Experiment 4

Induction Motor-Rotating Fields

4.1 Introduction

The induction motor is by far the largest single load on electrical power systems. It is the most common type of electric motor. The samples available in the laboratory consist of single phase and three phase motors with horsepower ranging from 1/12 HP to 1/4 HP.

This is the first of the experiments on induction motors. In this one the magnetic flux behavior in the machine will be emphasized.

An appendix is attached to this experiment giving an analysis of a simple model for the squirrel-cage induction motor.

4.2 References

Of particular importance in this experiment are Sections 4.1 to 4.6 where the magnetic fields are discussed.

Much of the experiment is discussed in Sections V.A and V.B of the IEEE Reprint.

4.3 Background Information

The essential phenomenon to investigate and understand in this experiment is the induction of currents and the resultant production of flux in moving conductors. The exciting currents can be either DC or AC. Both cases will be studied.

There can be two basically separate time-varying phenomena present in the experiment. These are the motion of the rotor conductors and the time-variation of the exciting current when AC excitation is used. With DC exciting current the magnetic fields are determined by the moving conductors alone.

A schematic for the single-phase induction motor is shown in Figure 4.1. It has two phases wound about axes at 90 degrees on the stator. One axis is called the direct- or d- axis and is the magnetic axis of the 'main' winding. The other axis is called the quadrature- or q- axis, and is the magnetic axis of the 'start' winding.

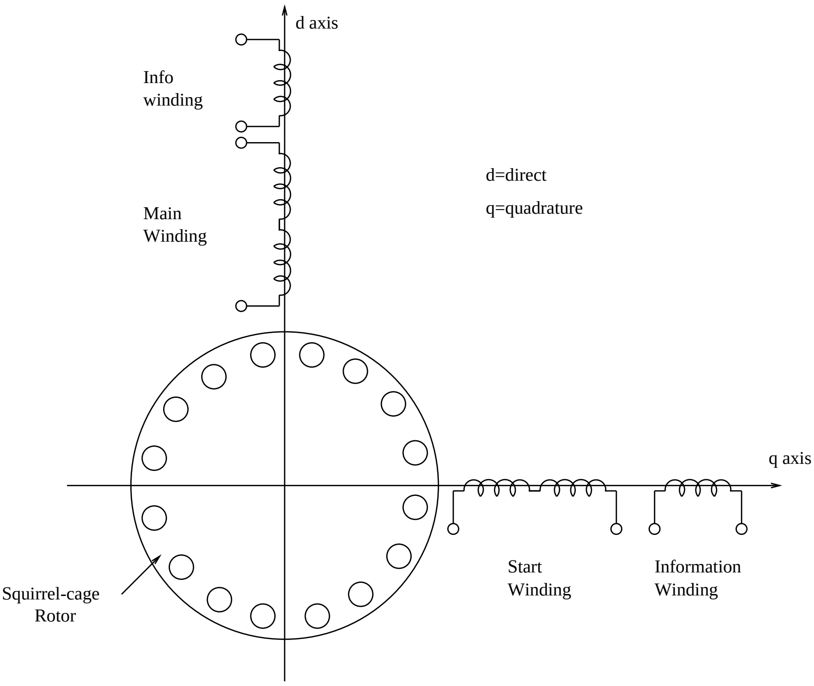

Figure 4.1: Windings in the lab two-phase induction motor

The two windings may be identical or they may have quite different electrical characteristics. In general each will have the same number of poles.

The rotor is of rugged construction, which is one reason why induction motors are rugged and relatively inexpensive. A sketch of a squirrel- cage rotor is shown in Figure 4.2. It has metal end rings holding the rotor bars at each end, and the whole structure is embedded in steel laminations. The electrical resistance between bars is very low. The rotor bar configuration is axisymmetric.

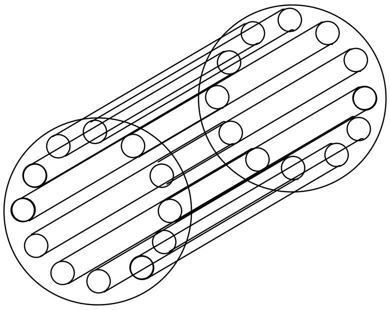

Figure 4.2: Rotor bars in a squirrel cage rotor

When DC current is applied to the direct axis and the rotor is stationary, then flux is set up along the direct axis. Since the quadrature axis is perpendicular to it no flux is coupled to the start winding. Flux travels across the air-gap and through the rotor steel, thus threading the rotor bars.

When the rotor starts turning, conductors start cutting through flux and, by Faraday's law, and voltages (EMF) are induced in the rotor bars. Currents flow in the rotor bars in certain directions in an attempt to hold the flux linkages of the rotor constant. This leads to a component of flux along the quadrature axis, in addition to that along the direct axis during the starting and stopping transients. When the rotor reaches constant velocity, the end result is complete cancellation of the direct-axis flux by the reaction flux of the rotor currents. The reaction flux in effect is equal and opposite to the direct-axis flux and cancels it out. The details of this are discussed fully in the IEEE Reprint on pages 1566 and 1567. This flux behavior can be studied in detail with the aid of the information windings.

When AC current is applied to the information winding the situation is quite different because the rotor position changes with time while the motor runs and the currents also change with time. If the rotor is turning at or near synchronous speed, there is a synchronized relationship between flux maxima in time and rotor position relative to the direct axis. The induced quadrature-axis flux is also sinusoidal in time but is out of phase with the direct-axis flux. The combination of two fluxes along magnetic axes displaced by 90^0 with a 90^0 phase difference in time leads to a rotating magnetic field. As is well known, the rotating magnetic field is fundamental to torque production in a rotating machine, and thus the conditions are established for generating torque.

The flux situation with AC excitation of the main winding is shown in Figure 4.3 for the rotor at standstill. The direct-axis flux can be broken into two contra-rotating flux components of equal amplitude. As soon as the rotor starts to move, the flux component that rotates in the same direction is increased by the reaction flux.

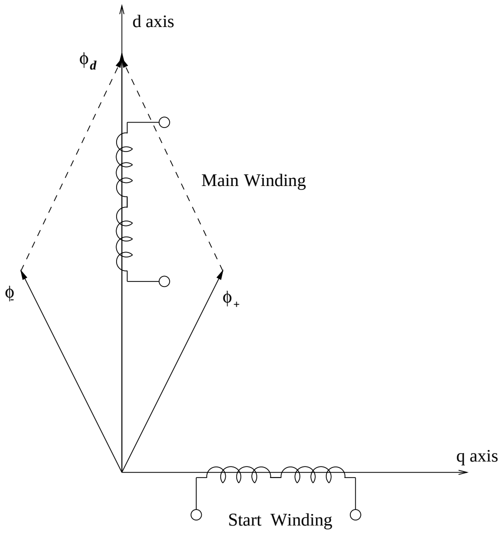

Figure 4.3: Fluxes in an induction motor at standstill

Clockwise rotation makes Φ_+ dominant and the magnetic field becomes a rotating field moving in the clockwise direction, pulling the rotor along. Likewise counter-clockwise motion makes Φ_- dominant.

The flux components when the rotor is moving clockwise are shown in Figure 4.4. Only the main winding is excited. Because of the induced currents in the moving rotor, the Φ_+ component is increased.

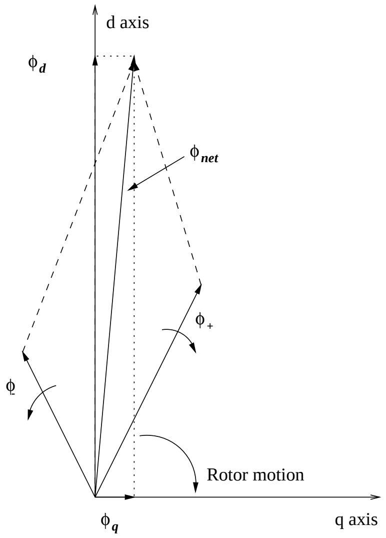

Figure 4.4: Flux components for clockwise rotation

The resultant flux Φ_{net} is no longer along the d-axis but now has a component along the q-axis. When the rotor is near synchronous speed the Φ_d and Φ_q components of Φ_{net} are almost equal and 90 degrees out of phase in time.

Many details of AC operation are discussed on pages 1567 and 1568 of the IEEE Reprint, including descriptions of several observations that can be made.

4.4 Equipment

A split-phase induction motor is used as the test motor in this experiment because it has information windings on both magnetic axes. It is a 1/12 HP, two-pole machine with a normal operating speed of 3450 RPM. It is numbered Item 5 and the terminal connections are shown in Figure 4.5.

The test motor will be driven by a second motor in parts of the experiment. The drive motor will be Item 6, a two-pole, single-phase motor.

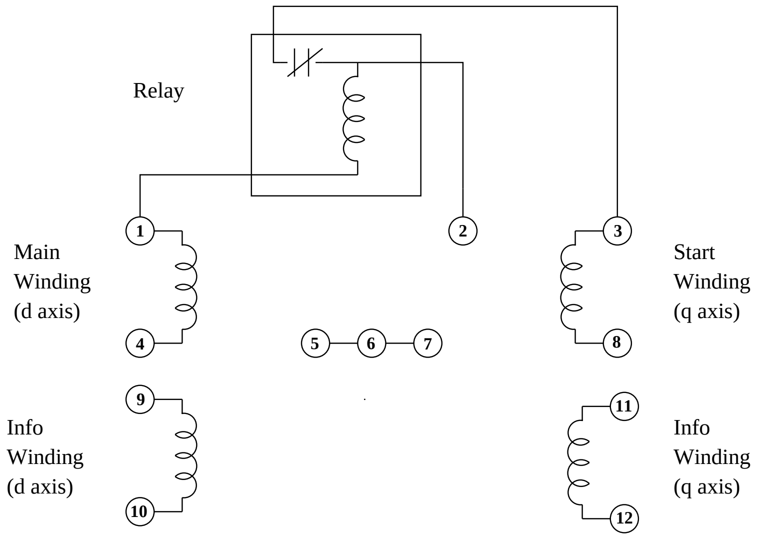

Figure 4.5: Terminal Connections for machine 6

4.5 Experiment

1. Connect motor No.6 as shown in Figure 4.6. Monitor the inputs to the DAS with the oscilloscope to make sure the values are not saturating.

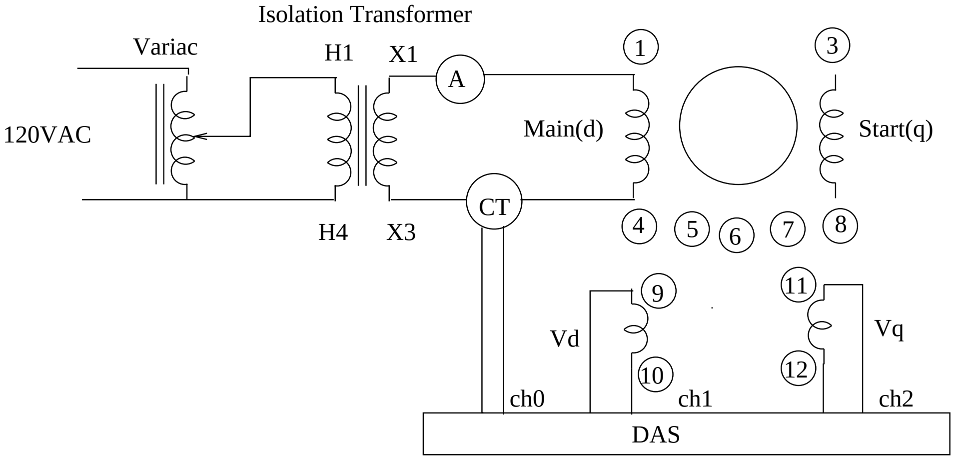

Figure 4.6: Connection diagram for a 2-phase induction motor

2. Now slowly turn up the AC voltage with the variac. Note that the motor will not turn unless the rotor is first turned slightly by hand, and that the motor will spin in either direction. Note also that the motor will not start unless the variac voltage setting is large enough. Observe starting current and u_d and u_q on the screen and plot them. Explain.

3. Observe the Lissajous figure when the voltage is turned off and the motor is still running. Observe the slow collapse of the flux trapped in the squirrel cage rotor. How

many revolutions does the rotor make while the flux decays to a negligible amount? Observe on the oscilloscope v_d and v_q as currents collapse also. Explain.

4. With the AC voltage applied and the motor running, observe the voltage v_d (blue) and v_q (red) as functions of time. Φ_d and Φ_q are plotted against each other in the lower window. The lower right window is the same figure just auto-ranged to get a better view at low voltages. Note that the Lissajous figure is in the form of an ellipse or circle. This implies a rotating magnetic field. Note the relative phase of Φ_d and Φ_q as functions of time when the motor is running in one direction or the other. Discuss how your observations fit into the cross-field theory.

5. Print your results out and explain why they vary with time as they do. (See p. 1568 of the IEEE reprint). Reduce voltage and explain why the bump on u_d moves faster and is larger. Why is this bump only on u_q and not on u_d?

6. Connect the single-phase AC motor to the HP DC supply shown in figure 4.7, with a variable drive DC motor used to rotate it. Monitor v_d and v_q on the AC motor using the analog-to-digital channels. Energize the main winding with DC while the motor is sanding still. Record v_d and v_q immediately upon turning DC on and upon turning DC off. Now record v_d and v_q as the DC is on and the DC motor is turned on and off. You must start sampling just before throwing the DC motor switch on and off. Record the sequence clearly, as you follow the flux change and the motor is turned on and off. Discuss the flux variations in terms of the Faraday Law and the shielding effect of the highly conducting rotor. (Optional)

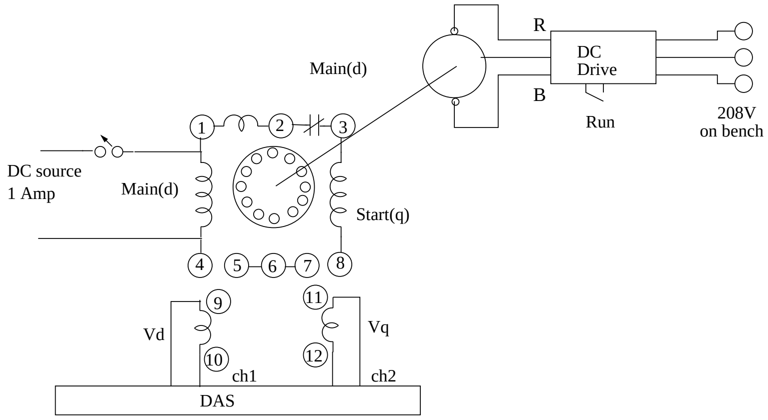

Figure 4.7: Connections for the second part of the experiment