Bangladesh University of Engineering and Technology

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Course Title: Energy Conversion Laboratory

Project Report

Rewinding of a 3-Phase Squirrel Cage Induction Motor

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Table of Contents

Introduction

The basic idea of an induction motor is to produce torque for rotating mechanical load by the means of electromagnetic induction. We have designed an asynchronous AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. We have used a rotor where the inner component connected to the output shaft – looks like a cage which is also known as the 'Squirrel cage rotor'.

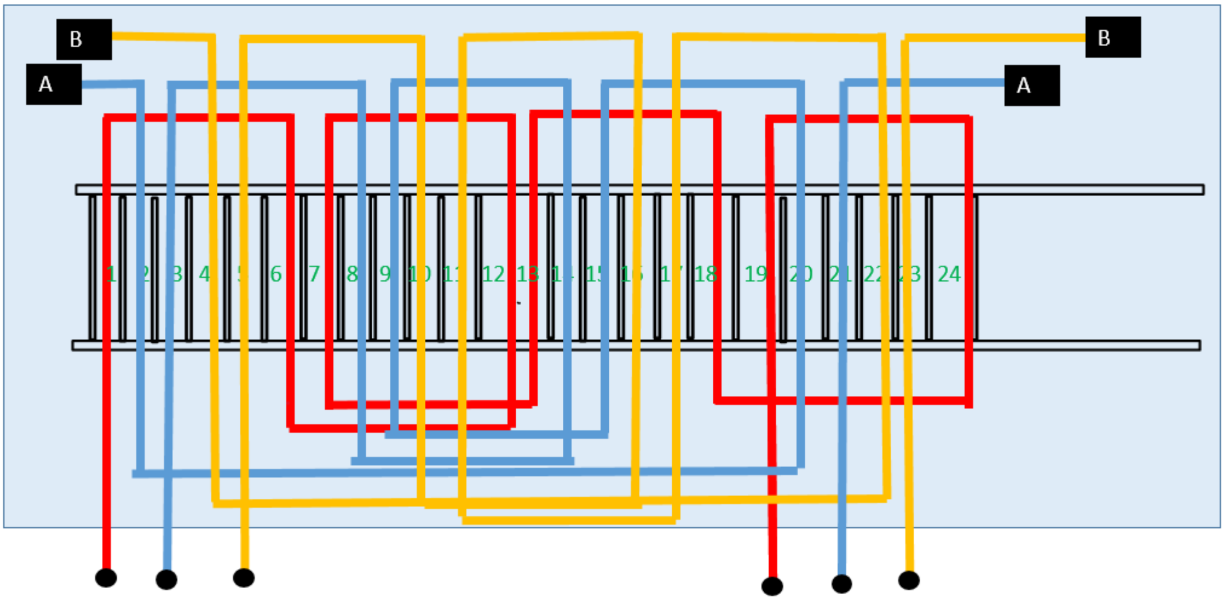
Theory

Workings of a squirrel induction motor are based on the electromagnetic theory. A rotating magnetic field with synchronous speed is created when a three-phase AC is applied to the stator winding. The rotor bars experience voltage induced by this rotating magnetic field. As a result, current passes through the rotor. These rotor currents produce a self-magnetizing field that interacts with the stator field. Now, according to electromagnetic law, the rotor field starts to work against its cause. The rotor current zeros out when the rotating magnetic field captures the rotor moment. Then there would be no relative velocity between the rotor and rotating magnetic field.

The rotor thus experiences zero tangential force and temporarily moves with reduced momentum. The rebuilding of the relative motion between the rotating magnetic field and the rotor induces the rotor current once again following this reduction in the rotor's moment. As a result, the rotor's tangential force for rotation is restored, and it begins by starting to follow the rotating magnetic field. The rotor in this instance maintains a constant speed that is lower than the rotating magnetic field and synchronous speeds. Here, slip is used to measure the speed disparity between the rotor and the rotating magnetic field. By multiplying slip and supply frequencies, one may determine the rotor's final frequency.

Winding Diagram

Coil Placement and Connections



Explanation:

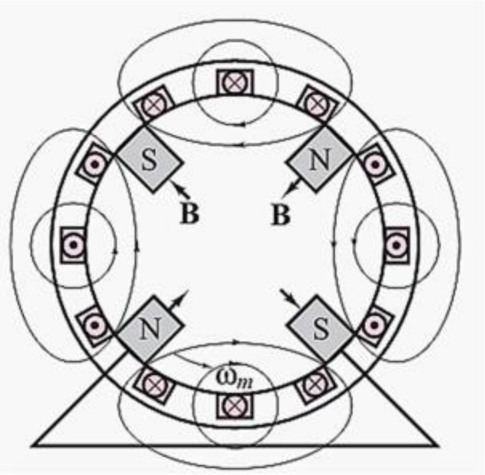
Our motor is a 4 pole 3 phase induction motor. There are 24 slots in the stator. The number of slots will be equally distributed among the three phases.

So, slots per phase = 24 / 3 = 8

As each slot is for one arm of a coil and a coil has two arms, total number of coils = 24/2 = 12

As the number of coils per phase and the number of poles are equal, it can be said that corresponding coils of each phase that are 120 degrees apart from each other will produce one pole of the 4 poles of the stator. As the corresponding coils are 120 degrees apart and they are powered by three phase power, they will make their respective pole rotating. Thus 4 pole rotating magnetic field is produced.

The picture below shows the relative positions of the 4 poles of a 12-slot stator as an example



From this, the angle between two consecutive poles = 360 / 4 = 90 degree.

So, the angle spanned by one single coil in a 24-slot stator = 90 degrees. (Coil-pitch)

The angle separation of two consecutive slot = 360 / 24 = 15 degrees (Slot-pitch)

So, number of slots spanned by each coil = Coil-pitch / Slot-pitch = 6

This means that, if one arm of a coil is placed in slot number 1, the other arm of the coil will be placed in slot number 6. This coil between 1 and 6 is one of 4 coils of a phase. The second coil of the phase will be placed at the next slot, number 7, and slot number 12. The rest of the coils of this phase will follow the same rule

Again, the three phases are 120 degrees apart. That corresponds to 120 / 15 = 8 stator slots. So, the three phases are 8 stator slots apart from each other. However, as the stator is circular, we can put coils of consecutive phases 60 degrees apart i.e., 60 / 15 = 4 stator slots apart. That means, if the first coil of phase A is in the 1st slot, the first coils of phase B and phase C will be in the 5th slot and the 9th slot respectively.

In a 4-pole rotating magnetic field, each north pole is followed by a south pole and vice versa. This gives us information about how to connect the coils of each phase to produce these consecutive north and south poles. The direction of current flow in coil 1 of phase A will be opposite to that of coil 2 of the same phase. To keep the magnetic strengths of the poles same, the same current should be flowed through the coils. So, the coils of each phase will be connected in series. However, to produce consecutive north and south poles, two consecutive coils of a phase must be connected in a manner opposite to each other.

From the discussion above, we can now show the distribution of coils of each phase and their connections in the tables below. Here, the numbers represent stator slot number and the plus and minus sign represent the oppositeness of the poles that the coils of each phase will produce.

Phase – A

Slot Number for each coil	Direction of Current Flow
1-5	+
7-12	-
13-18	+
19-24	-

Terminals 6 and 12, 7 and 13, 18 and 24 will be shorted for series connection. Terminals 1 and 19 will be used for power supply.

Phase – B

Slot Number for each coil	Direction of Current Flow
5-10	+
11-16	-
17-22	+
23-4	-

Terminals 10 and 16, 11 and 17, 22 and 4 will be shorted for series connection. Terminals 5 and 23 will be used for power supply.

Phase – C

Slot Number for each coil	Direction of Current Flow
9-14	+
15-20	-
21-2	+
3-8	-

Terminals 14 and 20, 15 and 21, 2 and 8 will be shorted for series connection. Terminals 9 and 3 will be used for power supply.

Calculations

Maximum Flux per pole

$$\emptyset' = (0.00145 + \frac{0.003}{P})\sqrt{\frac{60P_s}{f}}$$

Where,

$P = Number\ of\ poles$

$P_s = Rated\ Output\ power\ in\ horse\ power\ (hp)\ unit$

$$f = frequency$$

For our motor, $P_s = 325\ W = 0.4357\ hp\ , P = 4\ , f = 50\ Hz$

$$\therefore \emptyset' = \left(0.00145 + \frac{0.003}{4}\right)\sqrt{\frac{60 \times 0.4357}{50}} = 0.00159076887\ Wb$$

Winding Factor

$$N_{sl} = \frac{S_1}{Pm}$$

Where, S

$_1 = Slots\ Number = 24$

$P = Pole\ number = 4$

$$m = Phase = 3$$

So,

$$N_{sl} = \frac{24}{4 \times 3} = 2\ slots\ per\ pole\ per\ phase$$

$$\therefore There\ are\ \frac{S_1}{P} = \frac{24}{4} = 6\ slots\ per\ pole$$

Pitch in Electrical degree, $e = 180°$

Pitch factor,

$$K_p = \sin\left(\frac{e}{2}\right) = 1$$

$$\gamma_1 = \frac{180 \times P}{S_1} = \frac{180 \times 4}{24} = 30°$$

$$K_d = \frac{\sin\left(\frac{N_{sl}\gamma_1}{2}\right)}{N_{sl}\sin\left(\frac{\gamma_1}{2}\right)} = \frac{\sin\left(\frac{2 \times 30}{2}\right)}{2 \times \sin\left(\frac{30}{2}\right)} = 0.9659$$

$$K_{\omega 1} = K_p K_d = 0.9659$$

By choosing a single current winding,

$$C_s = \frac{0.97aV_1}{2.22K_{\omega 1}PN_{sl}f\emptyset'} = \frac{0.97 \times 1 \times \frac{410}{\sqrt{3}}}{2.22 \times 0.9659 \times 4 \times 2 \times 50 \times 0.00159076887} \approx 156\ conductor\ per\ slot$$

Full load current,

$$I_s = \frac{P_s \times 746}{\sqrt{3} \times V_L \times pf \times \eta} = \frac{0.4357 \times 746}{\sqrt{3} \times 410 \times 0.85 \times 0.77} = 0.7\ A$$

For this maximum current (0.7 A) for chassis wiring

Wire Size=31 AWG

Wire Diameter=0.00893 inches

Work Flow

- **Disassemble**
  After observing the nameplate of the motor, we opened the both end of the motor and brought out the rotor. After this, using hammer and chisel We cut the old windings.

- **Insulation**

By cutting fiber paper into equal rectangular shape we provided electrical insulation.

- **Coil Insertion**

Before forming new coils, we measured the size of coil loop by inserting a single wire loop between two slots which are 6 slots apart. The coils were then inserted in the stator slots. At first, one arm of the coil was tied. The other arm was inserted. Coils were placed such that there were 4 empty slots between them. After placing one coil, the next was placed keeping one empty slot between corresponding arms of the coils. For example, if the first coil was placed at the 1st and 6th slot, the second was placed at the 3rd and 8th slot. In this way, all coils could be placed easily.



- **Connection**

The coils of each phase were connected in series connection. The connection sequence has been described in the theory part of this report. Wires were brought out from coils and the insulation of the wire was removed. Then the terminals of the coils were connected in a series manner. All 6 coil terminals were not connected. These were for supplying current to the coils- two terminals for each phase. These wires were brought out from the top of the stator. They were connected to the power supply ports that were already present on the stator. Three terminals were then shorted and the other three were kept open. Thus, the supply terminals were wye connected. Then we varnished the motor.


- **Reassemble**
  Then we have reassembled all the parts again.

Final Rewinded Motor

Output of laboratory test

No Load Test	
Parameters	**Values**
Voltage	345 V
Current	0.45 A
Power (Per Phase)	11 W

Blocked Rotor Test	
Parameters	**Values**
Voltage	120 V
Current	0.7 A
Power (Per Phase)	39 W

DC Test	
Parameters	**Values**
Coil 1	43.7 Ω
Coil 2	42.6 Ω
Coil 3	42.9 Ω

Equivalent Circuit

Calculation

DC test:

$R_1 = \frac{43.7+42.6+42.9}{3} = 43.067\ \Omega$

Blocked Rotor Test:

VT= 120 V

Pin = 3*39 W = 117 W

I rated = 0.7 A

$\text{Cos}\ \phi = \frac{Pin}{\sqrt{3}*V*I}$ = (117)/(√3 *0.7) = 0.804

$\sin \phi = 0.595$

$|ZLR| = (120)/(\sqrt{3} * 0.7)$

$RLR = |ZLR| * \cos \phi$

$= 98.97 * 0.804$

$= 79.575 = (R_1 + R_2)$

So,

$R_2 = (79.575 - 43.067) = 36.533\ \Omega$

$XLR = |ZLR| * \sin \phi$

$= 58.85 = X1 + X2$

For design class B,

$X1 = 0.4 * XLR = 23.332\ \Omega$

$X2 = 0.6 * XLR = 35.298\ \Omega$

No load Test:

$VL = 345V$

$IL = 0.45A$

$Pin = 33W$

$V\varphi = 345 / \sqrt{3} = 199.18V$

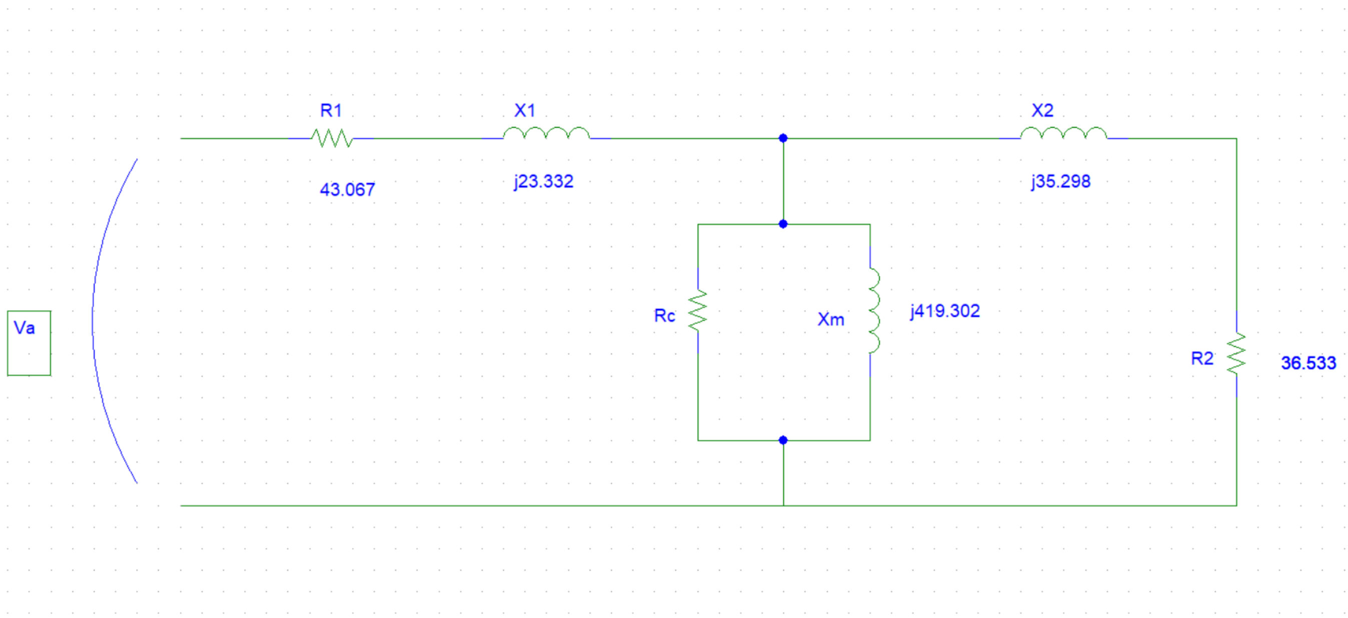
$|Zeq| = V\varphi / IL \cong X1 + Xm$

$X1 + Xm = 442.6352$

$Xm = 442.6352 - 23.332 = 419.302\ ohm$

Equivalent Circuit Parameters	
Parameters	**Values**
R_1	43.067 Ω
R_2	36.533 Ω
X_1	23.332 Ω
X_2	35.298 Ω
X_m	419.302 Ω

Schematics



Torque Speed Characteristics Curve

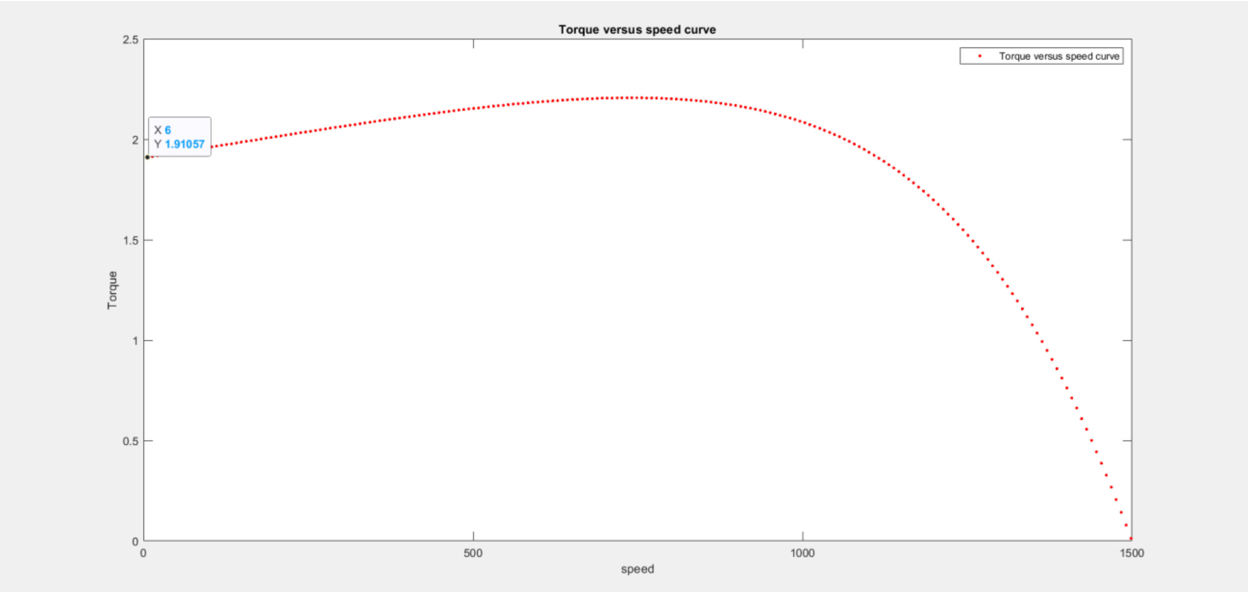
Matlab Code:

```
%3 Phase Induction motor torque speed characteristics:
clc;
% circuit parameters
r1= 43.067;    x1= 23.332;  r2= 36.533;   x2= 35.298;   xm= 419.302;
%operating voltage and frequency
v_line=415;
 v_phase=v_line/sqrt(3);
 f=50;
n_syc=120*f/4;
 w_syc=2*pi*f;
%calculate the thevnin theorem
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);

%Range of s from 0.001 to 1
s=0.001:0.005:1;
 L=size(s,2);
%machine speed in rpm
nm=(1-s)*n_syc;
 for i=1:L
      r=r2/s(i);
    t_ind(i)=((3*v_th^2*r)/w_syc)/((r_th+r)^2+(x_th+x2)^2);
 end
plot(nm,t_ind,'r.');
hold on;

xlabel('speed');ylabel('Torque');title('Torque versus speed curve');
legend('Torque versus speed curve');
```

<u>Output</u>:



Starting Torque =1.91 Nm

Total Cost of this Project

Instruments	Cost (BDT)
Motor	1200
Insulated Coper Wire	900
Varnish	40
Fiber	90
Miscellaneous	100
Total	**2330**

Limitations

1. **Number of turns in each slot**: The number of turns might not be exactly the same in each coil. There might have an error of ±2 number of turns.

2. **Amount of Air Gap**: It might not be maintained equally everywhere inside the motor construction.

3. **Less torque capability**: It was studied that if more wires are used in a single coil, the motor could carry out more load. On the other hand, if less coils are used, the motor could carry small load. Because of the complexity of inserting more wires in the slot gaps, we might not gain sufficient torque.

4. **Less Efficiency**: The diameter of the new wire we used was less than that of the old one we removed. As a result, the resistance of the new wire was also greater than that of the old one. This might be a reason behind the reassembled configuration to be less efficient.

5. **Weight of Copper Wires**: During the making of coils by the help of a wooden forma from copper wires, it was tried to maintain same weight of before, but the weight could vary slightly. Considering it negligible, we continued the winding process.

6. **Safety:** We could not ensure sufficient protection against the damage of insulation

Discussion

Our project was to rewind an old three phase induction motor. We faced some shortcomings due to our lack of prior experience in hardware work related to motor. We also had to wind the coil manually as we did not have any automatic winding machine. Still we managed to cross such obstacles and build our project.

We can use our project to reduce the cost of buying motor time and time again. A completely new motor will cost the consumer around 8000/- BDT, whereas the consumer can use our project, that is, a rewinded motor that will only cost 2330/- BDT. This is also an efficient way since we are recycling the raw materials to build up a motor. The gradual decrease of raw materials to build up electrical drives will surely be treated by recycling method.

The project lends us a thorough knowledge about the internal structure, coil arrangement, motor functioning procedure and much more. This knowledge will surely help us in the future to rewind an old induction motor into a motor of diversified applications.