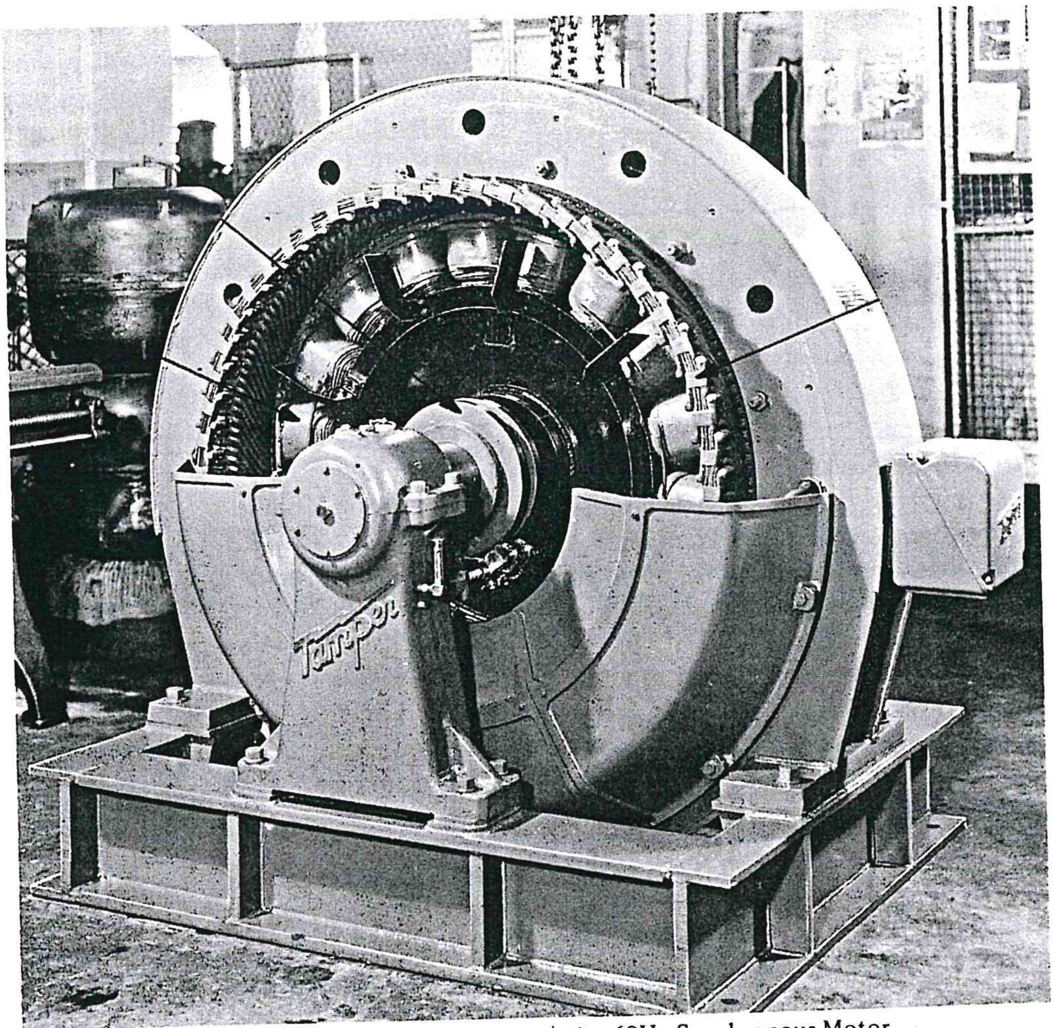
LABORATORY
EXPERIMENT
NO. 9

THE SYNCHRONOUS MOTOR



View of a 220kW, 2200V, 327 rev/min, 60Hz Synchronous Motor.

OBJECT

1. To observe the behavior of a synchronous motor connected to an infinite bus, as regards:
   a) Reactive power flow in the synchronous motor.
   b) Real power flow in the synchronous motor.
   c) Change in position of the rotor poles.

DISCUSSION

A synchronous motor has the same construction as an alternator, and hence possesses the same electrical properties. Indeed, an alternator can be made to run as a synchronous motor and vice-versa, the only distinction being that, as a motor, the machine receives electric power and converts it into mechanical power whereas, as an alternator, it does the reverse.

The circuit of a synchronous motor is identical to that of an alternator, consisting of a synchronous reactance X (per phase) and an induced AC voltage E_o created in the stator by the DC flux from the rotor poles. We shall first study the operation of the motor when it is connected to an

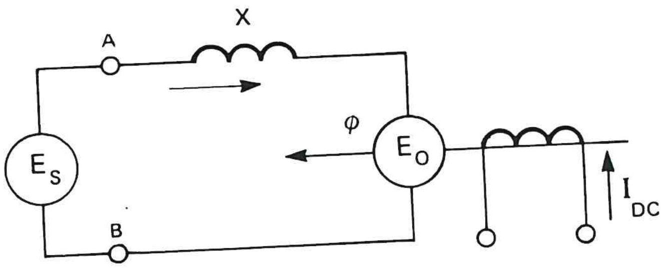


Fig. 9-1

infinite bus. An infinite bus is a source of electric power which is so immense that nothing we connect to it will change either its voltage, its frequency or the phase angles between its three phases. An infinite bus is, in effect, a source of voltage which has no internal impedance. The source E_s in *Fig. 9-1* is considered to be one phase of the infinite bus.

The circuit of *Fig. 9-1* looks very much like that of a transmission line in which E_s and E_o are the sender and the receiver voltages. In fact, the flow of real and reactive power in this circuit is dictated by the same factors as in the case of a transmission line. Briefly,

a) If E_o is in phase with E_s, and if the two voltages are unequal, reactive power will flow. (If E_o is less than E_s, reactive power will flow from the source to the motor. If E_o is greater than E_s then reactive power will flow from the motor to the source).

b) If E_o lags behind E_s, real power will flow from the infinite bus to the motor, giving it the energy to carry its mechanical load. Just as in the case of a transmission line, the maximum real power which can be delivered is equal to $(E_sE_o)/X_s$.

To vary the reactive power, E_o must be varied and this is readily done by changing the DC exciting current in the rotor windings.

To increase the real power, (for a fixed value of E_o and E_s) the phase angle between E_o and E_s must increase and this happens automatically when the mechanical load on the motor increases. When operating at no load, only a small amount of mechanical power is needed to overcome the windage and friction losses, consequently the motor draws only a small amount of real electric power. The phase angle between E_s and E_o is small under no-load conditions.

As the mechanical load is increased, E_o lags more and more behind E_s and when the lag is 90 degrees, the motor power will reach its maximum value. If the mechanical load is increased beyond this point, the machine will fall out of synchronism and come to a halt.

INSTRUMENTS AND COMPONENTS

Power Supply Module (220/380V 3φ, 0-220Vdc)	EMS 8829
DC Motor/Generator Module	EMS 8219
Synchronous Motor/Generator Module	EMS 8249
Resistance Module	EMS 8319
DC Metering Module (0.3/1.5A)	EMS 8419
AC Metering Module (0.25/0.25/0.25A/1.5/1.5/1.5A)	EMS 8428
AC Metering Module (500V)	EMS 8429
Three-Phase Watt-Varmeter Module (300W-300var)	EMS 8448
Strobe Light	EMS 8929
Timing Belt	EMS 8942
Connection Leads	EMS 9128

EXPERIMENTS

Caution: **High voltages are present in this Laboratory Experiment! Do not make any connections with the power on!**

☐ **9-1) Excitation and reactive power flow**

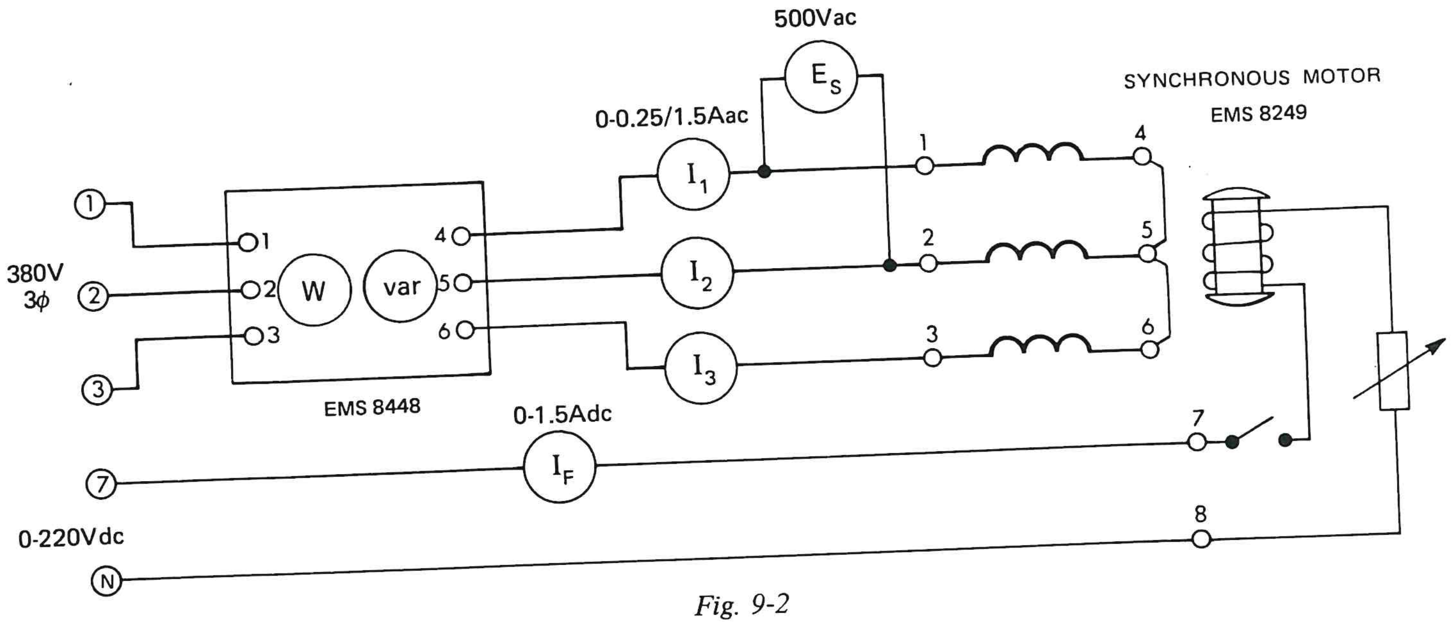


Fig. 9-2

Set up the experiment of *Fig. 9-2*, connecting the stator to the fixed AC supply via the watt-varmeter and three AC ammeters. The field of the synchronous motor is connected to the variable DC source, in series with a DC ammeter. **Note:** **The DC field should only be applied once**

VARIATION OF EXCITING VOLTAGE				
I_F (A)	E_S (V)	I (A)	W	var
0.05				
0.10				
0.15				
0.20				
0.25				
0.30				
0.35				
0.40				
0.45				
				0

Table 9-1

REAL POWER AND LOADING				
E_S (V)	I (A)	I_F (A)	W	var

Table 9-2

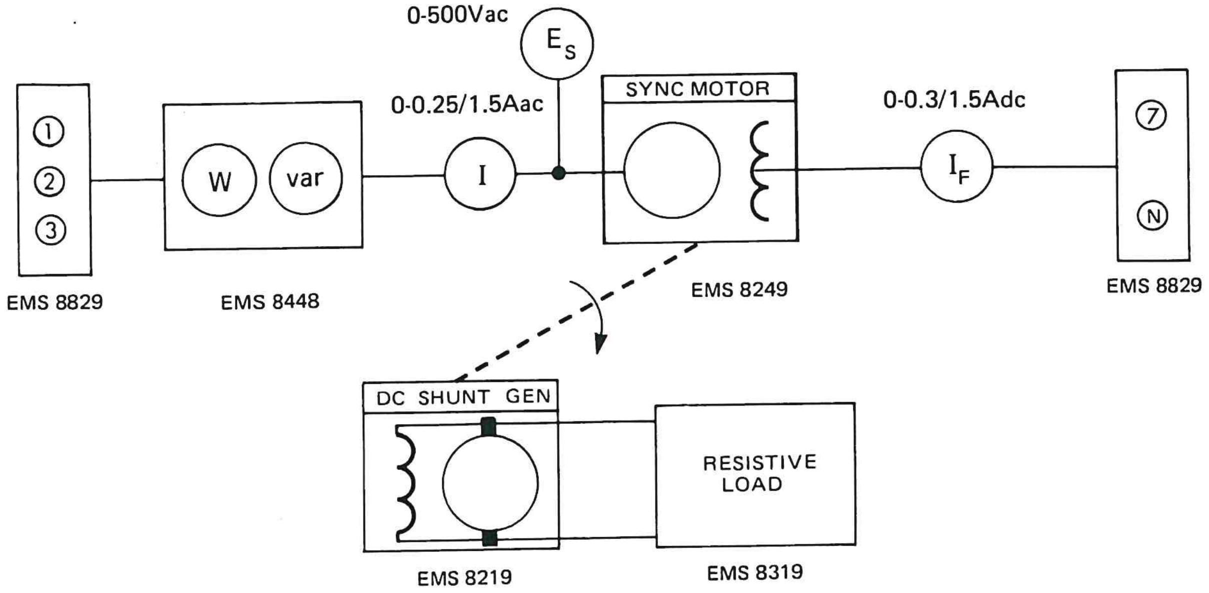


Fig. 9-3

the machine has come up to speed. The motor accelerates when 3-phase AC power is applied to the stator owing to the squirrel cage winding embedded in the poles.

Apply AC power, and then apply DC current to the field. Increase the field current until the reactive power is zero. Note that if the excitation is varied above or below this value, the reactive power changes from negative to positive.

Vary the DC excitation gradually, starting at *0.05A* and increase it in steps to *0.45A* and record your results in *Table 9-1*. Be sure to record the values of the particular case where *var = 0*.

☐ 9-2) **Loading and real power**

Couple a dc shunt generator to the synchronous motor as shown on *Fig. 9-3* and apply 3-phase AC power to the latter, followed by DC power to the rotor. Adjust the DC excitation so that the reactive power is zero when the generator shunt field current is minimum. Then, keeping the DC excitation of the synchronous motor constant, gradually load the motor by increasing the generator excitation and, observe the increase of active power.

Continue to increase the load until the synchronous motor falls out of step, i.e. loses synchronism. Remove power as soon as this happens.

☐ / 9-3) Repeat **Experiment** 9-2, but this time observe the position of the rotor with a strobe light as the load increases. The changing position of the rotor is the root cause of the increasing phase angle between E_s and E_o.

☐ 9-4) Repeat **Experiment** 9-2, and this time record your results in *Table 9-2*.

QUESTIONS AND PROBLEMS

1. The real power absorbed by a synchronous motor can be found in the same way, and using the same formulas as in a transmission line. Explain.

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2. A *2000kW* synchronous motor operates at a three-phase line-to-line voltage of *4kV*. It has a synchronous reactance of *4 ohms* per phase. Calculate:

a) The nominal full load current of the machine when the excitation voltage E_O (line-to-line) is *4kV*.

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b) The short-circuit current when the excitation voltage E_o (line-to-line) is *4kV*.

....

3. a) In **Problem** 2 if the excitation voltage E_o is equal to the terminal voltage *(4kV)*, what is the maximum real power which the motor can deliver without losing synchronism? ....

b) What is the rotor pole shift in electrical degrees, corresponding to the nominal load of *2000kW?* ....

4. The motor cannot operate in a stable manner when the rotor poles move beyond an angle of 90 electrical degrees from their no-load position. Can you explain why?

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5. If the motor in **Problem 2** is at the end of a transmission line which has a reactance of *8 ohms* per phase, what is the maximum power which the machine can develop, given that the sender voltage is $4kV$ and the induced voltage E_o is also $4kV$ (line-to-line)? ....

How does this maximum power compare with the nominal rating of the machine?

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Calculate by how much the rotor poles move from their no-load position before the motor loses synchronism. Why is this angle less than 90 degrees?

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Between which two voltages is the angle equal to 90 degrees when peak power has been attained?

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