SCHEME OF VALUATION

(Scoring Indicators)

Revision (2015) Course Code
6033
Course Title : SYNCHRONOUS MACHI NES AND FHP MOTORS

Qt No	Scoring Indicator	Split Up Score	Sub Total	Total
I 1	Single phase ,polyphase windings, Concentrated, distributed windings. Half coiled (Hemitropic), whole coiled windings. Single layer, double layer windings. Lap windings, Wave windings ,Concentric windings Full pitched and short chorded	Any 2 1+1	2	
2	a.EMF method(synchronous impedance method) b. MMF method(Ampere turn method) c. ZPF method(zero power factor method)	Any 2 1+1	2	10
3	It is a constant speed motor (synchronous speed), It can be operated under lag PF, lead PF, and UPF It can be used as synchronous condenser. Not self-starting It needs both AC and DC.	Any 2 1+1	2	
4	A synchronous condenser or a synchronouscompensator is a synchronous motor running without a mechanical load. It can generate or absorb reactive volt-ampere (VAR) by varying the excitation of its field winding. It can be made to take a leading current with over-excitation of its field winding.	2	2	
5	Resistance start or split phase 1 phase induction motor Capacitor start 1 phase induction motor Capacitor start capacitor run 1 phase induction motor Permanent capacitor 1 phase induction motor Shaded pole 1 phase induction motor	Any 2 1+1	2	
	PART B			

II	1.	Let Z_{ph} = number of conductors in series / phase = 2 T, where T is the number of turns / phase P = number of poles ϕ = useful flux per pole in weber f = frequency of the induced emf equal to $\frac{NP}{120}$ Hz N = rotational speed in r.p.m. K_c or K_p = pitch or chording or coil span factor $= \cos\frac{\alpha}{2}$ K_d or K_b = distribution factor / breadth factor $= \frac{\sin m\frac{\beta}{2}}{m \sin\frac{\beta}{2}}$ K_f = form factor = 1.11 for sinusoidal e.m.f. Total flux cut in one revolution of the rotor = $P\phi$ Wb Time taken to complete one revolution = $\frac{60}{N}$ second According to Faraday's Laws of Electromagnetic induction average e.m.f. induced / conductor $= \frac{\text{flux cut}}{\text{time taken}}$ $= \frac{P\phi}{60/N} = \frac{P\phi N}{60}$ Wb / second or volt $= \frac{P\phi}{60} \times \frac{120f}{P} = 2f\phi$ volt Average e.m.f. induced / phase = $2f\phi Z_{ph} = 4f\phi T$ volt RMS value of e.m.f. / phase = Average value of e.m.f. /phase × form factor $= 1.11 \times 4f\phi T$ $= 4.44 f\phi T$ volt If pitch factor 'K_c' and distribution factor K_d are considered then the actual e.m.f. induced will reduce. Actually induced e.m.f. / ph = 4.44. $K_c K_d f \phi T$ volt **E_{ph}* = 4 $K_f K_c K_d f \phi T$ volt.**	6	6	6x5=30

2

S.No.	Salient pole type rotor (or) Projected pole type	Non-salient pole type rotor (or) Smooth cylindrical type
1.	Rotor poles are projected.	Rotor outer surface is smooth (poles are not projected).
2.	More number of poles are present.	Two 'or' four poles are present.
3.	Large diameter (≈ 10m) & small axial lengths (≈ 3m).	Small diameter (≈ 1m) and large axial lengths (≈ 10 m).
4.	Used for low and medium speeds.	Used for high speeds (Turbo) (3000 rpm or 1500 rpm only).
5.	More windage losses.	Less windage losses (due to smooth surface).
6.	Water turbines are preferred.	Steam turbines are preferred.
7.	Construction is difficult.	Construction is easy.
8.	Perfectly not balanced.	Perfectly balanced.
9.	Air gap is present in between poles.	No air-gap in between poles.
10.	Flux is not uniform due to interpolar gap.	Flux is uniformly distributed.
11.	Field winding in the form of coils are placed on pole core.	Field winding is placed in the rotor slots.

Any 6

6

3

Armature Resistance (Ra) Test :

This test is conducted to determine the armature resistance R of the alternator. The armature resistanceper phase can be determined by voltmeter-ammeter method or by using Wheatstone bridge or by OHM meter. The connection diagram for measurement of armature resistance by voltmeter-ammeter method as shown in Fig.

A battery is connected across any one phase of the alternator stator (or armature). The resistance 'R' is varied until rated current flows through the winding.So armature resistance/phase,

$$R_a = \frac{\text{Voltmeter reading}}{\text{Ammeter reading}}$$

Under running conditions the R will be slightly more due to increase in temperature and skin effect. Hence for all practical purposes the R = 1.6 Rd is taken.

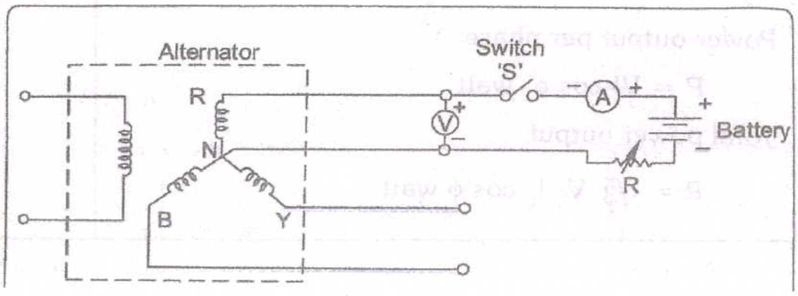


Fig 3+3

6

4

We are interested in the active power transmitted from source A to source B (or vice-versa. From Fig. 2.10 (a)

$$E_1 = E_2 + jIX \quad \text{....... (1)}$$

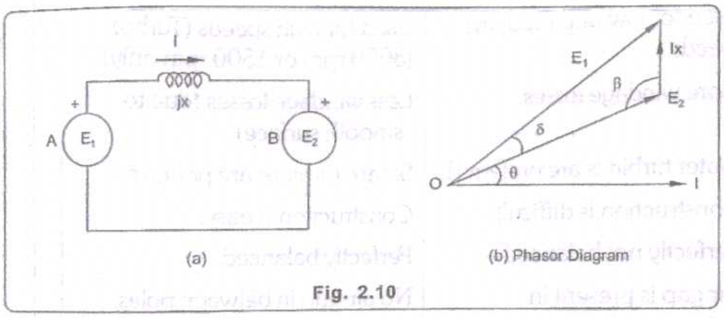
Let E_1 = generated emf

E_2 = load emf

X = reactance

θ = Power factor/load angle

δ = angle between E_1 and E_2



(a) (b) Phasor Diagram

Fig. 2.10

Active power absorbed by load B, $P = E_2 I \cos\theta$ .... (2)

From sine law of traingles, we have

$$\frac{IX}{\sin\delta} = \frac{E_1}{\sin\beta} = \frac{E_1}{\sin(90+\theta)} = \frac{E_1}{\cos\theta}$$

$$\text{Consequently, } I\cos\theta = \frac{E_1 \sin\delta}{X} \quad \text{......(3)}$$

Substituting in equation (2) we get

$$P = E_2 \frac{E_1 \sin\delta}{X} = \frac{E_1 E_2}{X} \sin\delta \quad \text{......(4)}$$

The acitve power received by B = Power delivered by A

$$\text{Hence, Power developed, } P = \frac{E_1 E_2}{X} \sin\delta \text{ watt}$$

For a given values of terminal voltage current/load and power factor, the power developed by an alternator is given by

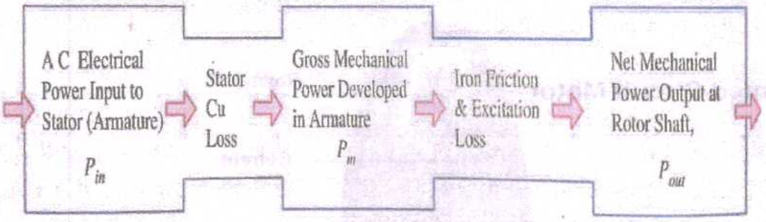
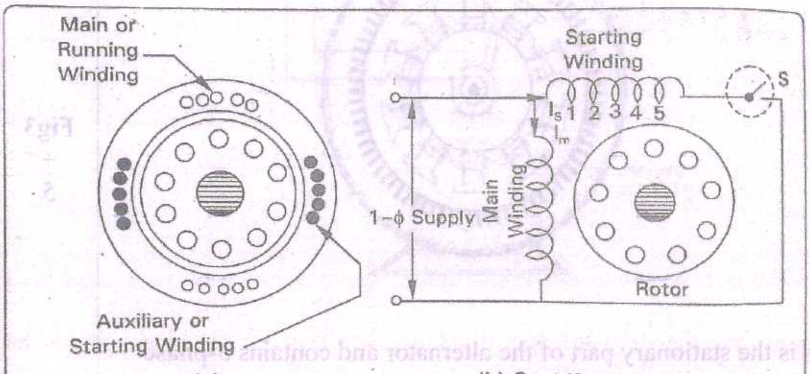
Power output per phase

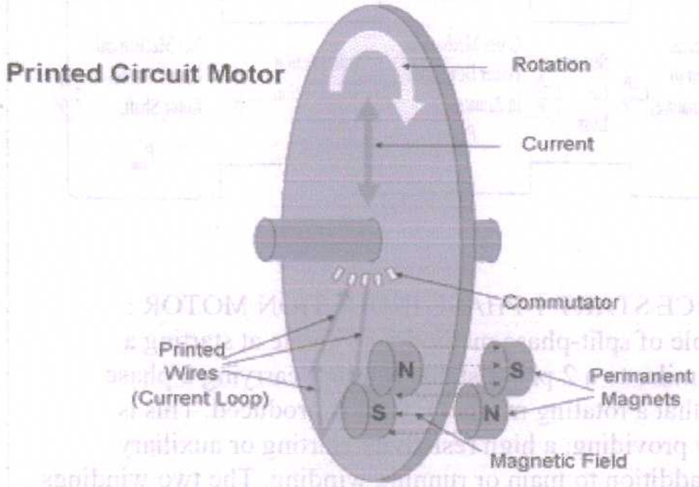
$$P = VI\cos\phi \text{ watt}$$

Total power output

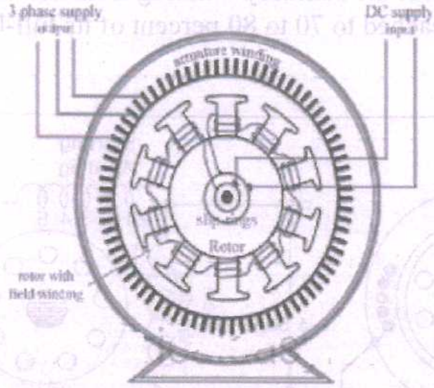
$$P = \sqrt{3}\, V_L I_L \cos\phi \text{ watt}$$

6 6

5	Power input/phase in stator $P = VI_a \cos\phi$ Armature (*i.e.*, stator) Cu loss $= I_a^2 R_a$ Mechanical power in armature $P_m = E_b I_a \cos(\alpha - \phi)$ Iron, excitation & friction losses Output power P_{out} Different power stages in a synchronous motor are as under : 	6	6	
6	RESISTANCE START 1-PHASE INDUCTION MOTOR : The principle of split-phase method is to create at starting a condition similar to a 2 phase stator winding carrying 2 phase currents so that a rotating magnetic field is produced. This is achieved by providing, a high resistivity starting or auxiliary winding in addition to main or running winding. The two windings are spaced 90^0 apart and are connected in parallel across the 1phase supply. A centrifugal switch S is connected in series with auxiliary or starting winding and is located inside the motor. Its function is to automatically disconnect the auxiliary winding from the supply when the motor has reached to 70 to 80 percent of its full-load speed.  (a) (b) Centrifugal Switch System	4+ Fig2	6	

7	A **Printed Circuit Board** or a **Disc Armature motor** consists of a rotor disc made of non-magnetic and non-conducting material. The armature winding and the commutator are printed with copper on both the sides of the disc. The disc armature is placed between two sets of permanent magnets mounted on the ferromagnetic plates. Brushes are placed around the inner periphery. The arrangement of the assembly of the motor provides axial flux through the armature. The Torque in the motor is produced by the interaction of the axial flux and the current flowing through the armature disc.  	3+ Fig3	6

PART C
MODULE 1

III (i)	 **Stator** is the stationary part of the alternator and contains 3-phase	Fig3 + 5	8

armature windings. Stator core is built up of silicon steel laminations to reduce eddy current losses. Consists of stator frame, stator core and stator windings. Stator slots are mainly of open, closed or semi closed types.

Rotor:

The rotor is rotating part of the alternator. It carries a field winding which is supplied with dc current through two slip rings by a separate dc source§ There are two types of rotors:

-> Salient pole type rotor

->non-salient pole type rotor.

Salient pole rotors have large diameter and shorter axial length. They are generally used in lower speed electrical machines, say 100 RPM to 1500 RPM.

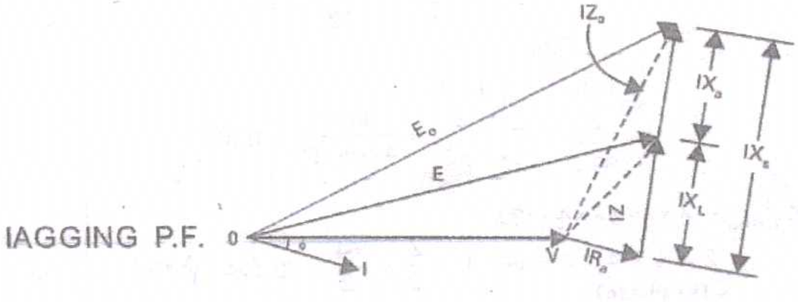
As the rotor speed is lower, more number of poles are required to attain the required frequency. In **salient pole** type of rotor consist of large number of **projected poles** (salient poles) mounted on a magnetic wheel.

Slip rings are used as a means of providing DC excitation to the rotor of the **Alternator**.

brushes provide power to the field coil which is physically mounted on the rotating shaft.

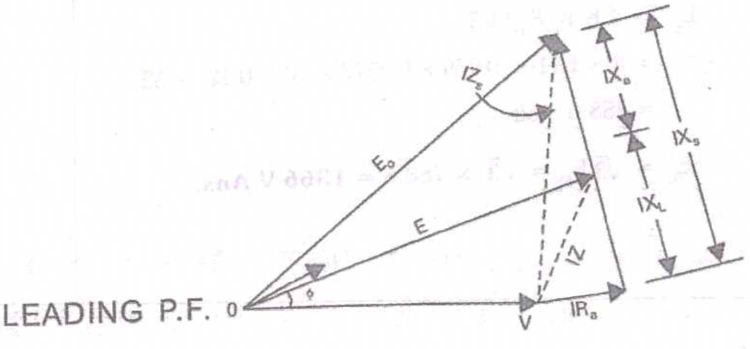
exciter in a generator(**alternator**) is to provide stationary rotating magnetic field.

III (ii)

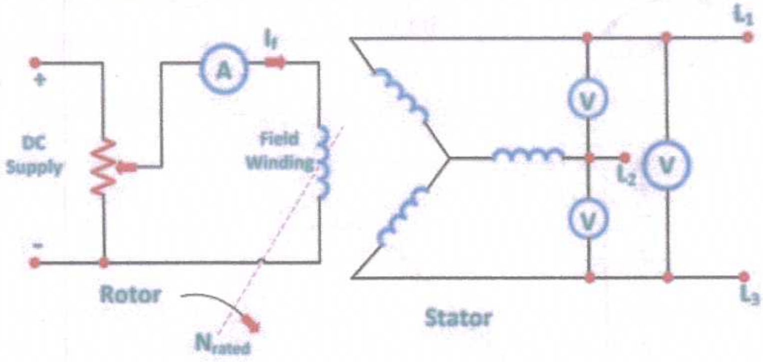
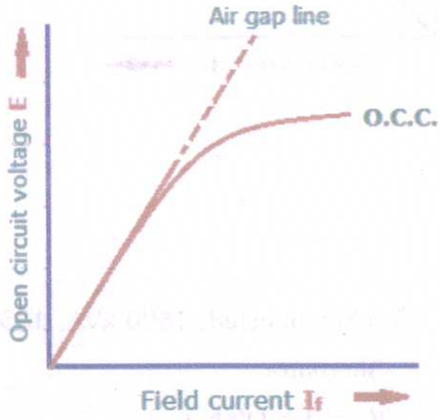


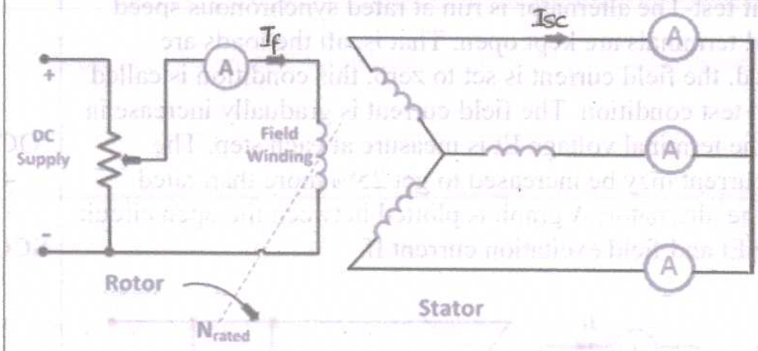
2*3.5

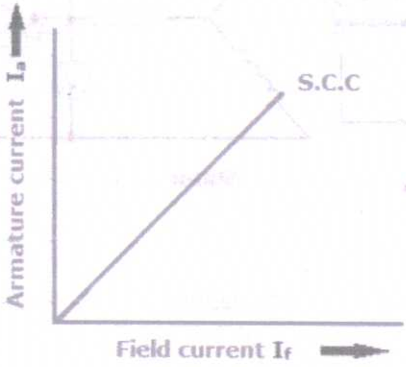
7



IV (i)	1. It is easy to insulate stationary armature winding (33 kV or more). 2. Stator winding is not subjected to centrifugal forces. 3. Stator winding (stator) voltage rating can be increased. 4. It needs only two slip rings on d.c. side. 5. Sparking at brushes is completely avoided. 6. Perfect mechanical balance is obtained on stator winding. 7. It is easy to insulate slip-rings which are on d.c.(low ratings). 8. The rotor weight is less compared to stator weight and hence can run with high speeds. 9. The output current can be collected from the fixed terminals on the armature to load.	Any 7 = 7	7
IV (ii)	$P = 4$ $\phi = 0.12$ Wb conductors / slot = 4 coil span = 150^0 $m = 4$ $E_L = ?$ $\alpha = (180 - 150) = 30^0$ $K_c = \cos\frac{30^0}{2} = \cos 15^0 = 0.966$ No. of slots / pole, $n = 4 \times 3 = 12$; $\beta = \frac{180}{n} = \frac{180}{12} = 15^0$ $K_d = \frac{\sin\frac{m\,\beta}{2}}{m\,\sin\frac{\beta}{2}} = \frac{\sin\frac{4\times15}{2}}{4\times\sin\frac{15}{2}} = \frac{\sin 30^0}{4\times\sin 7.5^0} = 0.9577$ $Z_{TOTAL} = 4\times4\times3\times4 = 192$ $Z = 4 \times 4 \times 4 = 64$; $T = \frac{Z}{2} = \frac{64}{2} = 32$ (per phase) (per phase) Assuming $f = 50$ Hz and $K_f = 1.11$ $E_{ph} = 4\,K_f\,K_c\,K_d\,f\,\phi\,T$ $= 4 \times 1.11 \times 0.966 \times 0.9577 \times 50 \times 0.12 \times 32$ $= 788.6$ volt $E_L = \sqrt{3}\,E_{ph} = \sqrt{3} \times 788.6 =$ **1366 V Ans.**	8	8

V (i)	Open circuit test-The alternator is run at rated synchronous speed and the load terminals are kept open. That is, all the loads are disconnected. the field current is set to zero, this condition is called open circuit test condition. The field current is gradually increase in steps, and the terminal voltage Et is measure at each step, The excitation current may be increased to get 25% more than rated voltage of the alternator. A graph is plotted between the open circuit test voltage Et and field excitation current If.   Short circuit test- The armature terminals are shorted through three ammeter(one ammeter).Care should we taken performing this test, and the field current should first decreased to zero before starting the alternator. Each ammeter should have range greater than the full rated value. The alternator run at synchronous speed. Then the field current gradually increased in step, and the armature current is measured at each step. A graph is plotted between the armature current Ia and field current If. The characteristic so obtained is called short-circuit characteristic (SCC).	OCC 4 + SCC 4	8	





V
(ii)

Given Data : 3-ϕ Y-connected, 1600 kVA, 13500 V Alternator

7 7

$R_a = 1.5\ \Omega/ph$

$X_s = 30\ \Omega/ph$

Load = 1280 kW

p.f. = 0.8 lead

% Regn = ?

$$\text{Load current, } 1 = \frac{1280 \times 10^3}{\sqrt{3} \times 13,500 \times 0.8} = 68.4 \text{ A}$$

$$\text{Voltage / phase} = \frac{13500}{\sqrt{3}} = 7794.2\ \text{V}$$

$$E_o = \sqrt{(7794\times0.8+68.43\times1.5)^2+(7794\times0.6-68.43\times30)^2}$$

$$= 6859.4\ \text{V}$$

$$\therefore\ \%\ \text{Regn} = \frac{E_0 - V}{V} = \frac{6859.4-7794}{7794}$$

$$= -11.89\ \ \textbf{Ans.}$$

VI
(i)

MMF method (Ampere tums method)

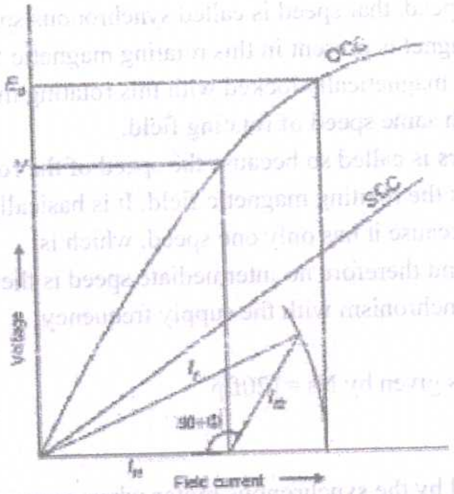
4+
Fig3

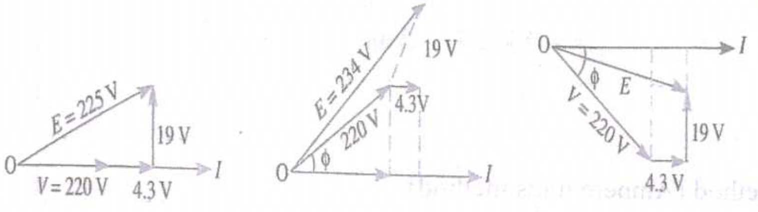
7

Tests: Conduct tests to find
OCC (upto 125% of rated voltagé)
SCC (for rated current}

Steps:

1. By suitable tests plot OCC and SCC
2. From the OCC find the field current If1 to produce rated voltage, V.
3. From SCC find the magnitude of field current If2to produce required armature current.
4. Draw If2at angle (90+ Φ) from where Φ is phase angle of current from voltage. if current is leading, take the angle of If2as (90-Φ)
5. Find the resultant field current, If and mark its magnitude on the field current axis,
6. From OCC find the voltage corresponding to If which will be Eo



VI (ii)	**Solution.** Full load rated current $I = 60,000/220 = 272.2$ A $IR_a = 272.2 \times 0.016 = 4.3$ V ; $IX_L = 272.2 \times 0.07 = 19$ V **(a) Unity p.f.** — Fig. 37.30 (a) $E = \sqrt{(V + IR_a)^2 + (I X_L)^2} = \sqrt{(220 + 4.3)^2 + 19^2}$ **=225V**  (a) (b) (c) Fig. 37.30 **(b) p.f. 0.7 (lag)** —Fig. 37.30 (b) $E = [V \cos \phi + IR_a)^2 + (V \sin \phi + IX_L)^2]^{1/2}$ $= [(220 \times 0.7 + 4.3)^2 + (220 \times 0.7 + 19)^2]^{1/2}$ **=234V** **(c) p.f. = 0.7 (lead)** —Fig. 37.30 (c) $E = [(V \cos \phi + IR_a)^2 + (V \sin \phi - IX_L)^2]^{1/2}$ $= [(220 \times 0.7 + 4.3)^2 + (220 \times 0.7 - 19)^2]^{1/2}$ **=208V**	6+Fig 2	8
VII (i)	**Synchronous Motor Working Principle** When a 3 phase electric conductors are placed in a certain geometrical positions (In certain angle from one another) Then a rotating magnetic field is generated. Now the rotating magnetic field rotates at a certain speed, that speed is called synchronous speed. Now if an electromagnet is present in this rotating magnetic field, the electromagnet is magnetically locked with this rotating magnetic field and rotates with same speed of rotating field. **Synchronous motors** is called so because the speed of the rotor of this motor is same as the rotating magnetic field. It is basically a fixed speed motor because it has only one speed, which is synchronous speed and therefore no intermediate speed is there or in other words it's in synchronism with the supply frequency. Synchronous speed is given by Ns =120f/p	8	8
VII (ii)	**Starting torque** It is torque developed by the synchronous motor when name plate voltage is applied to its armature winding. **Running torque** • It is torque developed by the synchronous motor under	7	7

running condition. It is determined by horse power and speed of the motor . P = Tω

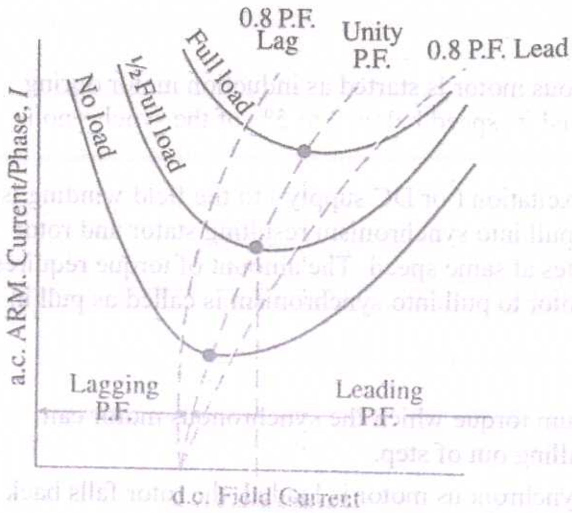
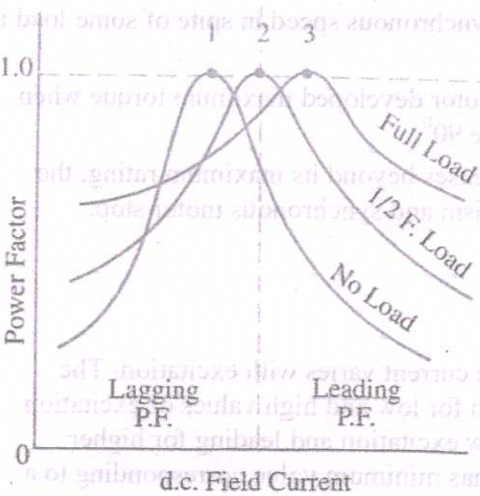
Pull in torque

- A synchronous motor is started as induction motor during starting condition and its speed below 2 to 5% of the synchronous speed.
- When the excitation (or DC supply) to the field winding is applied, the motor pull into synchronism resulting stator and rotor magnetic field rotates at same speed. The amount of torque requires for synchronous motor to pull into synchronism is called as pull in torque.

Pull out torque

- It is maximum torque which the synchronous motor can develop without pulling out of step.
- When the synchronous motor is loaded, the rotor falls back by some angle a is called as load angle. The stator and rotor magnetic fields rotates at synchronous speed in spite of some load is applied on the rotor.
- The synchronous motor developed maximum torque when the rotor falls back by angle 90^0.
- When the load increases beyond its maximum rating, the rotor steps out of synchronism and synchronous motor stop.

VIII (i)	The magnitude of armature current varies with excitation. The current has large value both for low and high values of excitation (though it is lagging for low excitation and leading for higher excitation). In between, it has minimum value corresponding to a certain excitation. The variations of I with excitation are shown in Fig.(a) which are known as 'V' curves because of their shape. For the same input, armature current varies over a wide range and so causes the power factor also to vary accordingly. When over-excited, motor runs with leading p.f. and with lagging p.f. when under-excited. In between, the p.f. is unity. The variations of p.f. with excitationare shown in Fig (b). The curve for p.f. looks like inverted 'V curve. It would be noted that minimum armature current corresponds to unity power factor.	4+ Fig4	8

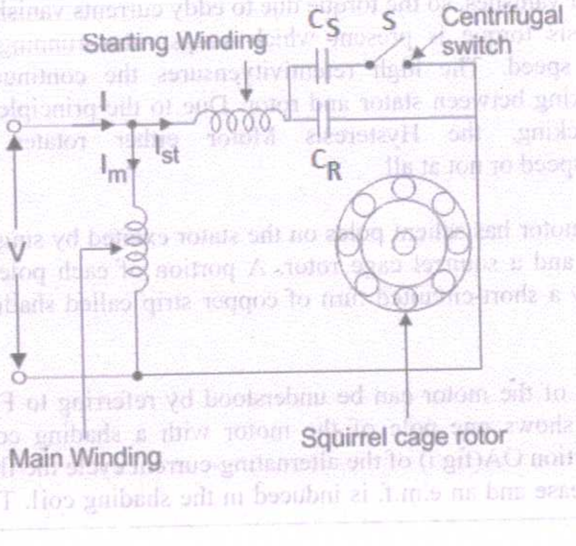
	(a)  (b) 		
VIII (ii)	**1. Using pony motors** In this method, the rotor is brought to the synchronous speed with the help of some external device like small induction motor. Such an external device is called 'pony motor'. Once the rotor attains the synchronous speed, the d.c. excitation to the rotor is switched on. Once the synchronism is established pony motor is decoupled. The motor then continues to rotate as synchronous motor. **2. Using Damper Winding** In a synchronous motor an additional winding consisting of copper bars placed in the slots in the pole faces. The bars are short circuited with the help of end rings. Such an additional winding on the rotor is called damper winding. This winding as short circuited, acts as a squirrel cage rotor winding of an induction motor. Once the rotor is excited by a three phase supply, the motors starts rotating as an	Any 3 = 7	7

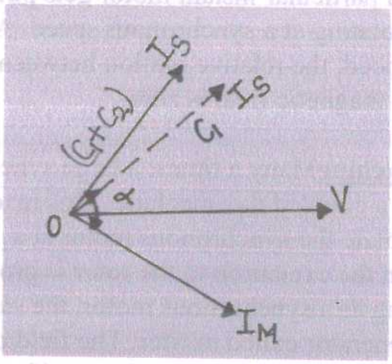
induction motor at sub synchronous speed. Then d.c. supply is given to the field winding. At a particular instant motor gets pulled into synchronism and starts rotating at a synchronous speed. As rotor rotates at synchronous speed, the relative motion between damper winding and the rotating magnetic field is zero.

3. Using Small D.C. Machine Many a times, a large synchronous motor are provided with a coupled d.c. machine. This machine is used as a d.c. motor to rotate the synchronous motor at a synchronous speed. Then the excitation to the rotor is provided. Once motor starts running as a synchronous motor, the same d.c. machine acts as a d.c. generator called exciter. The field of the synchronous motor is then excited by this exciter itself.

IX (i) Two capacitors are used in **capacitor start capacitor run motor** or two value capacitor motor, one for starting purpose and other for running purpose. Starting purpose capacitor is of electrolytic type and is disconnected from the supply when the motor attains 75% of synchronous speed with the help of centrifugal switch *S*, connected in series with C_s. The value of the two capacitors is different. Starting capacitor C_s, which is electrolytic type, is of high value. 4+ Fig4 8

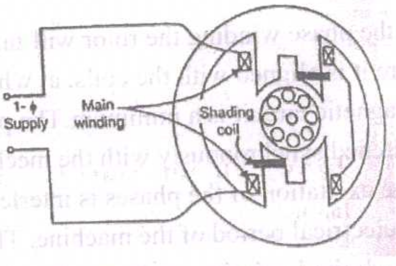
The *capacitor start capacitor run motor* gives the best running as well as starting conditions. Such motors operate as two-phase motors giving the best performance.Starting torque is high, starting current is reduced and gives better efficiency, better p.f. The only disadvantage is high cost.

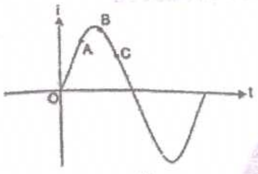


			
IX (ii)	Initially, when hysteresis motor is started it behaves as a single phase induction motor and while running it behaves as a synchronous motor. When stator is energised with single phase AC supply it produces rotating magnetic field, The main and auxiliary, both the windings must be supplied continuously at the start as well as in running condition so as to maintain the rotating magnetic field. This field induces poles in the rotor. The hysteresis phenomenon is dominant for the rotor material chosen and due to which rotor pole axis lag behind the axis of rotating magnetic field. Due to this, rotor poles get attracted towards the moving stator field poles. Thus rotor gets subjected to torque called hysteresis torque. This torque is constant at all speeds. When the stator field axis moves forward, due to high retentivity the rotor pole strength remains maintained. So higher the retentivity, higher is the hysteresis torque. Initially, rotor starts rotating due to the combined effect of hysteresis torque as well as torque due to eddy currents induced in the rotor. Once the speed is near about this, the stator pulls rotor into synchronism.. In such case, as relative motion between stator field and rotor vanishes, so the torque due to eddy currents vanishes. Only hysteresis torque is present which keeps rotor running at synchronous speed. The high retentivityensures the continuous magnetic locking between stator and rotor. Due to thc principle of magnetic locking, the Hysteresis Motor either rotates at synchronous speed or not at all.	7	7
X (i)	Shaded pole motor has salient poles on the stator excited by single-phase supply and a squirrel cage rotor. A portion of each pole is surrounded by a short-circuited turn of copper strip called shading coil. **Operation** The operation of the motor can be understood by referring to Fig. below which shows one pole of the motor with a shading coil. During the portion OA(fig i) of the alternating-current cycle the flux begins to increase and an e.m.f. is induced in the shading coil. The	4+ Fig4	8

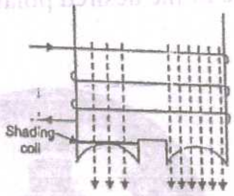
resulting current in the shading coil will be in such a direction (Lenz's law) so as to oppose the change in flux. Thus the flux in the shaded portion Of the pole is weakened while that in the unshaded portion is strengthened shown in Fig (ii).During the AB of the alternating-current cycle, the flux has almost maximum value and is not changing. Consequently, the flux distribution across the pole is uniform since current is flowing in the shading coil. As the flux decreases (portion to the alternating current cycle), current is induced in the shading coil so as to oppose the decrease in current. Thus the flux in the shaded portion pole is strengthened while that in the unshaded portion is weakened as shown in Fig iv.

The rotor is of the squirrel-cage type and is under the influence of this moving field. Consequently, a small starting torque is developed.

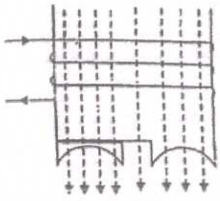




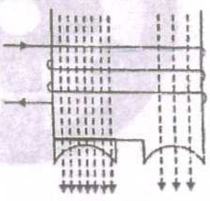
(i)



(ii)



(iii)



(iv)

X (ii)

SRM is electromagnetic and electrodynamic equipment which converts the electrical energy into mechanical energy. The electromagnetic torque produced on variable reluctance principle.

SRM make use of

- Power semiconductor switching circuitry and
- Rotor position sensor.

SRM is singly excited and doubly salient electrical motor. It has salient poles on both the rotor and stator but only one member carrying windings. The rotor has no windings, magnets and cage winding but it is built from a stack of salient pole lamination.

7 7

The stator is made up of silicon steel stampings with inward projected poles. The number of poles of stator can be either an even number or an odd number. Most of the motors available have an even number of stator poles (6 or 8). Individual coil or a group of coils constitute phase windings. Each of the phase windings are connected to the terminals of a power semiconductor switching circuitry, whose input is dc supply.

The rotor is also made up of silicon steel stampings with outward projected poles. Number of poles of rotor is different from the number of poles of the stator. In most of the available motors the number of poles of the rotor is 4 or 6 depending upon the number of stator poles 6 or 8.

If current is applied to the phase winding the rotor will turn until it reaches a position where it is aligned with the coils, at which point the reluctance of the magnetic circuit is a minimum.The phase currents are always switched synchronously with the mechanical position of the rotor.The excitation of the phases is interleaved equally throughout the electrical period of the machine. This means that torque of the desired polarity can be produced continuously.