Circle Diagram of Tree phase Induction Motor

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1 Circle Diagram of Induction Motor

1.1 Overview

Circle diagram approach to predict the performance of motor is an elegant graphical method. From the test data (no load & block rotor tests), locus of the tip of the input current phasor is drawn to scale. Torque line, output line and slip line (representing slip values from 0 to 1) are drawn in order to quickly predict the performance of the maotor.

1.2 Summary

In this unit usefulness of circle diagram is emphasised. Once the circle diagram is drawn from the test data for a given motor, we can predict the torque, ouput mechnical power, current drawn from the supply, power factor and efficiency of the motor at any slip. In short, perfomance evaluation of the motor can be carried out much more easily without referring to the equivalent circuit.

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1.3 Objectives

After going through the unit, students will be able to

1. draw to scale the circle diagram of the motor.
2. draw the output and torque line.
3. draw slip line
4. estimate torque, ouput mechnical power, current drawn from the supply, power factor and efficiency of the motor at any slip from the circle diagram.

1.4 Suggested material to meet the objectives

Circle diagram basics

The tip of the current phasor is found to lie on a circle when resistance is varied from 0 to∞ in a series $R-L$ circuit excited by a constant voltage and frequency source. This is depicted in figure 1. When $R=0$ the circuit is purely inductive and current drawn from the supply will be maximum and equal to V/X, lagging supply voltage by 90°. Incidentally V/X is the diameter of the circle. As the value of R is increased, impedance of the circuit is increases and value of the current drawn from the supply decreases. One of the intermediate operating point is shown by S on the circle diagram in figure 1. The length SM is equal to $I\cos\theta$. For a constant supply voltage V, SM also represent power input to the circuit since $P = V\,I\,\cos\theta$. If we consider the equivalent circuit of the induction motor neglecting stator impedance and magnetizing reactance, as shown in figure 2. The

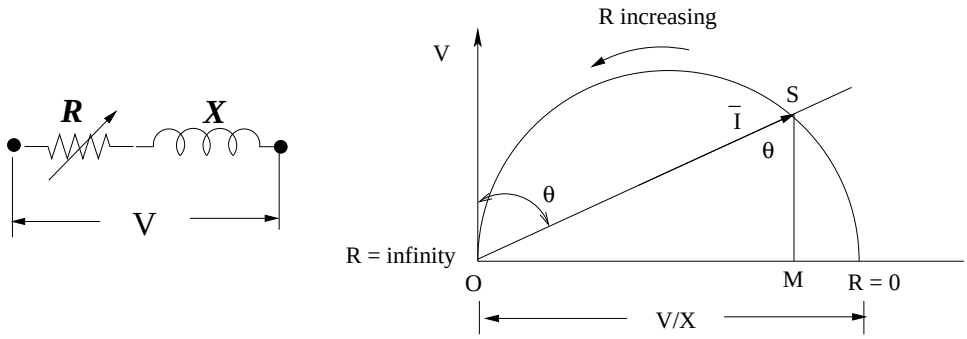

Figure 1: Locus of the current phasor.

value of the resistance here gets changed as slip s varies from 1 to 0. Operating point S corresponds to $s = 1$ and the point O corresponds to $s = 0$. Full load operating point may be at P. The arc OPS in fact, represents the current locus for motor operation. It may be noted that power factor improves as slip value decreases. The following points with regard to figure 2 may be noted.

1. At starting $s = 1$, current drawn is given by the length OS.
2. At $s = 1$, power drawn is given by SM.
3. Since power drawn is equal to power in r_2'/s, at $s = 1$ the air gap power. Therefore, the length SM also represents the starting torque. Also note at $s = 1$, output mechanical power is zero.
4. The length SM also represents the rotor copper loss ie., SM $= (\text{OS})^2 r_2'$.

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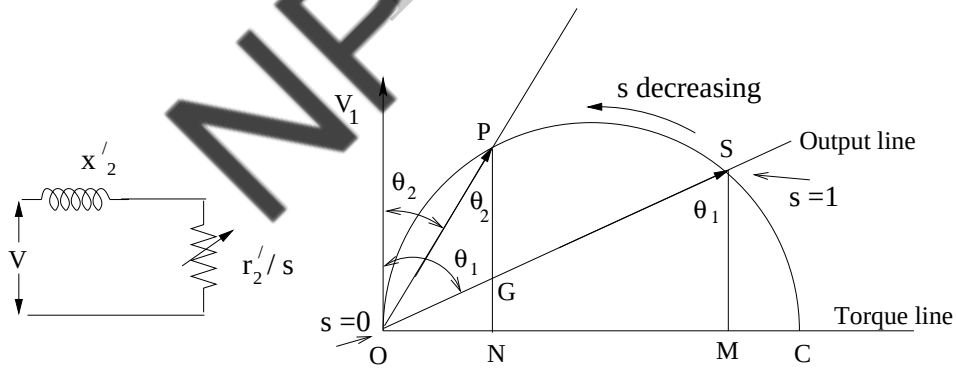

Figure 2: current locus based on simplified equivalent circuit of IM.

Let us now consider the operating point corresponding to the full load operation with slip s. In this case, folloeing points may be noted.

1. current drawn is given by the length OP at power factor $\cos\theta_2$.
2. Total Power drawn is given by PN.
3. Air gap power, hence torque is also given by PN.
4. In this a part of the total power drawn will be lost as rotor copper loss and the remaining part will appear as mechanical power.

Now the question is which length will represent the rotor copper loss and which length will represent mechanical power output? It may be noted,

$$\begin{aligned}
\frac{\text{rotor copper loss at } s}{\text{rotor copper loss at slip } s=1} &= \frac{\mathrm{OP}^2 r_2'}{\mathrm{OS}^2 r_2'} = \frac{\mathrm{OP}^2}{\mathrm{OS}^2} \\
\text{but, } \frac{\mathrm{OP}^2}{\mathrm{OS}^2} &= \frac{\mathrm{ON.OC}}{\mathrm{OM.OC}} = \frac{\mathrm{ON}}{\mathrm{OM}} \\
\therefore \frac{\text{rotor copper loss at } s}{\text{rotor copper loss at slip } s=1} &= \frac{\mathrm{ON}}{\mathrm{OM}} \\
\text{or,} &= \frac{\mathrm{GN}}{\mathrm{SM}} \text{ from similar triangles OGN and OSM} \\
\text{thus, rotor copper loss at } s &= GN \\
\text{and mechanical power at } s &= PN - GN = PG
\end{aligned}$$

The line OC is called the torque line and the line OS is called the output line.

The above circle diagram has been drawn neglecting stator impedance and the no load current. Now we shall try to draw the circle diagram taking these factors into account. Let us relook at the complete equivalent circuit equivalent circuit shown in figure 3 In this case total current drawn

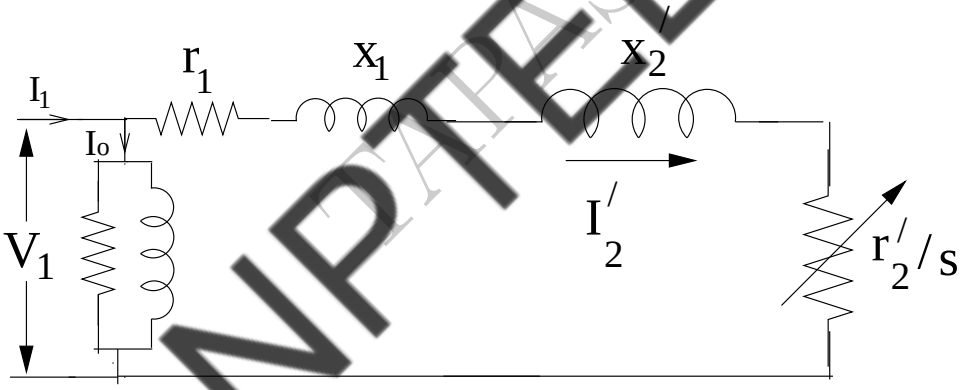

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Figure 3: Equivalent circuit.

from the supply is $I_1 = I_o + I_2'$, where I_o is the no load current and practically does not vary with the slip s. I_2' however, will follow the locus of a semi circle. Taking this into account, the modified locus of the currents are shown in figure 4

Consider first the operating point S ($s = 1$). Here SQ represent the total power drawn from the supply and this should be the sum of rotational loss, stator copper loss and rotor copper loss since the mechanical power output at $s = 1$ is zero. The length OL = MQ = $V_1 I_o \cos\theta_o$ give the rotational loss. Therefore, SQ - QM = SM must give the sum of stator copper loss and rotor copper loss. If MJ:JS is made equal to the ratio $r_1 : r_2'$, then MJ will give stator copper loss and JS will give rotor copper loss. Also note air gap power at $s = 1$ is JS and therefore it also represent starting torque developed.

Now consider a general operating point at P with slip s and join OJ to get the point H on PM. With a little bit of geometry, it can easily be shown that NH represent stator copper loss and HG represent rotor copper. PG will give the mechanical power output. Air gap power and torque developed will be given by the length PH. Efficiency of the motor at slip s is given by $\eta =$ PG/PK. Thus we find that the performance of the induction motor can easily be obtained from the circle diagram. This technique is obviously a graphical technique. To make this technique much more useful, a slip line could be added which will help us to locate the operating point from the knowledge of slip value. The steps of drawing the slip line are given below.

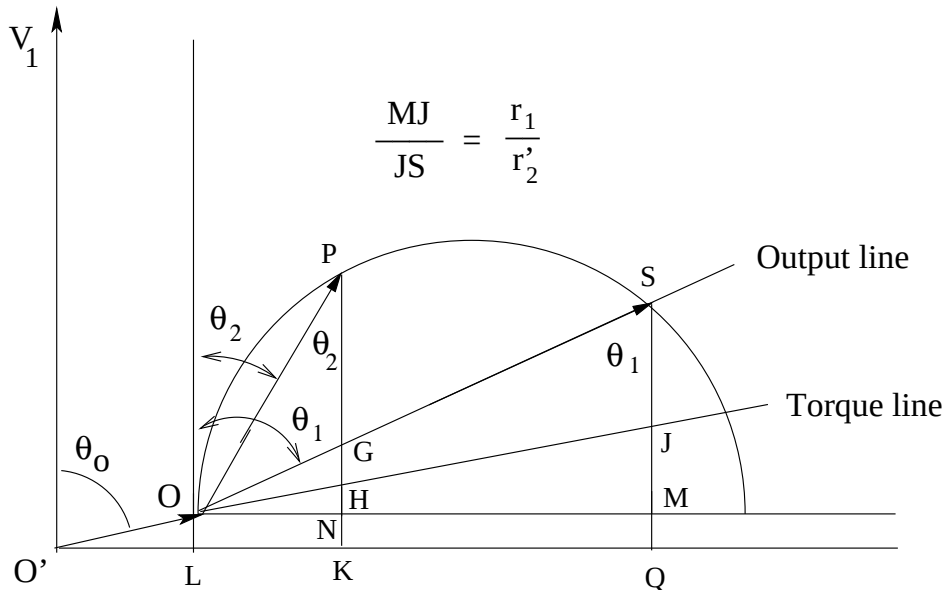

Figure 4: Circle diagram taking all losses into account.

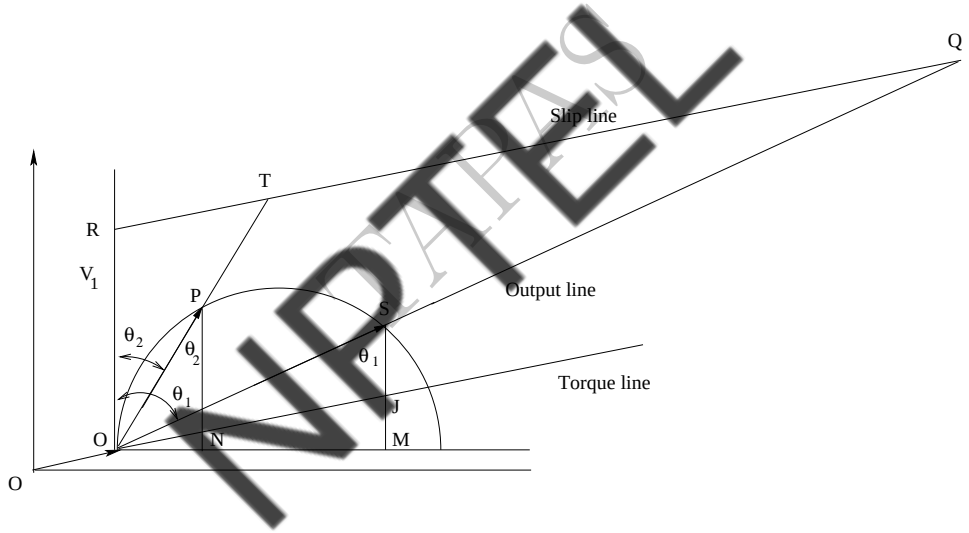

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Figure 5: Slip line.

1. Take any arbitrary point R on the tangent drawn at O to the circle.
2. Draw a line RQ parallel to the torque line.
3. Extend the line OS to cut RQ at Q.
4. Consider the whole length RQ to represent slip = 1 and divide the line in small divisions to represent different values of slips. Point R corresponds to $s = 0$ and point Q corresponds to $s = 1$.
5. Extend OP to cut the slip line at T. It can be shown that RT = s corresponding to the operating point P.

1.5 Problems