LAB REPORT: THREE-PHASE INDUCTION MACHINE

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1. Summary

This report details the operation, modelling and characteristics of a *three-phase induction machine*. It attempts to provide a concise overview of the enitre experiment. Where the results of the experiments conducted are presented in graphical form, the raw data and the necessary calculations to produce the graphs can be found in the log book. The logbook also contains the derivation and evaluation for the equations cited.

2. Introduction

This report will investigate the operation of a three-phase induction machine through several experiments. Further experiments will attempt to characterise the machine in the form of quantities that can be applied to a mathematical model of the machine. It will then be possible to compare the characteristics exhibited by the model with the characteristics observed in the actual machine.

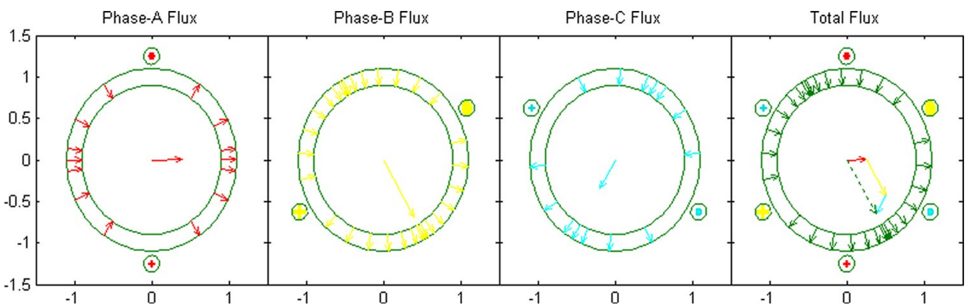

FIGURE 1. Flux produced by each phase of the induction machine.

The simplest form of motor is a single phase electrical machine. This works by rotating a single coil of wire in a magnetic field, or by rotating a magnetic field inside a coil of wire. If a sinusoidal current is applied to the wire a varying magnetic field is produced. The magnet inside the coil will continuouly flip round in order to keep itself pointing in the opposite direction to the field produced by the wire. The momentum

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that the magnet has as it flips will cause the resulting motion to be circular: the motor will spin.

A three-phase induction machine improves on this crude method of producing mechanical motion. The flux produced by each phase of the induction machine combine under vector addition to produce a flux that rotates rather than "flips" (*Figure 1*). This means that the resulting motion of the rotating part of the machine (rotor) is much smoother compared to a single phase machine.

Any number of phases, greater than one, can be used in this manner to produce a rotating flux. However, it is common to use three phases because it uses the same number of conductors as a two phase machine and is 95% efficient as opposed to 90% efficient. As the number of phases increases so does the number of conductors, and therefore the complexity, of the machine increases and the gain in efficiency becomes less and less substantial. Three phase machines are considered to be the best compromise between cost and efficiency.

3. Observation of induction machine operation

The idea of the experiments presented in this section is to build up a feel for how the induction machine behaves. Therefore, the line voltages were kept low to avoid excess current at low speeds.

3.1. **Observation of rotor current.** A current flows in the rotor due to the EMF induced as the stator flux cuts its conductors[1]. This current was measured as a voltage drop across a small resistor placed in series with the rotor conductors. Measurements were taken from the equipment set up with a stator line-to-line voltage of 20V. The rotor was rotated at speeds between 0rpm and 1,500rpm and the frequency and magnitude of the voltage across the resistor were recorded. This produced the graphs in figure 2.

The graph shows that as the speed of the rotor increases the amount of current flowing in the rotor decreases. As the flux produced by the stator rotates, it induces a voltage across the rotor. This causes current to flow, which in turn produces a torque. When the speed increases, the torque decreases and so does the current: the power available goes into spinning light loads fast rather than heavy loads slowly. This is described in equation 1;

$$T_{em} = \frac{3I_R'^2 R_R'}{s\omega_s} \tag{1}$$

When the rotor is stationary the flux will cut the rotor coils at synchronous speed; the frequency of the currents induced will be the same as the frequency of the currents in the stator. As the rotor spins faster the relative speed of rotation of the stator flux will decrease. This in

[1] Experiment P lab sheet

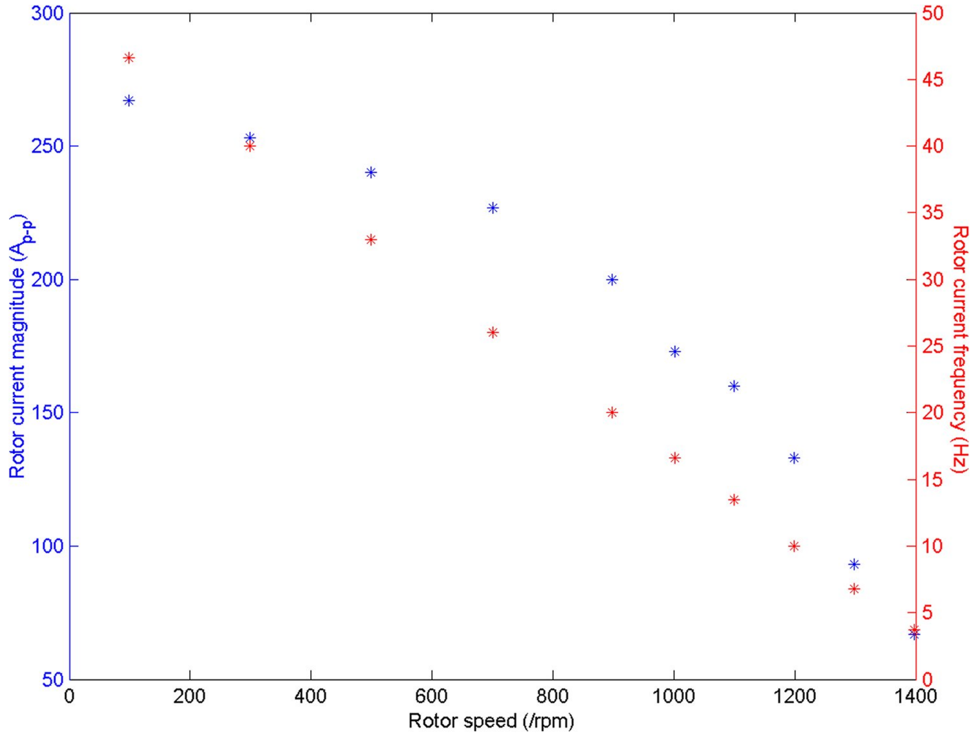

FIGURE 2. Rotor current frequency and rotor current magnitude against rotor speed.

turn will cause the frequency of the currents induced in the stator to decrease.

3.2. **Observation of torque-speed characteristics.** Measurements were taken from the induction machine in order to verify that the torque-speed characteristic was as expected. The line-to-line voltage was set at 20V. Readings for torque and speed were taken between 200rpm and 1,500rpm.

Figure 3 shows that the torque-speed characteristic is mostly as expected. It would however, been helpful if the torque had been measured for speeds greater than 1,500rpm. At sychronous speed the torque exerted by the induction motor is zero. If the speed is increased further the torque becomes negative and the machine begins to act like a generator rather than a motor: the rotor is being driven by the load rather than driving the load.

4. MODELLING THE INDUCTION MACHINE

The machine was modelled through the use of an equivalent circuit. The equivalent circuit used was a simplified model of the induction machine and is shown in figure 4.

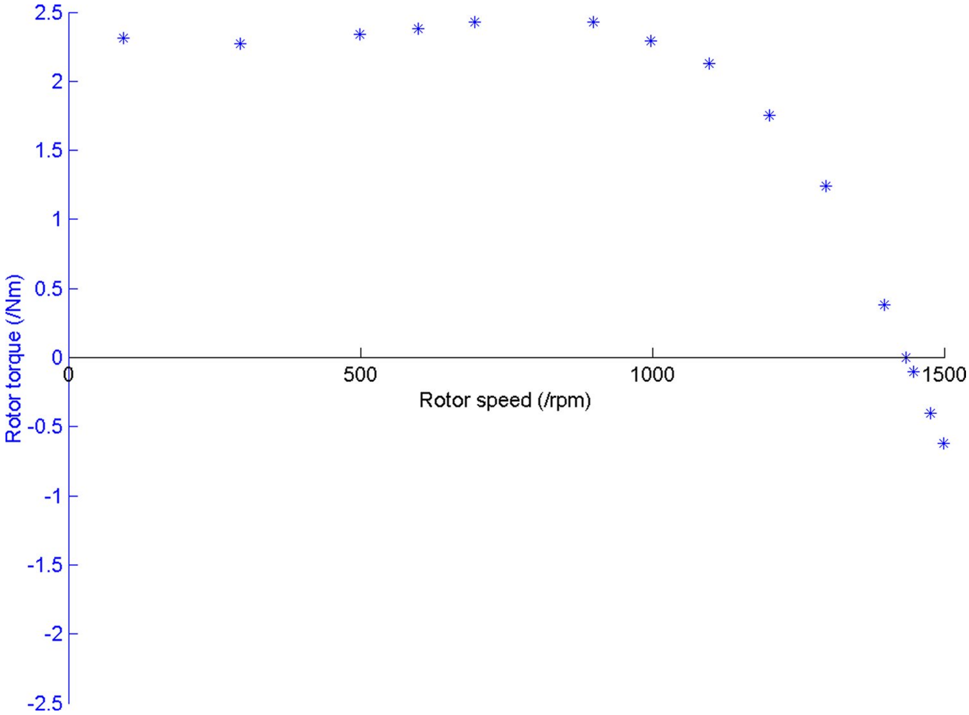

FIGURE 3. Rotor torque agains rotor speed.

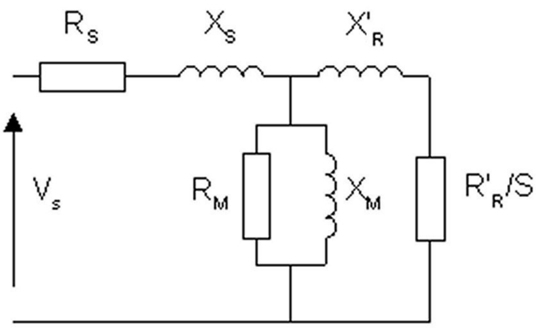

FIGURE 4. Simplified model of the induction machine.

R'_R, X'_R and X_S were found by conducting a standstill test. This ensures that the *slip* associated with the machine is one (*Equation 2*)

$$S = \frac{\omega_s - \omega_R}{\omega_S} \tag{2}$$

and therefore, $\frac{R'_R}{S}$ reduces to just ${R'_R}^2$. X_S and X'_R are also assumed to be equal. R_S was given as 0.095Ω. The lab sheet also provides equations 3 & 4 that can be manipulated to deduce the variables in question.

[2]Experiment P lab sheet

R'_R	$128m\Omega$
X_S	$176m\Omega$
X'_R	$176,\Omega$

FIGURE 5. Results of the standstill test.

R_M	22.26Ω
X_M	4.366Ω

FIGURE 6. Results of the synchronous test.

$$V_S = I((R_S + R'_R) + j(X_S + X'_R)) \tag{3}$$

$$P = I^2(R_S + R'_R) \tag{4}$$

V_S and P can be measured easily with the assistance of a power analyser, yielding the results shown in figure 5.

R_M and X_M were found by conducting tests on the machine at sychronous speed. The slip associated with the machine at this speed is zero. The values for the unknowns were determined by measuring the power supplied to the machine and then using the values obtained to solve equations 5 & 6.

$$V_S = I(\frac{1}{R_M} + \frac{1}{jX_M})^{-1} \tag{5}$$

$$P = I^2 R_M \tag{6}$$

The results are shown in figure 6.

Once all the parameters for the model had been found, they were then inserted into the supplied MATLAB simulation. The results of this simulation and the characteristics exhibited by the actual machine are compared in the next section.

5. Characterising the induction machine

In order to compare the characteristics of the model to the actual machine, torque-speed data was measured. To ensure that stator or rotor currents did not become excessive, readings were only taken between 1,400rpm and 1,550rpm: around the synchronous speed. The results produced by the model and the characteristics exhibited by the actual machine are compared in figure 7.

Figure 7 shows that, apart from the first two points, the measured data fairly closely follows the calculated data. The model appears to have been largely successful - it has produced a good representation of the behaviour exhibited by the actual machine.

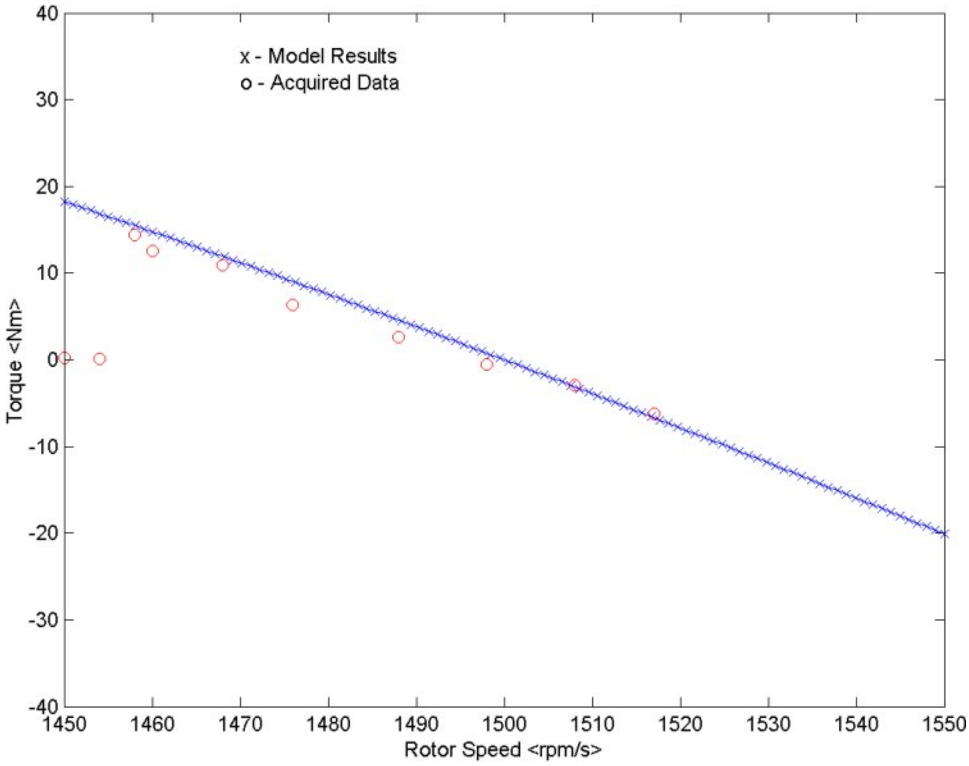

Figure 7. Comparison between the calculated and actual characteristics of the induction machine

6. Conclusions

- A three phase arrangement can be up to 95% efficient and provides a good balance between cost and effeciency. This is especially true when compared to single phase systems which are only around 60% efficient.
- The simplified equivalence circuit that was used to model the induction machine was found to give results that closely match the characteristics exhibited by the actual machine.
- The accuracy of measurements taken from the machine leaves a large amount of room for improvement although this may be difficult with the equipment provided.

It has been shown that the induction machine is a useful and efficient method of converting electrical energy into mechanical energy, or vice-versa. It is also easy to model and manipulate which makes it easy to adapt to various different situations in which it could be used.