Measurement of induction motor characteristics

ES163 Electrical and Electronic Systems

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Summary

The aim of the laboratory is to increase understanding of the use of simple 3-phase power systems and current, voltage, power, power factor and mechanical power. Also to develop and understanding of a small 3-phase induction motor. This was achieved by investigating the characteristics of the induction motor at the rated voltage under a range of loads until the motor stalled. It was found that the motor speed under normal operation does not vary much with load. It was also found, by plotting a graph that the efficiency of the motor is at a maximum at its rated load. The specifications on the motor's nameplate were found to be slightly different from the measured values. Speed was found to decrease as the applied torque was increased and the power factor was found to increase as the power output increased. A VA diagram was drawn for the motor at the rated load. The experiment showed roughly the expected results with a slight variation compared to the motor specifications.

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Introduction

A large proportion of energy used in industry is consumed by electrical drives. Many types of motor are available but the three-phase induction motor is by far the most common. Its basic capabilities are limited but may be extended using electronic controls.

In order to specify a drive system the speed and torque (and hence power) required by the load must be matched by the capabilities of the drive. The basic characteristic of a drive is its torque-speed curve which is obtained experimentally on a dynamometer (a specially designed brake). The test system used in this exercise comprises a small motor connected to an electromagnetic dynamometer and a tachometer (an electrical speed-measuring device). The torque on the brake is measured by a strain gauge, and signals from this and from the tachometer are fed into a control box. This control box provides a manual adjustment of the braking torque and gives displays of speed and torque (measured) and mechanical power (calculated from speed & torque). The energy from the drive is dissipated as heat from the fins on the casing of the dynamometer.

The experiment is designed to determine characteristics of a small induction motor and help develop knowledge of 3-phase supplies.

See Laboratory instruction sheet (appendix A)

Theory

Voltage current and phase angle in single-phase systems

The voltage varies sinusoidaly (e.g. v=240sin ωt) and the current varies in a similar way, I=10sin(ωt + Φ) the angle Φ may be zero, positive (current leading voltage) or negative (voltage leading current) depending on the circuit. Both current and voltage are usually expressed as root mean squared (rms) values, which are equal to the peak values divided by $\sqrt{2}$

In most practical situations the circuit is inductive and current lags the voltage. If the rms voltage across the load is V, the rms current through it is I and the phase angle between V and I is Φ, the power delivered to the load is VIcosΦ. Cos Φ is the power factor and by convention is positive when the current lags voltage. The product of V and I is known as 'volt-amps' or VA ('apparent power') and VIsinΦ is 'reactive volt amps' or VAr ('reactive power')

Three phase systems

Industrial power consumers are usually connected to a three-phase supply. In many circumstances this may be regarded as three interconnected single-phase supplies. The three voltages are displaced by 120º relative to each other and share one common conductor which is known as the neutral. If the three loads are similar the current in the neutral is zero. Basic three-phase systems may be analysed by considering one phase only. The phase voltage, V_p, is the voltage between a line and neutral. The line voltage, V_L, is the voltage between any to lines and is $\sqrt{3}\,V_p$.

For further information see Appendix A: Laboratory Sheets.

Apparatus and Methods

Apparatus

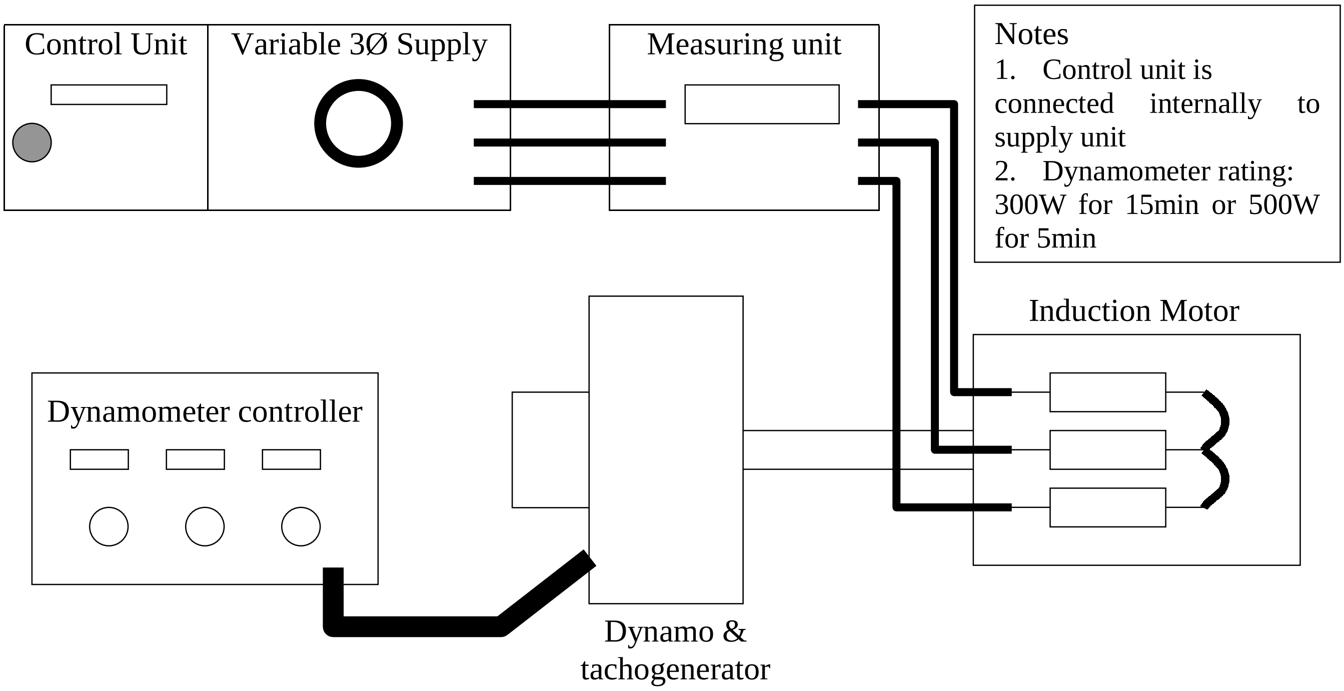
Electrical power test panel (Feedback) equipped with:
Three-phase supply control unit, ref. 60-100 (‘The control unit’)
Variable three-phase /dc supply 5A, ref. 60-125 (‘The supply unit’)
Single & three-phase measurement unit, ref. 68-100 (‘The measuring unit’)
Electrical machines test bed (Leroy Somer) equipped with
Induction motor rated at 0.3kW 50Hz 1440rpm
(Delta-connected: 220V 1.75A, Star-connected 380V 1.00A)
Tachometer & powder brake dynamometer (Leroy Somer Modmeca), rated at 300W for 15min, 500W for 5min & equipped with overload trip.
Dynamometer control box (Modmeca 3)
9 Connecting leads.

Methods

The single-phase circuit breaker with no-volt release on the control unit and the power switch on the measuring unit were switched on. The 3-phase energy meter was checked and the selector switch set to 4-wire it was then switched on and set to line voltages. The energy meter can be used to measure voltage, current, power, power factor, energy, frequency, and crest factor. (For further information see Appendix A: Laboratory instruction sheets.)

The three-phase power circuit breaker on the supply panel was set to off, the variable output control knob to zero, and the output voltage selector to 1 (three-phase).
The three phase outputs, L1, L2, L3, and N on the supply panel were connected to the respective inputs on the measuring unit. The three-phase circuit breaker with no-volt release on the control panel and the three-phase circuit breaker on the supply panel were switched on. The variable output control was set to about 25% and the line voltages were checked (on the energy analyser) and noted. The phase voltages and the line voltages were compared and it was noted that $V_L = \sqrt{3}\,V_p$. The variable control was set back to zero and the three-phase power breaker switched off.
The induction motor was connected in a star configuration and the three terminals L!, L2 and L3 on the right of the measuring unit were connected to U1, V1 and W1 on the motor. The three-phase power breaker was switched on and the variable output control was slowly increased until the motor started. The voltage was increased to the rated value of 380V line to line. It was noted that the speed of the motor while running was not greatly affected by the voltage.
The dynamometer control box was set to manual control of torque and the manual control was set to zero. The speed range was set to 200.min and the power range to 300W. The unit was then switched on.

Figure1 - Connections for load tests on induction motor



The values of torque, speed, mechanical power, voltage, current, power factor, and electrical power input were noted at this no load state.
The load torque was increased in steps of 0.5Nm and values of torque, speed, mechanical power, voltage, current, power factor, and electrical power input were noted at each value. The torque was increased until the motor was running at the rated power of 300W. VA and VAr were measured at this point. The torque was again increased in steps of 0.5Nm and measurements taken until the motor stalled. Measurements were taken fast to prevent the motor overheating in this high load state. When the motor stalled the load torque was immediately set to zero and the motor allowed to run in a no-load state in order to cool down.

Observations and Results

Line to neutral voltages:

L1	L2	L3
68.7V	69.8V	69.8V

Display shows voltage: 120V

So: $\sqrt{3} \times 69.7 = 120$

Therefore: 120V is expected.

The speed is not greatly affected by the voltage.

No Load State:

Torque	Speed	Mechanical Power	Voltage	Current	Power Factor	Electrical power input
0.0Nm	1445min^{-1}	1.2W	380V	581mA	0.33	127W

Table of measured values (varying load torque):

V (V)	I (mA)	PF	P Elec (W)	P Mech (W)	n (min^{-1})	T (Nm)
380	581	0.33	127	1.2	1445	0.0
379	634	0.50	210	78.5	1430	0.5
379	701	0.61	280	140.6	1417	1.0
379	806	0.70	368	210.5	1399	1.5
379	938	0.77	473	288.3	1380	2.0
380	962	0.78	492	300.0	1372	2.1
380	1080	0.81	576	349.2	1350	2.5
380	1280	0.84	703	411.0	1313	3.0
380	1520	0.85	840	452.0	1272	3.5
380	1850	0.85	1120	491.0	1182	4.0

At rated power (300W): VAr = 397 VAr
VA = 631VA

Specification of motor on nameplate:

	V	Hz	min^{-1}	kW	cos ϕ	A
Δ	220	50	1440	0.30	0.66	1.75
✤	380	50	1440	0.30	0.66	1.00

Analysis and Discussion of Results

The following graphs are required:
1. Torque vs. Speed
2. Power Factor vs. Power Output
3. Percentage efficiency vs. Power Output

For the third graph, valued for percentage efficiency are required. These may be calculated using the following formula:

$$\frac{100 \times \text{mechanical power}}{\text{electrical power in}}$$

For each value of load

The results are shown in the table below:

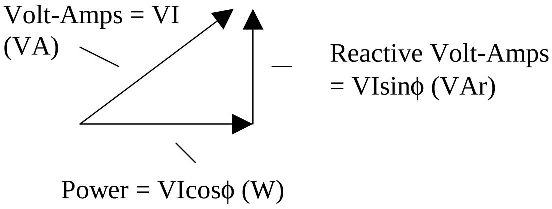
V (V)	I (mA)	PF	P Elec (W)	P Mech (W)	n (min^{-1})	T (Nm)	%age Efficiency
380	581	0.33	127	1.2	1445	0.0	0.9%
379	634	0.50	210	78.5	1430	0.5	37.4%
379	701	0.61	280	140.6	1417	1.0	50.2%
379	806	0.70	368	210.5	1399	1.5	57.2%
379	938	0.77	473	288.3	1380	2.0	61.0%
380	962	0.78	492	300.0	1372	2.1	61.0%
380	1080	0.81	576	349.2	1350	2.5	60.6%
380	1280	0.84	703	411.0	1313	3.0	58.5%
380	1520	0.85	840	452.0	1272	3.5	53.8%
380	1850	0.85	1120	491.0	1182	4.0	43.8%

Table of Graphs

Graph 1: Torque vs. Speed .... Page 9
Graph 2: Power Factor vs. Power Output .... Page 10
Graph 3: Percentage efficiency vs. Power Output .... Page 11

Note the point showing the values at the rated power on each graph.

VA Diagram



VA Diagram for motor at full load (300W)

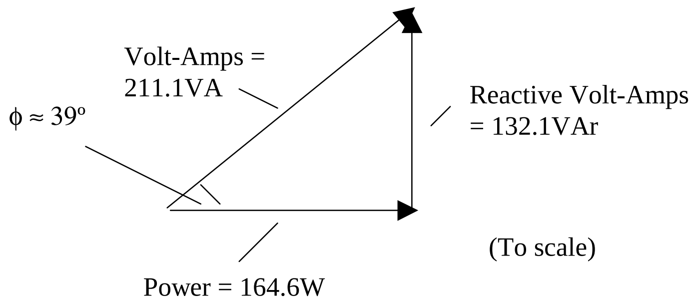
Motor measurements at full load (300W)

Torque	Speed	Mechanical Power	Voltage	Current	Power Factor	Electrical power input	Volt-Amps	Reactive Volt-Amps
2.1Nm	1372min^{-1}	300W	380V	962mA	0.78	492W	631VA	397VAr

$$V_L = \sqrt{3}V_p$$

V_p	I
219V	0.962A

Power	Volt-Amps	Reactive Volt-Amps
164.6WW	211.1VA	132.1VAr



It has been noted from the Torque vs. Speed graph that until the motor stalls speed does not vary much with load. The rest of the torque speed curve (n = 0 to n = stall speed) is virtually impossible to measure as the motor does not operate below the stall speed.

The efficiency of the motor at the rated load can be calculated using the following formula:

$$\frac{100 \times \text{mechanical power}}{\text{electrical power in}}$$

From the measured value this is calculated as 60.9%
The power factor at the rated load was measured as 0.78

Specification of motor on nameplate:

	V	Hz	min^{-1}	kW	cos ϕ	A
Δ	220	50	1440	0.30	0.66	1.75
✣	380					1.00

Values measured at full load (300W Star connected)

Torque	Speed	Mechanical Power	Voltage	Current	Power Factor	Electrical power input	Volt-Amps	Reactive Volt-Amps
2.1Nm	1372min^{-1}	300W	380V	962mA	0.78	492W	631VA	397VAr

The measured speed is close to the rated value as is the current. However the power factor is higher than the expected value.
The test results do not exactly confirm the specification on the nameplate. From the nameplate the expected power can be worked out as 434W therefore expected efficiency should be 69% which is slightly higher than the measured value.

From the graph of Power factor vs. power output is may be observed at small loads that the power factor and efficiency reduce dramatically. This is a disadvantage as if efficiency decreases then cost of electrical power will rise. A company will also be charged more for loads on the supply with a low power factor. Both of theses are undesirable in an industrial situation and therefore it is not viable to run the motor at small loads.

As the motor is overloaded the efficiency reduces but the power factor rises and levels off. This is caused by the load reducing the speed of the motor which reduces the back emf produced in the coils, decreasing the resistance and drawing more current, without increasing motor speed.

Conclusions

The results show the characteristics of a small 3 –phase induction motor connected in a star configuration. The efficiency of the motor was found to be a maximum at the rated power. The speed was found to decrease as the applied torque increased. The power factor was found to increase as the power output increased. It was found that the motor speed under normal operation does not vary much with load. It was found that at small loads operation is undesirable, with a low power factor and a low efficiency. The specifications on the motor's nameplate were found to be slightly different from the measured values. The efficiency of the motor at the rated load was found to be about 60% which was less than the 69% expected. The results for the investigation were in line with what would be expected.

Bibliography

Laboratory Sheet: ES163 Electrical and Electronic Systems: Measurement of induction motor characteristics (Attached)

Lecture notes: ES163

Reference

Edward Hughes (rev. I McKenzie Smith):
"Electrical Technology" 7th Edition, Longman 1995,
Ch. 32 pp 542-547 & Ch. 41 pp 698-703

Appendices

Appendix A: Laboratory Instruction Sheets

1. Instruction Sheet
2. Theory: Three phase power systems and safety devices
3. Feedback/Elcontrol Operation