

Lab 13: Wound rotor induction motor.

Objective: *to examine the construction of a 3-phase wound rotor induction motor; to understand exciting current, synchronous speed and slip in this motor; to determine its starting characteristics; to observe the rotor and stator currents at different speeds; to observe the characteristics of a wound rotor induction motor at no-load and full-load; to observe speed control using an external variable resistor.*

Equipment: Power Supply, DAI, Wound rotor induction motor (8231), Electrodynamometer (8960), timing belt.

Theory:

The creation of a rotating stator field using 3-phase power is similar to the principle of the split-phase or two-phase (*capacitor run*) system. In the 3-phase system, a rotating magnetic field is generated in three phases instead of two. When the stator of a 3-phase motor is connected to a 3-phase power source, currents flow in the three stator windings and a revolving magnetic field is established. These three exciting currents supply the reactive power to establish the rotating magnetic field. They also supply the power consumed by the copper and iron losses in the motor.

The speed of the rotating magnetic field is entirely determined by the frequency of the three phase power source, and is known as the synchronous speed. The frequency of electric power systems is accurately maintained by the electric power companies. Therefore, the synchronous speed of the stator field [rpm] remains constant.

The wound rotor consists of a rotor core with three windings in place of the conducting bars of the squirrel cage rotor. In this case, currents are induced in the windings just as they would be in shorted turns. However, the advantage of using windings is that the wires can be brought out through slip rings so that resistance, and, therefore, the current through the windings, can be controlled.

The rotating stator field induces an alternating voltage in each winding of the rotor. When the rotor is at standstill the frequency of the induced rotor voltage is equal to that of the power source. If the rotor is now rotated by some external means – in the same direction as the rotating stator field – the rate at which the magnetic flux cuts the rotor windings will diminish. The induced voltage and its frequency will drop. When the rotor revolves at the same speed and in the same direction as the rotating stator field, the induced voltage, as well as its frequency, will drop to zero. (*The rotor is now at synchronous speed*). Conversely, if the rotor is driven at synchronous speed, but in the opposite direction to the rotating stator field, the induced voltage, as well as its frequency, will be twice the value as when the rotor was at standstill. A considerable voltage appears across the rotor windings on open circuit, and this voltage varies linearly with rotor slip in rpm, becoming zero at synchronous speed.

If the rotor windings are short-circuited, the induced voltage will cause large circulating currents in the windings. To supply this rotor current, the stator current must increase in value above its ordinary exciting current level. The power consumed (VA) in the rotor windings (and associated circuitry) must be supplied by the stator windings. Therefore, we should expect the following:

- a) At *standstill*, or at *low speed*, the rotor currents, stator currents and torque will be high.
- b) At *synchronous speed*, the rotor current and torque will be zero, and the stator will only carry the exciting current.
- c) At *any other motor speed*, the currents and the developed torque will be between the above extremes.

The three ends of the 3-phase rotor windings are brought out to three slip rings mounted on the rotor shaft. The brushes bearing on the slip rings play an important role in realizing maximum advantage from the wound rotor motor. By connecting the brushes through rheostats, it becomes possible to develop a higher starting torque than is possible with a squirrel cage motor. On starting, the full resistance of the rheostats is maintained in the rotor circuit, thus providing the very maximum starting torque.

As the motor approaches normal operating speed, the rheostat resistance is gradually reduced until it is out of the circuit entirely at full speed. Although the starting torque of the wound rotor motor is higher, it is not as efficient as the squirrel cage motor at full speed, because the resistance of the rotor windings is always more than that of a squirrel cage motor.

A special feature of the wound rotor motor is its variable speed capability. By varying the rheostat resistance, it is possible to vary the percentage of slip and thus, vary the motor speed. In such cases, below full speed operation means the motor is running at reduced efficiency and horsepower. In addition, because of the high rotor resistance, the motor is made more susceptible to variation in speed as the load changes.

The **power output** (in horsepower) of the motor delivered to the load is defined as follows:

$$P_{out, hp} = \frac{1.4 \cdot \omega_{rpm} \cdot T_{Nm}}{10\,000} \quad (13-1)$$

where ω_{rpm} is the motor speed in revolutions per minute, T_{Nm} is its torque in Newton-meters.

Keep in mind that one horsepower equals approximately to 746 W. The **reactive power** [var] can be computed as:

$$Q = \sqrt{S^2 - P^2} \quad (13-2)$$

where S is the apparent power [VA], P is the real power [W] consumed by the motor. The **efficiency of the motor** is:

$$efficiency = \frac{P_{out, W}}{P} \cdot 100\% \quad (13-3)$$

where $P_{out, W}$ is the output power delivered to the load in Watts. The **motor losses**, therefore, are estimated as:

$$Losses = P - P_{out, W} \quad (13-4)$$

Experiment:

- 1) Examine the construction of the wound rotor induction motor (use Figure 13-1 for reference).

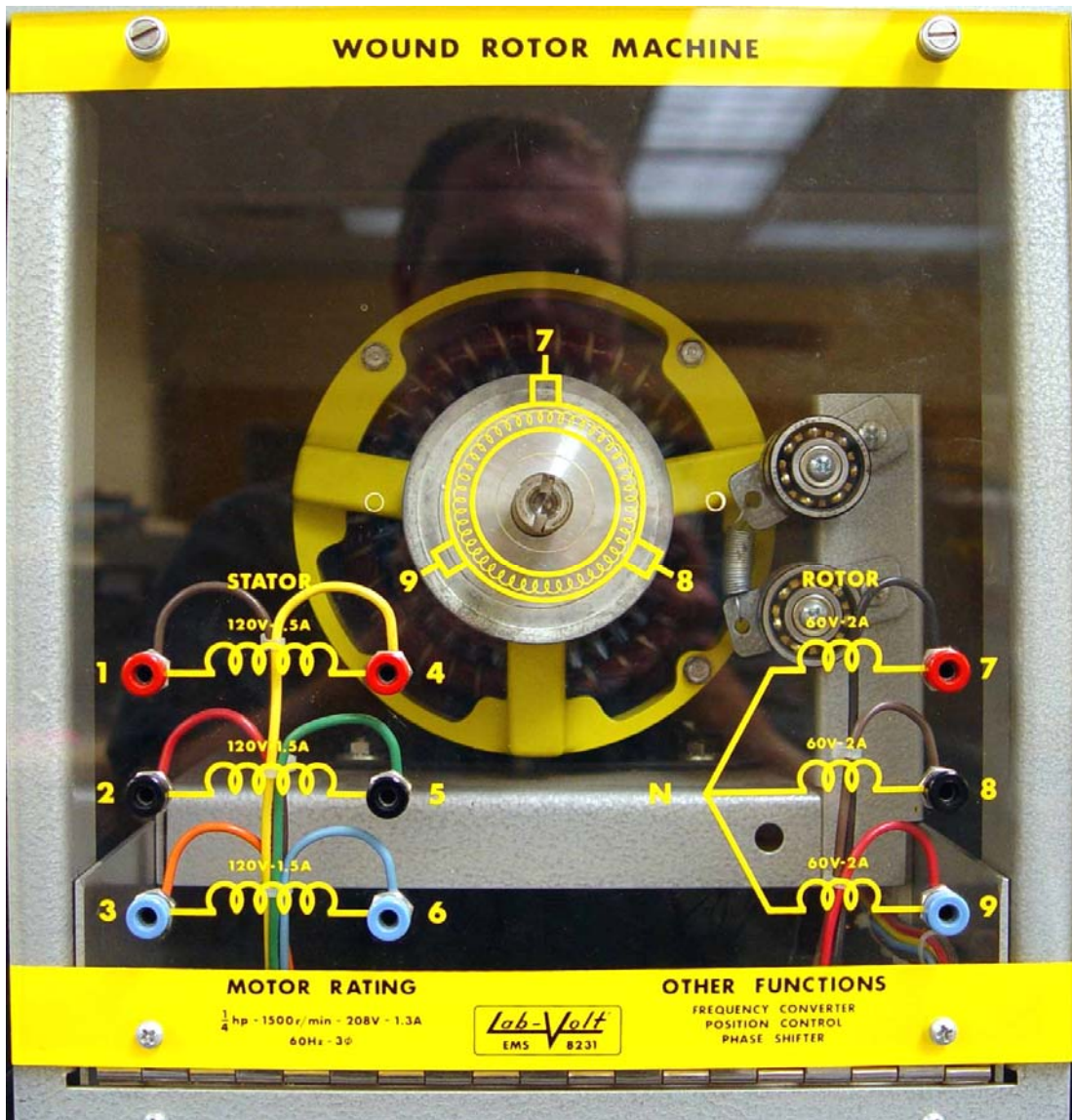


Figure 13-1

Identify the three rotor slip rings and brushes. Identify the rotor windings: note that they consist of many turns of small diameter wire evenly spaced around the rotor. Note that the rotor windings are Y-connected. Identify three stator windings and their terminals.

- 2) Connect the circuit shown in Figure 13-2. Note that three stator windings are connected to the variable 3-phase output of the PS (terminals 4, 5, and 6).

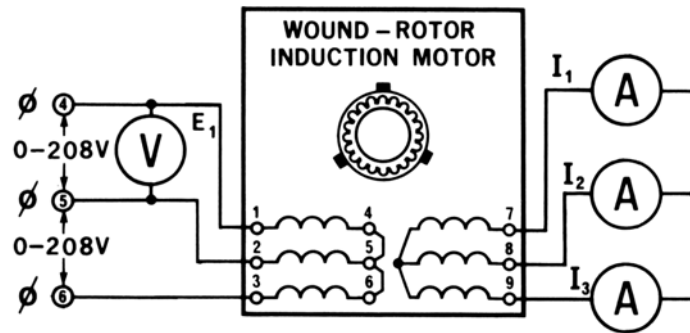


Figure 13-2

Couple the electro-dynamometer to the motor with the timing belt. Connect the dynamometer to the fixed low voltage AC source by the grey cable. Using thin red wires, connect the “torque” and “speed” outputs of the dynamometer to the “T” and “N” terminals of the DAI; connect “ground” terminals of dynamometer and DAI. Set the “MODE” switch of the dynamometer to the “DYN” position and the dynamometer load control switch to the “MAN”. Set the dynamometer control knob to its utmost clockwise position for a maximum starting load for the motor.

- 3) Turn ON the PS and adjust for approximately 100 V as measured by E_1 . Measure and record in a Data table the values of three rotor currents, input voltage, and the developed torque. Gradually reduce the load on the motor. Measure and record in your Data table the values of three rotor currents, input voltage, and the developed torque for the following values of the load: 0.4, 0.3, 0.2, and 0.1 Nm. Return the voltage to zero and turn OFF the PS.
- 4) Construct the circuit shown in Figure 13-3. Note that this time three stator windings are connected to the fixed 3-phase output of the PS (terminals 1, 2, and 3).

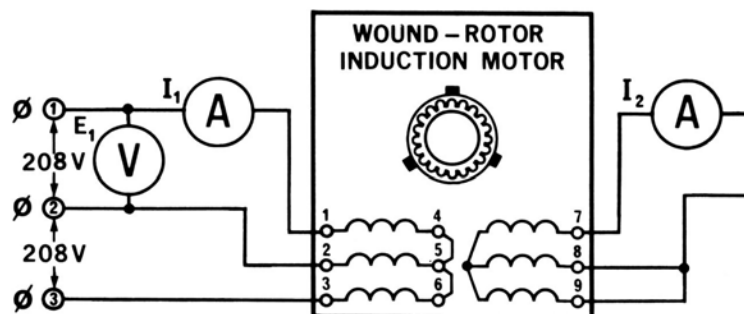


Figure 13-3

Set the dynamometer control knob to its utmost clockwise position for a maximum starting load for the motor.

- 5) Turn ON the PS and **quickly** measure and record in a new Data table the values of E_1 , I_1 , I_2 and the developed starting torque. Turn OFF the PS.
- 6) Construct the circuit shown in Figure 13-4. Note that three stator windings are connected to the variable 3-phase output of the PS (terminals 4, 5, and 6) and the rotor windings are connected to speed control rheostat.

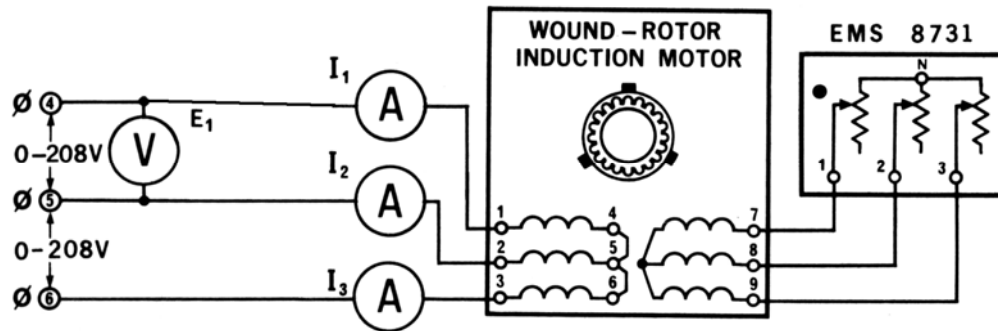


Figure 13-4

Set the speed control rheostat at its utmost counter-clockwise position for zero resistance. Set the dynamometer control knob to its utmost counter-clockwise position for a minimum load. Turn ON the PS and adjust the input voltage to 208 V. The motor should be running. Measure and record in a new Data table the values for line voltage, three line currents, the torque and the motor speed. Repeat the same procedure for loads of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, and 1.4 Nm while recording the values for line voltage, three line currents, the torque and the motor speed in the Data table. Maintain the input voltage of 208 V. Return the voltage to zero and turn OFF the PS.

- 7) Set the speed control rheostat at its utmost clockwise position for maximum resistance. Set the dynamometer control knob to its utmost counter-clockwise position for a minimum load. Turn ON the PS and adjust the input voltage to 208 V. The motor should be running. Measure and record in your Data table the values for line voltage, three line currents, the torque and the motor speed. Repeat the same procedure for loads of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, and 1.4 Nm while recording the values for line voltage, three line currents, the torque and the motor speed in the Data table. Maintain the input voltage of 208 V. Return the voltage to zero and turn OFF the PS.
- 8) With the load torque of 1.0 Nm, rotate the speed control rheostat knob from its utmost clockwise to the utmost counter-clockwise position. Make notes on your observations of motor speed and torque.
- 9) Construct the circuit shown in Figure 13-5.

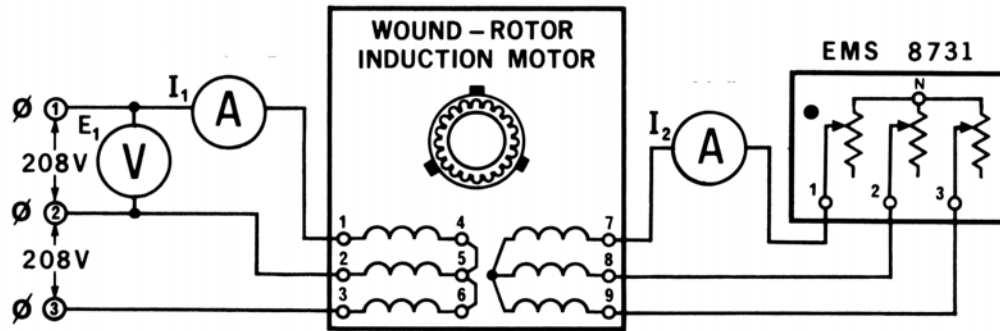


Figure 13-5

Set the dynamometer control knob at its utmost clockwise position for a maximum starting load. Set the speed control rheostat knob at its utmost clockwise position for a maximum resistance. Turn ON the PS and quickly measure and record the stator voltage and current, the rotor current, motor speed, and the developed starting torque. Turn OFF the PS and disassemble your circuit.

In your report:

- 1) Using Matlab and the data collected in Part 3, plot on the same axes three rotor currents and the average rotor current as functions of torque. Make these four curves distinguishable. What do you conclude from these graphs?
- 2) For the data collected in Part 5, calculate and report the apparent power to the motor at the starting torque. Calculate and report the full-load torque assuming that the full-load motor speed is 1500 rpm and the $\frac{1}{4}$ hp is delivered to the load. Calculate and report the ratio of starting torque to the full load torque.
- 3) If the stator voltage of a wound rotor motor is reduced by 50 % of the rated value, by how much the starting current, the apparent power, and the starting torque will be reduced?
- 4) Using Matlab and the data collected in Parts 6 and 7, plot on the same axes the motor speed as a function of the load for two positions of the speed control rheostat. Make these two curves distinguishable and label them. Compute and plot on the separate axes the apparent power as a function of load two positions of the speed control rheostat. Make these two curves distinguishable and label them. What do you conclude from these graphs?
- 5) For the data collected in Parts 6 and 7, compute and report the power delivered by the motor to the load under the full-load (1 Nm) conditions. What do you conclude?
- 6) For the data recorded in Part 8, calculate and report the apparent power to the motor at the starting torque. Assuming that the full-load is 1 Nm, calculate and report the ratio of the starting torque to the full-load torque. Calculate and report the ratio of the starting current to the full load current.