Project Report

September 08, 2023

DESIGNING A THREE PHASE SQUIRREL CAGE INDUCTION MOTOR

Course No. | EEE 206 Course Title | Energy Conversion Laboratory

Submitted To-

- *Dr. Md. Nasim Ahmed Dewan*
  Professor
  Department of EEE, BUET

- *Sadat Tahmeed Azad*
  Lecturer
  Department of EEE, BUET

Submitted By-
Group | 01
Section | EEE A1

ID	Name
2006001	*Meftaul Alam Seyam*
2006002	*M. Samin Salek*
2006003	*Abrar Assaeem Fuad*
2006004	*Mahee Rashid Chowdhury*
2006005	*Ashik Abrar Naeem*
2006006	*Alvee Rahman*
2006007	*M. A. Mosabbir Antor*

Bangladesh University of Engineering and Technology

Course No: EEE 206

Course Name: Energy Conversion Laboratory

A Report On

Designing a Three Phase Squirrel Cage Induction Motor

Submitted To:

Dr. Md. Nasim Ahmed Dewan
Professor
Department of EEE
Bangladesh University of Engineering and Technology, Dhaka-1000.

Sadat Tahmeed Azad
Lecturer
Department of EEE
Bangladesh University of Engineering and Technology, Dhaka-1000.

Submitted by:

2006001 – Meftaul Alam Seyam
2006002 – M. Samin Salek
2006003 – Abrar Assaeem Fuad
2006004 – Mahee Rashid Chowdhury
2006005 – Ashik Abrar Naeem
2006006 – Alvee Rahman
2006007 – M.A. Mosabbir Antor
Department of Electrical and Electronic Engineering
Bangladesh University of Engineering and Technology, Dhaka -1000

Forwarding Letter

September 08, 2023

Dr. Md. Nasim Ahmed Dewan
Professor
Department of EEE
Bangladesh University of Engineering and Technology, Dhaka-1000.

Sadat Tahmeed Azad
Lecturer
Department of EEE
Bangladesh University of Engineering and Technology, Dhaka-1000.

Subject: Report submission on a project entitled "*Designing a Three Phase Squirrel Cage Induction Motor*" of course no. EEE 206 (Energy Conversion Laboratory)

Dear Teachers,

With due respect and humble gratitude, we want to state that we belong to Group No. 01 (A1) in Energy Conversion Laboratory (EEE 206). As a part of this course, we were supposed to work on a project. Words cannot describe our gratefulness for this opportunity you have given us to work on the project named "*Designing of a Three Phase Squirrel Cage Induction Motor*". This project enabled us to closely observe the physical construction of this highly used induction motor as well as to construct it according to our own design. Our prime motive of this project which was turning an old motor into a running one by designing the windings and insulations of it, by constructing it with new wires and insulating materials and getting the rated value of speed, was accomplished successfully with a little bit of error and mistakes in the winding process. Here is the complete project report with details of our work submitted.

We solemnly apologize for the involuntary mistakes of ours and hope that you would be kind enough to pardon us and oblige thereby.

Sincerely,

2006001 – Meftaul Alam Seyam
2006002 – M. Samin Salek
2006003 – Abrar Assaeem Fuad
2006004 – Mahee Rashid Chowdhury
2006005 – Ashik Abrar Naeem
2006006 – Alvee Rahman
2006007 – M. A. Mosabbir Antor
Department of Electrical and Electronic Engineering
Bangladesh University of Engineering and Technology, Dhaka-1000.

Table of Contents

1. Objectives

- To design a three-phase squirrel cage induction motor.
- To obtain the motor equivalent circuit parameters by performing necessary tests.
- To plot the torque vs speed characteristics of the motor.
- To justify the effect of the motor on the environment and ecosystem.

2. Introduction

Induction motor is a widely used motor from household to industrial applications. It is basically consisted of a stationary stator and a rotor which can rotate continuously around its axis. A three-phase set of voltage is applied to the stator of the motor which produces a rotating magnetic field. This magnetic field therefore induces voltage on the rotor and a current flows. This current also produces a rotor magnetic field which interacts with the stator magnetic field and a net torque is produced that creates rotary motion.

Basically, a machine with only a continuous set of amortisseur windings is called an induction machine. Such machines are called induction machines because the rotor voltage (which produces the rotor current and magnetic field) is induced in the rotor windings rather than being physically connected by wires. The distinguishing feature of an induction motor is that no dc field current is required to run the machine.

Although it is possible to use an induction machine as either a motor or a generator, it has many disadvantages as a generator and so is only used as a generator in special applications. For this reason, induction machines are usually referred to as induction motors.

There are two types of induction motor. One is the squirrel cage induction motor and the other is the wound rotor induction motor. In this project, we will be working with a three-phase squirrel cage induction motor.

3. Motor Specifications

The purchased induction motor's specifications on the nameplate are given in the following table:

Rated Power	200 W
Rated Voltage(50 Hz)	400 V
Rated Current(50 Hz)	0.63 A
Rated Speed	1430 rpm
Insulation Class	F

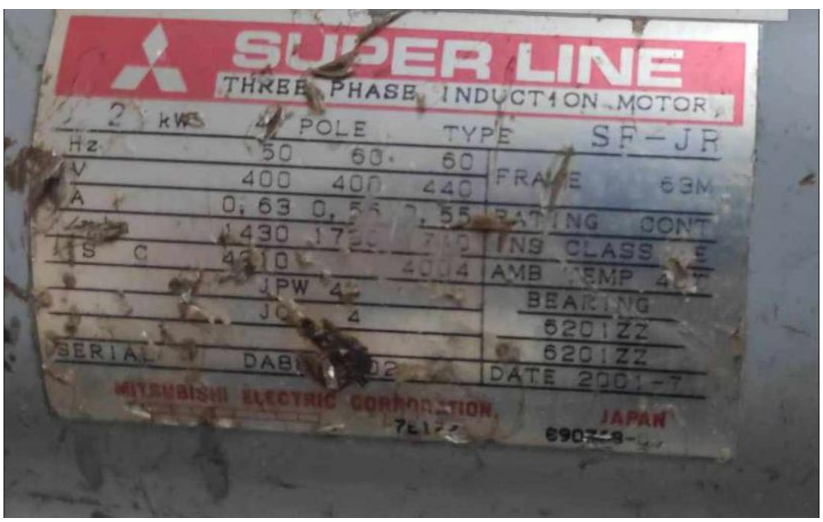


Fig 1: Nameplate of the purchased motor.

4. Construction

Our motor consists of the following parts-

1. Stator
2. Squirrel cage rotor
3. Casing
4. Cooling Fan

Stator:

The stator has 24 slots. The motor was designed to have 24 slots, fractional pitch, and double layer distributed winding. Hence, 24 coils were needed to design the stator. The coils were made using copper wire. The three-phase power supply is given in the stator and a rotating magnetic field consisting of 4 poles is generated. The coils were placed in a ferromagnetic core and insulations were placed in between. The insulation class F was chosen which can handle a maximum temperature rise of 105℃ from the ambient temperature of 40℃. The insulation consists of materials or combinations of materials such as mica, glass fiber, asbestos, etc., with suitable bonding, impregnating or coating substances, as well as other materials or combinations of materials, not necessarily inorganic. It protects the ferromagnetic core from overheating.

Fig 2: Construction of stator.

Rotor:

The rotor does not have any windings, instead it has some conducting bars shorted by a large shorting ring. The conducting bars are placed inside laminated iron core. The bars are skewed to reduce slot harmonics. Some fan blades come out of the rotor to cool down the rotor. This is the main rotating part of the motor and is connected to the shaft. The rotor design class is A.

Fig 3: Squirrel cage rotor.

Casing:

It is the outside cover of the motor made of metal. It supports and protects the internal components (stator and rotor).

Cooling Fan:

A cooling fan is connected with the rotor. Hence, the cooling fan rotates with the rotor and dissipates the heat generated. It protects the motor from overheating.

Fig 4: Cooling fan.

5. Winding Type and Calculations

Winding Type:

Chosen Winding Type	**4-pole Fractional Pitch Double-Layer Distributed Winding**
Connection Type	Y

Pitch Factor Calculation:

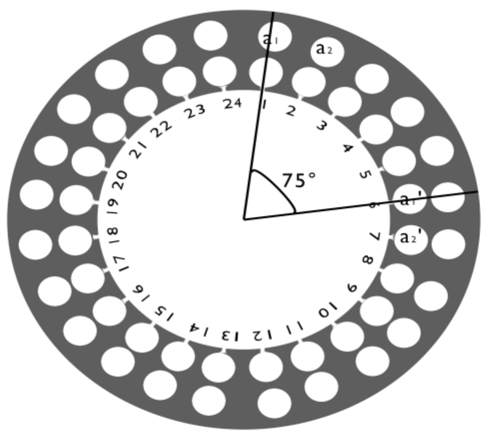


Fig 5: Coil Pitch

Coil Pitch(Mechanical)	$75°$
Coil Pitch(Electrical), ρ	$75° \times 2 = 150°$
Pitch Factor, K_p	$\sin\left(\frac{\rho}{2}\right) = 0.9659$

Distribution Factor Calculation:

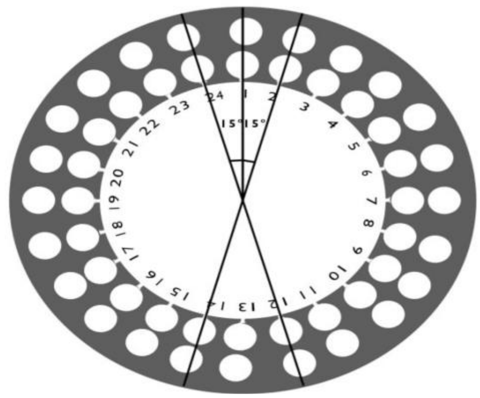


Fig 6: Slot Pitch & Phase Belt

Slot Pitch(Mechanical)	$\frac{360°}{24} = 15°$
Slot Pitch(Electrical), γ	$15° \times 2 = 30°$
Slots Per Phase Belt, n	2
Distribution Factor, K_d	$\frac{\sin\left(\frac{n\gamma}{2}\right)}{n\sin\left(\frac{\gamma}{2}\right)} = 0.9659$
Winding Factor, K_w	$K_p \times K_d = 0.933$

Flux Per Pole Calculation:

Slot Length, L	5 cm
Diameter, D	6.9 cm
Number of Poles, P	4
Average Flux Density, B_{av} [1]	0.5 T
Flux Per Pole, ϕ	$\frac{B_{av} \times \pi \times D \times L}{P} = 1.35 \times 10^{-3}\ Wb$

Turns and Wire Size Calculation:

Turns Per Phase, N_p	$\frac{E}{\sqrt{2}\pi f \emptyset K_w} \approx 825$
Turns Per Coil, N_c	$\frac{N_p}{i} = \frac{N_p}{8} \approx 103$
Wire Cross Section, A	$\frac{I_{rated}}{\delta} = 0.105\ mm^2 \approx 29\ SWG$

Here,
Phase Voltage, E = $\frac{400}{\sqrt{3}} = 230.94\ V$; [Y Connected]
Rated Current, I_{rated} = 0.63 A
Current Density, $\delta = 6\ A/mm^2$; [Can be up to 95 A/mm^2 for Cu [6] but kept at small values for small induction motors[1]]
Number of coils per phase, *i* = 8

Standard Wire Gauge	Diameter		Turns of wire		Cross-sectional area		Res. per length (for copper wire)		Mass per length		Current Capacity / A	
	in	mm	in^{-1}	mm^{-1}	kcmil	mm^2	Ω/kft	Ω/km	lb/ft	kg/m	750 kcmil/A	500kcmil/A
27	0.0164	0.417	61.0	2.40	0.269	0.136	127	415	817μ	0.00122	0.359	0.538
28	0.0148	0.376	67.6	2.66	0.219	0.111	155	510	665μ	990μ	0.292	0.438
29	0.0136	0.345	73.5	2.89	0.185	0.0937	184	604	562μ	836μ	0.247	0.370

Fig 7: Part of Standard Wire Gauge Table[3]

6. Winding Diagram

Before winding the stator, we have to know how it should be done. Our motor is a 4-Pole. We have a 24-Slot double layer stator. Pole pitch is $\frac{5}{6}$. So, two side of a coil will be at an angle of 75°. It means they will be 5 slots apart. Now, if a phase starts from slot 1 it will make a coil between slot 1 and 6. After making the coil the wire will come back to slot 2 and will make another coil between slot 2 and 7 as it is a distributed winding. Current in these two coils will circulate in the clockwise direction. After making these two coils the wire will make a coil between slot 13 and 8 and then between slot 12 and 7 in a way that current in these two new coils will circulate in the counterclockwise direction. In this way the wire will make another pair of coils between slot 13 and 18 and between 14 and 19 in a way that clockwise current circulation occurs. And then for making the 4th Pole another pair of coils required between slot 1 and 20 and between 24 and 19 is made for counterclockwise current circulation. The other two phases (b and c) will make the coils in the same manner except that phase b and phase c will start from slot 5 and 9 respectively and they will end up in slot 23 and 3 respectively. The order of slots for each phase is given below.

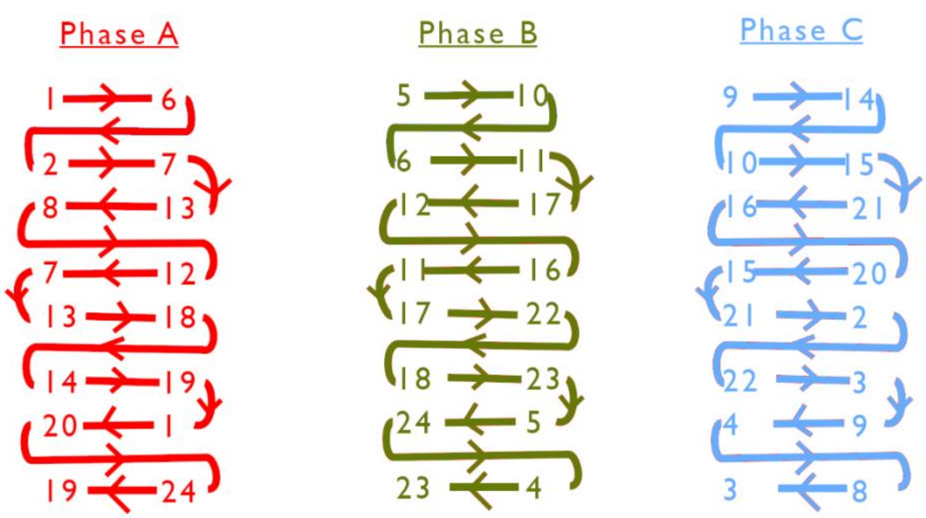
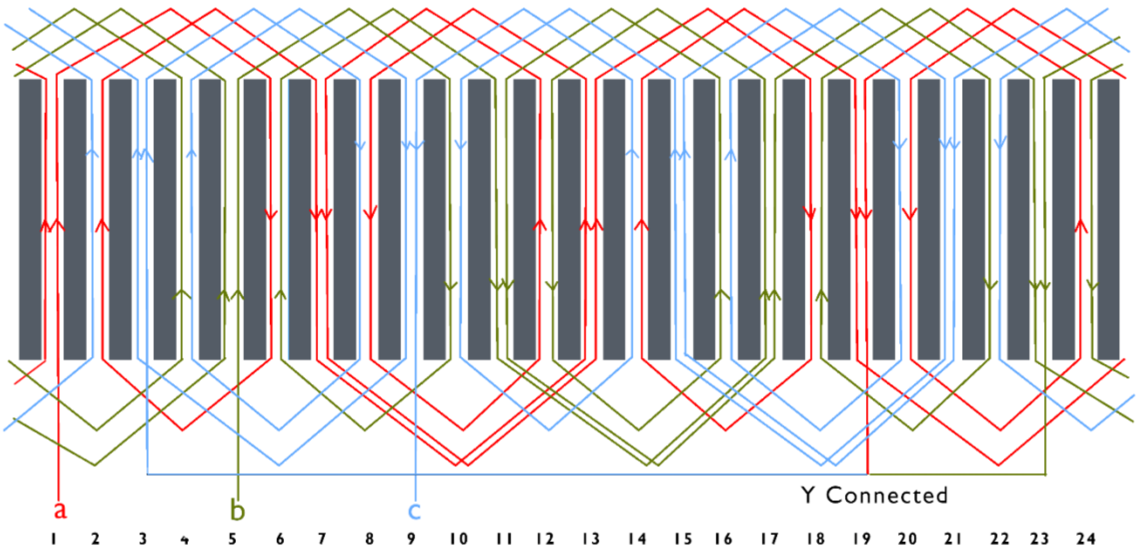
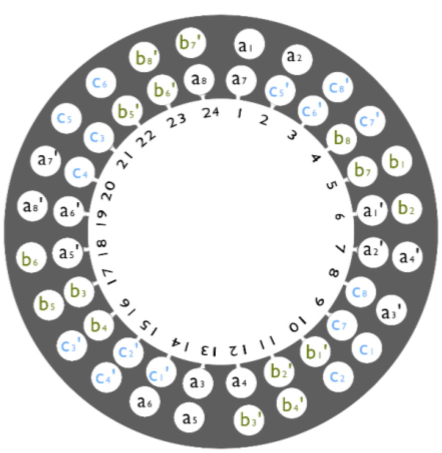


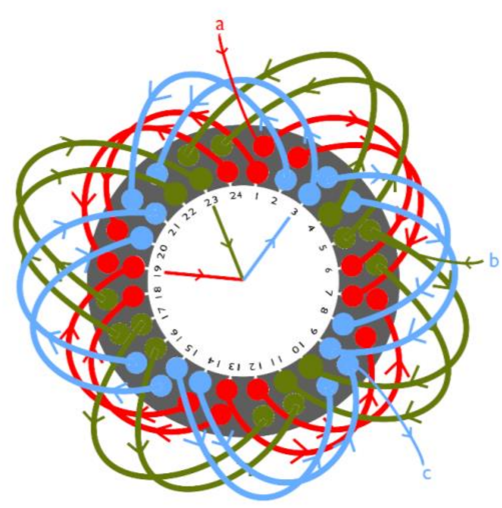
Fig 8: Winding Order

Now, we are ready to face the actual winding diagram. It is given in figure below. We can see that two wires are placed in each slot. In reality, there are not just two wires. They are a representation for a side of a coil consisting of many turns. And the two wires are for the two layers in each slot as our stator is double layer. The left wire is in the outer layer and the right layer is in the inner layer. A circular diagram and a more realistic view of our winding is shown in the figures below.



Winding Diagram of Three Phase 4-Pole 24-Slot Double Layer Stator





Top View

Fig 9. Winding Diagrams(Circular diagrams on the bottom)[5]

7. Wire Selection

Options:

Copper wire, Aluminium wire, Silver wire

Copper wire:

Advantages:

- Very high conductivity (5.96*10e7 S/m), so wire cross section area will be smaller for a certain current which will lower material cost. Moreover, the volume of stator will be small.
- Low cost
- Availability

Disadvantages:

- High density (8.96g/cm^3). So, the motor weight will increase.
- Toxic, affects plant growth in soil, damages kidney and liver when consumed.

Aluminium wire:

Advantages:

- Lightweight (Density of 2.7g/cm^3). This will lower the weight of the motor.
- Low cost.
- Availability
- Environment friendly

Disadvantages:

- Comparatively lower conductivity (3.69*10e7 S/m), so wire cross section area will be larger than that of coppers. This will increase material cost. Moreover, the volume of the stator will increase.

Silver wire:

Advantages:

- Very high conductivity (6.3*10e7 S/m). Higher than both copper and aluminium.

Disadvantages:

- Substantially high cost.
- Not easily available

Conclusion:

Copper wire provides the best performance at low cost. But its effect on the environment cannot be neglected. As there is no other better option than copper, copper is used in the windings.

8. Insulation

When current flows through a wire, there will be an energy loss due to the I^2R effect. This energy is lost in the form of heat energy. Therefore, the machine will be heating up when it is being operated. To make sure that there is no serious damage done to the motor during operation at rated condition, engineers use various types of insulation coating to insulate the ferromagnetic material core from overheating. Depending on the temperature that they can withstand, there are several classes.[2]

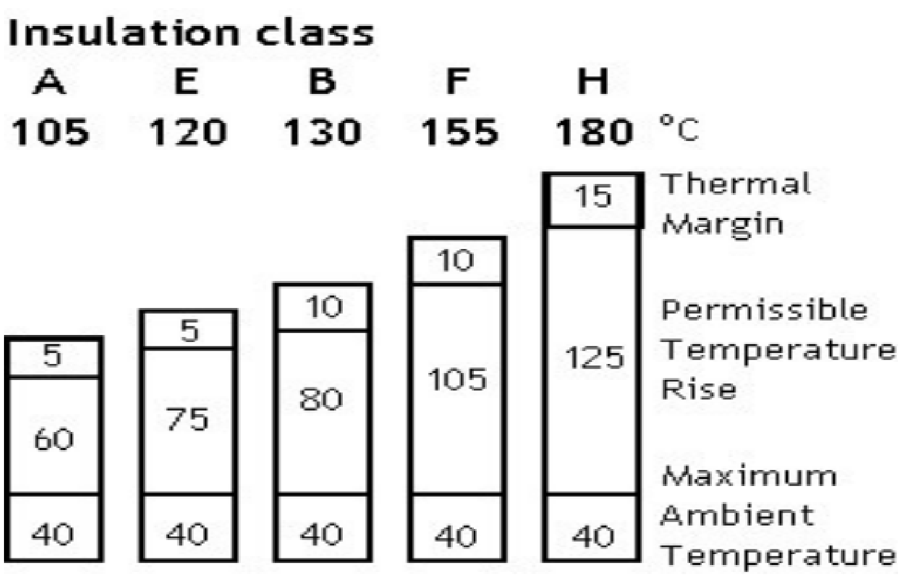


Fig 10: Various insulation classes[7]

The maximum allowable temperature for each insulation class is determined by their maximum permissible temperature rise with respect to the maximum ambient temperature of 40° C.

According to a rule of thumb, for each 10° C temperature rise from the threshold temperature, the machine's lifetime cuts by half. The graph below confirms this empirical relation between the lifetime of a machine and the temperature rise.

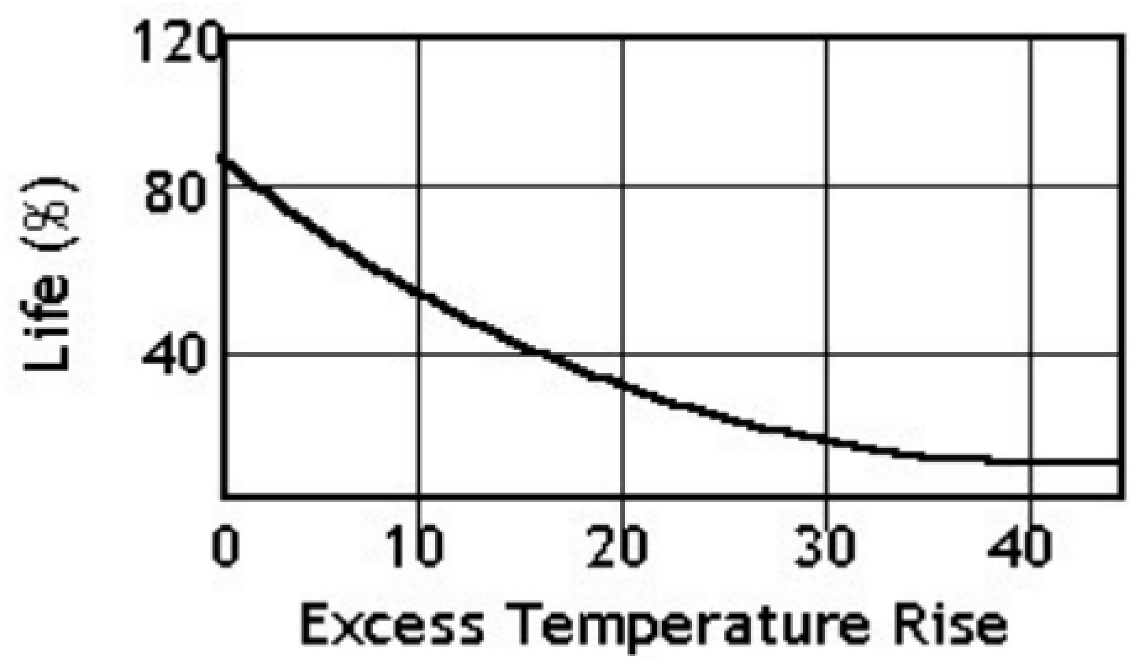


Fig 11: Lifetime expectancy curve vs temperature rise above threshold

Three factors to consider for choosing insulation class-

- Safety
- Cost
- Lifetime

Higher insulation class provides better safety and longer lifetime. However, it also means higher cost. In the case of our induction motor, we have prioritized the safety and the lifetime of the machine while choosing the insulation class and chosen class 'F' as the insulation class of our induction motor. Class 'F' insulation class can withstand a temperature rise of 105° C above the ambient temperature. So, we can consider it to be reasonably safe for our machine.

Fig 12: Fish paper Insulation

Fig 13: Polyester Insulation

Fig 14: Insulation Placed in slots

Fish Paper Insulation:

Fish paper – or vulcanized fiber – is a durable and flexible type of fibrous electrical insulation paper. Fish paper is also unique because it is more resistant to heat and cold comparable plastic materials. Electrical-grade Fish paper is a vulcanized fiber material that is frequently used for electrical insulation and is commonly die cut to create unique parts for specific applications.

Polymer Insulation:

Polyester insulation is environmentally friendly as it is 45% recyclable plastic. Its durability rating is more than 50 years. It is waterproof and heat resistant. It can be used as an insulating material encircling the stator slots.

Varnishing:

Varnishing the windings of an electric motor or generator functions to insulate the windings from contaminants, to make the windings rigid and tight, and to dissipate heat. Increasing the efficiency of the machine.

9. Constructing the Designed Motor

1. Disassembling the Motor: The motor was disassembled by removing the screws of the casing. Then the rotor was pulled out of the stator. The cooling fan was removed from the rotor shaft.

Fig 15: Disassembled motor parts.

2. Removing the Stator Coils: The stator coils were cut and pulled out of the stator. The insulators were removed, and the slots were cleaned thoroughly.

Fig 16: Removing stator coils.

3. Placing Insulators: Insulation class F was chosen to design the motor. F class of materials were cut according to the slot's size and placed between the slots.

Fig 17: Placing insulators.

4. Making Stator Coils: 24 coils were made by using copper wire having a standard wire gauge of 29. Each coil contained 103 turns. The coils were made using a tool which allowed the coils to have the same size as the stator slots.

Fig 18: Making stator coils.

5. Placing Stator Coils: According to the calculation each coil spanned 5 slots. So the two ends of the coils were placed 5 slots apart. After placing the coils, insulators were inserted in the slots.

Fig 19: Placing stator coils.

6. Connecting the Coils: The coils were connected to make a double layer distributed 4 pole stator. The extension of the coils was separated using insulators.

Fig 20: Redesigned stator.

7. Assembling the Motor: The rotor was connected with the casing and the motor was sealed using screws. The cooling fan was connected to the rotor shaft.

Fig 21: Assembling the motor.

8. Testing the motor: The motor was tested in the lab and its performance was found satisfactory with the calculations.

9. Performing the Locked-Rotor Test: The shaft of the rotor was locked using a wrench and the locked rotor test was performed using an ammeter, a voltmeter and a wattmeter.

Fig 22: The locked-rotor test.

10. Performing the No-Load Test: The motor was allowed to run without any load and voltmeter, ammeter and wattmeter were connected to it.

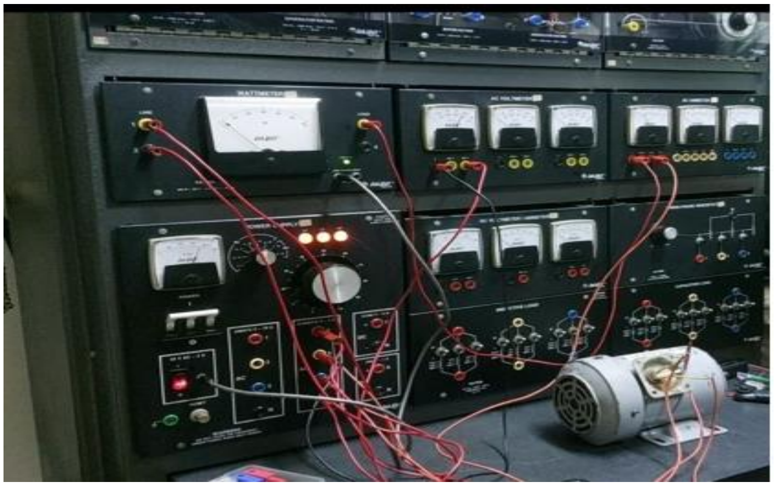


Fig 23: The no-load test.

11. Measuring the Stator Resistance: The stator resistance per-phase was measured using a multimeter.

10. Equivalent Circuit

No Load Test:

P_{in} = 25 W (per phase)

V_T = 360 V

I_L = 0.5 A

$\rightarrow X_1 + X_M = \frac{360}{0.5\times\sqrt{3}}\ \Omega = 415.69\ \Omega$

DC Test:

$2R_1 = 81\ \Omega$

$\rightarrow R_1 = 40.5\ \Omega$

Locked Rotor Test:

P_{in} = 25 W (per phase)

V_T = 80 V

I_L = 0.63 A (rated current)

$|Z_{LR}| = \frac{80}{0.63\times\sqrt{3}}\Omega = 73.31\ \Omega$

$\cos(\Theta) = \frac{25\times 3}{0.63\times 80\times\sqrt{3}} = 0.859$

$\rightarrow \Theta = 30.8°$

$R_1 + R_2 = |Z_{LR}| \cos(\Theta) = 62.97\Omega$

$\rightarrow R_2 = (62.97 - 40.5)\ \Omega = 22.48\ \Omega$

$X_1 + X_2 = |Z_{LR}| \sin(\Theta) = 37.52\ \Omega$

Our motor has a design class A rotor.

So, $X_1 = X_2 = \frac{37.52}{2}\ \Omega = 18.76\ \Omega$

$\rightarrow X_M = (415.69 - 18.76)\ \Omega = 396.93\ \Omega$

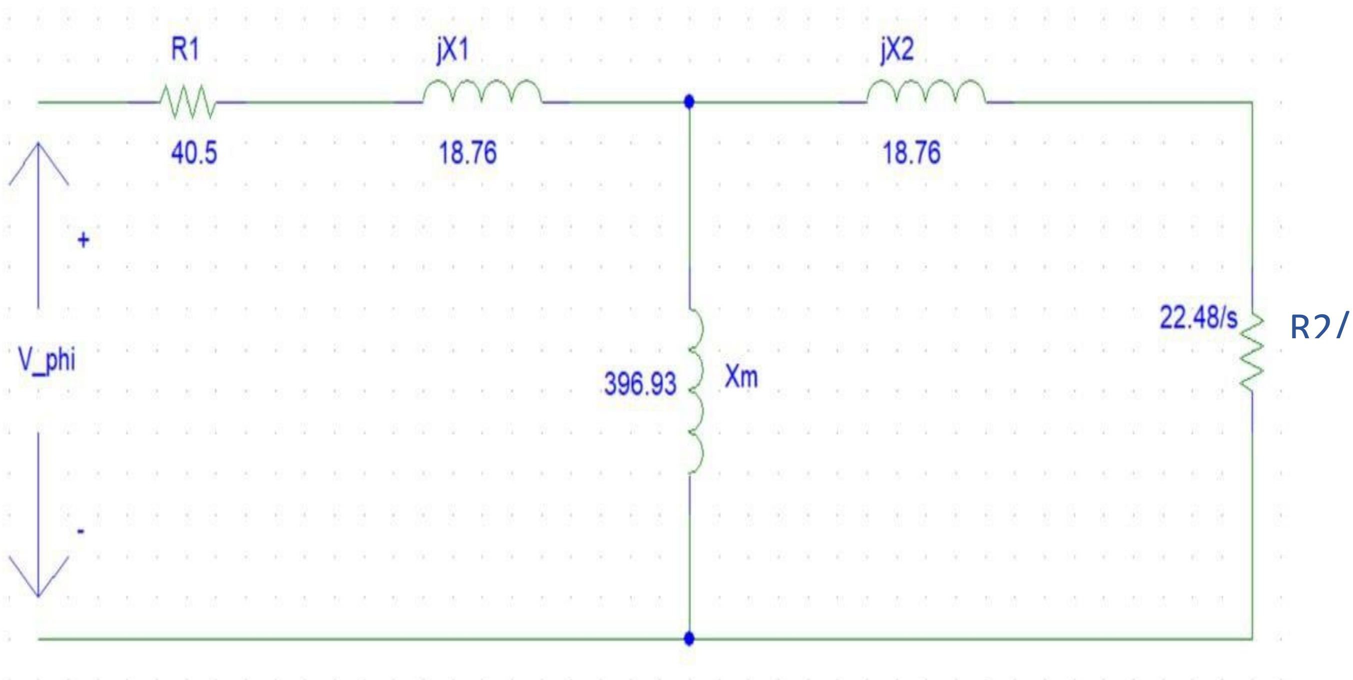


Fig 24: Equivalent circuit of the induction motor

11. Torque-Speed Characteristics

MATLAB Code for Torque-Speed Characteristics:

```
clear all

clc

close all


p = 3000;

R1 = 40.5;

R2 = 22.48;

X1 = 18.76;

X2 = 18.76;

Xm = 396.93;

V_phase = 230.94;

n_sync = 1500;

w_sync = 50*pi;

V_th = V_phase * (Xm/sqrt(R1^2 + (X1 + Xm)^2));

Z_th = ((j * Xm) * (R1 + j * X1))/(R1 + j * (X1 + Xm));

R_th = real(Z_th);

X_th = imag(Z_th);

s = (0.001:1:p)/p;

n_m = n_sync*(1 - s);


for i = 1:p


t_ind(i) = (3 * V_th^2 * R2/s(i))/(w_sync * ((R_th + R2/s(i))^2 + (X_th + X2)^2));
```

```
end

t_max = max(t_ind);
n_m_tmax = n_m(t_ind == t_max);
n_m_start = min(n_m);
t_start = t_ind(n_m == n_m_start);
n_rate = 1435.5;
t_rate = 1.53;
x = [n_m_start,n_m_tmax,n_rate];
y = [t_start,t_max,t_rate];

hold on

plot(n_m,t_ind,'Color','b','Linewidth',2.0);
xlabel('\bf\itn_{m}(rpm)');
ylabel('\bf\tau_{ind}(N.m)');
title('\bfInduction motor torque-speed characteristics');

grid on;

plot(x,y,'*');
text(n_m_start,t_start,sprintf('Starting torque = %.4f N.m',t_start),'VerticalAlignment','top');
text((n_m_tmax-200),t_max,sprintf('Pull-out torque = %.4f
N.m\n\n',t_max),'VerticalAlignment','bottom');
text((n_m_tmax-200),t_max,sprintf('Speed at pull-out = %.4f
rpm\n',n_m_tmax),'VerticalAlignment','bottom')
text((n_rate-62),t_rate,sprintf('Rated torque = %.4f\n\n',t_rate),'HorizontalAlignment','right');
```

```
text((n_rate-30),t_rate,sprintf('Rated speed
= %.4f\n\n\n\n\n',n_rate),'HorizontalAlignment','right','VerticalAlignment','top');

hold off
```

Obtained Torque-Speed Characteristics Curve:

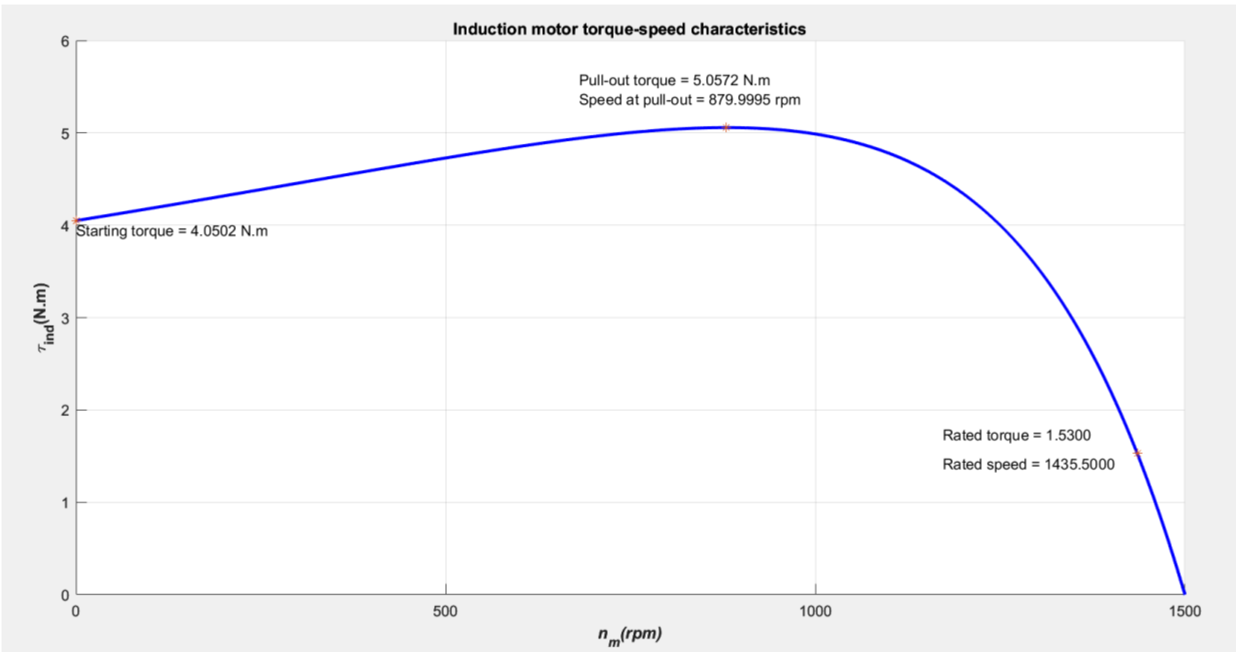


Fig 25: Torque vs speed characteristics.

Summary of the obtained results:

Characteristics	Value
Starting-torque	4.05 Nm
Pullout-torque	5.06 Nm
Speed at pullout-torque	880 rpm
Torque at rated speed(1430 rpm)	1.53 Nm

12. Complications and Limitations

Complications:

- Unavailability of professional tools required unavoidable assistance of professional workers.
- Placing coil inside the slots.
- Cutting the old winding.
- Placing insulating cover on slot after placing the coil.
- Mismatch between the calculated wire size and available wire size.
- Lack of essential instruments caused laborious assembling and disassembling of all the parts of the motor.

Limitations:

- The magnetic flux density was not exactly measured.
- Turns per coil is not the same for every coil since turns are counted by weighing the coil.
- Air gap may not be equal everywhere inside the motor which may introduce discrepancy from ideal behavior.
- The insulation class chosen could be more durable but due to high cost a moderate quality class of insulation was chosen.

13. Costing

Components	Quantity	Price (BDT)
Induction Motor	1	2,300
Copper wire	570 gm	670
Professional Cost	-	980
Total		3,950

14. Future Scope of Work

⇒ The designed motor can be used in real life by mounting its shaft with other machines like pumps, blowers, machine tools etc.

⇒ Using proper tools and measuring instruments the toque-speed characteristics may be determined experimentally to make the analysis more accurate.

15. Effect on environment

A three-phase induction motor has many mechanical parts such as the stator, the rotor, windings etc. All of these components are composed of certain elements which may be harmful for the environment. Since the industrial revolution has initiated a trend of automation which has no sign of slowing down. Electromechanical equipment will be manufactured at a higher pace in the coming days. Thus, the environmental effect of these equipment should be considered with proper attention. Our project work also requires this investigation. To start off we must identify the primary harmful components used in the project.

Harmful Component	Effect
Copper wire	Toxic metal
Insulation paper	Non-biodegradable
Varnishes	Emit high level of VOC's

Now, to reduce the negative effects of these components we tried to take proper actions for each of the components.

Copper wire:

According to the Agency for Toxic Substances and Disease Registry, industries released an estimated 1.4 billion pounds of copper into the environment in 2000. Copper toxicity can result from chronic or long-term exposure to high levels of copper through contaminated food and water sources. Symptoms of this condition include diarrhea, headaches, and in severe cases, kidney failure.

Copper contamination can be made in water, soil, and air. But the soil and food contamination are more relatable to our project. Copper wire is the most cost efficient and electrically superior material for usage. Thus, using copper was unavoidable. But copper mainly affects the environment if it is disposed of in the open. Thus, we recycled the old winding we found initially and planned on recycling the new winding after wearing out of the motor. In this way available copper will not be able to affect the environment.

Insulation Paper:

Non-biodegradable materials are hazardous to the environment because they take a lot of time to get decomposed to its elements. Thus, we used polymer insulation and fish paper insulation. Each insulation is eco-friendly. Thus, there disposal will not negatively affect the environment.

Varnishes:

Varnishes contain VOC's (Volatile Organic compound). When VOC's react with oxygen, they can form 'bad' ozone in the presence of sunlight. This is a contributory factor to the greenhouse effect and a cause of **global warming. One study by C.E.P.E. attributes paints and varnishes to causing as much as five percent of all VOC emissions.**

Varnishes should be used in minimum amount, and it should be used as the instruction manual. Proper protective measure is also essential applying varnishes. Furthermore, after usage the cleaning of brushing instruments is also necessary using proper solvents.

16. Achieved Program Outcomes

1. **PO(a)- Engineering knowledge:**
    - Rewinding the motor required knowledge of motor constructions.
    - Determining the equivalent circuit of the motor required prior knowledge of the non-ideal equivalent circuit.
    - Equivalent circuit determination required knowledge of the SCC and OCC test.

2. **PO(i)-Individual work and teamwork:**
    - Each group member's individual work was crucial in the project.
    - Merging all individual works required teamwork and co-ordination.
    - Reaching a conclusion and crucial decision-making required teamwork.

3. **PO(j) - Communication :**
    - Buying motor and necessary items required active communication.
    - Teamwork and task management required communication.

4. **PO(h)-Ethics:**
    - No unethical measure was taken in conducting the project.
    - The overall project objectives do not contain any unethical applications.
    - Future works related to this project do not include any unethical goals.

5. **PO(c)- Design/development of solutions:**
    - We designed the three-phase induction motor by performing proper calculations and later constructed the motor according to the calculated parameters

6. **PO(g)-Environment and sustainability:**
    - The wire material was chosen to minimize the harm to the environment and society as a whole.

- The number of poles, number of turns, rated current and other parameters were adjusted to get the desired output in the most feasible way.
- The old windings were planned to be recycled. Which is not only environment friendly but also cost effective.

17. Conclusion

Our primary goal of the project was to design a three-phase induction motor. The total project work gave us an insight into the construction of the motor. Although, prior to conducting the project we gathered as much knowledge as possible about the construction and the working principle of the motor. But hands-on activities gave a deeper look into the concepts we have learned. Furthermore, finding the equivalent circuit was also a part of the objective. The equivalent circuit helps to make necessary circuit simulations for the motor such as the torque-speed characteristics curve obtained by MATLAB. The winding diagram for the motor also gave us a good understanding of the wire connection. A perfect stator winding connection is crucial for overall motor performance. Some graphics software's were used while drawing the winding diagram. Moreover, while observing the calculation we came to find that many estimated values were not available in practical sense. Thus, adjustments were required. However, some preferences were given only for mitigating negative environment impacts. Such as the wire insulation, recycling the old wire, proper disposal of the non-biodegradable insulation paper etc. Some decisions were made to make the project more economical. This practice helps us to be a better engineer. As engineers need to complete any task efficiently and cost effectively. As a result, some tradeoffs were unavoidable between performance and cost. Additionally, each step of the project has some certain outcomes. All the outcomes we obtained or tried to obtain are part of the 11 program outcomes or POs. Each of the POs have their unique characteristics. We couldn't achieve all the POs in this project. But we tried to mention how, and by which task we achieved the PO's. Additionally, we tried to gather relevant knowledge from various sources, and we tried to give proper reference to every single source we benefitted from. The project is mainly focused on an electrical component but redesigning it and implementing it requires a lot of other subskills. This gives us an idea that only technical knowledge is not enough. Rather other subskills to back the core knowledge is also important.

List of References

1. “DESIGN OF INDUCTION MOTOR.” Accessed: Sep. 08, 2023.[Online]. Available:https://www.jcboseust.ac.in/electrical/images/induction_motor_design.pdf

2. *The Association of Electrical & Mechanical Trades :: Classification of Insulation Systems*. (n.d.-b). https://www.theaemt.com/resource-support/resource-support-resources/general-engineering/classification-of-insulation-systems#:~:text=Class%20F%20insulation%20consists%20of,higher%20than%20Class%20B%20materials

3. “Engineering Tables/Standard Wire Gauge - Wikibooks, open books for an open world,” *en.wikibooks.org*. https://en.wikibooks.org/wiki/Engineering_Tables/Standard_Wire_Gauge

4. S. J. Chapman, *Electric machinery fundamentals*, 5th ed. New York: Mcgraw-Hill, 2012.

5. *A textbook of electrical technology, vol. II : AC & DC machines in S.I. system of units*. New Delhi: S. Chand And Company Limited, 2019.

6. P. Mart, “Copper Wire: Resistance, Specific Heat Capacity, and Current Density,” *ThePipingMart Blog*, Dec. 21, 2022. https://blog.thepipingmart.com/metals/copper-wire-resistance-specific-heat-capacity-and-current-density/#:~:text=Current%20Density%20of%20Copper&text=The%20maximum%20recommended%20current%20density (accessed Sep. 08, 2023).
7. McFadyen, S. (n.d.). *Motor insulation.* https://myelectrical.com/notes/entryid/154/motor-insulation