MODULE TITLE : ELECTRICAL MACHINES

TOPIC TITLE : SYNCHRONOUS INDUCTION MOTORS

LESSON 2 : CONSTRUCTION OF SYNCHRONOUS INDUCTION MOTORS

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INTRODUCTION

Whilst the induction motor can never quite attain synchronous speed, the synchronous motor will only operate at synchronous speed. No matter what the load conditions or the variation in supply voltage, the motor will run at a speed controlled only by the frequency of the supply and the number of poles on the motor. If the load exceeds the torque which the motor is capable of generating at the synchronous speed, then the motor will stall. In addition, the synchronous motor will not accelerate a load from standstill and it is necessary to employ other means of developing starting torque. Some methods involve :

- the use of a Pony induction motor
- the use of clutch and brake gear
- starting the motor as an induction motor.

The synchronous induction motor is a combination of an induction motor and a synchronous motor. It can be started as an induction motor and run as a synchronous motor.

In this lesson, we shall study the types of construction and the operation of the synchronous motor, and aspects of the synchronous induction motor.

YOUR AIMS

On completion of this lesson you should be able to:

- describe how a synchronous motor produces a driving torque

- describe the construction of the stator and rotor of a synchronous induction motor.

METHOD OF PRODUCING TORQUE IN A SYNCHRONOUS MOTOR

Before we can understand the operation of the synchronous induction motor, it is necessary to understand the means by which a torque is generated in a synchronous motor.

Consider two identical synchronous alternators connected to the same set of busbars at a time when they supply no load and where the driving power to each is just sufficient to supply the losses, as illustrated in FIGURE 1.

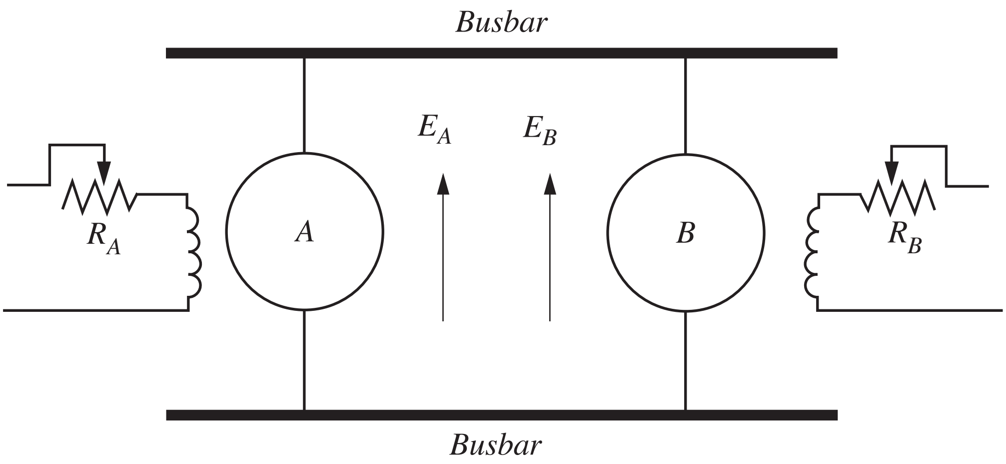


FIG. 1 Alternators Operating in Parallel

The e.m.f.s of the two alternators are acting in the same direction relative to the busbars but, in relation to each other, they are in opposition. These e.m.f.s are shown in the phasor diagram, FIGURE 2(a) and, being equal and opposite, no current will flow in the system.

If the driving torque to alternator B is reduced so that it is no longer sufficient to supply the losses in the machine, the rotor of B falls back in relation to the rotor of alternator A and the two e.m.f.s are no longer exactly in antiphase.

This is illustrated in FIGURE 2(b) for the condition when the rotor of alternator B has moved through an angle θ relative to its original position.

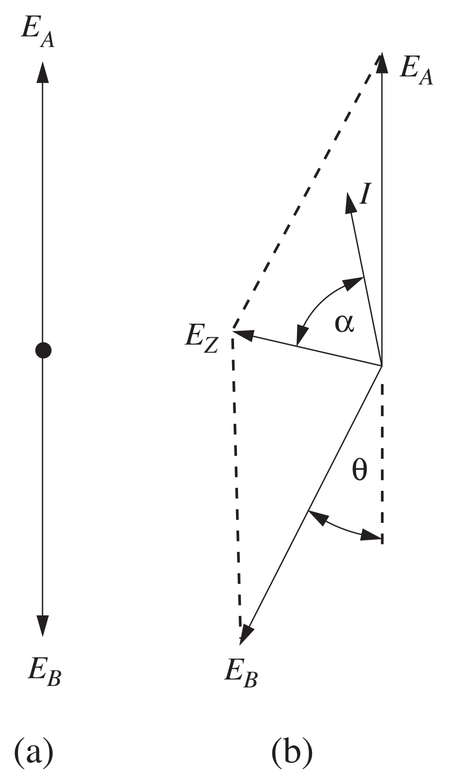


FIG. 2 Effect of Reducing Driving Torque on One Machine

The resultant e.m.f. in the closed circuit formed by the two alternators is E_Z and this causes a current I, which lags E_Z by the angle α, to circulate through the alternators.

$$I = E_Z/2Z_S \text{ and } \alpha = \tan^{-1} X_S/R$$

where R = the phase resistance of each alternator

X_S = the phase synchronous reactance of each alternator

Z_S = the phase synchronous impedance of each alternator.

Since the resistance is very small by comparison to the synchronous reactance, α is almost 90° and the current I is almost in phase with E_A and in antiphase to E_B. This means that A is acting as a generator and B as a motor.

The larger the value of θ, the larger the circulating current and the greater the driving torque (so long as θ does not exceed about 80°).

Once the torque generated by the motor effect of B exactly compensates for the reduction in the driving torque, equilibrium will be reached and the two alternators will continue to run at the same speed but B will lag behind A by the angle θ.

If the drive to the alternator B is removed completely and a load attached, alternator B continues to operate as a motor and will run at the same speed as alternator A. This will continue as long as the load is not sufficient to cause the angle of lag to exceed about 80°, above which point the resultant current is in phase quadrature with the e.m.f. generated in B and no synchronising power is produced to hold the alternator in synchronism. As a consequence, alternator B pulls out of synchronism and stops rotating, that is, it stalls.

Since the synchronous machine can be operated as alternator or motor, the operation of synchronous motors is identical to that of synchronous alternators. Synchronous motors, unlike alternators, are usually distributed as a.c. industrial loads, remote from the point of generation. The busbars become transmission lines supplying the motors and other loads.

THE SYNCHRONOUS MOTOR STATOR

The stator construction for the synchronous motor is a distributed, three-phase winding, exactly as described for the induction motor in the previous topic and, when connected to a three phase-supply, produces a flux which rotates at synchronous speed relative to the winding.

THE SYNCHRONOUS MOTOR ROTOR

Two types of rotor can be employed with this motor, the salient-pole rotor and the cylindrical or non-salient pole rotor.

(a) The Salient-Pole Rotor

The salient-pole rotor is constructed from a stack of laminations with a cross-section as shown in FIGURE 3 for a two-pole rotor. The field distribution resulting from the excitation and the armature fields is also shown.

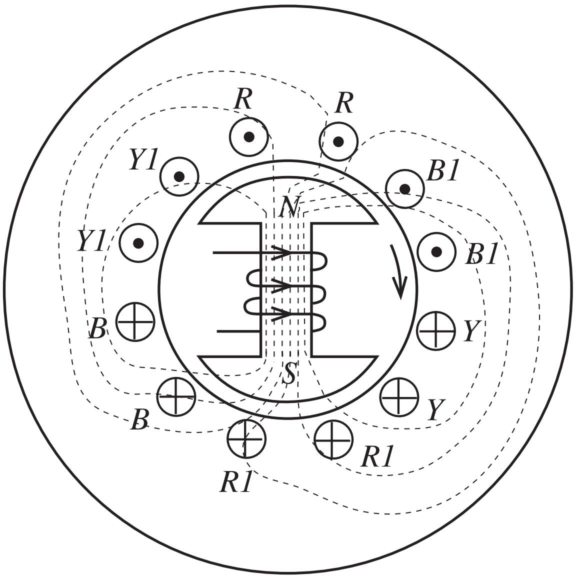
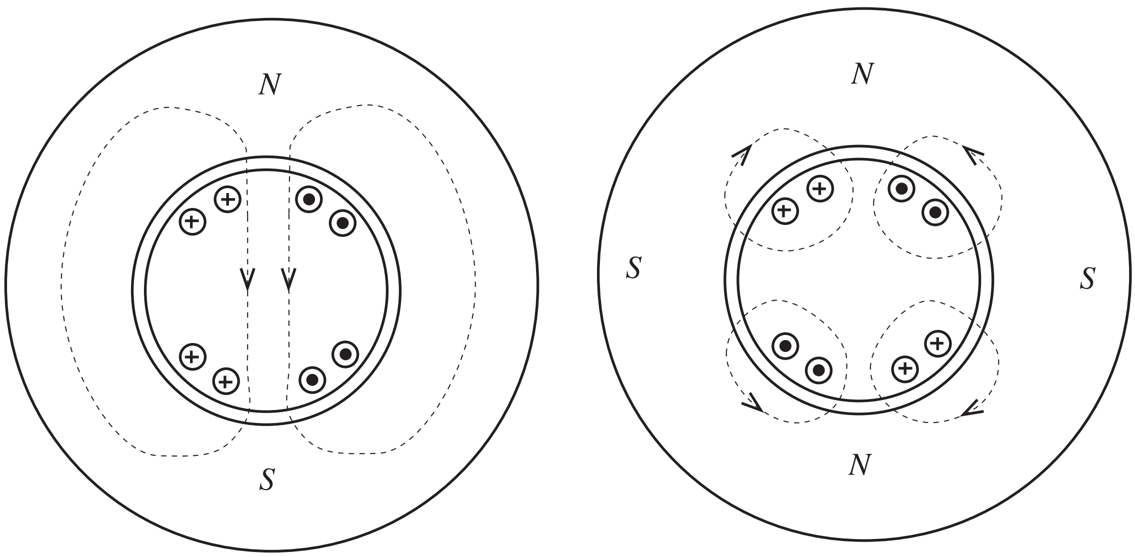


FIG. 3 Salient-pole Synchronous Motor Flux Distribution

Due to the high windage losses, this type of rotor is normally used on low speed motors with six poles or more.

(b) Cylindrical Rotor

The cylindrical rotor is manufactured from a cylindrical casting with slots cut into it to house the field winding. As the rotor is always stationary **with respect to the rotating flux**, there will be no hysteresis or eddy current losses in it and it does not need to be laminated. The windings comprise a number of concentric coils forming each pole and, due to difficulties in winding, only two sets of coils are fitted. These can be connected in the standard fashion (FIGURE 4(a)) to give a two-pole rotor or can be connected to give a four-pole rotor by generating concentric poles. This type of rotor is shown in FIGURE 4(b) with two concentric coils per pole. In practice there could be four or even six coils in larger machines. Note that the stator windings have been omitted for clarity.



(a) Two-pole Cylindrical Rotor (b) Four-pole Cylindrical Rotor

FIG. 4

As this type of rotor is limited to four poles, it is only used in high speed machines (500 rev min^{-1} and above with 50 Hz supplies).

In both the salient-pole rotor and the cylindrical rotor, it is necessary to supply the rotor winding from an external d.c. source in order to produce a unidirectional flux in the rotor and, therefore, the rotor is fed through slip rings.

DISADVANTAGES OF THE SYNCHRONOUS MOTOR

The big disadvantage with the synchronous motor is that it is not self starting and needs to be accelerated to synchronous speed by some external means and then synchronised with the supply. This can be achieved by means of an auxiliary motor, but this is expensive, takes up additional floor space and leads to a complicated starting procedure. A better solution is to use the synchronous induction motor.

THE SYNCHRONOUS INDUCTION MOTOR

This machine is a combination of the synchronous motor and the induction motor. The machine starts as an induction motor and then changes over to synchronous operation once it has reached its operating speed.

In one form, the standard synchronous motor with either the salient-pole rotor or the cylindrical rotor is fitted with an auxiliary squirrel-cage winding. (In the case of the salient-pole motor, this cage only has rotor bars in the pole faces.)

The motor is started as an induction motor on no load and can use any method of starting (D.O.L, auto-transformer or star/delta) depending on the size of the motor and the limitations of the supply. During this period, the rotor winding is not supplied with any d.c. current and is running purely as an induction motor. Once the acceleration has taken place, the motor will be running to within 2% of its synchronous speed.

At this point, the d.c. supply to the rotor is energised. The resultant flux due to the stator winding is then moving past the rotor poles at a slow speed and produces a low frequency alternating torque superimposed on the induction motor torque. The rotor is accelerated at one moment and retarded the next and, if there is no load on the motor, this fluctuation is sufficient to bring the rotor up to synchronous speed. The rotor then 'locks in' and continues to run in synchronism with the rotating field. When this occurs there is no flux cutting the squirrel cage conductors, no current flows through them, therefore, and they have no effect on the characteristics of the motor.

As the starting torque is very low (especially with an incomplete cage), this method of starting the synchronous motor can only be used when the motor can be started off-load or with a very light load.

The alternative form of the synchronous induction motor uses a wound rotor and its construction is identical to that of the wound rotor induction motor except for d.c. supply to the rotor and a wider air gap.

In this machine, the d.c. supply is connected between two of the rotor slip rings as shown in FIGURE 5 opposite.

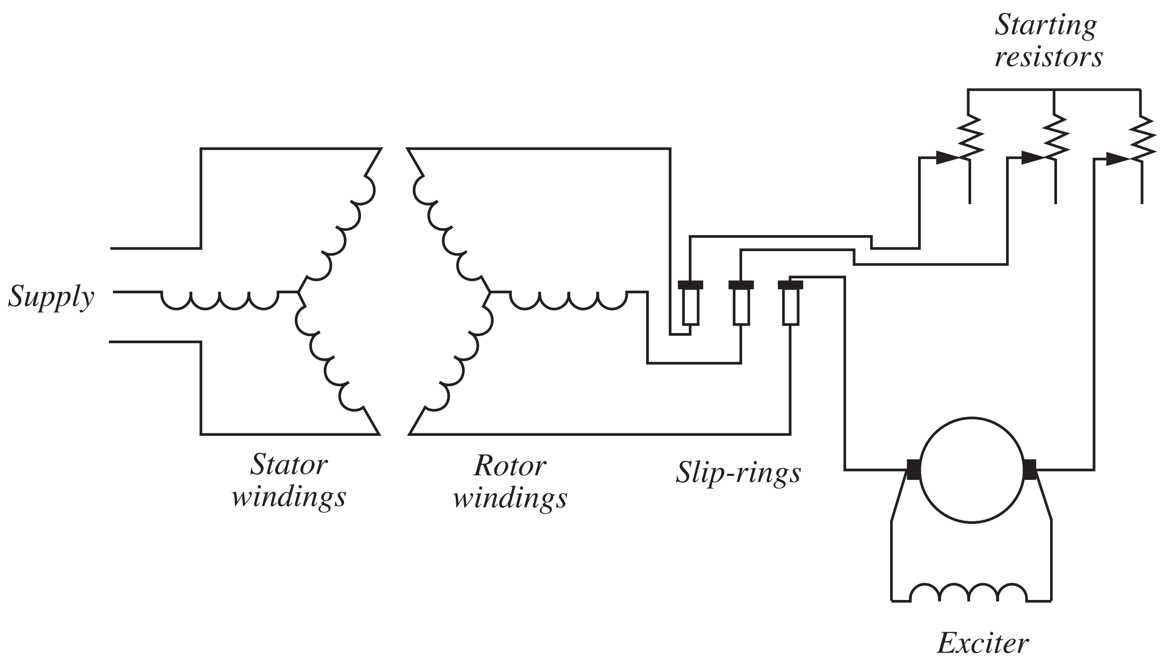


FIG. 5 Wound Rotor Synchronous Induction Motor

With this method of starting, the field of the exciter is left de-energised and the motor is started as a normal wound-rotor induction motor. By selecting the correct value of starting resistors, the motor can now be made to produce maximum torque on starting and can therefore start under load.

Once the maximum speed of the induction motor has been reached, the slip rings are short-circuited and the field of the exciter energised. Once more, a low frequency alternating torque is superimposed on the induction motor torque and the machine pulls into synchronism and runs as a synchronous motor.

On first consideration, it does not appear that the rotor will reproduce a unidirectional flux but the phasor diagram for the fluxes generated by the three phases (FIGURE 6 below) shows clearly that the resultant flux produces just two poles in the rotor and has the same characteristics as the rotor of the synchronous motor.

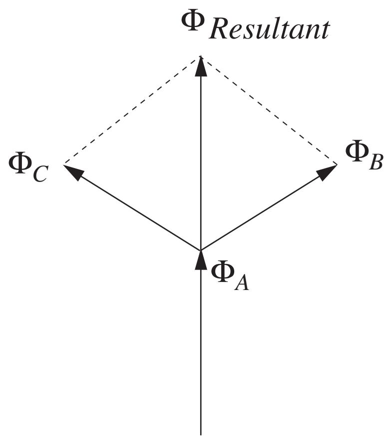


FIG. 6 Flux Phasor Diagram

NOTES

SELF-ASSESSMENT QUESTIONS

1. What are the two types of rotor used with synchronous motors?

2. What is the speed of a four-pole synchronous motor when connected to a 50 Hz supply?

3. Why are salient-pole rotors usually used in slow speed motors?

4. Draw the starting circuit for a synchronous induction motor with a wound rotor.

NOTES

ANSWERS TO SELF-ASSESSMENT QUESTIONS

1. Salient-pole rotor and cylindrical rotor.

2. Synchronous speed $n_s = \dfrac{\text{supply frequency}}{\text{number of pole pairs}}$

$$= \frac{f}{p} \times 60 \text{ rev min}^{-1}$$

$$= \frac{50 \times 60}{2} = 1500 \text{ rev min}^{-1}$$

3. The cylindrical rotor is difficult to manufacture with more than four poles. The high windage losses associated with the salient pole design are not so important at low speeds.

4.

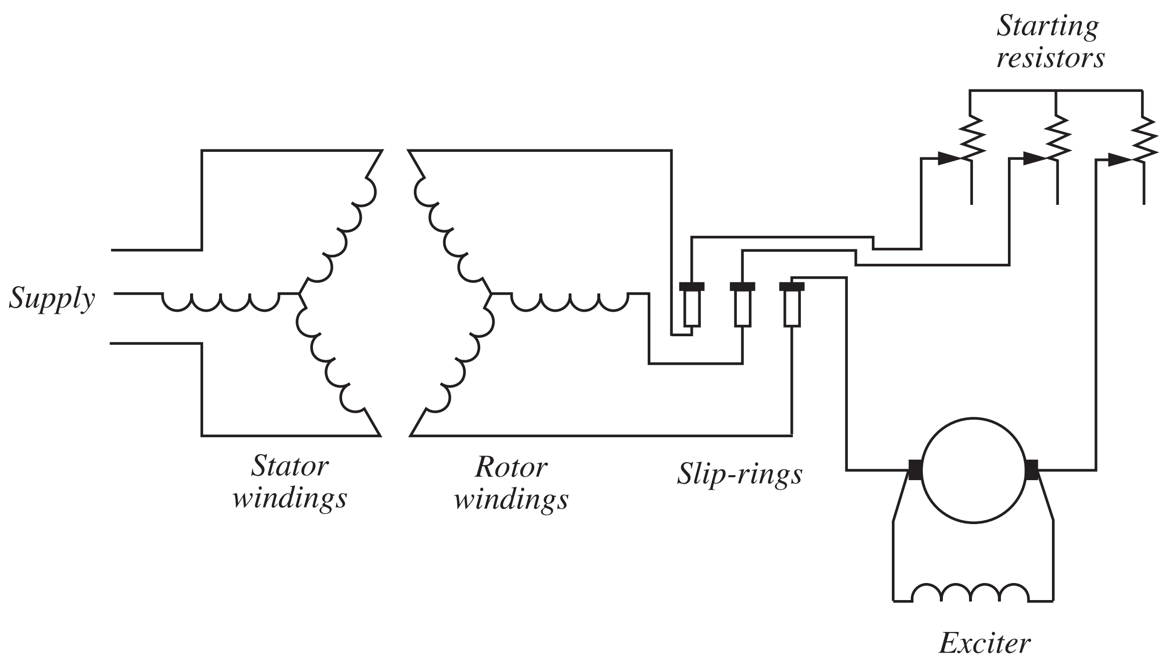


FIG. 7

SUMMARY

In this lesson we have been introduced to the synchronous induction motor, aspects of its construction and methods of starting the machine.

In the next two lessons we shall consider different methods of excitation of the rotor, the characteristics of the motor and its applications.