Iowa State University
Electrical and Computer Engineering
E E 452. Electric Machines and Power Electronic Drives

Laboratory #12
Induction Machine Parameter Identification

Summary

The squirrel-cage induction machine equivalent circuit parameters will be obtained through a series of measurements. These parameters can be used to simulate motor performance, and aid in the design of motor drive applications. The procedure described here is based on *IEEE Standard 112-2004*.

Learning objectives

- Perform a locked rotor test, no-load test, and load point test.
- Analyze measurements to obtain the squirrel-cage induction machine parameters for use in the equivalent circuit.

Background material (should be read before coming to the lab)

- *IEEE Standard Test Procedure for Polyphase Induction Motors and Generators* (*IEEE Standard 112-2004*).
- *IEEE Standard Test Code for Resistance Measurement* (*IEEE Standard 118-1978*).
- Krause, section 6.8.

Exercises and Questions

Instructions: every student should deliver his/her own report at the end of the lab session, even though the experiments are conducted in groups. You may want to answer the questions as you go along the exercises. Time yourselves according to the recommendations below.

1. Pre-lab assignment

The squirrel-cage induction machine can be described by the steady-state equivalent circuit shown in Figure 1.

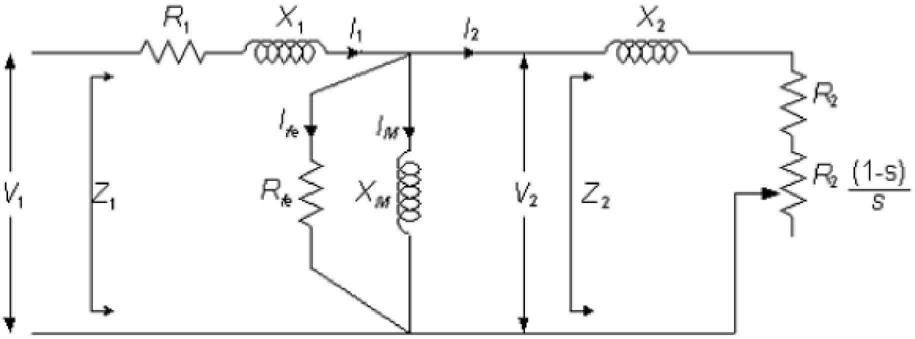

Figure 1. Equivalent circuit for squirrel-cage induction machine (from *IEEE Standard 112-2004*).

Refer to page 24 of *IEEE Standard 112*, or your textbook, for a description of the circuit quantities.

To analyze any particular machine, it is necessary to know the actual parameter values. Nameplate data does not include these parameters. In addition to the nameplate information, a series of tests will be performed, from which parameter values can be extracted. The procedure of this lab is a summary of *Method 4* in *IEEE Standard 112*.

Three types of tests will be performed:

1) Locked rotor test at rated frequency and rated current
2) No-load test at rated frequency and rated voltage
3) Full-load Slip at rated frequency and rated voltage

All tests will be performed with a three-phase, 0-208 V, 60 Hz power supply, derived from the utility grid. Differential voltage probes, current probes, oscilloscope, dynamometer, and a tachometer will also be required.

For each test, it will be necessary to measure the stator line-to-line voltage (V_{rms}), line current (A), phase (s), and rotor speed (rpm). Ambient temperature ($^\circ C$) will also be necessary for resistance measurements.

Use the provided MATLAB script to record and analyze the data you obtain. Before beginning the tests, go through the script to understand how your measurements are being used to extract the machine parameters.

The MATLAB script can be followed as a procedure; start at the beginning and work your way through to the end. The procedure is summarized here.

1) Obtain nameplate data, and define constants.
2) Directly measure stator winding resistance, using a digital multimeter.
3) Do the no-load and locked rotor tests to obtain stator and rotor leakage inductance, and magnetizing inductance.
4) Do a no-load test to obtain friction and windage loss and core resistance.
5) Do full load slip test to obtain rotor resistance.

DELIVERABLE 1: Read through *IEEE Standard 112* and the provided MATLAB script. You must understand how and why all tests are being performed. Note any deviations from the procedure, or any assumptions/simplifications that are being made. See Krause pp. 247-249 for additional information.

CAUTION!
Verify all hardware configurations with your group members and T.A.

2. Nameplate Quantities and Constants [10 minutes]

Examine the machine nameplate. Identify the rated frequency, voltage, current, and temperature. Determine the number of poles, number of phases, synchronous speed, and NEMA design letter. Record this data appropriately in the MATLAB script.

Use the guidelines of *IEEE Standard 112*, section 5.9.2.2 to determine the ratio of X_1 to X_m, identified by *Xmratio* in the script.

3. Stator Resistance, R_1 [10 minutes]

Determine the stator winding connection, *wye* or *delta*. If the connection is unknown, you can assume either a delta or wye connection. Whichever you decide, make sure to adhere to your assumption. Because the equivalent circuit is per phase, where the input voltage is line-to-neutral, it is convenient to assume a wye connection.

With the stator terminals open-circuited, measure the resistance between each phase input. If the stator is wye connected, divide the measurement by two to obtain the per-phase stator resistance. If the stator is delta connected, your measurement is of the parallel combination of one phase with the other two phases; manipulate the measurement appropriately.

The provided MATLAB script assumes a wye connection.

4. Leakage and Magnetizing Inductances, X_1, X_2, X_m [60 minutes]

Perform the *no-load test* described in *IEEE Standard 112* section 5.5. Make sure your motor is not connected to any load; keep all belts disconnected. Connect the Lab-Volt variable three-phase supply to the stator terminals. Increase the voltage to 208 V to make the motor spin near synchronous speed.

Measure the terminal voltage, line current, and phase angle for each phase; measure [$\tilde{V}_{ab}, \tilde{V}_{bc}, \tilde{V}_{ca}$] and [$\tilde{I}_a, \tilde{I}_b, \tilde{I}_c$]. Also measure the rotor speed; it should be very close to synchronous speed. From the measurements, formulate the line-to-neutral voltage and phase current phasors. Then compute the real and reactive power input to the machine. Stop the motor and move to the next test.

Perform the *locked rotor test* described in *IEEE Standard 112* section 5.9.2.1. This test requires the stator to be supplied with a frequency of 60 Hz, and stator voltage amplitude at which the line current is at rated value. The voltage where this will happen will be lower than rated. The rotor must not turn during this test.

Note: The impedance of the wound rotor machine varies with rotor position. Follow the guidelines of section 5.9.2.1, (page 26) in the standard, for determination of the rotor position.

Because the applied terminal voltage is low, on the order of 10-20% rated value, a relatively small torque is developed. The Lab-Volt dynamometer can apply a sufficiently large torque to prevent rotation.

Warning! Do not grab a rotating shaft, serious injury may occur.

With the rotor locked, and the machine energized to rated current, record the voltage, current, and phase as necessary. From the measured values, formulate the voltage and current phasors, and calculate the input real and reactive power. These calculations are provided in the MATLAB script.

Using equations (30) through (35) in the standard, compute the stator and rotor leakage inductance, and magnetizing inductance, through an iterative process. Implementation of these calculations is provided in the MATLAB script.

Note: It is necessary to define an initial estimate of the stator leakage inductance.

5. **Friction & Windage Losses** [40 minutes]

As the rotor is moving, losses occur due to the motion of the shaft. Motion dependent losses include friction between bearing surfaces, and different types of drag as the rotor surface moves through the air. The sum of these rotational losses will be referred to as the friction and windage loss, identified as *PlossFW* in the MATLAB script.

Perform another *no-load test*. This time, perform the tests at a range of voltages, described in the standard to be from 125% rated voltage, down to a level at which the current magnitude begins increasing. As you will see, reducing the stator voltage results in a subsequent reduction in the current amplitude. This trend continues to a certain voltage; as the voltage is reduced beyond this level, the current will begin to rise due to reduced rotor resistance at high slip values.

The Lab-Volt supply won't provide 125% rated value (260 V for a machine rated 208 V). Perform the tests from rated value down to the point at which the current magnitude begins to increase. Reduce the voltage in increments of 10 V.

For each voltage level, record the line-to-line voltage, line current, and phase. Averaging the three measurements per voltage level will account for any difference from one phase to another.

Use the measurements to obtain the input real power. Use R_1 to calculate the stator resistive loss, identified by *Psir* in the script. Subtract the stator loss from the input power, to obtain the remaining power, which is equal to the electromechanical power transferred to the rotor plus rotor *I^2*R* loss plus friction and windage losses. Plot the resulting power versus the stator voltage. These calculations are provided in the script.

Run the script to generate the plot. You may need to insert a "return" command to stop the script prematurely. As the script runs, you will be asked to analyze the plot. Observe the trend, and estimate the zero-voltage intercept. The power at this point is the estimated friction and windage loss. Enter this estimate in the MATLAB command window when prompted, in units of watts.

6. Core Resistance, R_{fe} [10 minutes]

Real power losses occur in the iron core of the machine. These losses are due primarily to magnetic hysteresis and eddy currents, and are represented as a core resistance, R_{fe}.

Use the no load test input power, of section 4 (*Friction and Windage*), with the estimated friction and windage loss, to estimate the core loss, identified by *Ph0* in the script. The method applied here ignores rotor real power loss. This is an appropriate assumption, since during the no load test, the slip is very close to zero, making the rotor resistance, R_2/s, very large. All calculations are provided in the script.

7. Rotor Resistance, R_2 [20 minutes]

In the model of Figure 1, the rotor resistance is a function of slip. To find the value of R_2, a load test will be performed. Real and reactive power, in conjunction with slip and previously found parameters, will be used.

Do a *full load slip test*, as described in section 5.6 of *IEEE Standard 112*. Run the machine at rated voltage and rated frequency. Use the dynamometer to apply a mechanical load. Apply a load such that the rotor spins at the nameplate value.

Measure the stator voltage, line current, phase angle, and rotor speed. Use a digital tachometer to accurately measure the rotor speed. Follow the equations of section 5.9.5.2 to calculate the rotor resistance. All necessary calculations are provided in the MATLAB script.

Note: The slip equation of section 5.3 in the standard has a typo, it should be
slip speed = $n_s - n_t$.

After all tests have been performed and measured data entered, run the script to calculate the machine parameters.

DELIVERABLE 2: Email your MATLAB script to the T.A. The T.A. should be able to run the script and see your measured machine parameters.

8. Torque vs. Speed and Simulation of the Measured Machine [20 minutes]

With the machine parameters now found, use the MATLAB script of Lab 9 to plot the torque vs. speed curve of this machine.

Note: You will need to modify the electromagnetic torque equation to include the core resistance, R_{fe}. The new torque equation should be

$$T_e = 3\frac{P}{2}\frac{V_{Th}^2 R_2}{(s\omega_e)\left[\left(R_{Th}+\frac{R_2}{s}\right)^2+(X_{Th}+X_2)^2\right]} \tag{1}$$

where

$$Z_{Th} = R_{Th} + jX_{Th} = \frac{1}{\frac{1}{R_1+jX_1}+\frac{1}{Z_m}} \tag{2}$$

and

$$Z_m = \frac{R_{fe}*jX_{fe}}{R_{fe}+jX_{fe}}. \tag{3}$$

DELIVERABLE 3: Email the torque vs. speed curve and simulation results to your T.A.

9. Conclusion [10 minutes]

Write about one or two things you learned in this lab that you think are important or interesting, and why.