ELECTRICAL MACHINES LABORATORY

EE451

INDUCTION MOTOR

LOADING CHARACTERISTIC EXPERIMENT

DR. MUSTAFA AL-REFAI

IMPORTANT!!!!!

WARNINGS

- In the machinery laboratory, you will be working with rotating machinery. As the electrical machines operate at high speed, touching or holding the rotating part is extremely dangerous during the operation. Ties, scarves, jewellery etc. should not be worn during the experiment. Students with long hair should especially be careful.
- Never forget the fact that you will be working with voltages and currents, which may be hazardous to human life. Use one hand only while making or checking terminal connections; even if you know that the supply is switched off.
- Make sure that your assistants have checked your setup before switching on the supply and proceeding with the experiment.
- Machinery experiments require teamwork and coordination, both for the successful completion of an experiment and the safety of the group members. Therefore, be careful at all instants of the experiments.
- **Do not start an experiment before you have fully read and understood the "Experiment" section. Keep the object of the experiment in your mind, at least until you have finished your work. It is also a good idea to read "Results and Conclusion" section before starting the experiment, so that you know why you will be performing each step of the procedure and what kind of data will be required from you in preparing the report.**

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INSTRUCTIONS

- The lab report must be submitted within one week of the completion of the lab work. It must be typewritten.
- Reports should be at most 11 pages long. They should contain: Title page, Objectives/Aims, Background/Summary of Experiment, Results and Observations, Discussions and Questions, and Conclusion.

PRE-LAB TEST QUESTIONS AND CALCULATIONS

Fill in the blanks.

1. The relative difference in speed between the actual rotor speed and the synchronous speed of the stator field is called the____________.
2. The direction of rotation of an induction motor may be changed by________.
3. In order to operate an induction machine as a generator the rotor has to be driven at a speed _______ than the synchronous speed.
4. Answer the following questions.
5. The general formula relating power, torque and speed is P = Tω with P in watts, T in Newton meters, ω in radians/sec. Derive the formula with appropriate constants for P in hp, T in lbf-in, ω in r.p.m.
6. The 3φ induction machine in your lab has the following rated values current = 1.2 A, voltages (L-L) = 208 V , speed = 1670 r.p.m., power = ¼HP From these values, calculate the rated torque in lbf-in. Trated = ______ lbf-in.
7. A 3φ, y connected induction motor is operating at rated load conditions. At this rated load, the following data is obtained. TLOAD = 9 lbf.in I = 1.0A VLL = 200V W1+ W2 = Total Power Input = 250W N = 1680 r.p.m. Calculate the following quantities.

a. Apparent power S _______

b. Reactive power, Q _______

c. Input power factor, pf _______

d. Horse power, HP _______

e. Efficiency η _______

8. Draw a typical torque versus speed curve for an induction motor. Carefully show the location of the following points on the axes of the graph.

i. Synchronous speed, ns,

ii. Starting torque, Ts

iii. Maximum torque, T_{max}

iv. Identify the region of the curve in part 8a where the motor cannot be operated.

9. Given the nameplate information and the motor-generator set, Figure 1, answer the following:

Induction Motor	**DC Generation**
5 Horsepower	1.08 Field Amps
208 Volts	120 Volts
15.7 Amps	36.8 Amps
1800 RPM	1800 RPM
60 Hz	

a. Is the input power to the induction motor electrical or mechanical?

b. Is the output power from the induction motor electrical or mechanical?

c. Is the input power to the DC generator electrical or mechanical?

d. Is the output power from the DC generator electrical or mechanical?

e. From the nameplate data, is the rated induction motor power a single phase or three phase value?

f. What is the rated full load current per phase?

g. What is the rated full load voltage per phase?

h. Given the DC generator efficiency as ηdc, the load power is PL Watts and the induction motor input power is Pin Watts, derive the following two terms.

i. The efficiency of the motor-generator set, ηm-g (ie. the system input-output efficiency).

j. The efficiency of the induction motor, ηind.

10. Draw the equivalent circuit of one phase of a three-phase induction motor. If the induction motor slip equals zero (s=0) what type of test does this represent? Is the rotor current under this condition equal to zero, explain? Can we measure the rotor current?

11. If the induction motor slip equals one (s=1) what type of test does this represent? What type of input voltage would you expect is required to obtain the rated current, answer in approximate percentages of full rated voltage.

12. Fill in the blanks.

A. The relative difference in speed between the actual rotor speed and the synchronous speed of the stator field is called the .

B. The direction of rotation of an induction motor may be changed by

________.

C. In order to operate an induction machine as a generator the rotor has to be driven at a speed ____________________ than the synchronous speed.

13. Answer the following questions.

14. The general formula relating power, torque and speed is $P = T\omega$ with P in watts, T in Newton meters, ω in radians/sec. Derive the formula with appropriate constants for P in hp, T in lbf-in, ω in r.p.m.

15. The 3φ induction machine in your lab has the following rated values. current = 1.2 A , voltages (L-L) = 208 V speed = 1670 r.p.m. power = ¼HP

From these values, calculate the rated torque in lbf-in. T_{rated} = _______lbf-in.

16. A 3φ, y connected induction motor is operating at rated load conditions. At this rated load, the following data is obtained. T_{LOAD} = 9 lbf.in I = 1.0A V_{LL} = 200V, $W_1 + W_2$ = Total Power Input = 250W N = 1680 r.p.m. Calculate the following quantities.

a. Apparent power S ___

b. Reactive power, Q ___

c. c. Input power factor, pf _________

d. Horse power, HP ____

e. Efficiency η __

17. Draw a typical torque versus speed curve for an induction motor.

18. Carefully show the location of the following points on the axes of the graph.

a. Synchronous speed, n_s,

b. Starting torque, T_s

c. Maximum torque, T_{max}

d. Identify the region of the curve in part (a) where the motor cannot be operated.

OBJECTIVES

To observe the characteristics of the wound-rotor induction motor at no load and at full load.

Background

The three-phase induction motor carries a three-phase winding on its stator. The rotor is either a wound type or consists of copper bars short-circuited at each end, in which case it is known as squirrel-cage rotor. The three-phase current drawn by the stator from a three-phase supply produces a magnetic field rotating at synchronous speed in the air-gap. The magnetic field cuts the rotor conductors inducing electromotive forces which circulate currents in them. According to Lenz's Law, the EMFs must oppose the cause which produces them; this implies that the rotor must rotate in the direction of the magnetic field set up by the stator. If the rotor could attain synchronous speed, there would be no induced EMF in it. But on account of losses, the speed is always less than the synchronous speed.

In this experiment the induction motor drives a DC generator. The field of the DC generator is excited separately. Loading the generator by means of a resistor load rack in turn loads the motor. When the motor drives a load, it has to exert more torque. Since torque is proportional to the product of flux and current, with increasing load the relative speed (slip) between the rotor and the rotating magnetic field must also increase.

The three-phase induction motor behaves as a transformer whose secondary winding can rotate. The basic difference is that the load is mechanical. Besides, the reluctance to the magnetic field is greater on account of the presence of the air-gap across which the stator power is transferred to the rotor. The no-load current of the motor is sometimes as high as 30 % to 40 % of the full-load value. The performance of an induction motor may be determined indirectly by loading a DC generator coupled to its shaft as is done in this experiment.

AC induction motors are ideal for most industrial and commercial applications because of their simple construction and low number of parts, which reduce maintenance cost.

Three-phase AC power is supplied to the windings of the stator of the induction motor. A rotating sinusoidal magnetic field is produced. The speed of rotation of the stator magnetic field is described as the synchronous speed *ns* and is given by

$$n_s = \frac{120 f}{P} \qquad \textbf{(1)}$$

where:

ns is the synchronous speed (rpm)

f is the frequency of the AC supply (Hz)

P is the number of poles in the motor.

For example, in Singapore the AC supply has a frequency of 50 Hz. For most common AC motor, which has 4 poles, the synchronous speed can be calculated as:

$$n_s = \frac{120 \times 50}{4} = 1500 rpm$$

The rotor of the induction motors can be either wound rotor type or squirrel cage type. Wound-rotor induction motors have a three-phase winding, similar to the stator winding, on the rotor. Wound-rotor induction motors can be controlled to operate at different torques and speeds. However, they are usually significantly more expensive than squirrel cage rotor motors.

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:

$$P_{out,hp} = \frac{1.4 \times \omega_{rpm} \times T_{Nm}}{10000} \qquad (2)$$

where ω*rpm* is the motor speed in revolutions per minute, *TNm* 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:

$$Q = \sqrt{S^2 - P^2} \qquad (3)$$

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

$$efficiency = \frac{P_{out,W}}{P} \times 100\% \qquad (4)$$

where $Pout,W$ is the output power delivered to the load in Watts. The motor losses, therefore, are estimated as:

$$Losses = P - P_{out,W} \qquad (5)$$

INSTRUMENTS AND COMPONENTS

DESCRIPTION	MODEL
AC Voltmeter	8429
Connection Lead Set	8550
DC Motor/Generator	8551
Wiring Module DC Motor/Generator	8552
Wound Rotor Induction Motor	8555
Wiring Module for Wound Rotor Motor	8556
AC Ammeter	8564
Three-Phase Wattmeter	8565
Field Rheostat	8574
Three-Phase Power Supply	8575
Electrical Tachometer (2 kW)	8930
Coupler	8943

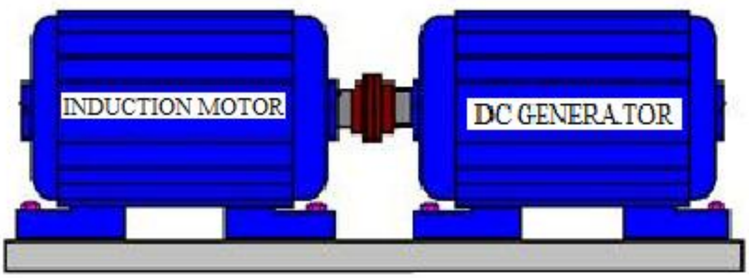

Fig.1. induction motor cupplied with d.c generator

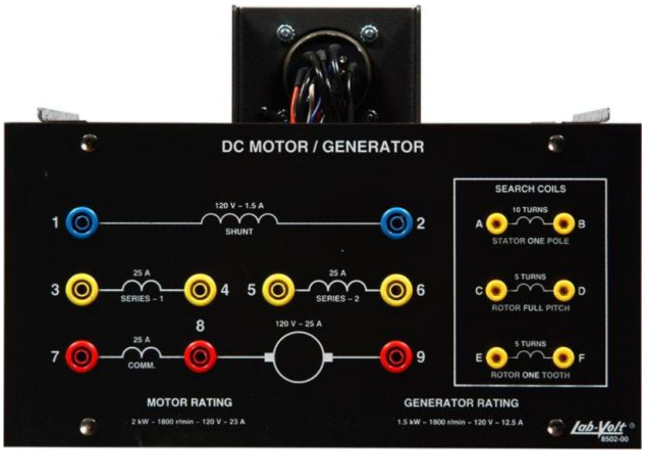

Fig.2. Wiring Module for DC Motor/ Generato

Fig.3. DC Motor/Generator

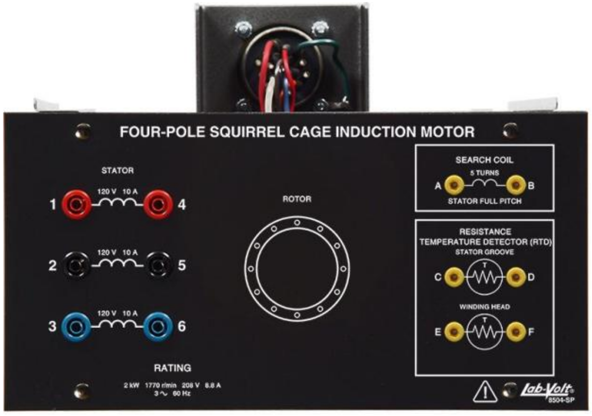

Fig.4. Wiring Module for Squirrel-Cage Induction Motor

Fig. 3.Four-Pole Squirrel-Cage Induction Motor

PROCEDURE

Warning:

High voltages are present in this experiment!
DO NOT make any connection while the power is ON.

Lab Volt EMS **8555**, Power ________kW, Speed __________rpm

Stator Voltage ______V, Stator Current _____A

Calculate rated torque = ___________________________ = ________ N.m

1. Record the rated voltage, current and speed of the motor and the generator. The generator is used to load the motor.
2. Connect your Wound-Rotor and DC Motor/Generator to their respective Wiring Modules.
3. Install your Electrical Tachometer Module on your Wound-Rotor Machine.
4. connect the circuit shown in Figure 2.
5. Set the Three-Phase Rheostat control knob at its full cw position for maximum resistance at starting.
6. Gradually adjust E_i to 380 V ac. The motor should be running.
7. When the starting procedure is finished, set the Three-Phase Rheostat control knob at its full ccw position.
8. Measure and record in Table.1, the three line currents, the wattmeter indication, the torque and the motor speed.
9. Return the voltage to zero and turn off the Power Supply.
10. Couple the Wound-Rotor Machine to the DC Motor/Generator using a rubber Coupler.
11. Turn on the Power Supply and repeat Procedure steps 5) to 9) for each of the load resistance values listed in Table.1, while maintaining the input voltage at 380 V ac.

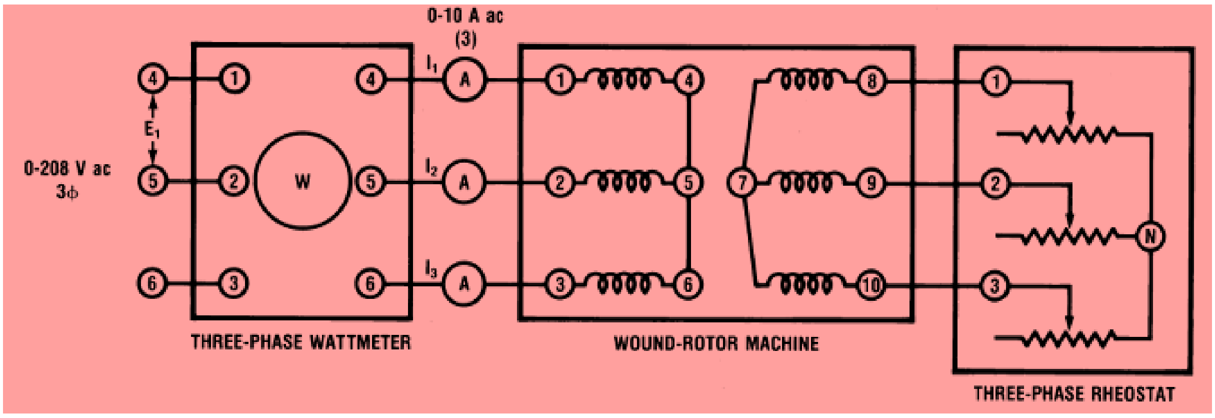

Figure 1. circuit connection for induction motor

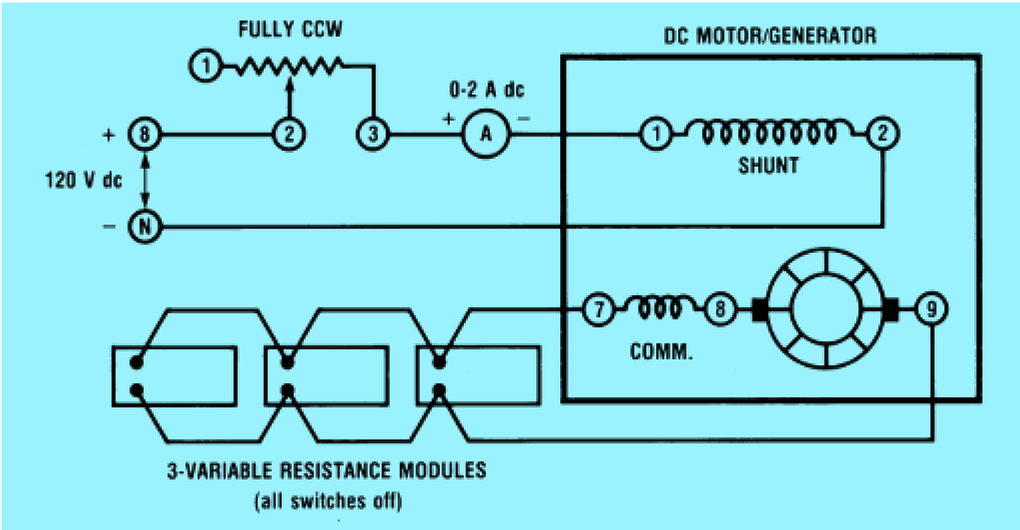

Figure 2. circuit connection for dc generator

12. Return the voltage to zero and turn off the Power Supply.

Table . 1: Ohms Resistance

LOAD	I_1	I_2	I_3	W	TORQUE	SPEED
Ω	**A**	**A**	**A**	**W**	**Nm**	**r/min**
∞						
1 x 220						
3 x 220						
3 x 110						
(3 x 110) + (3 x 440)						
*(3 x 110) + (3 x 220)						

* Note: Take these last measurements quickly. If the motor stops, return the voltage to zero, reset the Three-Phase Rheostat overcurrent circuit breaker, turn off the load resistors, and repeat Procedure steps 5 a) to 9) recording the remaining measurements.

REPORT

1) Using the results of parts 4-6 plot the output torque of the induction motor versus speed (speed on the x-axis, with the axis running from 0 to synchronous speed). **Do not hand plot the data**.

2) Theoretically, the torque at a given speed varies with the square of the voltage. From the graph in (1), comment on your experimental results.

3) Using the results of parts 4-6 plot the power efficiency of the induction motor versus speed (speed on the x-axis, with the axis running from 0 to synchronous speed). The input power is read from the wattmeter. The output power is the product of the speed and the torque. Be sure to use consistent units. **Do not hand plot the data**..

5) Present the voltage and current waveforms you sketched in step 8 of the proceedure. Comment on the harmonic distortion and discuss what power quality problems there may be.

Add a scale on each left side axis using 0 to 10 A for Current, 0 to 100% for Power Factor and Efficiency, and 1750 to 1800 RPM for Speed.

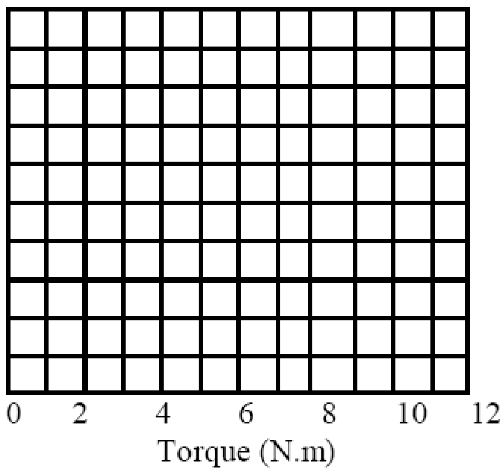

Figure 1 Current vs. Torque

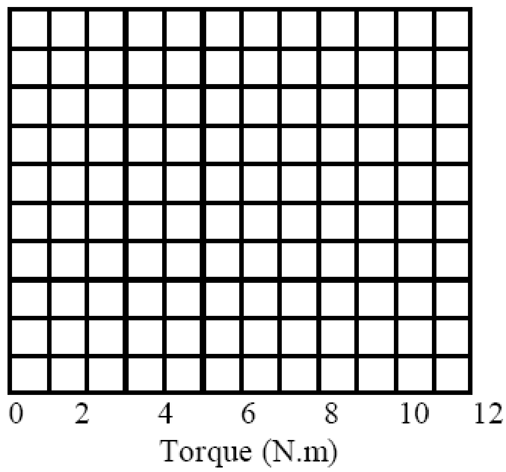

Figure 2 p.f. vs. Torque

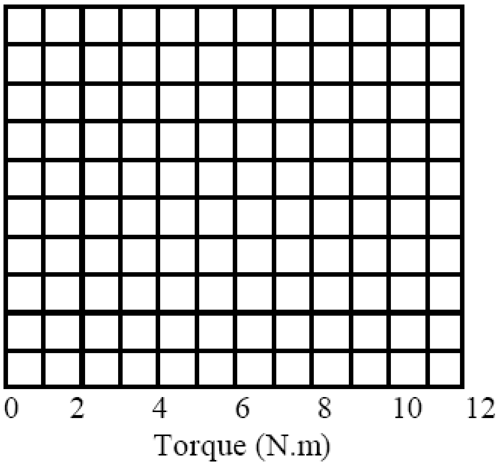

Figure3 .Efficiency vs. Torque

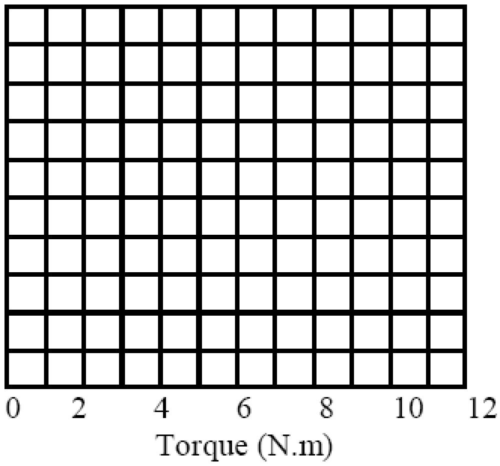

Figure 4. speed vs. Torque