UNIT-IV Permanent Magnet Machines

PERMANENT MAGNETS:-

Permanent magnets are magnetic materials that retain their magnetism after being magnetized (retain alignment after removing the external field).

- Magneto static energy has been stored in permanent magnets.
- The maximum energy product (BH)max represents the strength of the magnet.
- The strongest hard materials are N_D - Fe - B based materials.
- The transition metals usually provide the high magnetization and the rare"earths the high anisotropy.

Types of Permanent Magnets:-

These are three main types of magnets:

(a) Permanent magnets
(b) Temporary magnets
(c) Electromagnets

(a) **Permanent Magnets:-** These are four clauses of permanent magnets-

- Neodymium iron boron (NdFeB or NIB).
- Samarium cobalt (SmCo).
- Alnico.
- Ceramic and ferrite.
- **Br** is the measure of its residual magnetic flux density in Gauss, which is the maximum flux the magnet is able to produce. (1 Gauss is like 6.45 lines/sq. in.).
- **He** is the measure of the coercive magnetic field strength in oversted, or the point of which magnet becomes demagnetized by an external field. 1 Oersted is like 2.02 ampere-turns/inch).
- $\mathbf{BH_{max}}$ is a term of overall energy density. The higher the number, the more powerful the magnet.
- $\mathbf{T_{coef}}$ **of Br** the temperature co-efficient of Br in terms of % per degree centigrade.
- This tells you how the magnetic flux changes with respect to temperature. - 0.20 means that if the temperature increases by 100 degrees centigrade, its magnetic flux will decrease by 20%.

Magnetization Characteristics:-

In order to attain maximum magnetic potential, it is necessary to magnetize a material to its saturation point.

- **R Series Samarium Rare Earth Magnets**: Demagnetization characteristics differ depending on the coercively HcJ of the magnet. Therefore, a greater magnetic field is needed to achieve saturated magnetization for magnets with greater coercively.
- **N Series Neodymium Rare Earth Magnets:-** These magnets are excellent in

magnetization, and virtually stable in regard to coercively. However, special care is needed when re-magnetizing these magnets after demagnetization.

Permanent Magnet Generator:-

A permanent magnet generator is basically a power producer that makes use of magnets to instead of gas or any substitute power source. Since these generators make use of magnets, they do not require any maintenance.

In general, a regular generator works by burning fuel to rotate a turbine which then generates energy where as, the greatest thing about a permanent generator is that instead of using power and fuel, the magnet generator works by using the resistive and attractive forces of magnets to generate electrical energy. As a permanent magnet generator is self driven, there is no necessity to use another fuel source for it.

The permanent magnet generators can also be called as an 'alternator', because it generates alternating current (AC). It does not generate 'mains voltage' or utility power AC. It generates as low voltage, three phase AC, then changes it into direct current (DC) for charging a 12 V battery.

The PMG consists of:

- A steel spine and shaft
- A stator containing coils of wire
- Two magnet rotors
- A rectifier

The stator consists of six coils of copper wire, cast in fibre glass resin. This stator casting is mounted on to the spine, it does not enough wires from the coils takes the electricity to the rectifier, which changes AC to DC for charging the battery. The rectifier is mounted on the aluminum 'heat sink' to keep it cool.

The magnet rotors are mounted on bearing which tum on the shaft. The rear rotor is behind the stator and enclosed with in it. The front one is on the outside, fixed to the rear one by long studs which pass through a hole in the stator. The wind turbine rotor will be mounted on the same studs. They will tum the magnet rotors, and move the magnets past the coils. Magnetic flux passes from one rotor to the other through the stator. This moving magnetic flux produces the electric power.

BRUSH LESS DC MOTORS:-

The term brush less DC motor is applied to many configurations of ac synchronous motors in which semiconductor control is used to control such that maximum torque is obtained at a given speed. In a conventional motor the mechanical contactor, the commutator, maintains 90° electrical degrees space displacement between the rotor and stator magnetic fields to provide for the required torque.

Theoretically, the stator and rotor functions of a machine can be inverted, putting the field system on the rotor. In this method each of the stator phase winding is energized sequentially by a power transistor (or) thyristor by means of a signal from position sensor placed on the rotor. Because of the rotor position feedback triggering of thyristors/transistors, the stator and rotor field always remain in synchronism as the frequency of triggering automatically adjusts to rotor speed. The length of on-time of thyristors determine the motor torque magnitude. Thus by means of electronic circuitry brushless motors can be controlled for both constant and variable torque operation.

The brushless DC motors, while being generally more expensive for the same kW\w rating, than commutator and brush motor possess certain advantages-over the conventional motors. They are:

- They require less or no maintenance
- They have a much longer operating life
- There is no risk of explosion or possibility of RF radiation due to arcing.
- They produce no brush or commutator particles or gases as byproducts of operation.
- They are capable of operation submersed in fluids, combustible gases and may even be hermetically sealed**.**
- They are generally more efficient than brush-type dc servomotor or conventional de motors.
- They provide a more rapid response and a fairly linear output torque vs input current characteristics, which lends itself to servo applications.

Schematic and operation:-

The schematic diagram of a brushless de motor shows the three phases of the stator and rotor with*'d'* and *'q'* -axis. The stator is connected to a variable voltage current source through an inductor and an investor comprising six SCR's (S_1 to S_6)' Diodes are connected across SCR's to protect these from the *L(di/dt)* voltage induced in the armature coil undergoing commutation. Position sensors placed on the rotor provide signal to the sensor decoders and gate drivers which cause the SCR's to be fired in sequence so as to be in synchronism, with the rotor's mechanical position. The stator and rotor fields thus get locked into each other and remain in synchronism at any rotor speed.

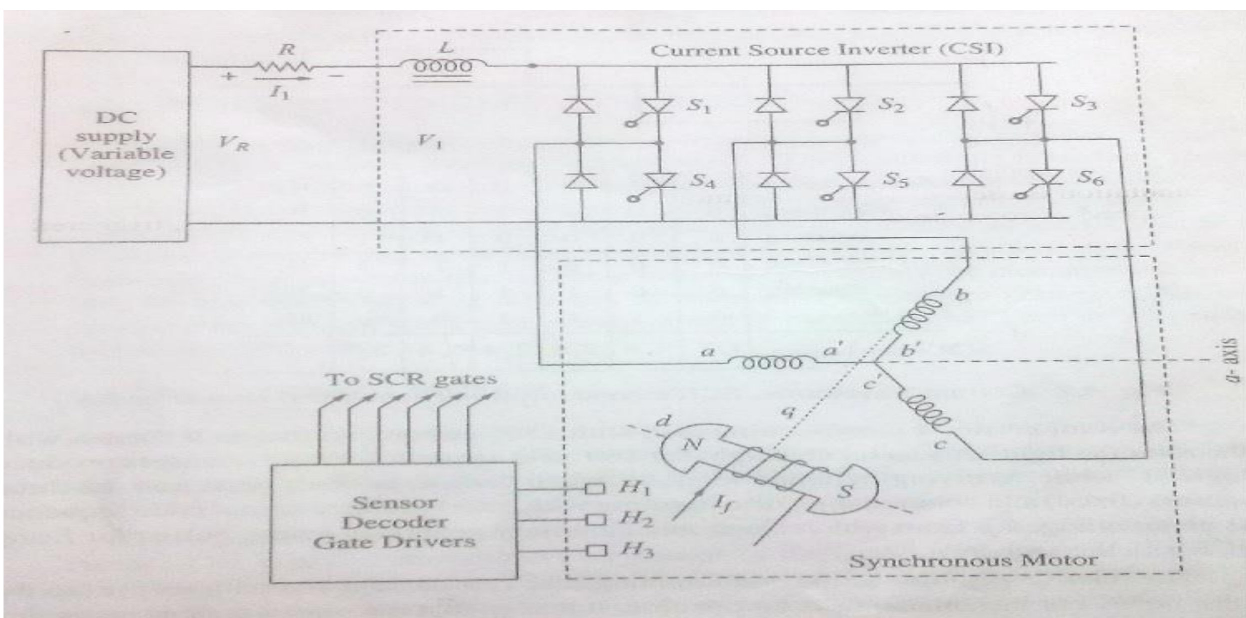
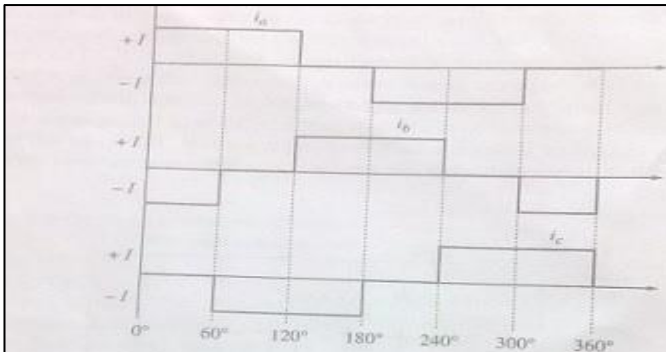


Fig. 4.1 Brussless dc motor: schematic and operation

Ideal phase current are pulses of ±I lasting 120° electric each half and displaced from each other 120° electrical phase to phase. Actual current wave forms differ from the ideal rectangular current waves by gradual rises and falls. Such as inverter where ac current flows in form of constant current pulses is known as Current Servo Inverter (CSI).

Sequence of inverter firing follows from the phase current waveforms. For this sequence of SCR firing 120° or 60° elect spaced sensor codes are generated by means of light sensitive or Hall effect sensors.

The rotor carries a commutating disc with 180° cut-out, so that as it rotates with the rotor the light sensors receive light for 180° and are dark for 180°. Sensors produce logic' l ' while receiving light and logic '0' when dark.



Sensors codes	1	1	1	0	0	0	H_1
120° elect.	0	0	1	1	1	0	H_2
Spacing	1	0	0	0	1	1	H_3
60° elect.	0	0	0	1	1	1	H_1
Spacing	0	0	1	1	1	0	H_2
	0	1	1	1	0	0	H_3
SCR's conducting	1, 5	1, 6	2, 6	2, 4	3, 4	3, 5	

Fig. 4.2 Current waveforms, SCR's conducting sequence and sensor codes

PERMANENT MAGNET DC MOTORS:-

PMDC motors are smaller in size than the corresponding rated field wound type motors, this fact partially off-sets the high cost of permanent magnets. These motors offers shunt type characteristic and can only be armature controlled. The risk of permanent magnetism getting destroyed by armature reaction (at starting/reversing or heavy overloads) has been greatly reduced by the new PM materials.

RELUCTANCE MOTOR:-

A synchronous reluctance motor is similar to a synchronous AC machine and is described in the section on AC motors. The rotor has salient poles but the stator has smooth, distributed poles where as both the switched and variable machines have salient poles for both the rotor and the stator.

The operating principle of the basic reluctance motor is similar to switched reluctance motor. The synchronous reluctance motor is designed to run on main frequency alternating current and it uses distributed stator winding similar to those used in squirrel cage induction motors. The roles however needs salient poles to create a variable reluctance in the motor's magnetic circuit which depends on the angular position of the rotor.

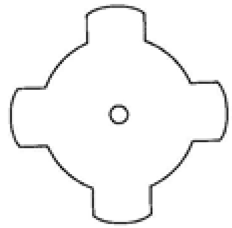


Fig. 4.3 Rotor of synchronous reluctance motor

In a reluctance type synchronous motor, a rotor has magnetic poles which have a low magnetic reluctance in an axial direction of the magnetic poles, and have a high magnetic reluctance toward a circumference of the rotor. The magnetic poles have less components orthogonal to axes thereof, so that armature reaction will be reduced.

The synchronous motor is not self-starting without the squirrel cage. During run up it behaves as an induction motor but as it approaches synchronous speed, the reluctance torque takes over and the motor locks into synchronous speed.

Operating Principle:-

When a piece of magnetic material is free to move in a magnetic field, it will align itself with the magnetic field to minimize the reluctance of the magnetic circuit. To put it another way the piece will orient itself towards the magnetic pole creating the field. The torque on the rotor created in this way is called the reluctance torque.

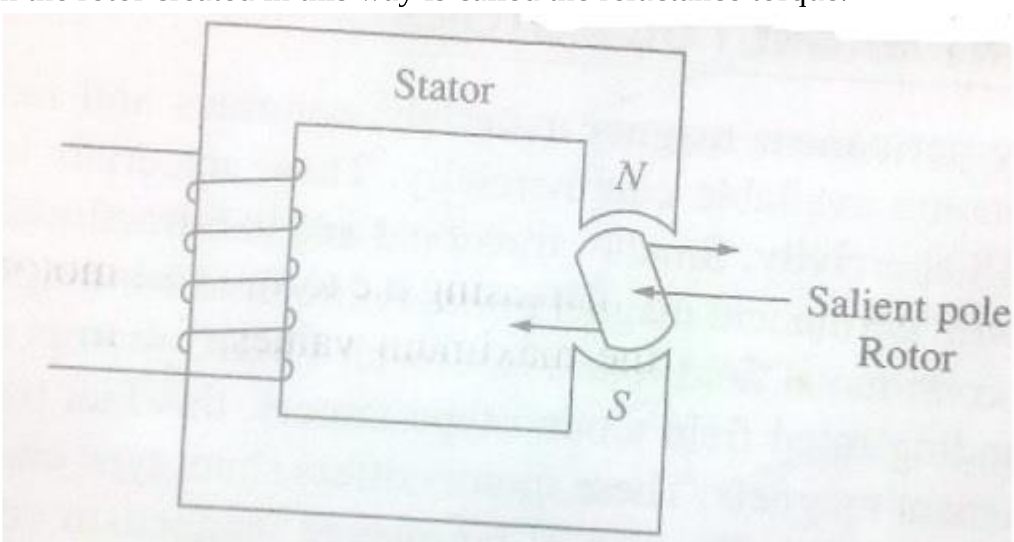


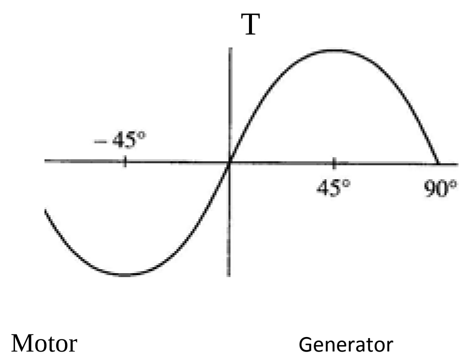
Fig. 4.4 Variable Reluctance Motor

When the spaces or notches between the rotor poles are opposite to the stator poles the magnetic circuit of the motor has a high magnetic reluctance, but when the rotors poles are aligned with the stator poles the magnetic circuit has a low magnetic reluctance. When a stator pole pair is

energized the nearest rotor pole pair will be pulled into alignment with the energized stator poles to minimize the reluctance path through the machine. As with brushless permanent magnet motors, rotary motion is made possible by energizing the stator poles sequentially causing the rotor to stop to the next energized pole.
A poly phase inverter energizes appropriate poles pairs based on shaft position. The excitation of stator poles must be timed precisely to correspond with the rotor position. So that it occurs just as the rotor pole is approaching. The reluctance motor thus requires position feedback to control the motor phase commutation. This feedback control can be provided by using position sensors such as encoders or Hall effect sensors to feedback the rotor angle to trigger the commutator at the appropriate point.

Torque - δ Characteristics

In synchronous reluctance motor, the speed is constant by varying the load for fixed frequency. From the above Fig. 4.5, by increasing the torque, the motor speed becomes constant. When the torque exceeds the maximum values, the motor goes to out of synchronism.



Torque- δ Characteristic

HYSTERESIS MOTOR:-

The stator of a hysteresis motor is wound with main and auxiliary windings with a permanently connected capacitor for phase splitting The capacitor is selected to create balanced 2-phase conditions. The rotor is a smooth solid cylinder of hard steel (this has high hysteresis loss) and does not carry any winding (no rotor bars).

Both the rotor windings are distributed such as to create a rotating field with as nearly a sinusoid ally space distribution as possible; this is necessary to keep down iron- loss due to space harmonics of the field. The phenomenon of hysteresis causes the rotor magnetization to lag behind the stator-created mmf wave. As a consequence, the rotor flux lags by an angle 0 the stator mmf axis. Figure 4.7(a) shows the magnetic condition in the motor at any instant.

As the angle 0 is hysteresis-dependent, it remains constant, at all rotor speeds. The interaction torque between stator and rotor field therefore is constant at all speeds. Under the influence of the hysteresis torque the rotor accelerates smoothly and finally

runs at synchronous speed with angle 8 getting adjusted to the load torque. This is a constant to the "pull-in" phenomenon in a reluctance motor when it synchronizes. Constancy of the hysteresis torque is demonstrated by the derivation given below.

The hysteresis loss is expressed as-

$$P_h = k_h f_2 B^x$$

Where, B =maximum flux density

$f_2 = s f$ = rotor frequency

$$\text{Power across air gap} = P_h / S$$

$$\text{Torque developed} = P_h / S W_s = K_h S_f B^2 / W_s$$

$$= K_h f B^2 / W_s = \text{Constant}$$

Another component of torque caused by eddy current loss is simultaneously created in the motor. This can be derived as-

$$P_e = k_e f_2^2 B^2$$

$$= k_e S^2 f^2 B^2$$

$$T = \frac{P_e}{\omega_s} = \left[\frac{k_e f^2 B^2}{\omega_s}\right] S$$

As per above equation, the eddy current torque is highest at start and reduces linearly with slip vanishing at synchronous speed. This torque component aids the hysteresis torque at starting, endowing excellent starting characteristics to the hysteresis motor.

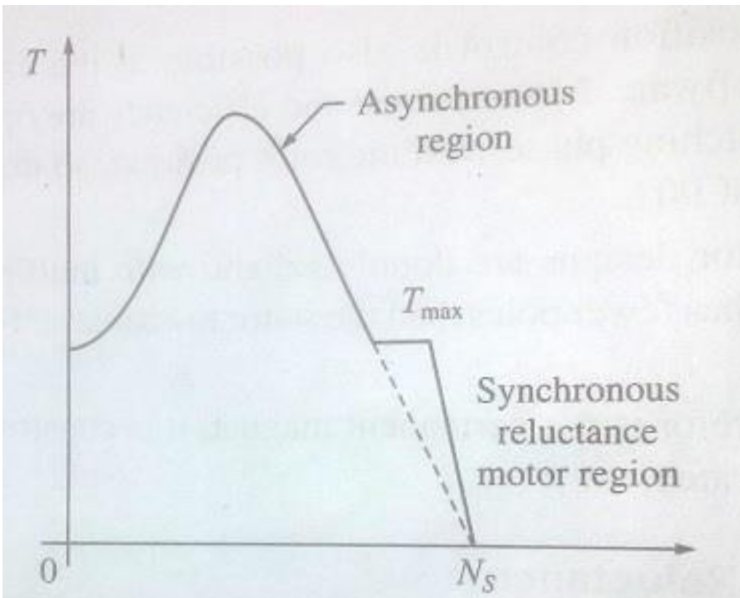


Fig. 4.5 Speed-torque characteristics

PERMANENT MAGNET SYNCHRONOUS MOTORS:-

Permanent magnet synchronous motors are commonly known as permanent magnet AC motors (PMAC). They are classified according to the nature of voltage induced in the stator as sinusoid ally excited and trapezoid ally excited. These PMAC motors are commonly known as sinusoidal PMAC and trapezoidal PMAC motors.

A sinusoidal PMAC motor has distributed winding (similar to wound field synchronous motor) in the stator side. Shown in figure

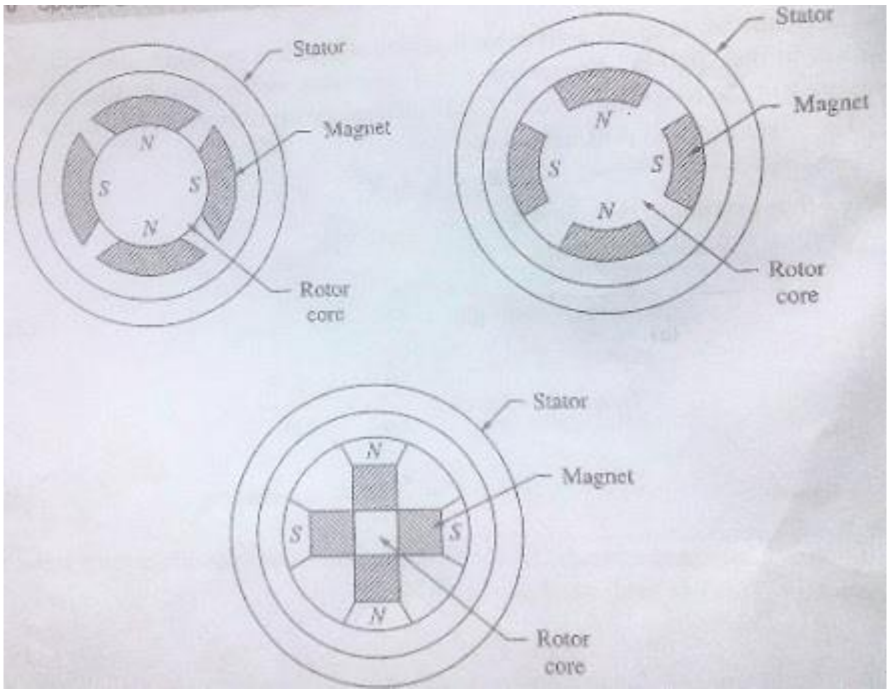


Fig. 4.6 Different type of PMSM

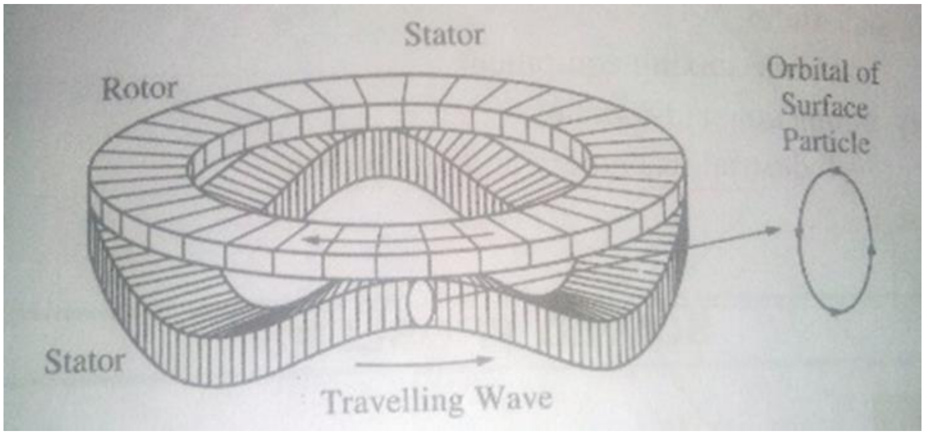
The rotor poles are so shaped that the voltage induced in a stator phase winding has a sinusoidal waveform. The stator of trapezoidal PMAC motor has concentrated windings and a rotor with a wide pole arc.

PCB MOTOR:-

Operating Principle:-

PCB motors consist of two parts: The stator, which holds the actuators and electrical connecting circuit; and the rotor, which is pressed onto the surface of the stator and delivers the mechanical output.

A travelling wave is generated over the stator surface, acting like a flexible ring to produce elliptical motion on the rotor interface. The elliptical motion of the contact surface propels the rotor and the connected drive-shaft. The teeth attached to the stator can be used to increase rotational speed. Operation depends on friction between the moving rotor and stator as well as amplitude and quality of the wave travelling on the stator.



A travelling wave is generated within the stator by activating two modes simultaneously. These modes are induced by a drive circuit performing $\cos(\omega t)$ and $\sin(\omega t)$ signals, respectively, close to the mechanical resonance of the stator ring. The travelling wave's direction can be reverse by changing the sign on one of the drive signals.

Rotor:-

The rectification of the micro-motion is achieved by pressing the rotor on top of the stator. The frictional force between the two causes the rotor to spin. The resulting motion transfer operates as a gear and leads to a much lower rotation speed than the wave frequency. The rotor could be a special ring-shaped material attached to an output shaft, or it could be an integral part of the application that needs to be turned. Since the rotor is a passive component there is a great deal of freedom in the design. Most important is the surface behavior which must be compatible with the stator teeth material in order to produce the friction needed to drive the application.

Features of PCB Motors

- Direct drive, no gears, slack-less.
- High torque and holding torque.
- Built-in clutch, tamper proof/safe.
- Non-magnetic.
- Fast start & stop actions.
- Optional position sensor.

Applications

- Medico
    - Microscope focus
    - Dosing equipment
- Camera - Pen, Tilt &Zoom.
- Instrumentation.
- Telecom.
- Video and audio.
- Factory automation and robotics.
- Defense.