Induction Machine Characterization

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1 INTRODUCTION

The objective of this lab was to get hands on experience with Induction motors. We specifically used a machine with a dynamometer connected to it. The tests we completed were to find the parameters of the motor with which we could make a circuit model of it. Further, we were also exposed to LabView software through which we controlled the dynamometer and got readings of speed and torque. From the last lab this was a step up as the motor was a lot bigger and provided a lot more force.

All data/measurements taken are provided in the appendix at the bottom of the document.

2 RESULTS

2.1 *Machine Parameterization*

To get the different circuit parameters to create a model we completed a few tests: No Load Test (Open Circuit Test), Blocked-rotor test (short-circuit test), and the DC test. With the data collected from these we can do a few calculations to approximate the parameter values to an acceptable degree.

To Find R_c and X_m we can use the No Load test as almost no current is going through to the rotor side. To set this up we spin the dyno at 3600 RPM which is the synchronous speed of our motor, giving us no load. This is the data we collected:

Table 1: No-Load Test

Voltage	Current	Power
Vab = 205.4V	Ia = 2.01A	66W
Vcb = 205.8V	Ic = 2.01A	66W

We first find the power factor by the watt meter readings:

$$\phi = \arctan \frac{\sqrt{3} \cdot (P_{\text{wm1}} - P_{\text{wm2}})}{P_{\text{wm1}} + P_{\text{wm2}}} = 84.86^\circ$$ **Equation 1.**

$$PowerFactor = \cos\phi = .09$$ **Equation 2.**

With the power factor we can find Rc and Xm currents and approximate their values.

$$R_{\text{c}} = \frac{V}{I \cdot \cos\phi} = 655.54 ohms$$ **Equation 3.**

$$X_{\text{m}} = \frac{V}{I \cdot \sin\phi} = 59.2 johms$$ **Equation 4.**

To get the stator values R_s, X_s and rotor value R_r and X_r we can use the locked-rotor test (short circuit test) as all the current is flowing directly to rotor.

Table 2: Blocked-Rotor Test

% of Rated current	Vab (V)	Vcb (V)	Ia (A)	Ic (A)	Speed	Power
100	39.7	39.8	5.19	5.22	0 RPM	209W
80	33.2	33.1	4.20	4.19	0 RPM	136W
60	26.3	26.2	3.15	3.14	0 RPM	77W
40	18.9	18.8	2.05	2.04	0 RPM	32.5W
20	11.9	12.0	1.06	1.08	0 RPM	9W

Next to get stator resistance R_s we can use the DC test.

$$R_s = \frac{V}{2I} = 1.32ohms$$ **Equation 5.**

With this found we can use the results from short circuit test to find R'_r.

$$R_s + R'_r = \frac{P}{3I^2} = 2.57ohms$$ **Equation 6.**

So, R'_r = 2.57 - 1.32 = 1.25ohms

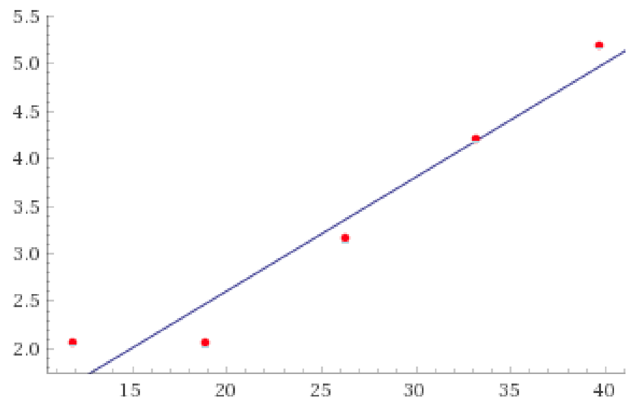
We can also find X_{eq}:

$$Z_{eq} = X_s + X'_r + R_s + R'_r = \frac{V}{I} = \frac{39.7/\sqrt{3}}{3.04 + 4.22j} = 2.57 + 3.58johms$$ **Equation 7.**

$$X_{eq} = X_s + X'_r = 3.58johms$$ **Equation 8.**

Further with the Blocked-rotor data we can find the starting current.

Graph of Ia vs Vab from Blocked-rotor test.



The starting current would be very high but for a very small instant of time, also known as inrush current. From the line of best fit the inrush current comes out to 27.6A which is reasonable as it is 5-6 times bigger than the rated current.

2.2 *Operation Power Losses*

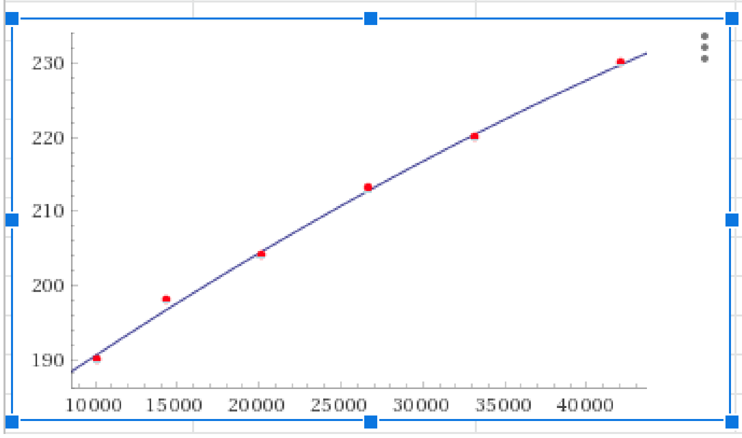
Now that we have found the parameters, we can approximate power losses through core, copper, windage and friction.

Since we have the No Load operation data we know that:

$$P_{\text{no load}} = P_{\text{F+W}} + P_{\text{Core}} + P_{\text{copper loss}} \qquad \textbf{Equation 9.}$$

Through the data acquired in our friction and windage losses we can get a good curve fit.

Voltage	power
42,107.04	230
33,233.29	220
26,666.89	213
20,164	204
14,400	198
10,160.64	190



The Y intercept of this line is at 175W which can be approximated as the friction and windage losses.

2.3 *Torque and Speed*

After using the IEEE standard 112 and refining the circuit parameters, a more accurate analysis can be done. Based on the these new parameters we can plot the expected torque vs speed curve.

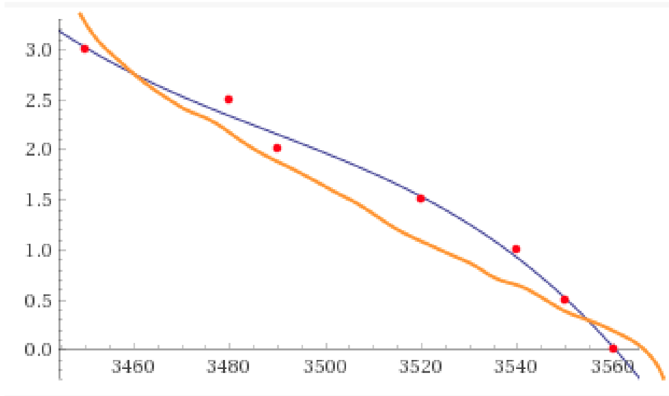
Load test data:

Table 3: Load Test

Torque (Nm)	Ia (A)	Ic (A)	Vab (V)	Vcb (V)	Speed (RPM)	Power (W)
0	2.22	2.22	205	205	3560	350
.5	2.25	2.27	205	205	3560	382
1	2.60	2.65	204	205	3555	588
1.5	3.02	3.08	204	204	3520	785
2.0	3.5	3.55	203	203.5	3490	985
2.5	4.03	4.09	202.8	203	3480	1190
3.0	4.61	4.66	202.3	202.6	3450	1400

The data collected form this test does not give a very accurate torque vs speed curve for low speeds however, it matches closely the expected graph near synchronous.

Orange is expected torque and blue is torque from dynamometer.



With the part E data we can also compute the the reactive power into the motor.

$$S^2 = P_{\text{F+W}} + P^2 + Q^2 = (\sqrt{3} * 204 * 2.6)^2 = 588^2 + Q^2 \qquad \textbf{Equation 10.}$$

This gives us reactive power Q = 706VAR, and a power factor of .64.

Further we can also compute motor characterisitics near 0 slip as we ran the motor close to synchronous speed in this test.

The equation to the curve fit is: $y = 93.3592 - 0.0261494x$

By using the circuit parameters and equation 4.22 in the lab manual we get a slope of 0.03265 which is close as we did not run exactly close to synchronous speed every time (varying amounts of slip).

Lastly, we can compute the efficiency of the induction motor. This is given by the following equation:

$$\eta = \frac{P_{\text{out, mech}}}{P_{\text{in, elec}}} \qquad \textbf{Equation 11.}$$

Mechanical power out can be given by this formula:

$$P_{\text{out, mech}} = Torque \cdot Speed(rad/s) = 3.0 \cdot 3450 \cdot 2\pi \cdot \frac{1}{60} = 1083.8W \qquad \textbf{Equation 12.}$$

So our **efficiency** is 1083.8/1400 = 0.7741 = 77.41%.

3 CONCLUSION

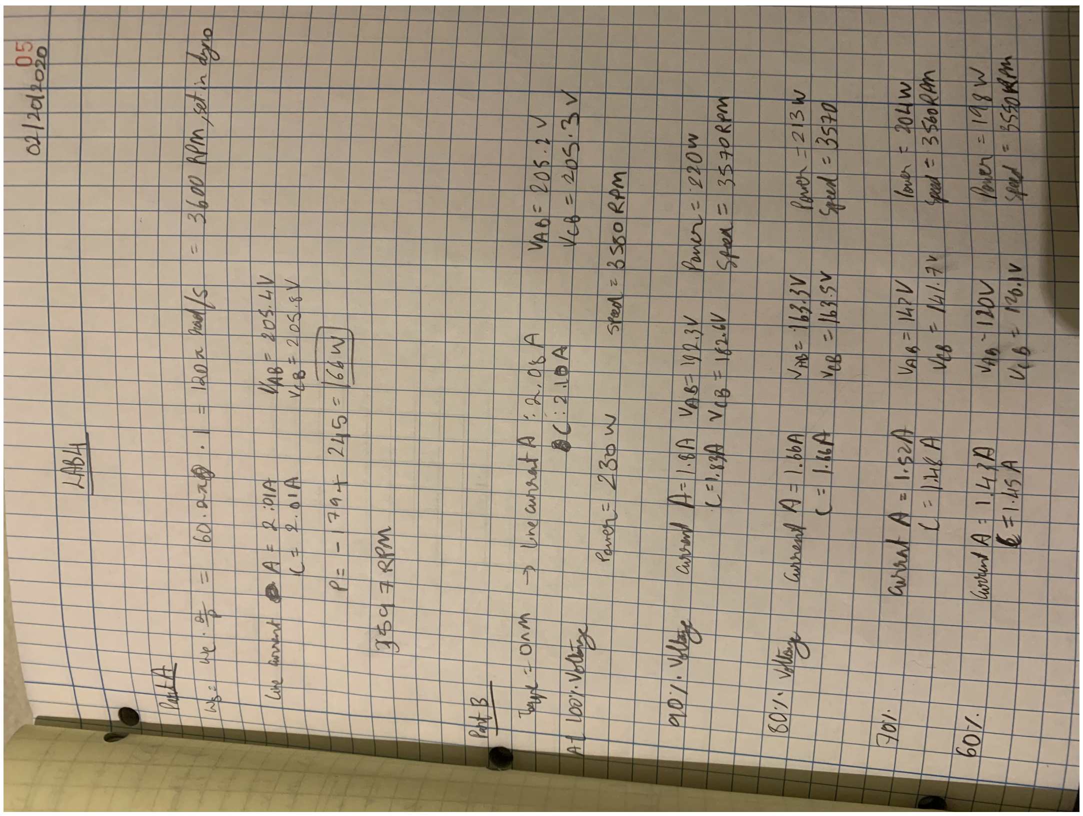
This lab gave us a good look into induction motors and their functionality. The tests we conducted are used in industry to characterize motors in a similar fashion. Further, the different operating ranges while conducting different tests make more sense as we do not want to damage the motor. The parameterization helps create a more familiar circuit that is easier to work with rather than empirically calculating everything. Overall it was a very good lab.

4 REFERENCES

[1] P.W. Sauer, P.T. Krein, P.L. Chapman, *ECE 431 Electric Machinery Course Guide and Laboratory Information*, University of Illinois at Urbana-Champaign, 2005.

5 APPENDIX

Raw Data:



Part E

Torque: 0 Nm · Line current A = 2.22A, C = 2.22A; V_{AB} = 205V, V_{CB} = 205V; ~~Power~~ = 390W; Speed = 3560

Torque = .4 Nm

Torque = .5 — current A = 2.25A, C = 2.27A; V_{AB} = 205V, V_{CB} = 205V; Power = 382W; Speed = 3560 RPM

Torque = .5

Torque = 1 — A = 2.6A, C = 2.65A; V_{AB} = 204V, V_{CB} = 205V; Power = 588W; Speed = 3555 RPM

Torque = 1.05

Torque 1.5 — A = 3.02A, C = 3.01A; V_{AB} = 204V, V_{CB} = 204V; Power = 785W; Speed = 3520 RPM; Torque = 1.54

Torque 2.0 — A = 3.5A, C = 3.55A; V_{AB} = 203V, V_{CB} = 203.5V; Power = 985; Speed = 3490 RPM; Torque = 2.04

.5 — A = 4.04A, C = 4.09A; V_{AB} = 202.8V, V_{CB} = 203V; Power = 1190; Speed = 3480 RPM; Torque = 2.5

0 — A = 4.61A, C = 4.66A; V_{AB} = 202.3V, V_{CB} = 202.6V; Power = 1.4kW; Speed = 3450 RPM; Torque = 3.05

50% — Line current A = 1.46A, C = 1.40A; V_{AB} = 100.8V, V_{CB} = 100.6V; Power = 190W; Speed = 3520

Part C

Rated Current = 5.2A at 230V

current A = 5.19A, C = 5.22A; V_{AB} 34.4V, V_{CB} = 39.8V; Power = 209W; Speed = 0 RPM

80% current A = 4.20A, C = 4.19A; V_{AB} = 33.2V, V_{CB} = 33.1V; Power = 136W; Speed = 0 RPM

60% Current A = 3.15A, C = 3.14A; V_{AB} = 26.3V, V_{CB} = 26.2V; Power = 77W; Speed = 0 RPM

40% current A = 2.05A, C = 2.04A; V_{AB} = 16.9V, V_{CB} = 16.8V; Power = 32.5W; Speed = 0 RPM

20% Current A = 1.06A, C = 1.08A; V_{AB} = 11.9V, V_{CB} = 12.0V; Power = 9W; Speed = 0 RPM

Part D

A-B I_a = 5.20A, V_{AB} = 13.75V

A-C I_a = 5.19A, V_{AC} = 13.7V

B-C I_B = 5.18A, V_{BC} = 13.76V

C-B I_C = 5.20A, V_{CB} = 13.9V