PROBLEMS

7.1 A 1ϕ, 120 V, 60 Hz, 4-pole induction motor is rotating in the clockwise direction at a speed of 1728 rpm. Calculate per unit slip of the motor for:

(a) The direction of rotation.
(b) The backward direction.

7.2 A 1ϕ, 120 V, 60 Hz, 1/4 hp, 1720 rpm split-phase motor gave the following reduced voltage test results when the motor is locked:

<table>
<thead>
<tr>
<th></th>
<th>Main winding</th>
<th>Auxiliary winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied voltage</td>
<td>$V = 25 \text{ V}$</td>
<td>$V = 25 \text{ V}$</td>
</tr>
<tr>
<td>Current</td>
<td>$I_m = 4.5 \text{ A}$</td>
<td>$I_a = 1.7 \text{ A}$</td>
</tr>
<tr>
<td>Power</td>
<td>$P_m = 65 \text{ W}$</td>
<td>$P_a = 32 \text{ W}$</td>
</tr>
</tbody>
</table>
Calculate

(a) The phase angle between \(I_m\) and \(I_a\).

(b) The locked rotor current if full voltage is applied to the winding.

7.3 The nameplate specifications for a single-phase capacitor-start induction motor are \(1\phi\), 110 V, \(\frac{1}{2}\) hp, 1720 rpm, 8.0 A, 60 Hz. The following test data are obtained for this motor:

- Stator main winding resistance = 2.0 \(\Omega\)
- Blocked motor test (auxiliary winding disconnected), \(V = 52\) V, \(I = 8.0\) A, \(P = 255\) W
- No-load test, \(V = 110\) V, \(I = 4.5\) A, \(P = 100\) W

(a) Obtain the double revolving field equivalent circuit for the motor.
(b) Determine the no-load rotational loss.

7.4 A \(1\phi\), \(\frac{1}{2}\) hp, 115 V, 1725 rpm, 60 Hz, four-pole, capacitor-start induction motor has the following equivalent circuit parameters for the main winding:

\[
R_1 = 2.2 \Omega, \quad R'_2 = 3.5 \Omega
\]
\[
X_1 = 2.5 \Omega, \quad X'_2 = 2.5 \Omega, \quad X_{mag} = 60 \Omega
\]

The core loss at 115 V is 20 W, and the friction and windage loss is 15 W. The motor is connected to a 115 V, 60 Hz supply and runs at a slip of 0.04. While running, the starting winding remains disconnected. Determine the speed, input current, power factor, input power, developed torque, output power, efficiency, and rotor copper loss.

7.5 The motor in Examples 7.1 and 7.2 runs at rated speed. Determine the ratio of the forward flux to the backward flux.

7.6 A \(1\phi\), 120 V, 60 Hz split-phase induction motor has the following standstill impedances:

Main winding : \(Z_m = 2.8 + j4.8\)
Auxiliary winding : \(Z_a = 8 + j6\)

Determine the value of the capacitor to be connected in series with the auxiliary winding and the turns ratio \(a = (N_a/N_m)\) to produce a pure forward mmf wave.

7.7 A single-phase, 120 V, 60 Hz, \(\frac{1}{2}\) hp, 1740 rpm split-phase fan motor gave the following test results:

<table>
<thead>
<tr>
<th></th>
<th>V</th>
<th>I</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>No load test</td>
<td>120.0</td>
<td>4.0</td>
<td>110.0</td>
</tr>
<tr>
<td>Standstill test (main winding)</td>
<td>41.0</td>
<td>5.8</td>
<td>115.0</td>
</tr>
<tr>
<td>Standstill test (auxiliary winding)</td>
<td>38.0</td>
<td>7.0</td>
<td>200.0</td>
</tr>
</tbody>
</table>
Main winding resistance = 1.85 Ω.

(a) Obtain an equivalent circuit for the motor for running conditions.
(b) Determine the no-load rotational loss.
(c) Determine the efficiency at the rated speed.

For the motor in Problem 7.7:
(a) Determine the standstill impedances of the main and auxiliary windings.
(b) An external starting resistance \( R_s = 2 \) Ω is added in series with the auxiliary windings, and the motor is connected to a 1φ, 120 V, 60 Hz supply.
   (i) Draw a phasor diagram of the currents \( I_m \) and \( I_a \), and the voltage \( V \), with and without the added resistance \( R_s \).
   (ii) Compare the starting torques and starting currents with and without the added resistance.

Repeat Problem 7.8 if an external starting capacitor \( C_s = 500 \mu \text{F} \) is added in series with the auxiliary winding.

A single-phase, 120 V, 60 Hz, four-pole, capacitor-start induction motor has the following standstill impedances:

- Main winding: \( Z_m = 5.5 + j4.8 \)
- Auxiliary winding: \( Z_a = 8.5 + j5.0 \)

(a) Determine the value of the starting capacitor required to produce a 90° phase shift between the currents in the main and auxiliary windings.
(b) Compare the starting torques with and without the starting capacitor.
(c) Draw phasor diagrams for \( I_m \), \( I_a \), and \( V \), with and without the starting capacitor.

A single-phase, \( \frac{1}{2} \) hp, 230 V, 60 Hz, four-pole, 1710 rpm induction motor has the following equivalent circuit parameters for the main winding:

\[
R_{1m} = 9.5 \ \Omega, \quad R_2' = 10.8 \ \Omega \quad X_{1m} = X_2' = 12.0 \ \Omega, \quad X_{\text{mag}} = 260 \ \Omega
\]

At 230 V and rated speed, the core loss is 30 W, and the friction and windage loss is 15 W. The motor is connected to an 1 φ, 230 V, 60 Hz supply and runs at the rated speed. Determine
(a) The slip.
(b) The motor current.
(c) The input power factor.
(d) The input power.
(e) The developed torque.
(f) The output shaft power and shaft torque.
(g) The efficiency.
(h) The rotor circuit frequencies and the rotor cu-losses.
(i) The ratio of the forward flux to the backward flux.
7.12 A single-phase, 120 V, 60 Hz, four-pole, split-phase induction motor gave the following blocked rotor test data:

<table>
<thead>
<tr>
<th></th>
<th>V</th>
<th>I</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main winding</td>
<td>32</td>
<td>4</td>
<td>80</td>
</tr>
<tr>
<td>Auxiliary winding</td>
<td>40</td>
<td>4</td>
<td>128</td>
</tr>
</tbody>
</table>

(a) Determine the standstill impedances of the main and auxiliary windings.
(b) Determine the values of the resistances to be added in series with the auxiliary winding to obtain maximum starting torque.
(c) Compare the starting torques and starting currents with and without the added resistance in the auxiliary winding circuit if the motor is connected to a 120 V, 60 Hz supply.

7.13 A single-phase, 120 V, 60 Hz, four-pole, split-phase induction motor has the following standstill impedances:

Main winding: \( Z_m = 5 + j6.25 \)
Auxiliary winding: \( Z_a = 8 + j6 \)

(a) Determine the value of capacitance to be added in series with the auxiliary winding to obtain maximum starting torque.
(b) Compare the starting torques and starting current with and without the added capacitance in the auxiliary winding circuit when operated from a 120 V, 60 Hz supply.

7.14 A four-pole, 115 V, 60 Hz, 1710 rpm, capacitor-start single-phase induction motor has been designed to produce maximum starting torque per unit starting current. The motor has the following parameters:

\[
\begin{align*}
R_{1m} &= 1.5 \, \text{ohms}, \quad X_{1m} = 2.6 \, \text{ohms} \\
R_{1a} &= 2.5 \, \text{ohms}, \quad X_{1a} = 2.5 \, \text{ohms} \\
X_{\text{mag}} &= 40 \, \text{ohms} \\
R'_1 &= 1.0 \, \text{ohms}, \quad X'_1 = 1.6 \, \text{ohms} \\
N_a/N_m &= 1
\end{align*}
\]

Capacitor in series with auxiliary winding = 375 \( \mu \)F.

(a) Draw the equivalent circuit for the motor under starting conditions. Determine the value of the starting torque.
(b) Draw the equivalent circuit for the motor when it runs at the rated (i.e., full-load) speed. Determine the torque developed at this speed.
(c) Determine the ratio of the starting torque to the torque developed at the rated speed.

7.15 A single-phase, 120 V, 60 Hz, four-pole, split-phase induction motor has the following equivalent circuit parameters:

\[
\begin{align*}
R_{1m} &= 1.5 \, \Omega, \quad R_{1a} = 2.5 \, \Omega, \quad R'_1 = 1.0 \, \Omega \\
X_{1m} &= 2.5 \, \Omega, \quad X_{1a} = 2.5 \, \Omega, \quad X'_1 = 1.5 \, \Omega \\
X_{\text{mag}} &= 40 \, \Omega
\end{align*}
\]
Determine the standstill impedances \( Z_m, Z_a \) of the windings.

(b) Determine the starting torque and the starting current of the motor if it is started from rated voltage mains as a resistor split-phase motor.

(c) Determine the value of the capacitor to be connected in series with the auxiliary winding to produce maximum starting torque per ampere of starting current. Determine the value of the starting torque and starting current.

(d) Compare the starting torque per ampere of starting current for cases (b) and (c).

7.16 Determine the operating power factor, output power, and efficiency for the following single-phase motors when operated from a 120 V, 60 Hz supply at 1728 rpm. Assume the rotational loss to be 40 W.

(a) A four-pole, capacitor-start, single-phase induction motor with the following main winding equivalent circuit parameters:

\[
R_{1m} = 1.2 \, \Omega, \quad X_{1m} = 1.9 \, \Omega, \quad X_{mag} = 36 \, \Omega
\]

\[
R_2' = 1.6 \, \Omega, \quad X_2' = 2.0 \, \Omega
\]

(b) A compensated series motor with the same standstill input impedance as the main winding of the above induction motor. At 1728 rpm, both motors draw the same line current from the 120 V supply. Assume the same rotational loss as in the induction motor.

7.17 A single-phase, 400 V, 60 Hz, series motor has the following standstill impedance at 60 Hz.

\[
Z_1 = 1.6 + j10.0
\]

(a) DC supply: The motor is connected to a 400 V dc supply and rotates at 2000 rpm when loaded to draw a current of 20 A. Neglect rotational loss. Determine

(i) The mechanical power developed.

(ii) The efficiency.

(b) AC supply: The motor is connected to a 1φ, 400 V, 60 Hz supply and loaded to draw a current of 20 A. Determine

(i) The speed of the motor.

(ii) The supply power factor.

(iii) The mechanical power developed.

(iv) The efficiency.

(v) The starting torque. (Assume magnetic linearity.)

7.18 A single-phase, 120 V, 60 Hz series motor gave the following standstill impedances:

Without the compensating winding, \( Z_1 = 5 + j25 \)

With the compensating winding, \( Z_1 = 5.5 + j3.0 \)

(a) Uncompensated motor: The uncompensated motor is connected to a 120 V, 60 Hz supply and rotates at 1800 rpm when loaded to draw a current of 1.6 A. The rotational loss is 30 W. Determine the

(i) Supply power factor.

(ii) Mechanical power developed.

(iii) Efficiency.
(b) Compensated motor: The compensated motor is connected to a 120 V, 60 Hz supply and loaded to draw a current of 1.6 A. Determine the

(i) Speed of the motor.
(ii) Supply power factor.
(iii) Mechanical power developed.
(iv) Efficiency [assume the same rotational loss as in part (a)].

(c) The uncompensated motor is connected to a 120 V, 60 Hz supply. Determine the starting torque. Assume magnetic linearity—that is, no saturation.

7.19 Write a computer program to study the performance characteristics of the single-phase induction motor of Problem 7.4. For various speeds (1600 rpm to 1795 rpm in steps of 5 rpm) calculate the following:

Input impedance ($Z_{in}$), input current ($I_{in}$), input power factor (PF), input power ($P_{in}$), torque ($T$), mechanical power developed ($P_{mech}$), output (shaft) power ($P_{out}$), air gap power ($P_g$), rotor copper loss ($P_2$), and efficiency (Eff).

Assume that rotational losses remain constant over the speed range.

(a) Write a computer flowchart.
(b) Obtain a computer printout for the performance characteristics mentioned above in tabular form.