEPTH OF STATOR CORE(in m), dcs=0.012
ENTER THE DEPTH OF ROTOR CORE(in m), dcr=0.00764
ENTER THE VOLTAGE RATING, E=415
ENTER THE FREQUENCY, f=50
ENTER THE NO. OF POLES, p=2
ENTER THE WINDING FACTOR, Kw=0.924
CURRENT, Iph=7.804323
ENTER THE NO. OF CONDUCTORS/SLOT, Z=26
WIRE DIAMETER(WITH INSULATION),
do=1.751158mmdo=1.75
WIRE DIAMETER, di=1.300000mmdi=1.3
CURRENT DENSITY, J=5.882730A/mm2
ENTER THE CORE LENGTH, L=0.25
```

AVERAGE FLUX DENSITY, Bav=0.427085Wb/m2

SATURATION

FLUX DENSITY

STATOR TEETH, Bt=1.756906

STATOR YOKE, Bys=1.683850

ROTOR YOKE, Byr=1.705015,

ROTOR TEETH, Btr=2.156202Wb/m2

DO YOU WANT TO CHANGE THE STATOR LENGTH(y/n):n

LOSSES

ENTER THE LOSS FACTOR FOR STATOR TEETH(in W/Kg),

Sst=7.25

ENTER THE LOSS FACTOR FOR STATOR YOKE(in W/Kg),

Ssy=6.75

TOTAL NOLOAD LOSS, TNL=367.767944watts

BAR CURRENT DENSITY, Jb=5.490810

AREA OF ENDRING, ae=83.935951mm2

ENTER THE DEPTH OF ENDRING(in cm), de=10

ENTER THE THICKNESS OF ENDRING(in cm), te=12

COPPER LOSS, CL=395.125641watts

EFFICIENCY, Ef=82.83%

MMF CALCULATIONS

SLOT OPENING/GAP LENGTH=4.833333

ENTER THE CARTER'S CO-EFF, Kcs=0.64

AIR GAP MMF, ATg=260.064819AT

Bt=1.756906

ENTER THE AMP.TURNS/M, atst=10900

STATOR TEETH MMF, ATst=212.550003AT

Bys=1.683850

ENTER THE AMP.TURNS/M, atsc=8800

STATOR CORE MMF, ATsc=561.850708AT

Byr=1.705015

ENTER THE AMP.TURNS/M, atrc=8800

ROTOR CORE MMF, ATrc=33.000000AT

Btr=2.156202

ENTER THE AMP.TURNS/M, atrt=19000

ROTOR TEETH MMF, ATrt=164.730011AT

MAGNETISING CURRENT/PHASE, Im=10.950456A

LOSS COMPONENT OF NOLOAD CURRENT, Il=0.511641A

NOLOAD CURRENT, Io=10.962402A

NOLOAD POWERFACTOR, pfnl=0.046723

NOLOAD POWERANGLE, Pinl=87.366272

LEAKAGE REACTANCE

a1/a2=0.598131

pi=0.575

STATOR SLOT LEAKAGE REACTANCE, Slr=1.294483ohms

coil span/coil pitch=0.833333

Ks=0.87

OVERHANG LEAKGE REACTANCE, xo=0.745936ohms

ZIGZAG LEAKAGE REACTANCE, xs=0.411524ohms

TOTAL LEAKAGE REACTANCE, Xs=3.064928ohms

SHORT CIRCUIT CURRENT/PHASE, Isc=59.455616A

SHORT CIRCUIT POWERFACTOR, pfsc=0.649284

SHORT CIRCUIT POWERANGLE, Pisc=49.537487

COOLING CO-EFF, CCo=0.03

TEMPERATURE RISE, Temp=47.683937

DO YOU WANT TO CONTINUE(y/n):y

ENTER THE VOLTAGE RATING, E=360

CURRENT DENSITY, J=6.781481A/mm2

AVERAGE FLUX DENSITY, Bav=0.370484Wb/m2

SATURATION

FLUX DENSITY

STATOR TEETH, Bt=1.524063

STATOR YOKE, Bys=1.460689

ROTOR YOKE, Byr=1.479050,

ROTOR TEETH, Btr=1.870441Wb/m2

DO YOU WANT TO CHANGE THE STATOR LENGTH(y/n):n

LOSSES

ENTER THE LOSS FACTOR FOR STATOR TEETH(in W/Kg),

Sst=5.25

ENTER THE LOSS FACTOR FOR STATOR YOKE(in W/Kg),

Ssy=4.85

TOTAL NOLOAD LOSS, TNL=326.616058watts

BAR CURRENT DENSITY, Jb=6.329684

AREA OF ENDRING, ae=96.759499mm2

ENTER THE DEPTH OF ENDRING(in cm), de=10

ENTER THE THICKNESS OF ENDRING(in cm), te=12

COPPER LOSS, CL=525.081177watts

EFFICIENCY, Ef=81.21%

MMF CALCULATIONS

SLOT OPENING/GAP LENGTH=4.833333

ENTER THE CARTER'S CO-EFF, Kcs=0.64

AIR GAP MMF, ATg=225.598389AT

Bt=1.524063

ENTER THE AMP.TURNS/M, atst=3000

STATOR TEETH MMF, ATst=58.500000AT

Bys=1.460689

ENTER THE AMP.TURNS/M, atsc=2500

STATOR CORE MMF, ATsc=159.616669AT

Byr=1.479050

ENTER THE AMP.TURNS/M, atrc=3000

ROTOR CORE MMF, ATrc=11.250000AT

Btr=1.870441

ENTER THE AMP.TURNS/M, atrt=14500

ROTOR TEETH MMF, ATrt=125.715004AT

MAGNETISING CURRENT/PHASE, Im=5.160472A

LOSS COMPONENT OF NOLOAD CURRENT, Il=0.523811A

NOLOAD CURRENT, Io=5.186989A

NOLOAD POWERFACTOR, pfnl=0.101504

NOLOAD POWERANGLE, Pinl=84.216888

LEAKAGE REACTANCE

```
a1/a2=0.598131

pi=0.575

STATOR SLOT LEAKAGE REACTANCE, Slr=1.294483ohms

coil span/coil pitch=0.833333

Ks=0.87

OVERHANG LEAKGE REACTANCE, xo=0.745936ohms

ZIGZAG LEAKAGE REACTANCE, xs=0.873248ohms

TOTAL LEAKAGE REACTANCE, Xs=3.642083ohms

SHORT CIRCUIT CURRENT/PHASE, Isc=53.428070A

SHORT CIRCUIT POWERFACTOR, pfsc=0.583460

SHORT CIRCUIT POWERANGLE, Pisc=54.333267

COOLING CO-EFF, CCo=0.03

TEMPERATURE RISE, Temp=49.017319

DO YOU WANT TO CONTINUE(y/n):y
```

ENTER THE VOLTAGE RATING, E=315

CURRENT DENSITY, J=7.750263A/mm2

AVERAGE FLUX DENSITY, Bav=0.324173Wb/m2

SATURATION

FLUX DENSITY

STATOR TEETH, Bt=1.333555

STATOR YOKE, Bys=1.278103

ROTOR YOKE, Byr=1.294168,

ROTOR TEETH, Btr=1.636636Wb/m2

DO YOU WANT TO CHANGE THE STATOR LENGTH(y/n):n

LOSSES

ENTER THE LOSS FACTOR FOR STATOR TEETH(in W/Kg),

Sst=3.75

ENTER THE LOSS FACTOR FOR STATOR YOKE(in W/Kg),

Ssy=3.55

TOTAL NOLOAD LOSS, TNL=297.759064watts

BAR CURRENT DENSITY, Jb=7.233924

AREA OF ENDRING, ae=110.582275mm2

ENTER THE DEPTH OF ENDRING(in cm), de=10

ENTER THE THICKNESS OF ENDRING(in cm), te=12

COPPER LOSS, CL=685.820190watts

EFFICIENCY, Ef=78.91%

MMF CALCULATIONS

SLOT OPENING/GAP LENGTH=4.833333

ENTER THE CARTER'S CO-EFF, Kcs=0.64

AIR GAP MMF, ATg=197.398605AT

Bt=1.333555

ENTER THE AMP.TURNS/M, atst=1500

STATOR TEETH MMF, ATst=29.250000AT

Bys=1.278103

ENTER THE AMP.TURNS/M, atsc=1200

STATOR CORE MMF, ATsc=76.616005AT

Byr=1.294168

ENTER THE AMP.TURNS/M, atrc=1500

ROTOR CORE MMF, ATrc=5.625000AT

Btr=1.636636

ENTER THE AMP.TURNS/M, atrt=7600

ROTOR TEETH MMF, ATrt=65.892006AT

MAGNETISING CURRENT/PHASE, Im=3.330664A

LOSS COMPONENT OF NOLOAD CURRENT, Il=0.545750A

NOLOAD CURRENT, Io=3.375080A

NOLOAD POWERFACTOR, pfnl=0.163856

NOLOAD POWERANGLE, Pinl=80.610069

LEAKAGE REACTANCE

a1/a2=0.598131

pi=0.575

STATOR SLOT LEAKAGE REACTANCE, Slr=1.294483ohms

coil span/coil pitch=0.833333

Ks=0.87

OVERHANG LEAKGE REACTANCE, xo=0.745936ohms

ZIGZAG LEAKAGE REACTANCE, xs=1.352995ohms

TOTAL LEAKAGE REACTANCE, Xs=4.241767ohms

SHORT CIRCUIT CURRENT/PHASE, Isc=48.075199A

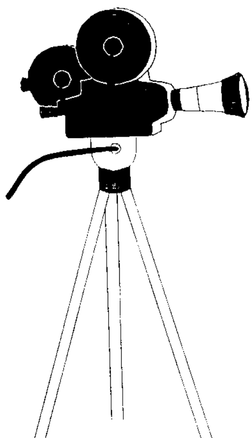
SHORT CIRCUIT POWERFACTOR, pfsc=0.525004

SHORT CIRCUIT POWERANGLE, Pisc=58.361065

COOLING CO-EFF, CCo=0.03

TEMPERATURE RISE, Temp=54.201145

DO YOU WANT TO CONTINUE(y/n):n



TEST RESULTS

AND

PHOTOGRAPHY

CHAPTER 6

TEST RESULTS AND PHOTOGRAPHY

6.1 DESIGN AND TESTING

A 5 H.P. 3 Phase 50 Hz, 3000 synchronous RPM submersible motor so as tested in the laboratory. The efficient for various voltages tabulated in table 7.1.

The tested results was found to be slightly different from that of the theoretical one .

The reasons for the above may be stated as follows.

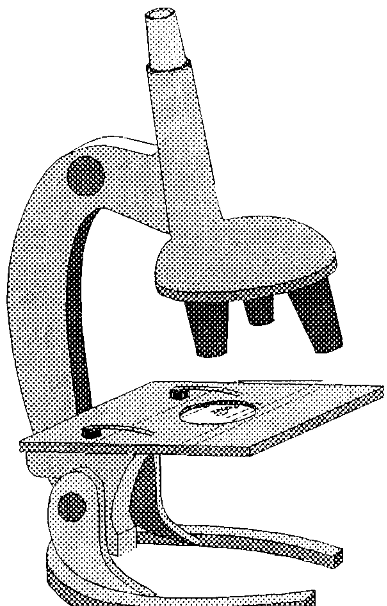
i. Use of low grade of material of stamping

ii. Reduction in the number of conductors per slot (26)

TEST RESULTS

S.No.	Voltage	Efficiency
1	415	73.13
2	360	69.37
3	315	69.87

TABLE 6.1



VARIABLE FREQUENCY OPERATION OF INDUCTION MOTOR

CHAPTER 7

VARIABLE FREQUENCY OPERATION OF INDUCTION MOTOR

7.1 INTRODUCTION

The variable frequency converter which acts as an interface between the utility power system and the induction motor must satisfy the following basic requirements

i) Ability to adjust the frequency according to the desired output speed.

ii) Ability to supply rated current on a continuous basis at any frequency.

This solid state circuitry is presented in such a way that the submersible motor should be capable of taking variable frequency in the range of 48Hz to 51Hz.

These converters can be classified based on the type of rectifier and inverter used as,

i) Pulse width modulation - Voltage Source Inverter (VSI) with diode rectifier

ii) Square wave VSI with Thyristor rectifier

iii) Current Source Inverter (CSI) with Thyristor rectifier

Fig 7.1 shows the block diagram of variable frequency inverter operation and Fig 7.2 shows the circuit diagram for the same. The Gate pulse to the Thyristors are given from the ultrasonic transducer(used for liquid level measurement). The waveforms for the pulse triggering circuit is shown in the fig 7.3

The basic difference between VSI and CSI is :-

In the VSI, the dc input appears as dc voltage source(ideally with no external impedance) to the inverter. On the other hand, in the CSI the dc input appears as a dc current source to the inverter.

For high power applications Cycloconverter may be used.

The Cycloconverter is used in the generation of variable frequency. The variable frequency source using the Cycloconverter principle may be used for the control of AC motors (Induction and synchronous). The function of the Cycloconverter is to convert a higher input frequency alternating current or voltage into a lower output frequency alternative current or voltage.

7.2 TRANSDUCERS

7.2.1 MEASUREMENT OF LIQUID LEVEL

7.2.1.1 ULTRASONIC METHOD

- The beam is projected downwards by the transmitter and is reflected back by the surface of the liquid contained in the tank.
- The beam is received by the receiver .
- The time taken by the beam is a measure of the distance traveled by the beam
- Therefore, the time 't' between transmitting and receiving a pressure pulse is proportional to the distance 'h' between the ultrasonic set and surface of the contents of the tank.

- $t \propto h' \propto (H-h)$

Since distance H between ultrasonic set and the bottom of the tank is fixed, time 't' is a measure of level 'h'

7.2.2 MEASUREMENT OF FLOW

7.2.2.1 ELECTROMAGNETIC FLOW METER

- It consists of a pair of electrodes (insulated buried flush in the opposite sides of a non-conducting, non-magnetic pipe carrying the liquid where flow is to be measured.
- The pipe is surrounded by an electromagnet which produces a magnetic field.
- This arrangement is analogous to a conductor moving across a magnetic field.
- Hence voltage is induced across the electrodes.

$E=Blv$ (volts)

E - Induced emf (volts)

B - Flux density (Wb/m^2)

v - Velocity of conductor (m/s)

ASSUMPTION

- Constant magnetic field ;

  Hence, voltage magnitude appearing across the electrodes is directly proportional to the velocity.

LIMITATIONS

Non-conducting pipe has to be used as output 'V' gets short circuits if metallic pipes are used.

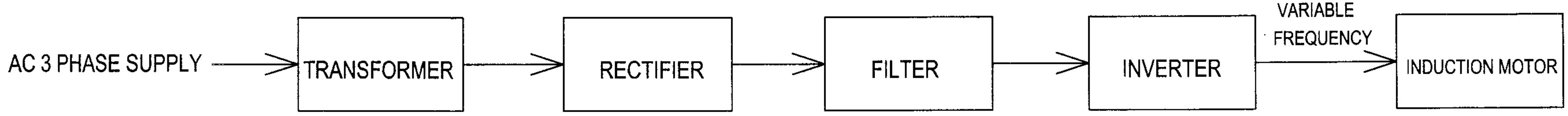
7.4 MEASUREMENT OF SPEED

7.4.1 PROXIMITY SENSOR

Proximity sensor is a device which is used to measure the speed of the submersible motor.

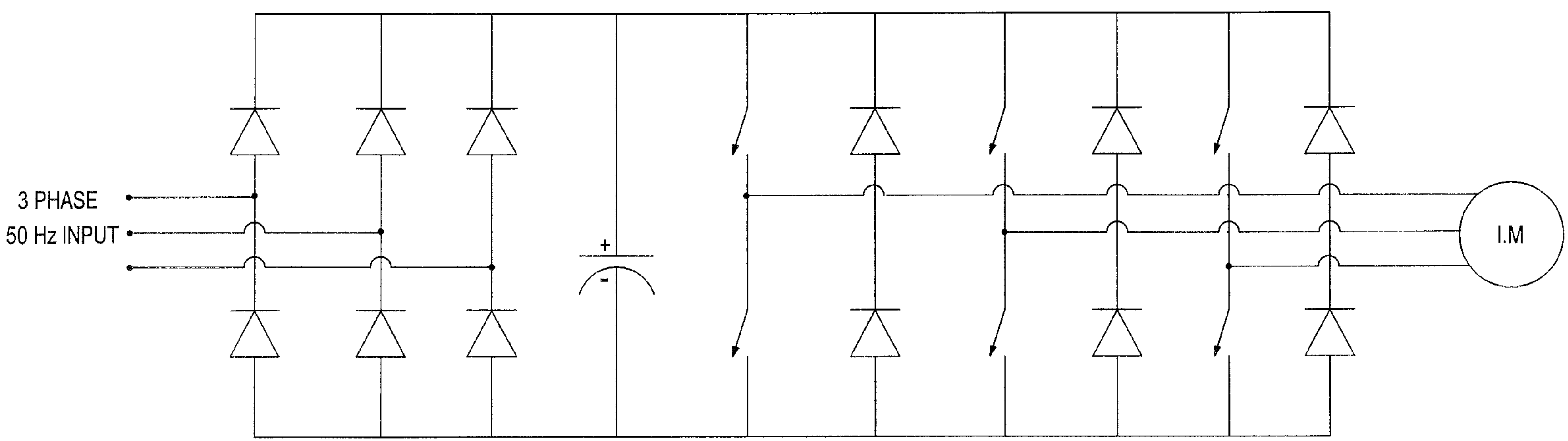
7.4.2. PRINCIPLE

The basic principle is that a digital pulse is produced when the projection fixed in the rotor core cuts the magnetic flux. The number of pulses use counted using the electronic counter and hence the speed can be measured.



BLOCK DIAGRAM OF VARIABLE FREQUENCY INVERTER

FIG 7.1



CIRCUIT DIAGRAM OF VARIABLE FREQUENCY INVERTER

FIG 7.2

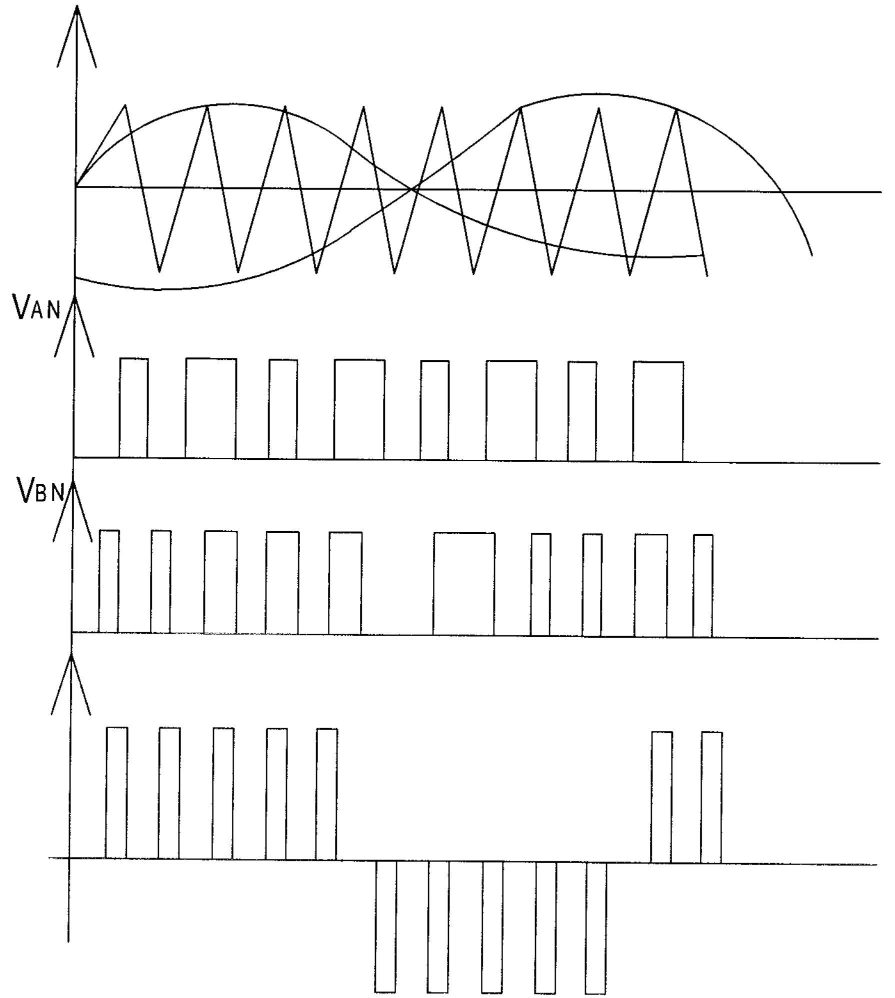
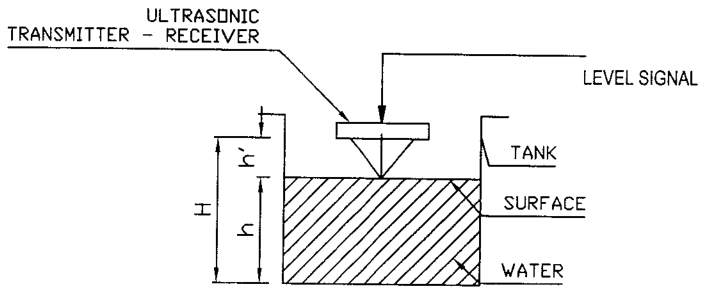
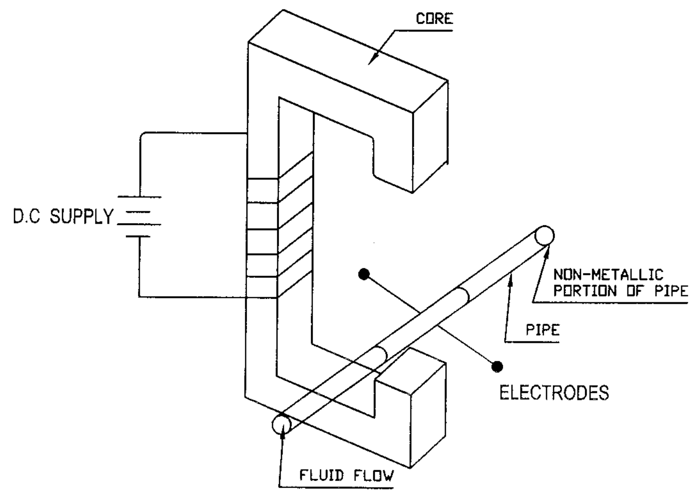


FIG 7.3 WAVEFORMS FOR PULSE TRIGGERING CIRCUIT



ULTRASONIC TRANSDUCER - LIGUID LEVEL MEASUREMENT

FIG 7.4



ELECTROMAGNETIC FLOW METER - FLOW MEASUREMENT

FIG 7.5

CONCLUSION

CHAPTER 8

CONCLUSION

The design of an energy efficient submersible motor has been successfully completed. Normally design of a motor is capable of withstanding 10 to 20% variation voltage. We have tried to design the motor for wide variation in voltage. The basic idea is the extra iron loss is compensated by reduced copper loss. The solid state circuitry for varying the frequency according to head level is presented. The cost of such solid state circuits is around to 5000/- per KVA. As per analysis this is paid back within six to eight month by the energy saved.

8.1 SUGGESTIONS FOR FURTHER IMPROVEMENT

The design may further be improved by considering the following,

1. The economical design of the inverter.
2. Design the submersible for wide various in the frequency. (i.e.) 45 Hz to 55 Hz

CHAPTER 9

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