THREE-PHASE INDUCTION MOTOR TEST

Various tests can be peformed on three-phase Induction Motor to determine its efficiency and other operating characteristics:

TYPES OF TEST

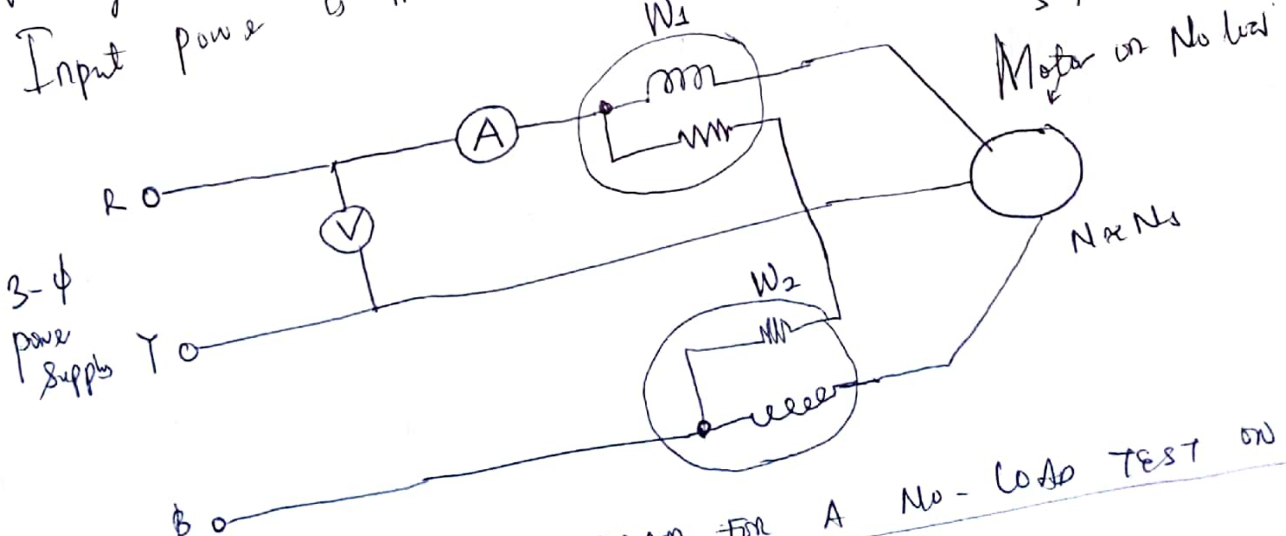
1. STATOR RESISTANCE TEST
2. NO-LOAD TEST
3. BLOCKED ROTOR TEST
4. HEAT RUN TEST

For the purpose of this course ~~we~~ will consider only the NO-LOAD TEST AND THE BLOCKED ROTOR TEST

NO-LOAD TEST

This Test Corresponds to the Open Circuit test on a Transformer, and it is used to determine the No-Load Current I_o, no-Load power factor $\cos\phi_o$, Windage and friction losses P_{wf}, No load Core loss P_i, no-Load power Input P_o, and no-Load resistance R_o and reactance.

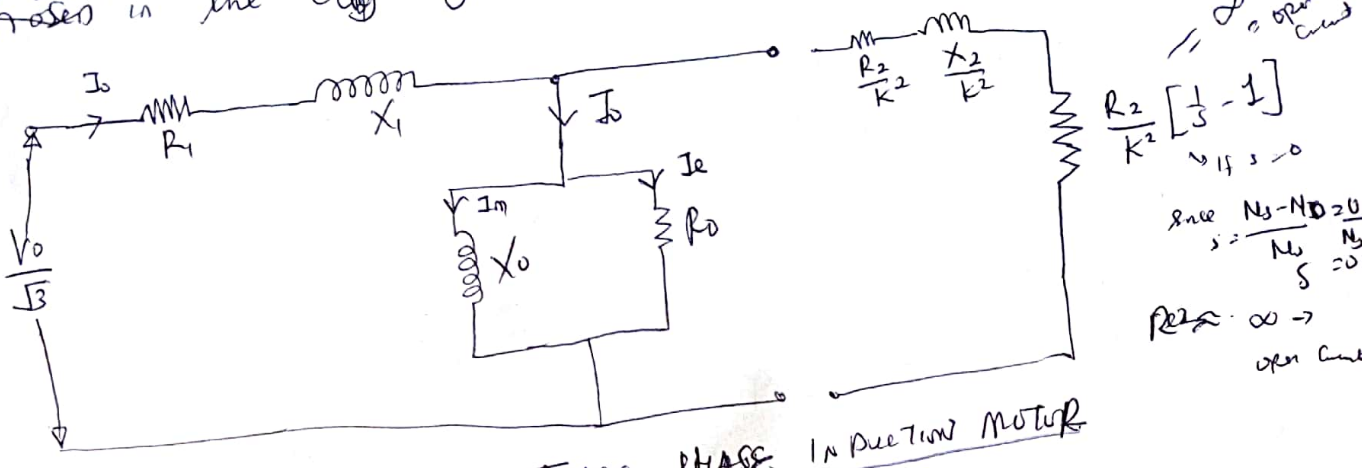
Note: This test is carried out with different values of applied voltage, below and above ~~the~~ its rated voltage, while the Input power is measured by two Watt meters



CIRCUIT DIAGRAM FOR A NO-LOAD TEST ON A 3-PHASE INDUCTION MOTOR

Note: Ⓥ → Voltmeter, W_1 = Watt meter 1, W_2 = Watt meter 2, Ⓐ - Ammeter

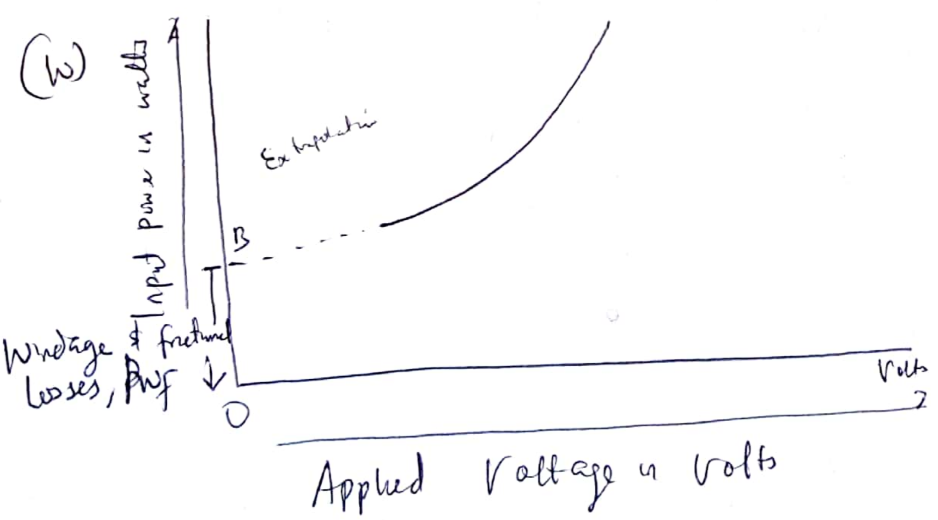
From the diagram above, ~~the~~ the motor runs on light load, and so the speed of the rotor is assumed to be equal to the synchronous speed ($N \approx N_s$). Also, the power input for all three phases P_0, voltage V_0 (line to line voltage) and current I_0, are measured by wattmeter (W_1, W_2), voltmeter V and ammeter A connected as shown in the ~~dig~~ diagram. (2)



EQUIVALENT CIRCUIT OF A THREE-PHASE INDUCTION MOTOR AT NO-LOAD

At No load, Power Input = Core loss P_i + Stator Copper loss P_{ci} + Windage and frictional losses P_{wf}.

Note: The Magnitude of the No-Load Current in an Induction Motor is about 30 to 40 % of full-load current. Also the Total Power Input is the difference of the two Wattmeter reading W_1 and W_2.



PLOT OF INPUT POWER IN WATTS AGAINST APPLIED VOLTAGE IN VOLTS

③

The plot above shows the variation of Input Power with applied Voltage, it can be seen that if the applied voltage in volts is extrapolated or extended to ~~extrac~~ Intersect with the vertical axis, at point B, where point B corresponds to the Input power when the Applied Voltage is zero, represents the windage and frictional loss $P_{w,f}$ (Note at Voltage = 0, the stator copper losses and core losses are also zero)

Stator copper losses = $3 I_o^2 R_1$.

while Core loss, P_i = Input power − [Stator Copper loss + Windage and frictional Loss P_{wf}]

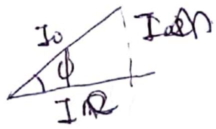
P_i is total Core losses

Also

No-Load Power factor, $\cos\phi = \dfrac{P_i}{\sqrt{3}\, V_o I_o}$; where I_o = no load current, V_o = applied voltage (Line to line)

Energy component of no-load current, $I_e = I_o \cos\phi_o = I_o * \dfrac{P_i}{\sqrt{3}\, V_o I_o} = \dfrac{P_i}{\sqrt{3}\, V_o}$

recall



Magnetising Component of No load Current $I_m = \sqrt{I_o^2 - I_e^2}$

No load impedance, $Z_o = \dfrac{V_o/\sqrt{3}}{I_o}$ — phase voltage

Note here we use phase value of V_o

No load Resistance, $R_o = \dfrac{V_o/\sqrt{3}}{I_e} = \dfrac{V_o/\sqrt{3}}{P_i/\sqrt{3}\, V_o} = \dfrac{V_{o\,phase}^2}{P_i}$

or $P_i = \dfrac{V_o^2}{R} = V_o^2 G_o$ where G_o = exciting conductance $G_o = \frac{1}{R_o}$

No load reactance, $X_o = \sqrt{Z_o^2 - R_o^2}$

Also $V_{phase} = I_e R_o$

$V_{phase} = I_m X_o$

Also Admittance $Y_o = I_o / V_{phase}$

Subceptance, $B_o = \sqrt{(Y_o^2 - G_o^2)}$

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EXAMPLE 1

In a No load test, an Induction motor took 10A (line current) and 450 Watts with a line voltage of 110V. If the stator resistance/phase is 0.05Ω and friction and windage losses amount to 135 Watts, Calculate the exciting Conductance/phase and Susceptance/phase (4)

1) Stator Cu loss
2) No load Core loss
3) Conductance per phase
4) Susceptance per phase

Solution

Stator Cu loss $= 3 I_0^2 R_1 = 3 \times 10^2 \times 0.05 = 15W$

~~Stator~~ Core loss $= 450 - 135 - 15 = 300W$

Voltage / phase $V = 110/\sqrt{3}$ V

But $P_i = \cancel{\frac{3V_0^2}{R}}$ or $V_0^2 G_0$

$P_i = \frac{V_{0\,phase}^2}{R_0} = \frac{\left(\frac{V_{Line}}{\sqrt{3}}\right)^2}{R_0} = \frac{V_{0\,Line}^2}{3 R_0} = \frac{V^2 G_0}{3}$

$P_i = \frac{V_{0\,phase}^2}{R_0}$

$300 = \frac{(110/\sqrt{3})^2}{R_0}$

$300 = \left(\frac{110}{\sqrt{3}}\right)^2 G_0$

$G_0 = \frac{300 \times 3}{110^2}$

$G_0 = 0.074$ Siemens / phase

$Y_0 = I_0 / V_{phase}$

$Y_0 = \frac{10}{\frac{110}{\sqrt{3}}} = \frac{10 \times \sqrt{3}}{110} = 0.158$ Siemens/ phase

$B_0 = \sqrt{(Y_0^2 - G_0)^2}$

$B_0 = \sqrt{0.158^2 - (0.074^2)} = \sqrt{0.025 - 0.0055}$

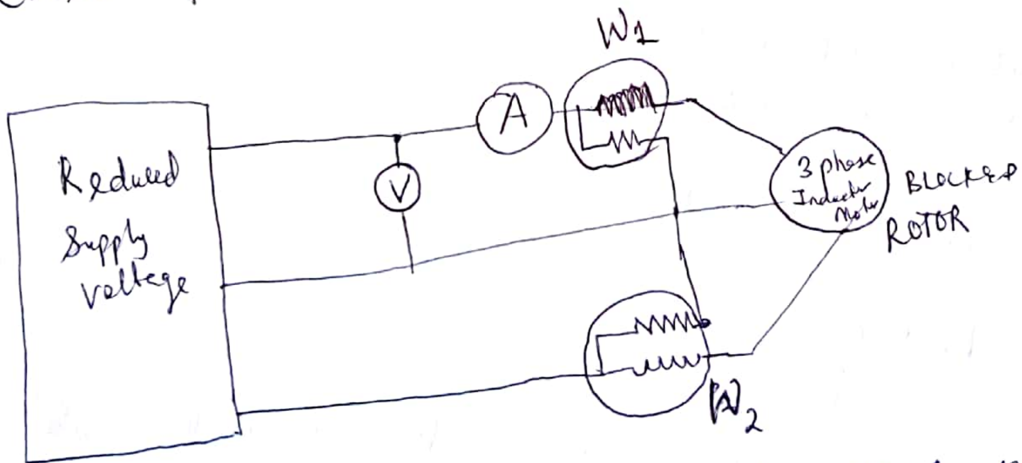
$B_0 = \sqrt{0.0195} = 0.14$ Siemens/ phase

BLOCKED - ROTOR TEST

This test is similar to the SHORT - CIRCUIT TEST OF A TRANSFORMER; and performed to determine the following

1. Short - Circuit Current Isc with Normal Voltage applied to the STATOR
2. Power factor on Short - Circuit
3. Total equivalent resistance of the motor, referred to the Stator R_{01}
4. Total equivalent reactance of the motor, as referred to the Stator X_{01}.

In this test the rotor is held firmly (Locked), and the rotor windings are short - circuited at slip - rings, in the case of WOUND ROTOR; while the STATOR is connected to variable source voltage. Note the ~~same~~ applied voltage to the STATOR terminal is 15 to 20 % of its normal value; and it is adjusted so that full-load current flows in the STATOR.



CIRCUIT DIAGRAM FOR BLOCKED ROTOR TEST ON A THREE PHASE INDUCTION MOTOR.

V - Voltmeter
W_1 - Watt meter 1
W_2 = Watt meter 2
A = Ammeter.

From the diagram above the values of Current, voltage and power input on Short-Circuit are measured by the Ammeter, Voltmeter and Wattmeter. ~~as shown~~

The Equivalent Circuit of the motor in this Case, is like that of a Transformer, with the secondary Circuit, however, the following assumptions are made.

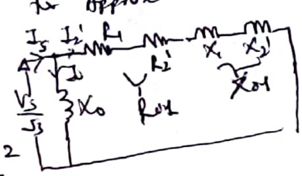
1) Slip, $S = 1$, because $N = 0$, so $\frac{N_s - 0}{N_s} = 1$.

2) R_0 [No load ~~resis~~ Core resistance] Can be ignored [Since the Core losses are very small.

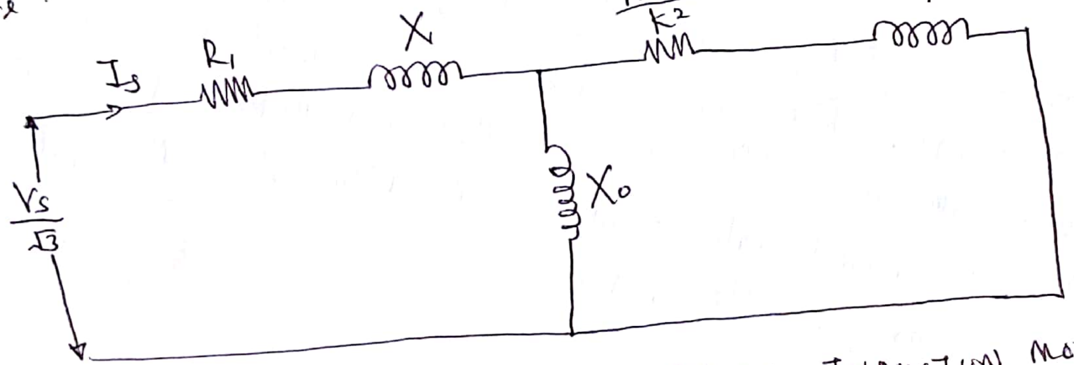
– for $\frac{R_2}{sK^2} > \frac{R_2}{K^2}$ when $s = 1$

or

For Approx



Therefore



EXACT EQUIVALENT CIRCUIT OF A THREE-PHASE INDUCTION MOTOR UNDER BLOCKED ROTOR CONDITION

BLOCKED ROTOR TEST EQUATIONS

1. $I_{sc} = I_s \times \frac{V}{V_s}$

Where I_{sc} is the Short-Circuit current when normal voltage V (Line to Line) is applied to the Motor

I_s = is the Short-Circuit Current, ~~with~~ when Short Circuit voltage (V_s) is applied to the Motor

V_s = is the Short-Circuit Voltage V_s, applied to the Stator. [recall, V_s is about 15% to 20% of V].

V is the normal Stator Voltage

(2) Power factor on Short-Circuit, is given as

$$\cos \phi_s = \frac{P_s}{\sqrt{3}\, V_s I_s}$$

Where P_s = Power Input on Short-Circuit
V_s = Short Circuit Voltage
I_s = Short Circuit Current

(3) Power Input on Short-Circuit, P_s = ~~Stator Input Ro~~

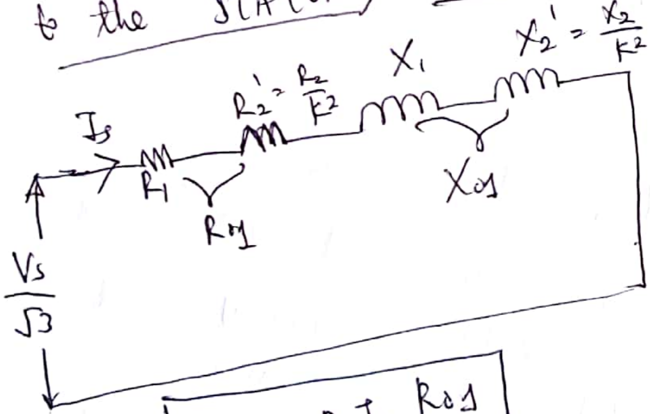
$$\boxed{P_s = \text{Stator Copper loss} + \text{Rotor Copper loss} + \text{Core loss}}$$

Neglecting Core loss, we have, where Stator Copper loss + Rotor Copper loss = $3 I_s R_{01}$.

recall $R_{01} = R_1 + R_2'$

so $\boxed{P_s = 3 I_s R_{01}}$

Using the Approximate Equivalent Circuit diagram during ~~Rotor~~ Rotor test referred to the STATOR, VERSION 2 [Neglect the Core parameters]



→ APROXIMATE EQUIVALENT CIRCUIT

so $\boxed{P_s = 3 I_s R_{01}}$

so R_{01}, Motor equivalent resistance per phase as referred to the STATOR, becomes

$$\boxed{R_{01} = \frac{P_s}{3 I_s^2}}$$

Motor equivalent Impedance per phase, as referred to the STATOR

$$\boxed{Z_{01} = \frac{V_s/\sqrt{3}}{I_s}}$$

Motor equivalent reactance per phase, as referred to the STATOR,

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$$

Recall, $R_{01} = R_2' + R_1$

where R_2' is the rotor resistance per phase, referred to the stator

where R_1 is the Stator resistance

so $\boxed{R_2' = R_{01} - R_1}$

Also if $X_1 = X_2'$

so $\boxed{X_1 = X_2' = \frac{X_{01}}{2}}$

EXAMPLE 2:

A 110-V, 3-phase, Star connected Induction motor takes 25A at a line voltage of 30V with rotor locked. With a line voltage of 110V, power input to the motor is 440W, and core loss is 40W. If the stator resistance per phase is given as 0.08Ω, find the equivalent leakage reactance/phase of the motor, and the ~~Stator and~~ Rotor resistance per phase.

Soln.

Short-Circuit voltage / phase, $V_s = 30/\sqrt{3} = 17.3\,V$

Short-Circuit Current $\Rightarrow I_s = 25\,A$ per phase

Short-Circuit ~~voltage~~

so $Z_{01} = \frac{V_{s\,phase}}{I_s} = \frac{17.3}{25} = 0.7\,\Omega$

Short-Circuit Input power to motor, $P_s = 440\,W$

recall,

$$P_s = 3\,I_s^2 R_{01} + \text{Core loss}$$

$$P_s - \text{Core loss} = 3\,I_s^2 R_{01}$$

$$440W - 40W = 3 * 25^2 * R_{01}$$

$$400 = 3 \times 25^2 \times R_{01}$$

$$R_{01} = \frac{400}{3 \times 625} = 0.21\,\Omega.$$

Therefore $$Z_{01} = \sqrt{(R_{01})^2 + (X_{01})^2}$$

so $$X_{01} = \sqrt{(Z_{01})^2 - (R_{01})^2}$$

$$X_{01} = \sqrt{(0.7) - (0.21)^2}$$

(i) equivalent leakage reactance/phase, X_{01} = $\boxed{X_{01} = 0.668\,\Omega}$

(ii) Rotor resistance per phase is

$$R_{01} = R_2' + R_1$$

$$R_2' = R_{01} - R_1$$

$$R_2' = 0.21 - 0.08 = 0.13\,\Omega$$