Electric Machines Laboratory
(EE2P001)

EXPERIMENT-11

PERFORMANCE CURVE OF 3 PHASE INDUCTION MOTOR

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Aim:

To perform no load and block rotor test on 3 phase induction motor.

APPARATUS:

INSTRUMENTS / EQUIPMENTS

SL.NO	INSTRUMENTS / EQUIPMENTS	TYPE	SPECIFICATION	QUANTITY
1	3-∅ VARIAC	IRON CORE	10A, 415 V	1 NO.
2	WATTMETER	LPF	5A, 600V, 0.2 P. F	2 NO.S
3	VOLTMETER	MI	(0-600 V) (0-150 V)	1 NO. 1 NO.
4	AMMETER	MI	(0-5/10 A)	2 NO.S
5	WATTMETER	UPF	10A, 125V	2 NO.S
6	CONNECTING WIRES	Cu	1.5 sq.mm	AS REQUIRED

MACHINES REQUIRED

SL.NO	MACHINE	SPECIFICATION	QUANTITY
1	3-phae Induction Motor	3.7 kW / 5 HP, 1430 RPM 415 V, 7.8 A, Delta connection.	1 No

Theory:

The circle diagram is the graphical representation of the performance ofthe electrical machines (such as induction motor, alternator etc). The circle diagram is drawn using the data obtained from no-load test and short circuit tests or,

In case of induction motor, block rotor tests. To find out the induction motor parameters which affect the performance of the motor, we do both no-load test and block rotor test.

No-load test:

The no-load test of induction machine, like the open circuit test on a transformer, gives information about exciting current and rotational losses. The test is performed by applying balanced rated voltage at ratedfrequency on the stator

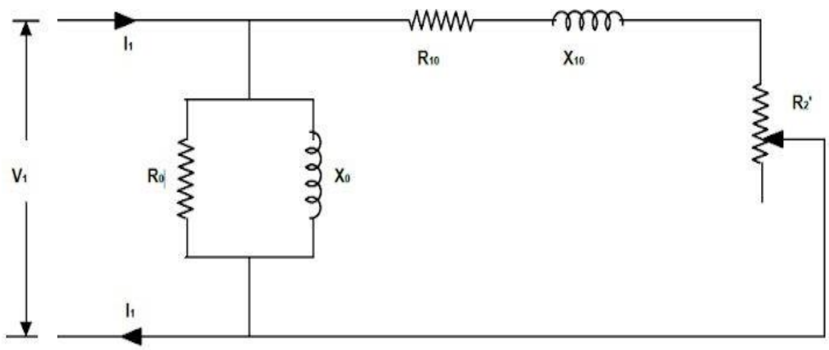
Windings. The small power provided to the machine is due to core losses, friction and winding loses. The machine will rotate at almost synchronousspeed, which makes slip nearly zero.

THE NO-LOAD POWER FACTOR $(\cos \phi_0) = \frac{P0}{(\sqrt{3} \times V0 \times I0)}$

WHERE,

P0 - POWER CONSUMED BY THE INDUCTION MOTOR AT NO LOADI0 – NO-LOAD CURRENT DRAWN BY THE INDUCTION MOTOR

V0 – LINE VOLTAGE SUPPLIED TO INDUCTION MOTOR



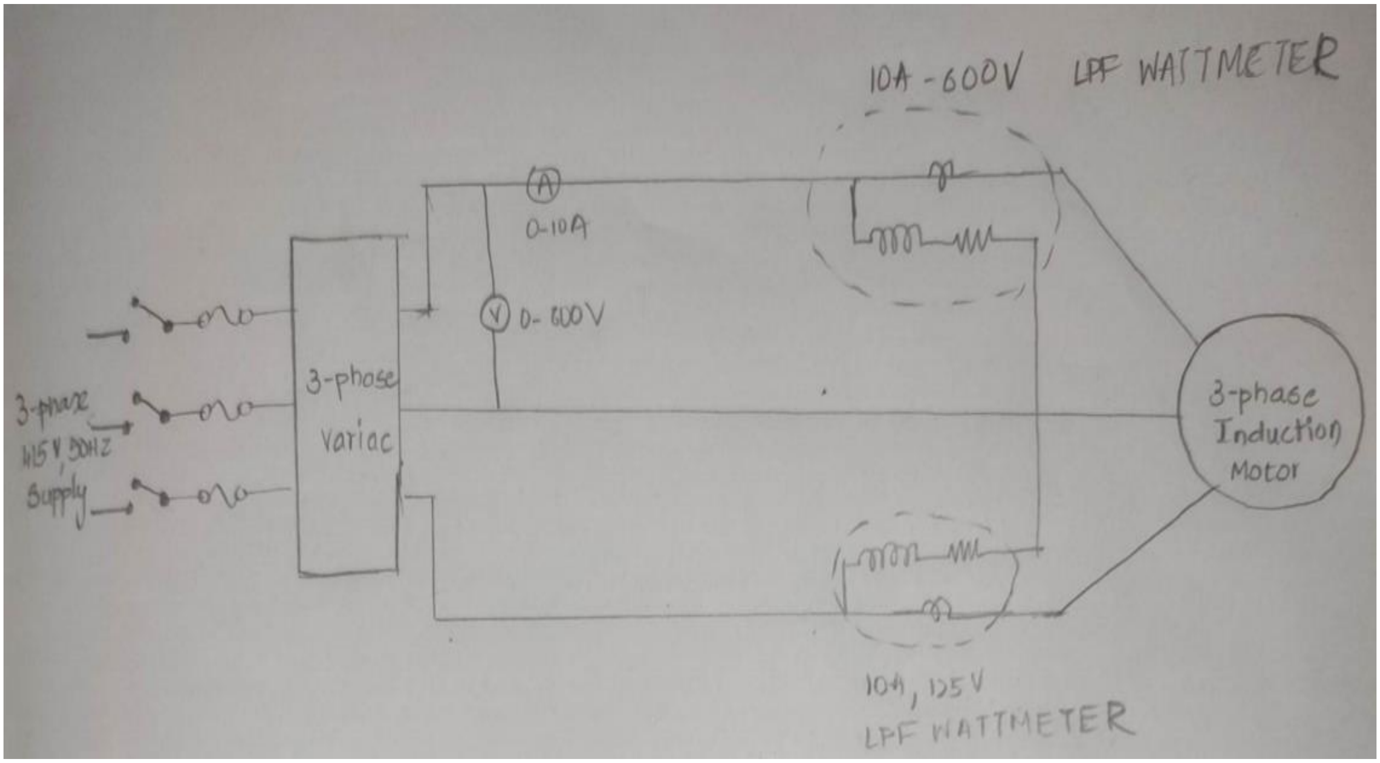
Equivalent Circuit diagram of Induction Motor

LOCK ROTOR TEST:

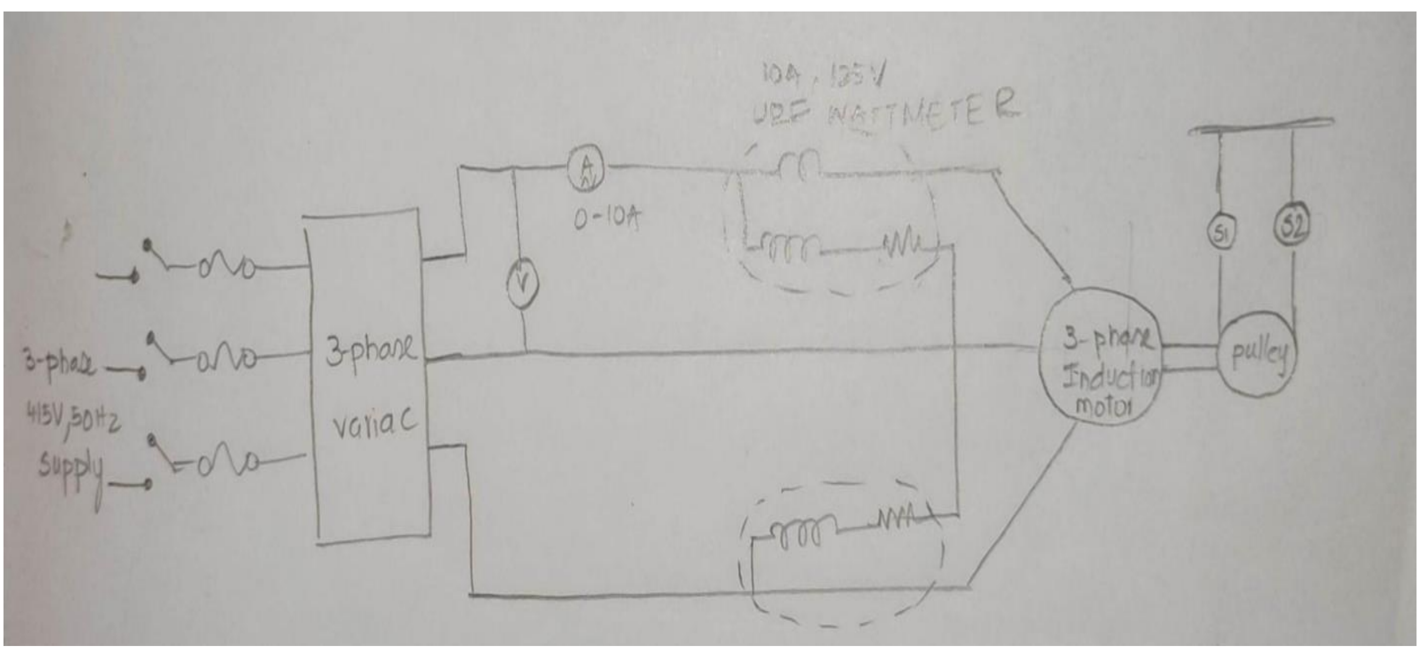
THE LOCKED ROTOR TEST OF INDUCTION MACHINE, LIKE SHORT CIRCUIT TEST ON A TRANSFORMER, PROVIDES THE INFORMATION ABOUT LEAKAGE IMPEDANCES AND ROTOR RESISTANCE. LOW VOLTAGE IS APPLIED TO STATOR WINDINGS TO CIRCULATE RATED CURRENT IN STATOR WINDING OF THE MOTOR BY KEEPING ROTOR AT STANDSTILL USING BRAKE DRUM ARRANGEMENT. MEASURE THE VOLTAGE AND POWER PER PHASE. SINCE THERE IS NO ROTATION SLIP, S=1.

THE NO-LOAD POWER FACTOR $(\cos \phi_{SC}) = \frac{Psc}{(\sqrt{3} \times Vsc \times Isc)}$

CIRCUIT DIAGRAM:



Circuit Diagram for No-Load Test



Circuit Diagram for block rotor Test

PRECAUTIONS:

- CONNECTION SHOULD BE RIGHT AND TIGHT.
- CHECK THE CIRCUIT CONNECTION THOROUGHLY BEFORE SWITCHING ON THE SUPPLY.
- INSTRUMENTS SHOULD BE CONNECTED IN PROPER POLARITY AND RANGE.
- DO NOT TOUCH ANY NON-INSULATED PART OF ANY INSTRUMENT OR EQUIPMENT.
- BE ENSURED THE ZERO SETTING OF INSTRUMENT IS ON RIGHT POSITION. AVOID PARALLAX ERROR.
- BEFORE SWITCHING ON THE SUPPLY, BE SURE THAT VARIABLE POINT OF VARIAC SHOULD BE AT ZERO.

PROCEDURE:

1). **NO-LOAD TEST**:

- CONNECT THE CIRCUIT AS SHOWN IN FIG-1.
- ENSURE THAT THE MOTOR IS UNLOADED AND THE 3-🚒 VARIAC IS SET AT ZERO POSITION.
- SWITCH ON THE SUPPLY AND INCREASE THE VOLTAGE GRADUALLY TILL THE RATED VOLTAGE OF THE MOTOR.
- NOTE DOWN THE READINGS OF ALL THE METERS IN OBSERVATION TABLE.
- SWITCH OFF THE A.C. SUPPLY TO STOP THE MOTOR.

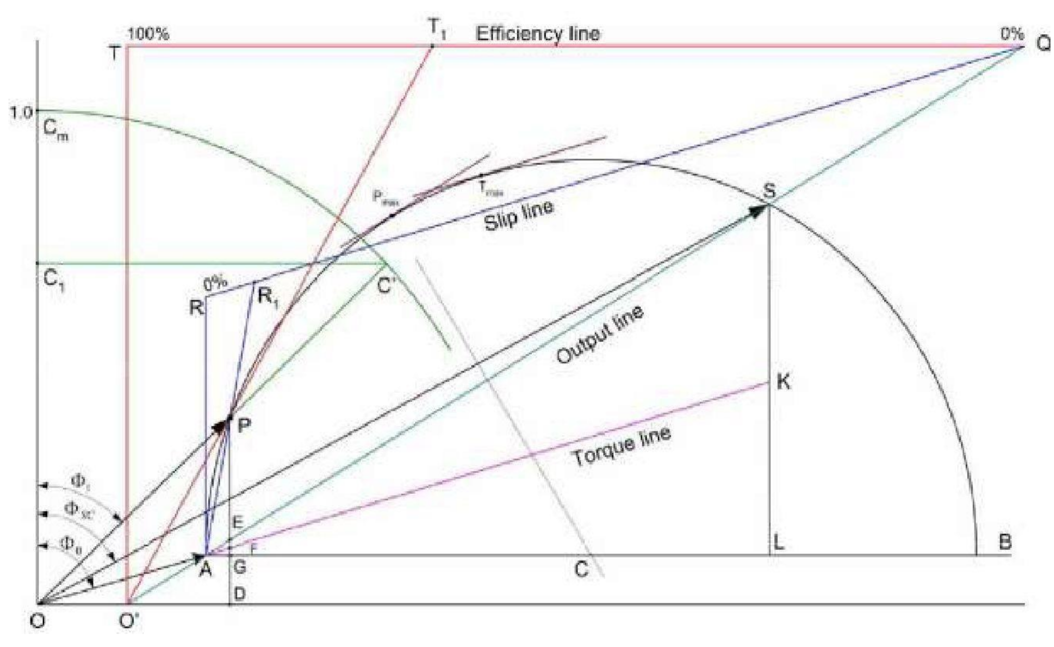
2). BLOCK ROTOR TEST:

- CONNECT THE CIRCUIT AS SHOWN IN FIG-2.
- READJUST THE 3-🚒 VARIAC AT ZERO POSITION.
- BLOCK THE ROTOR BY TIGHTENING THE BELT.
- SWITCH ON THE A.C. SUPPLY AND APPLY REDUCED VOLTAGE, SO THAT THE INPUT CURRENT DRAWN BY THE MOTOR UNDER BLOCKED ROTOR CONDITION IS EQUAL TO THE FULL LOAD CURRENT OF THE MOTOR.
- NOTE DOWN THE READINGS OF ALL THE METERS IN OBSERVATION TABLE.
- SWITCH OFF THE A.C. SUPPLY.
- MEASURE THE RESISTANCE PER PHASE OF THE STATOR WINDING.

3). CONSTRUCTION OF CIRCLE DIAGRAM

CONDUCT NO LOAD TEST AND BLOCKED ROTOR TEST ON THE INDUCTION MOTOR AND FIND OUT THE PER PHASE VALUES OF NO LOAD CURRENT I0, SHORT CIRCUIT CURRENT ISC AND THE CORRESPONDING PHASE ANGLES ①0 AND ①SC. ALSO FIND SHORT CIRCUIT CURRENT ISN CORRESPONDING TO NORMAL SUPPLY VOLTAGE. WITH THIS DATA, THE CIRCLE DIAGRAM CAN BE DRAWN AS FOLLOWS:

- WITH SUITABLE SCALE, RAW VECTOR OA WITH LENGTH CORRESPONDING TO I0 AT AN ANGLE ①0 FROM THE VERTICAL AXIS. DRAW A HORIZONTAL LINE AB.
- DRAW OS EQUAL TO ISN AT AN ANGLE ①SC AND JOIN AS.
- DRAW THE PERPENDICULAR BISECTOR TO AS TO MEET THE HORIZONTAL LINE AB AT C.
- WITH C AS CENTRE, DRAW A PORTION OF CIRCLE PASSING THROUGH A AND S. THIS FORMS THE CIRCLE DIAGRAM WHICH IS THE LOCUS OF THE INPUT CURRENT.
- FROM POINT S, DRAW A VERTICAL LINE SL TO MEET THE LINE AB.
- DIVIDE SL AT POINT K SO THAT SK: KL = ROTOR RESISTANCE: STATOR RESISTANCE.
- FOR A GIVEN OPERATING POINT P, DRAW A VERTICAL LINE PEGGED AS SHOWN. THEN PE = OUTPUT POWER, EF = ROTOR COPPER LOSS, FG = STATOR COPPER LOSS, GD = CONSTANT LOSS (IRON LOSS + MECHANICAL LOSS)
- TO FIND THE OPERATING POINTS CORRESPONDING TO MAXIMUM POWER AND MAXIMUM TORQUE, DRAW TANGENTS TO THE CIRCLE DIAGRAM PARALLEL TO THE OUTPUT LINE AND TORQUE LINE RESPECTIVELY. THE POINTS AT WHICH THESE TANGENTS TOUCH THE CIRCLE ARE RESPECTIVELY THE MAXIMUM POWER POINT AND MAXIMUM TORQUE POINT.



EFFICIENCY LINE:

- THE OUTPUT LINE AS IS EXTENDED BACKWARDS TO MEET THE X-AXIS AT O′ .
- FROM ANY CONVENIENT POINT ON THE EXTENDED OUTPUT LINE, DRAW A HORIZONTAL LINE QT SO AS TO MEET THE VERTICAL FROM O′. DIVIDE THE LINE QT INTO 100 EQUAL PARTS.
- TO FIND THE EFFICIENCY CORRESPONDING TO ANY OPERATING POINT P, DRAW A LINE FROM O′ TO THE EFFICIENCY LINE THROUGH P TO MEET THE EFFICIENCY LINE AT T1. NOW QT1 IS THE EFFICIENCY.

SLIP LINE:

- DRAW LINE QR PARALLEL TO THE TORQUE LINE, MEETING THE VERTICAL THROUGH A AT R. DIVIDE RQ INTO 100 EQUAL PARTS.
- TO FIND THE SLIP CORRESPONDING TO ANY OPERATING POINT P, DRAW A LINE FROM A TO THE SLIP LINE THROUGH P TO MEET THE SLIP LINE AT R1. NOW RR1 IS THE SLIP

POWER FACTOR CURVE:

- DRAW A QUADRANT OF A CIRCLE WITH O AS CENTRE AND ANY CONVENIENT RADIUS. DIVIDE OCM INTO 100 EQUAL PARTS.
- TO FIND POWER FACTOR CORRESPONDING TO P, EXTEND THE LINE OP TO MEET THE POWER FACTOR CURVE AT C′ . DRAW A HORIZONTAL LINE C′ C1 TO MEET THE VERTICAL AXIS AT C1. NOW OC1 REPRESENTS POWER FACTOR.

OBSERVATION:

NO-LOAD TEST				BLOCK ROTOR TEST			
V_0	I_0	W_{01}	W_{02}	V_{SC}	I_{SC}	W_{SC1}	W_{SC2}
415 V	4.1 A	120*8 = 960 W	-75*8 = -600 W	82 V	7.8 A	75*8 = 600 W	10*8 = 80 W

Calculations:

For No-Load Test :→

$W_{01} = 760W \quad ; \quad W_{02} = -600W$

$$\tan\phi = \sqrt{3}\left[\frac{W_{01} - W_{02}}{W_{01} + W_{02}}\right]$$

$$= 7.5055$$

$$\boxed{\therefore \phi = 82.41^\circ}$$

For Block Rotor Test

$W_{sc_1} = 600W \qquad W_{sc_2} = 800W$

$$\therefore \tan\phi_{sc} = \sqrt{3}\left[\frac{W_{sc_1} - W_{sc_2}}{W_{sc_1} + W_{sc_2}}\right]$$

$$= 1.3245$$

$$\boxed{\therefore \phi_{sc} = 52.95^\circ}$$

$$I_{sN} = I_{sc}\left(\frac{V_o}{V_{sc}}\right)$$

$$= 1.8\left[\frac{415}{82}\right]$$

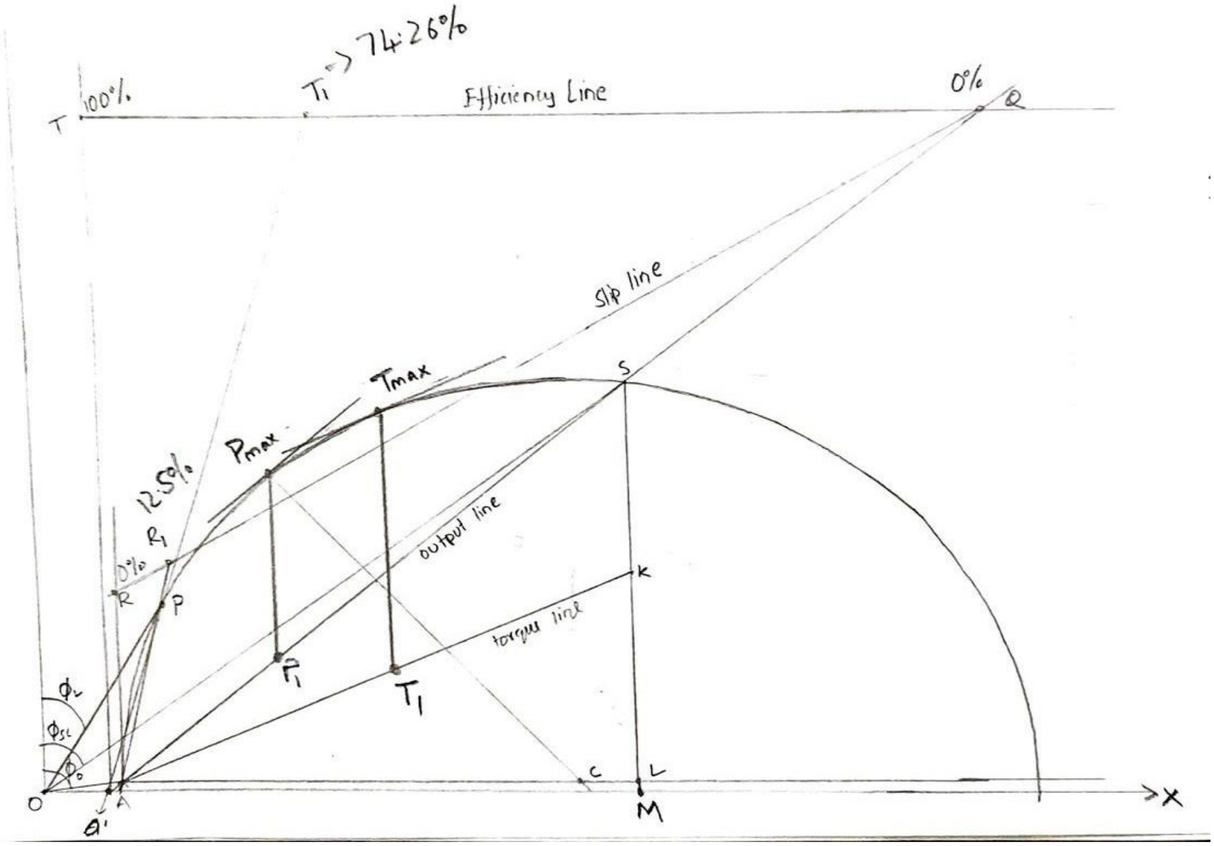
$$\boxed{\therefore I_{sN} = 39.475A}$$

For Operating Point :→

$$\cos\phi_L = \frac{415 \times 7.8}{3.7 \times 10^3}$$

$$= 0.8748 6$$

$$\boxed{\therefore \phi_L = 28.971^\circ}$$



Power Scale :

Input - Power at Rated Voltage = $\left(\frac{415}{82}\right)^2 \times 680$ [∵ $\left(\frac{V_0}{V_{sc}}\right)^2 \times P_{sc}$]

↳ [$P_{sc_1} = (W_{sc_1} + W_{sc_2})$]

length of SS' = Input Power at Rated Voltage

⇒ 7.8 = 17417.1624

∴ 1cm = 22329695 W

Max - Power :

= (length of Pmax to the output line vertically) × Power - Scale

= 3.7 × 2232.9695

= 8261.987 W //

Max Torque

= (length of Tmax to torque line vertically) × Power Scale

= 5.2 × 22329695

= 11611.44 synchro - W //

Efficiency :

$$\frac{QT_1}{QT} \times 100$$

$$= \frac{10.4}{40} \times 100$$

$$\boxed{\therefore \eta = 74.28\%}$$

Slip(S):-

$$= \frac{RR_1}{QR} \times 100$$

$$= \frac{1.85}{14.8} \times 100$$

$$\boxed{\therefore S = 12.5\%}$$

Best- Power factor :

$$\cos\phi = \frac{OC_1}{OC_m}$$

$$= \frac{6}{7}$$

$$\boxed{\therefore \cos\phi = 0.8571}$$

Discussion

1. **Why should there be a difference between D.C and A.C resistance?**

   AC resistance is the resistance of the conductors like capacitors, inductors also. The one defined here is inductive or capacitive reactance or impedance. In dc, frequency is Zero so capacitive reactance and inductive reactance are infinity and zero. The values of capacitance and inductance depends on the frequency of the voltage supplied. For DC the frequency is zero.

2. Are the core losses and mechanical losses constant for all operating conditions? Comment your view.

Mechanical losses occur at the bearing and brush friction loss occurs in wound rotor induction motors. These losses are zero at start and with increase in speed these losses increase. In a three-phase induction motor the speed usually remains constant. Hence these losses almost remain constant.

3. How does core losses vary with voltage and why?

The core loss depends on the frequency of the supply. The frequency of the stator is equal to the frequency of the supply itself whereas the rotor frequency is equal to the slip times the frequency of the supply which is always less than the stator frequency

4. Did the blocked rotor loss vary exactly proportional to square of the current? Explain the deviations if any.

We know that rotor loss Wcu = 3*i2*r. Here i is the reading which we named as Isc. We can write Is = Is * (V/Vs). So, it is proportional to square of the current

5. What are the possible errors due to the approximate equivalent circuit?

The approximate equivalent circuit is drawn just to simplify our calculation by deleting one node. The shunt branch is shifted towards the primary side. This has been done as the voltage drop between the stator resistance and inductance is less and there is not much difference between the supply voltage and the induced voltage. However, this is not appropriate due to following reasons-

1. The magnetic circuit of an induction motor has an air gap so exciting current is larger compared to a transformer so exact equivalent circuit should be used.
2. The rotor and stator inductance is larger in the induction motor.
3. In an induction motor, we use distributed windings.

6. What will happen if one line of the supply is cut off (a) When the motor is supplying full load (b) When the motoris at stand still.

A. When a three-phase motor loses one of the phase supply voltages then it is called Single Phasing. Single Phasing a case when any one phase out of the three phases fails. Since one of the phases is now disconnected, current through the other two phases will increase to produce the desired torque. The motor will run but would not be able to drive a rated load. The uneven torque results in abnormal noise and vibration in the motor. If the motor is operating at higher load near to the rated load, motor speed will drop gradually to zero. If a motor is operating at or less than 33%, it will continue to operate without any harm.

7. Does the no-load current steadily decrease as the supply voltage is reduced? If not, explain why?

The current taken by the motor, Im will INCREASE if the voltage V is reduced and the power factor will be REDUCED for a given connected load.

EXPLANATION: -

Let us assume that the load torque remains constant. With reduction in voltage the torque produced, T will reduce (T is proportional to V^2). So, the torque slip (T-s) characteristic at reduced voltage will have all its amplitudes reduced. So, in order to get the same torque required by the load the slip s will increase. Neglecting stator impedance and magnetizing branch current, the current Im now will be approximately =(1-Δ) V/√[(R2`/s) ^2+(X2) ^2], where Δ is the per unit reduction in V (=0.1 if there is a 10% reduction), R2 and X2 are the rotor resistance and standstill rotor reactance referred to the stator. The reduction in denominator will be more than the reduction in the numerator giving a higher current when voltage is reduced. For example, assume R2=0.1, X2=1.0 with a slip s=0.025 at rated voltage. The rotor current will be about 0.243xV. With a 10% reduction in voltage let the slip increase to 0.05. The current will now be about 0.4xV. Thus, there is an increase of current. But as the effective resistance decreases the power factor of this current will be reduced. Thus, the motor consumes more reactive power when the voltage is less than its rated value.

8. Why does one wattmeter give negative reading for No-load Test and Block rotor Test but positive reading for rated load condition?

A. The reason why a watt-meter displays a negative reading is due to the highly inductive nature of the induction motor at low-loads/no-load (similar to transformer).

Since in two Wattmeter method:

$$P_1 = V_{13} I_1 \cos(30 - \phi) = \sqrt{3} \times V I \cos(30 - \phi)$$

$$P_2 = V_{12} I_1 \cos(30 + \phi) = \sqrt{3} \times V I \cos(30 + \phi)$$

As phi increases beyond 60° P2 shows negative value

=>At a lower power factor one of the watt meters shows negative value.

9. Find out various losses occurring under full load condition, using the circle diagram.

The various losses occurring under full load condition, using the circle diagram are rotor copper loss and stator copper loss. (iron losses and mechanical losses areconstant).

11. Why is the no load power factor quite small in case of 3-phase induction motors?

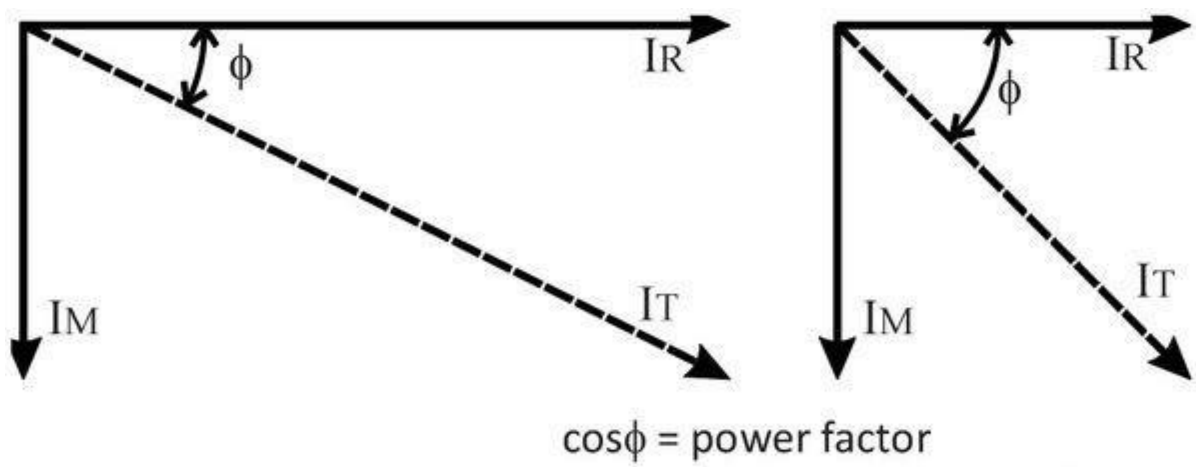
A. The main cause of low power factor is Inductive Load.

Three phase induction motors: Usually, Induction motor works

at poor power factor i.e. at:

Full load, Pf = 0.8 -0.9, Small load, Pf = 0.2 -0.3, No Load, Pf may come to Zero (0).

The total current in each winding of a motor. It is the vector sum of the load current Ir and the magnetizing current Im, as shown in the figure below.



(a): Full load (b): Half load

Generally the magnetizing current component is constant and does not change with load. It always lags the supply voltage by 90 degrees.

The load current component is proportional to the load on the motor, and is in phase with the supply voltage.

So as load is reduced, it can be seen that the angle phi increases towards 90 degrees. Thus, the power factor cos(phi) decreases towards zero.

12. Discuss the fact that the input power factor of the motor increases with increase in load.

The input power factor of the induction increases with increase in load because in general, the higher the resistance (a load), the higher the power factor. A higher power factor means that there is a tapping of electrical energy in terms of active power. And more active power means higher mechanical output to compensate for the increasing rotor resistance.