Lesson 15: Induction Motor Testing: Lock-Rotor and No-load Tests

ET 332b

Ac Motors, Generators and Power Systems

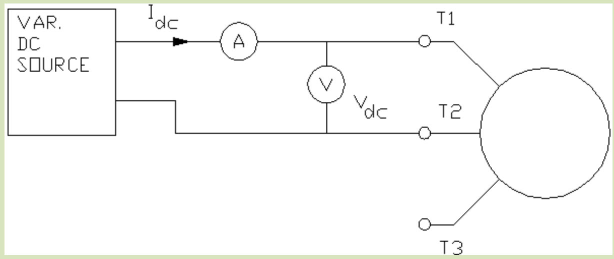
Learning Objectives

After this presentation you will be able to:

- Conduct locked rotor tests on 3-phase induction motors
- Conduct no-load tests on 3-phase induction motors
- Use measurements from lock rotor and no-load tests to find motor circuit parameters

Finding Induction Motor Parameters

Dc Test - finds R_1, the stator conductor resistance



Procedure: 1.) Apply dc voltage to stator
2.) Adjust dc source until rated current flows

Formulas

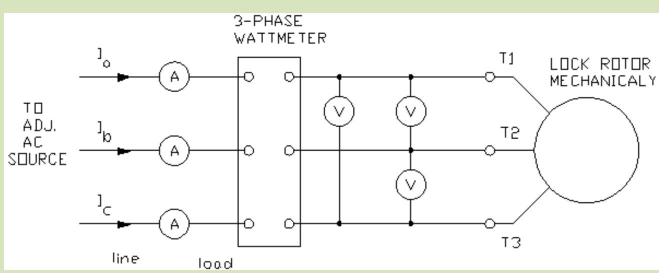
$$R_{dc} = \frac{V_{dc}}{I_{dc}}$$

For wye connected stator $R_1 = \frac{R_{dc}}{2}$

For delta connected stator $R_1 = 1.5 \cdot R_{dc}$

Finding Induction Motor Parameters

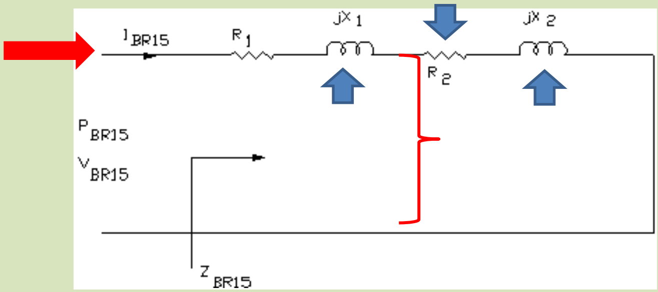
Locked rotor test - finds the rotor parameters (R_2, x_2) and stator reactance (x_1) .



Locked-Rotor Test Procedure
1.) connect ammeters wattmeters and voltmeters as shown above
2.) mechanically lock the motor rotor
3.) adjust the supply voltage until rated current flows
4.) measure V P and I (line-to-line voltage, line current and total active power)

Recommended practice is to perform test at 25% rated f (15 Hz)
Minimizes errors due to saturation (X's) and skin effects (R's)

Per Phase Circuit Model For Lock-Rotor Test



Finds rotor resistance R_2 and rotor and stator leakage reactances x_1 and x_2

Define Test Quantities

I_{BR15} = blocked rotor test current (15 Hz)
P_{BR15} = blocked rotor test power (15 Hz)
V_{BR15} = blocked rotor voltage (15 Hz)

$$P_{BR15} = \frac{P_T}{3}$$

$$R_{BR15} = \frac{P_{BR15}}{I_{BR15}^2}$$

Calculations

Find total impedance at 15 Hz

$$Z_{BR15} = \frac{V_{BR15}}{I_{BR15}}$$

$$R_{BR15} = R_1 + R_2$$

Find rotor R

$$R_2 = R_{BR15} - R_1$$

Locked-Rotor Test Calculations

Find the rotor and stator leakage reactances from locked rotor resistance and reactance

$$X_{BR15} = \sqrt{Z_{BR15}^2 - R_{BR15}^2}$$

Change to 60 Hz

$$X_{BR60} = \left(\frac{60\text{ Hz}}{15\text{ Hz}}\right) \cdot X_{BR15}$$

$$X_{BR60} = x_1 + x_2$$

Divide the leakage reactances based on the NEMA design types. Use the following table.

Design Type	A, D	B	C	Wound Rotor
x_1	$0.5 \cdot X_{BR60}$	$0.4 \cdot X_{BR60}$	$0.3 \cdot X_{BR60}$	$0.5 \cdot X_{BR60}$
x_2	$0.5 \cdot X_{BR60}$	$0.6 \cdot X_{BR60}$	$0.7 \cdot X_{BR60}$	$0.5 \cdot X_{BR60}$

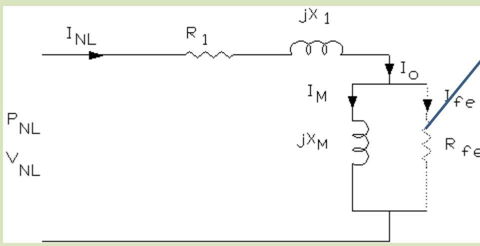
Induction Motor No-Load Test

No-load Test - Finds magnetizing reactance and combined friction, core and windage power losses.

No-Load Test Procedure

1.) Apply rated voltage and frequency with no mechanical load.
2.) Measure current voltage and power.
3.) Uses same test instrument setup as locked-rotor test. Measure I_L, V_L and P_T.

Model for No-load test



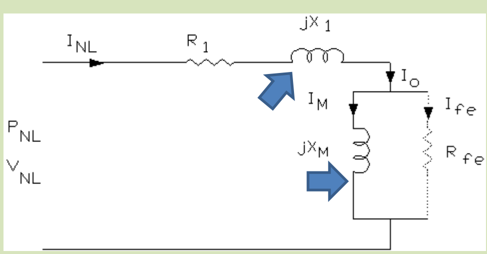
Since I_M >>> I_{fe} it is neglected in this test so R_{fe} omitted

Measure

P_{NL} = No-load power losses
I_{NL} = No-load current
V_{NL} = No-load voltage

Induction Motor No-Load Test Formulas

Find apparent and reactive power into unloaded motor



$$S_{NL} = V_{NL} \cdot I_{NL}$$

$$Q_{NL} = \sqrt{S_{NL}{}^2 - P_{NL}{}^2}$$

Use reactive power to find total reactance

$$X_{NL} = \frac{Q_{NL}}{I_{NL}^2}$$

No-load reactance is the sum of the magnetizing reactance and stator leakage

$$X_{NL} = x_1 + x_M$$
$$x_M = X_{NL} - x_1$$

Use no-load power to find rotational losses

$$P_{NL} = I_{NL}^2 \cdot R_1 + P_{core} + P_{stray}$$

Example 15-1: Following data is taken from no-load, locked rotor, and DC tests of a 3-phase, wye connected 40 HP, 60 Hz, 460 V, induction motor with a rated current of 57.8 A. The locked-rotor test is made at 15 Hz to minimize the errors due to saturation and skin effects. Determine the motor parameters and the total core, friction and windage losses. Draw the approximate equivalent circuit for the motor

Lock-rotor	No-load	DC Test
V_{line} = 36.2 V	460.0 V	V_{dc} = 12.0 V
I_{line} = 58.0 A	32.7 A	I_{dc} = 59.0 A
P_T = 2573.4 W	P_T = 4664.4 W	

Example 15-1 Solution (1)

Convert line voltages, currents and total power to per phase quantities

$$P_p = \frac{P_T}{3}$$

LOCKED ROTOR $P_{LR} = \frac{2573.4\text{W}}{3} = 857.8\text{W}$

NO-LOAD $P_{NL} = \frac{4664.4\text{W}}{3} = 1554.8\text{W}$

$I_{LR} = 58.0\text{A}$ FOR WYE CONNECTED $I_L = I_P$

$$V_{LR} = \frac{36.2}{\sqrt{3}} = 20.90\text{V} \qquad V_{NL} = \frac{460\text{V}}{\sqrt{3}} = 265.6\text{V}$$

$I_{NL} = 32.7\text{A}$

Example 15-1 Solution (2)

FIND R_1 FROM DC TEST VALUES

$$R_{dc} = \frac{V_{dc}}{I_{dc}} = \frac{12.0V}{59.0A} = 0.2034\,\Omega$$

For a wye connected motor

$$R_1 = \frac{R_{dc}}{2} = \frac{0.2034\,\Omega}{2}$$

$$\boxed{R_1 = 0.102\,\Omega/\text{phase}}$$

Stator winding resistance

Example 15-1 Solution (3)

Use locked-rotor test values to find rotor resistance, R_1 and stator/rotor leakage reactance x_1, x_2

$$|Z_{BR15}| = \frac{V_{LR}}{I_{LR}} = \frac{20.9V}{58.0A} = 0.3603\,\Omega \quad \text{TAKEN AT 15 HZ}$$

$$|R_{BR15}| = \frac{P_{LR}}{I_{LR}^2} = \frac{857.8W}{(58.0)^2 A} = 0.2550\,\Omega/\text{phase}$$

Find the rotor resistance

$$R_2 = R_{LR15} - R_1$$

$$R_2 = 0.2550 - 0.1020\,\Omega \boxed{= 0.1530\,\Omega/\text{phase}}$$

Example 15-1 Solution (4)

Now find X_{BR} at test frequency of 15 Hz

$$X_{BR15} = \sqrt{Z_{BR15}^2 - R_{BR15}^2}$$

$$X_{BR15} = \sqrt{0.3603^2 - 0.255^2} = 0.2545\ \Omega$$

Convert this result to 60 Hz

CONVERT TO 60 Hz $X_{BR60} = \frac{60\text{ Hz}}{15\text{ Hz}}(X_{BR15}) = \frac{60\text{ Hz}}{15\text{ Hz}}(0.2545\ \Omega)$

$$X_{BR60} = 1.0182\ \Omega$$

Example 15-1 Solution (5)

Now find X_m and power losses from no-load test data

$S_{NL} = V_{NL} I_{NL}$ ALL VALUES PER PHASE

$V_{NL} = 265.6\text{ V}$ $I_{NL} = 32.7\text{ A}$ $P_{NL} = 1554.8\text{ W}$

$$S_{NL} = (265.6\text{ V})(32.7\text{ A}) = 8684.5\text{ VA}$$

$$Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2}$$

$$Q_{NL} = \sqrt{8684.5^2 - 1554.8^2}$$

$$Q_{NL} = 8544.2\text{ VAR}$$

$$X_{NL} = \frac{Q_{NL}}{I_{NL}^2} = \frac{8544.2\text{ VAR}}{(32.7\text{ A})^2} = 7.99\ \Omega$$

$$X_{NL} = X_1 + X_m \Rightarrow X_m = X_{NL} - X_1$$

Example 15-1 Solution (6)

Need to find x_1 and x_2 to find the x_m value. Assume the motor is NEMA design B

$X_1 = 0.4 X_{BR60} \qquad X_2 = 0.6 X_{BR60}$

$X_1 = 0.4(1.0182\,\Omega) = \boxed{0.4073\ \Omega/\text{phase}}$

$X_2 = 0.6(1.0182\,\Omega) = \boxed{0.6110\ \Omega/\text{phase}}$

$X_m = 7.99\,\Omega - 0.4073\,\Omega$

$\boxed{X_m = 7.58\ \Omega/\text{phase}}$

TOTAL $P_{fw} + P_{core}$ $\qquad P_{NL} = I_{NL}^2 R_1 + P_{core} + P_{fw}$

$P_{NL} = 1564.8\text{W}$

$I_{NL} = 32.7\text{A}$

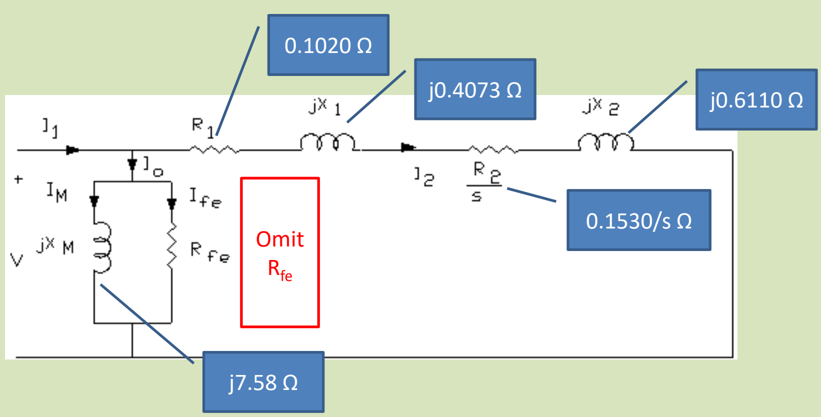
$R_1 = 0.102\,\Omega$

$P_{NL} - I_{NL}^2 R_1 = P_{core} + P_{fw}$

$1554.8\text{w} - (32.7)^2(0.102\,\Omega) = P_{core} + P_{fw}$

$\boxed{1446\ \text{w/phase} = P_{core} + P_{fw}}$

Approximate Equivalent Circuit



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END LESSON 15: INDUCTION MOTOR TESTING: LOCK-ROTOR AND NO-LOAD TESTS