SHAMBHUNATH INSTITUTE OF ENGINEERING AND TECHNOLOGY

SOLUTION

Subject Code : REE - 064 **Subject : Special Electrical Machines**

B.Tech. VI Semester

FIRST SESSIONAL EXAMINATION, EVEN SEMESTER, (2019-20)

Branch : EE/EN

SECTION – A

1. Attempt all question in brief.

a. Ns = 8 X 5 = 40

Nr = 50

Step angle = $\frac{Nr-Ns}{NrNs}$ X 360^0 = 1.8^0

b. In torque-pulse rate characteristics, the area in which we increase stepping rate for the motor and motor follows it without losing a step is called slewing range.

c. The Deep Bar Rotor in an induction motor is used to obtain high rotor resistance at starting and low rotor resistance at the running condition. Double cage rotor is used for obtaining high starting torque at a low value of starting current.

d. The detent torque is defined as the maximum load torque that can be applied to the shaft of an unexcited motor without causing continuous rotation.

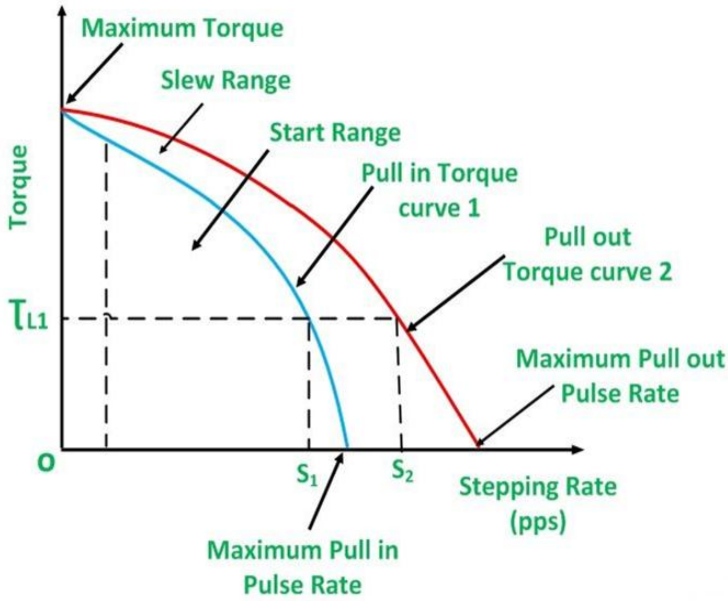
e. The torque of variable reluctance stepper motor is independent from direction of current so uni-polar drive circuit is used for VRSM.

SECTION – B

2. Attempt any <u>TWO</u> of the followings.

a. <u>Torque-pulse rate characteristics</u>

The torque pulse rate Characteristics of a Stepper Motor gives the variation of an electromagnetic torque as a function of stepping rate in pulse per second (PPS). There are two characteristic curves 1 and 2 shown in the figure below. Curve one is denoted by a blue colour line is known as the Pull-in torque**.** It shows the maximum stepping rate for the various values of the load torque at which the motor can start, synchronise, stop or reverse.



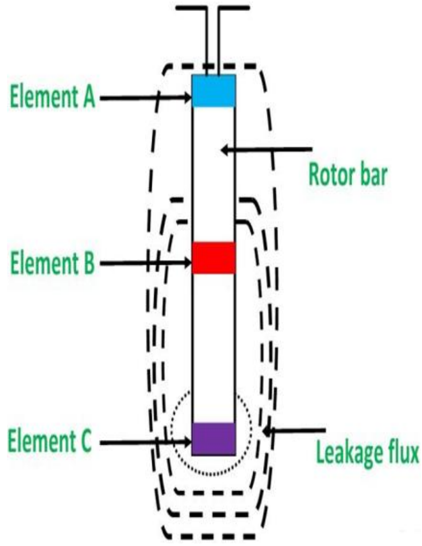
Similarly, the curve 2 represented by Red colour line is known as pullout torque characteristics. It shows the maximum stepping rate of the motor where it can run for the various values of load torque. But it cannot start, stop or reverse at this rate.

The motor can start, synchronise and stop or reverse for the load torque T_{L1} if the pulse rate is less than S_1. The stepping rate can be increased for the same load as the rotor started the rotation and synchronised. Now, for the load T_{L1}, after starting and synchronising, the stepping rate can be increased up to S_2 without losing the synchronism.

If the stepping rate is increased beyond S_2, the motor will lose synchronism. Thus, the area between curves 1 and 2 represents the various torque values, the range of stepping rate, which the motors follow without losing the synchronism when it has already been started and synchronised. This is known as **Slew Range**. The motor is said to operate in slewing mode

b. Deep-bar induction motor

The Deep Bar Rotor in an induction motor is used to obtain high rotor resistance at starting and low rotor resistance at the running condition.



A bar may be assumed to be made up of a number of narrow layers connected in parallel. The figure shows three layers A, B and C. The topmost layer element that is denoted by A is linked with the minimum leakage flux. Its leakage inductance is minimum. On the other hand, the bottom layer C links with the maximum leakage flux and thus, its leakage inductance is maximum.

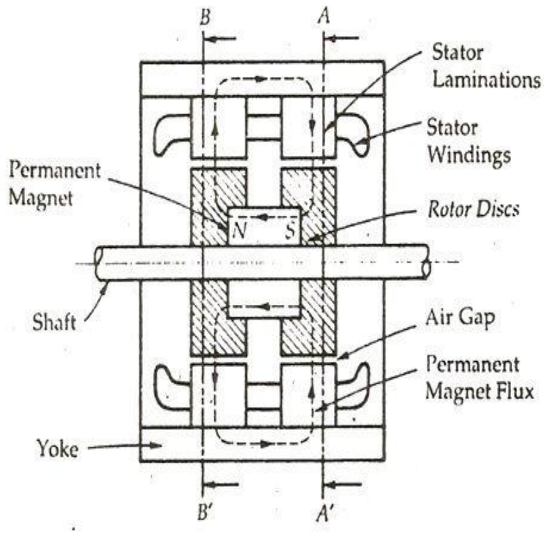
At the starting, the frequency of the rotor is equal to the supply frequency. The bottom layer element C offers more impedance to the flow of current than the top layer element A. Therefore; maximum current flows through the top layer and minimum current flows through the bottom layer.

The effective rotor resistance increases and the leakage reactance decreases, and this is because of the unequal current distribution of the current. The starting torque and the starting current is higher and lower, respectively because of the high rotor resistance at the starting condition.

The value of a slip and the frequency of the rotor is very small, under the normal operating conditions. The reactances of all the layers of the bars is small as compared to their resistances. The impedance of all layers of the bar is nearly equal, so the current flows through all parts of the bar equally. The rotor resistance of the motor is small because of the large cross-sectional area makes the rotor resistance small, which results in a better efficiency at the lower slip.

c. Hybrid stepper motor

The Hybrid Stepper Motor is a combination of the features of the Variable Reluctance Stepper Motor and Permanent Magnet Stepper Motor. In the center of the rotor, an axial permanent magnet is provided. It is magnetized to produce a pair of poles as North (N) and South (S) as shown in the figure.



At both the end of the axial magnet the end caps are provided, which contains an equal number of teeth which are magnetized by the magnet.

The rotor teeth are perfectly aligned with the stator teeth. The teeth of the two end caps are displaced from each other by half of the pole pitch. As the magnet is axially magnetized, all the teeth on the left and right end cap acquire polarity as south and north pole respectively.

One of the main advantages of the Hybrid stepper motor is that, if the excitation of the motor is removed the rotor continues to remain locked in the same position as before the removal of the excitation. This is because of the detent Torque produced by the permanent magnet.

Stepper motors are widely used in tape drives, floppy disc drives, printers, robotics etc.

d. Slip power recovery schemes can be classified into two types of drives, depending upon whether the slip power is returned to, or taken from the line or added to, or taken from the shaft power of the main motor

The two types are i) Constant torque drive ii) Constant power drive

In above two methods, slip frequency- adjustable voltages are inserted in the rotor circuit for induction motor speed control.

The slip power can either be returned to the supply or added to the main motor shaft output.

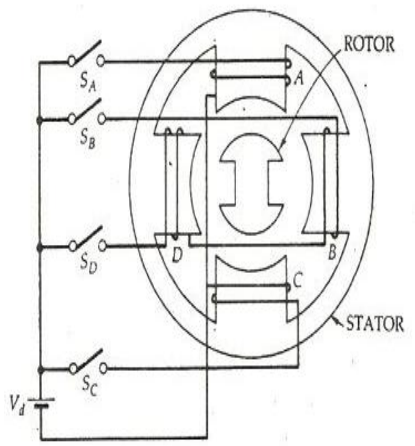
See example from class notes.

SECTION – C

3. Attempt any ONE part of the followings.

a. A single stack variable reluctance stepper motor has a salient pole stator. The stator has a concentrated windings which are placed over the stator poles. The number of phases of the stator depends upon the connection of the stator coils. There are three or four windings. The rotor is made up of ferromagnetic materials and carries no windings.

When a DC source is applied to the stator phase with the help of a semiconductor switch, a magnetic field is produced. The axis of the rotor aligns with the axis of the stator



The four phases A, B, C and D are connected to the DC source with the help of a semiconductor, switches S_A, S_B, S_C and S_D respectively as shown in the figure. The phase windings of the stator are energized in the sequence A, B, C, D, A. The rotor aligns itself with the axis of phase A as the winding A is energized. The rotor is stable in this position and cannot move until phase A is de-energized.

Now, the phase B is excited and phase A is disconnected. The rotor moves 90 degrees in the clockwise direction to align with the resultant air gap field which lies along the axis of phase B. Similarly the phase C is energized, and the phase B is disconnected, and the rotor moves again in 90 degrees to align itself with the axis of the phase

Thus, as the Phases are excited in the order as A, B, C, D, A, the rotor moves 90 degrees at each transition step in the clockwise direction. The rotor completes one revolution in 4 steps. The direction of the rotation depends on the sequence of switching the phase and does not depend on the direction of the current flowing through the phase. Thus, the direction can be reversed by changing the phase sequence like A, D, C, B, A.

b.

(i) At standstill, $s = 1$

Outer-cage impedance, $Z_{2o}' = R_{2o}' + jX_{2o}' = 0.3 + j0.4 = 0.5\angle 53.13^\circ\ \Omega$

Inner-cage impedance, $Z_{2i}' = R_{2i}' + jX_{2i}' = 0.1 + j1.5 = 1.503\angle 86.18^\circ\ \Omega$

Current through the outer cage

$$I_{2o}' = \frac{E_2'}{Z_{2o}'} = \frac{E_2'}{0.5} = 2E_2$$

Current through the inner cage $I_{2i}' = \frac{E_2'}{Z_{2i}'} = \frac{E_2'}{1.503}$

$$\frac{I_{2o}'}{I_{2i}'} = \frac{Z_{2i}'}{Z_{2o}'} = \frac{1.503}{0.5} = 3.006$$

Copper loss in the outer cage $P_{2o} = (I_{2o}')^2 R_{2o}'$

Copper loss in the inner cage $P_{2i} = (I_{2i}')^2 R_{2i}'$

Let τ_{2o} and τ_{2i} be the torques developed in the outer and inner cage

$$\frac{\tau_{2o}}{\tau_{2i}} = \frac{P_{2o}}{P_{2i}} = \left(\frac{I_{2o}'}{I_{2i}'}\right)^2 \frac{R_{2o}'}{R_{2i}'} = (3.006)^2 \times \frac{0.3}{0.1} = 27.1$$

(ii) At slip $= 5\% = 0.05$ pu

$$Z_{2o}' = \frac{R_{2o}'}{s} + jX_{2o}' = \frac{0.3}{0.05} + j0.4 = 6.013\angle 3.8^\circ\ \Omega$$

$$Z_{2i}' = \frac{R_{2i}'}{s} + jX_{2i}' = \frac{0.1}{0.05} + j1.5 = 2.5\angle 36.87^\circ\ \Omega$$

$$\frac{I_{2o}}{I_{2i}} = \frac{Z_{2i}'}{Z_{2o}} = \frac{2.5}{6.013} = 0.4158$$

$$\frac{\tau_{2o}}{\tau_{2i}} = \left(\frac{I_{2o}'}{I_{2i}'}\right)^2 \times \frac{R_{2o}'}{R_{2i}'} = (0.4158)^2 \times \frac{0.3}{0.1} = 0.518$$

4. Attempt any ONE part of the followings.

a. If transistors Q1 and Q2 are on during the first quarter of a switching cycle thn it causing current to flow in the phase coil from A to A’, the transition into the next quarter of the cycle calls for Q1 and Q2 to be switched off. Because of the magnetic storage associated with the current in coil A-A’, the current cannot be reduced to zero instantaneously. But as it attempts to do so, a large emf is induced in the coil with terminal A’ positive and A negative. This induced emf puts a positive voltage across diodes D3 and D4, thus furnishing a path for the switched off current in coil A-A’. The current decays rapidly because of the small time constant of the discharging circuit.

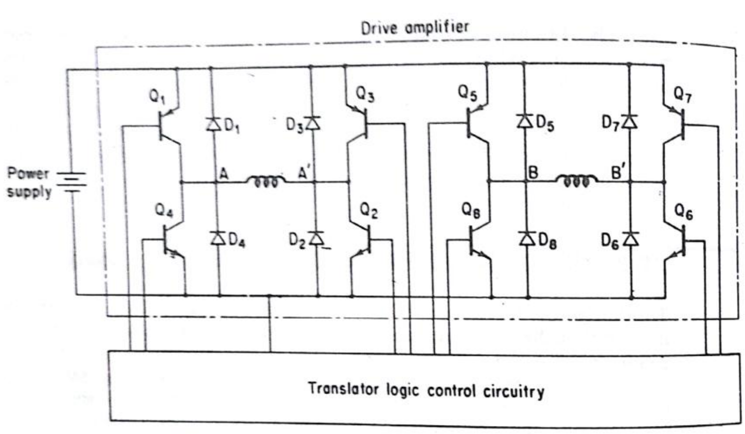


Fig. 22-4 Diagram illustrating the details of a bipolar drive amplifier.

Coil A-A'	Coil B-B'
ON+	OFF
OFF	ON+
ON-	OFF
OFF	ON-

b.

$R_1 = 0.25\Omega$, $X_1 = 3.5\Omega$, $R_{2o}' = 1.0\Omega$, $X_{2o}' = 0$, $R_{2i}' = 0.15\Omega$, $X_{2i}' = 3\Omega$

At starting $S = 1$

Impedance of the outer cage at starting

$Z_{2o}' = 1 + j0 = 1\angle 0^\circ\ \Omega$

Impedance of the inner cage at starting

$Z_{2i}' = 0.15 + j3 = 3.004\angle 87.1^\circ\ \Omega$

Since the two impedances Z_{2o}' and Z_{2i}' are in parallel.

$$Z_{e2}' = \frac{Z_{2o}' Z_{2i}'}{Z_{2o}' + Z_{2i}'} = (0.889 + j0.290)\ \Omega$$

Impedance of the stator

$Z_1 = R_1 + jX_1 = 0.25 + j3.5$

Equivalent impedance per phase of the motor referred to stator at starting $Z_{e1} = Z_1 + Z_{e2}' = 3.96\angle 73.2^\circ\ \Omega$

Stator starting current $I_1 = \dfrac{\text{Phase Voltage}}{\text{Total phase impedance}}$

$$= \frac{250}{3.96\angle 73.2^\circ} = 63.13\ A$$

starting torque per phase $= \dfrac{I_1^2}{\omega_s} \times$ equivalent rotor resistance

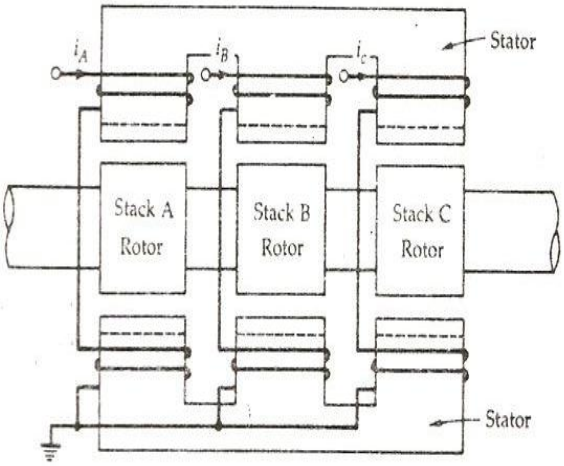
$$= \frac{(63.13)^2 \times 0.889}{2\pi \times (1000/60)} = 33.833\ Nm$$

Total starting torque $= 3 \times 33.833 = 101.5\ Nm$

5. Attempt any ONE part of the followings.

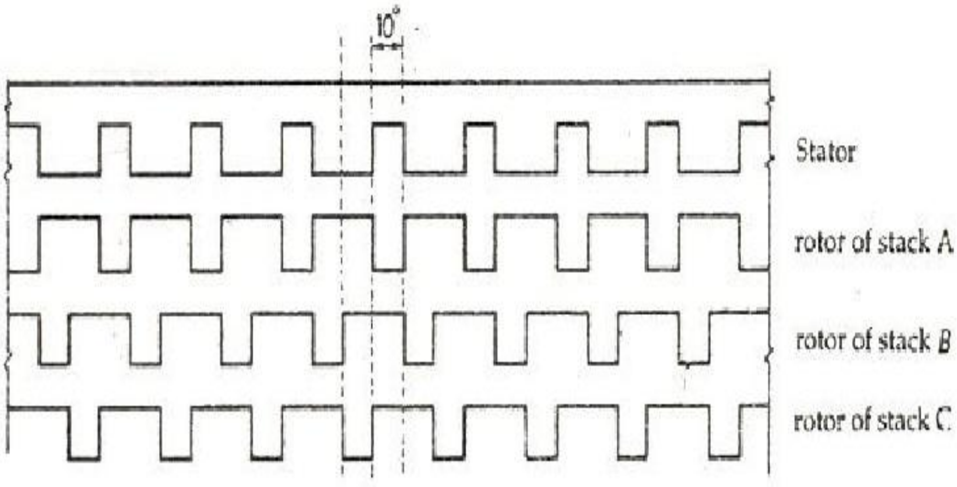
a. Multi Stack Variable Reluctance Stepper Motor

A Multi Stack or m stack variable reluctance stepper motor is made up of m identical single stack variable reluctance motor. The rotor is mounted on the single shaft. The stator and rotor of the Multi Stack Variable motor have the same number of poles and hence, the same pole pitch.
All the stator poles are aligned in a Multi-Stack motor. But the rotor poles are displaced by 1/m of the pole pitch angle from each other. The stator windings of each stack forms one phase as the stator pole windings are excited simultaneously. Thus, the number of phases and the number of stacks are same.

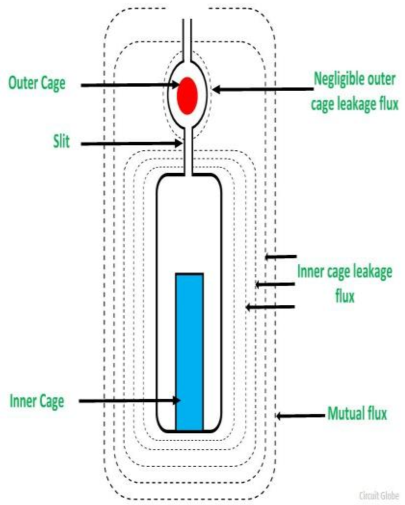


There are 12 stator and rotor poles in each stack. The pole pitch for the 12 pole rotor is 30, and the step angle or the rotor pole teeth are displaced by 10 degrees from each other.

When the phase winding A is excited the rotor teeth of stack A are aligned with the stator teeth as shown in the figure below.



b. Double Cage Induction Motor



A Double Cage Induction motor is that type of motor in which a double cage or two rotor windings or cages are used. This arrangement is used for obtaining high starting torque at a low value of starting current. The stator of a double cage rotor of an induction motor is same as that of a normal induction motor. In the double cage rotor of an induction motor, there are two layers of the bars.

Each layer is short-circuited by the end rings. The outer cage bars have a smaller cross-sectional area than the inner bars and are made of high resistivity materials like brass, aluminium, bronze, etc. the bars of the inner cage are made of low resistance copper. Thus, the resistance of the outer cage is greater than the resistance of the inner cage.

At starting, the voltage induced in the rotor is same as the supply frequency that is ($f_2 = f_1$). Hence, the leakage reactance of the inner cage winding as compared to that of the outer cage winding is much larger. The outer cage winding carries most of the starting current which offer low impedance to the flow of current. The high resistance outer cage winding, therefore, develops a high starting torque.

As the rotor speed increases, the frequency of the rotor EMF (f_r =sf) decreases. At normal operating speed, the leakage reactance of both the windings become negligibly small. The current in the rotor divides between the two cages and is governed by their resistances. The resistance of the outer cage is about 5 to 6 times that of the inner cage. Hence, the torque of the motor developed mainly by the low resistance inner cage and is developed under normal operating speed.

For the low starting torque requirements, an ordinary cage motor is used. For higher torque requirements a deep bar cage motor is used. A double cage motor is used for higher torques. The slip ring construction is used for large size motors. The starting torque and the starting periods is also large.