## STEPPER MOTORS

Stepper motor is known by its important property to convert a train of input pulses i.e. a square wave pulses into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle. So the stepper motor is an electromechanical device which actuates a train of step movements of of shaft in response to train of input pulses. The step movement may be angular or linear. There is one-one relationship between an input pulse and step movement of the shaft. Each pulse input actuates one step movement of the shaft. When a given number of drive pulses are supplied to the motor, the shaft gets turned through a known angle. The angle through which the motor turns or shaft moves for each pulse is known as the step angle, expressed in degrees.

As such angle is dependent on the number of input pulses, the motor is suitable for controlling position by controlling the number of input pulses. Such system, used to control the position is called position control system. The average motor speed is proportional to the rate at which the input pulse command is delivered. When the rate is low, the motor rotates in steps but for high rate of pulses, due to inertia, it rotates smoothly like d.c. motors. Due to this property it is also used in speed control systems. These motors are available in sub-fractional horse power ratings. As the input command is in pulses, the stepper motor is compatible with modern digital equipments.

Due to its compatibility with digital equipment, its market is greatly increased in recent times. The stepper motors are widely used in X-Y plotters, floppy disk drives, machine tools, process control systems, robotics, printers, tap drives and variety of other industrial applications.

### Types of Stepper Motors

The stepper motors can be divided into three categories :

1. Variable Reluctance Stepper Motors
2. Permanent Magnet Stepper Motors
3. Hybrid StepperMotors

**Variable Reluctance StepperMotor**

It is the most basic type of stepper motor. Thus helps to explain the principle of operation of the stepper motors.

The motors has a stator which is usually wound for three phases. The stator has six salient poles with concentrated exciting windings around each one of them. The stator construction is laminated and assembled in a single stack. The number of poles on the stator and rotor are different. This gives th motor ability, of bidirection rotation and self starting capability.

The rotor is made out of slotted steel laminations. If the number of stator poles are $N_s$ and the number of rotor poles are $N_r$ then for a three phase motor, the rotor

$$N_r = N_s \pm \left(\frac{N_s}{q}\right)$$

poles interms of and q are given by,

$$N_r = 6 \pm \left(\frac{6}{3}\right) = 8, 4$$

For example for Ns = 6 and q =3, the rotor poles are,

For our discussion, 4 pole rotor construction is selected. So rotor has 4 salient poles without any exciting winding as shown in the Fig.5.8.1

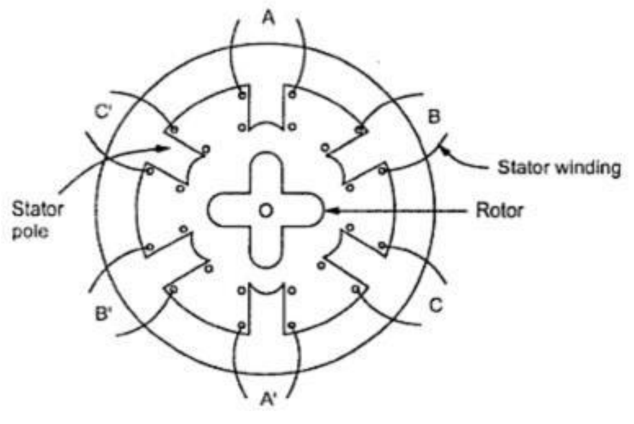


**Fig5.8.1 Schematic arrangement of variable**

The coils wound around diametrically opposite poles are connected in series and the three phases are energized from a d.c. source with the help of switches.

The basic driving circuit is shown in the Fig. 5.8.2

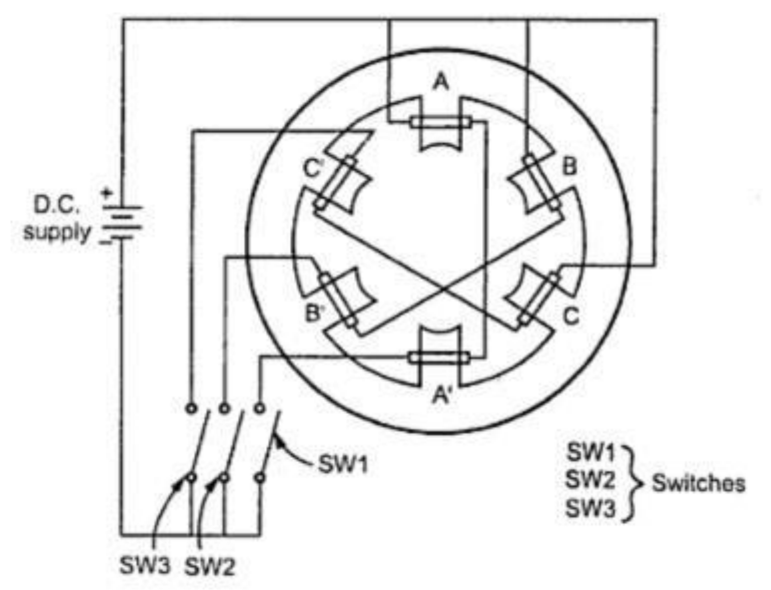


**Fig.5.8.2 Driving circuit**

**Operation**

The operation is based on various reluctance positions of rotor with respect to stator. When any one phase of the stator is excited, it produces its magnetic field whose axis lies along the poles, the phase around which is excited. Then rotor moves in such a direction so as to achieve minimum reluctance position. Such a position means a position where axis of magnetic field of stator matches with the axis passing through any two poles of the rotor. Let us see the operation when phases A, B and C are energized in sequence one after the other, with the help of switches SW1, SW2 and SW3.

1. When the phase AA' is excited with the switch SW1 closed, then stator magnetic axis exists along the poles formed due to AA' i.e. vertical. Then rotor adjusts itself in a minimum reluctance position i.e. matching its own axis passing through the two poles exactly with stator magnetic axis. This position is shown in the Fig. 3(a).

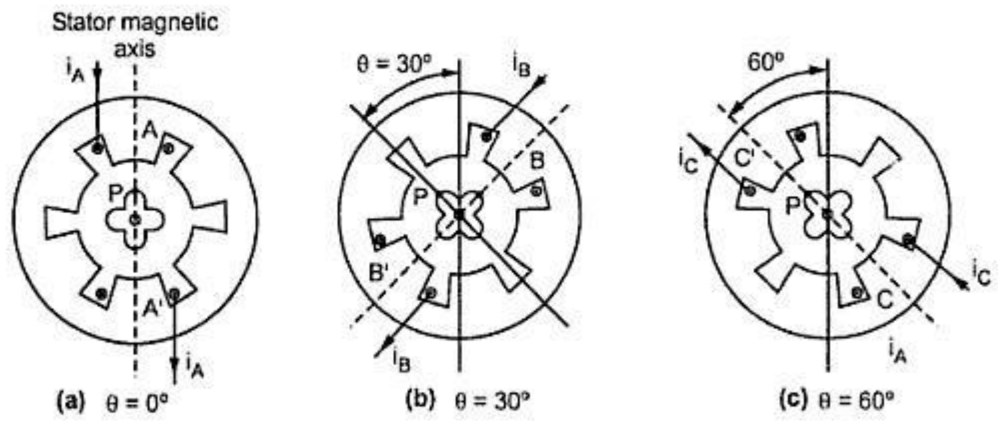


**Fig.5.8.3 Steps in variable reluctance**

2. When the phase BB' is excited with the switch SW2 closed and phase AA' de-energized with the switch SW1 open, then stator magnetic axis shifts along the poles formed due to BB;, shown dotted in the Fig. 3(b). Then rotor tries to align in the minimum reluctance position and turns through $30^o$ in anticlockwise direction. So axis passing through two diagonally opposite poles of rotor matches with the stator magnetic axis. This is the new minimum reluctance position. The point P shown on the rotor has rotated through $30^o$ in anticlockwise direction as shown in the Fig. 5.8.3

3. When the phase CC' is excited with the switch SW3 closed and the phases AA' and BB' are de-energized, then the stator magnetic axis shifts along the poles formed due to CC', shown dotted in the Fig. 5.8.4. Then to achieve minimum reluctance position, rotor gets subjected to further anticlockwise torque. So it turns through further $30^o$ in anticlockwise direction.

Hence point P is now at $60^o$ from its starting position, in anticlockwise direction as shown in the Fig. 3(c). By successively exciting the three phases in the specific sequecnce, the motor takes twelve steps to complete on revolution.

$$T_m = \frac{1}{2} i^2 \frac{dL}{d\theta}$$

Now if i is the current passing through the phase which is excited then the torque developed by the motor, which acts on the rotor is expressed as,

where L is the inductance of the relevant phase at an angle θ.

Since the torque is proportional to the torque of the phase current ($T \alpha\ i^2$), it is independent of the direction of i. The direction of rotation is totally decided from the sequence in which the phases are excited.

Important Observation

From the above discussion, the following important observations can be made :

i) The rotor can be moved in a specific direction, by exciting the stator phases in a specific sequence.

ii) When the phases are excited in the sequence A-B-C-A .........., the rotor moves in the anticlockwise direction, as explained earlier.

iii) When the phases are excited in the sequence C-B-A-C..........., the rotor moves in the clockwise direction, which can be easily verified.

iv) The distance through which the rotor moves when all three phases are excited once is called one rotor tooth pitch.

Rotor tooth pitch = $360^o/N_r$

v) The step angle is denoted as, and given by,

$\boldsymbol{\alpha_s = 360^o/qN_r}$

So for three phases and four rotor poles the step angle is,

$\boldsymbol{\alpha_s = 360^o/(3 \times 4) = 30^o}$

This is shown in the previous section. If the number of phases are increased to eight and the number of rotor poles to six then the step angle becomes,

$\boldsymbol{\alpha_s = 360^o/(8 \times 6) = 7.5^o}$

## Micro stepping

In the above discussion we have assumed that the windings are excited one at a time. If the two phases are excited simultaneously i.e. keeping AA' excited, the BB' is also excited with switch SW1 and SW2 closed, then the stator magnetic axis shifts to a mid position rather than along BB'. Hence rotor gets aligned along this moves through a half step i.e. $15^o$.

A logical extension of this technique is to control the currents in the phase windings so that several stable equilibrium positions are created. Normally the step angle is reduced by factor of 1/2, 1/5, 1/10, 1/16 or 1/32. This technique is called microstepping.

A further reduction in step angle can be achieved by increasing the number of poles of the stator and rotor by adopting different constructions such as,

i) Using reductiongear mechanism.

ii) Using multistack arrangement

## Reduction Gear Stepper Motor

Fig. 4 shows a reduction gear stepper motor. The stator has 8 salient poles and four phases for use as exciting winding. The rotor has 18 teeth and 18 slots uniformly distributed around. Each salient pole of the stator consists of two teeth, forming an interleaving slot of the same angular periphery as the rotor teeth or slots. When the coil A-A' is excited, the resulting electromechanical torque brings the rotor to the position as shown in the Fig. 5.8.4

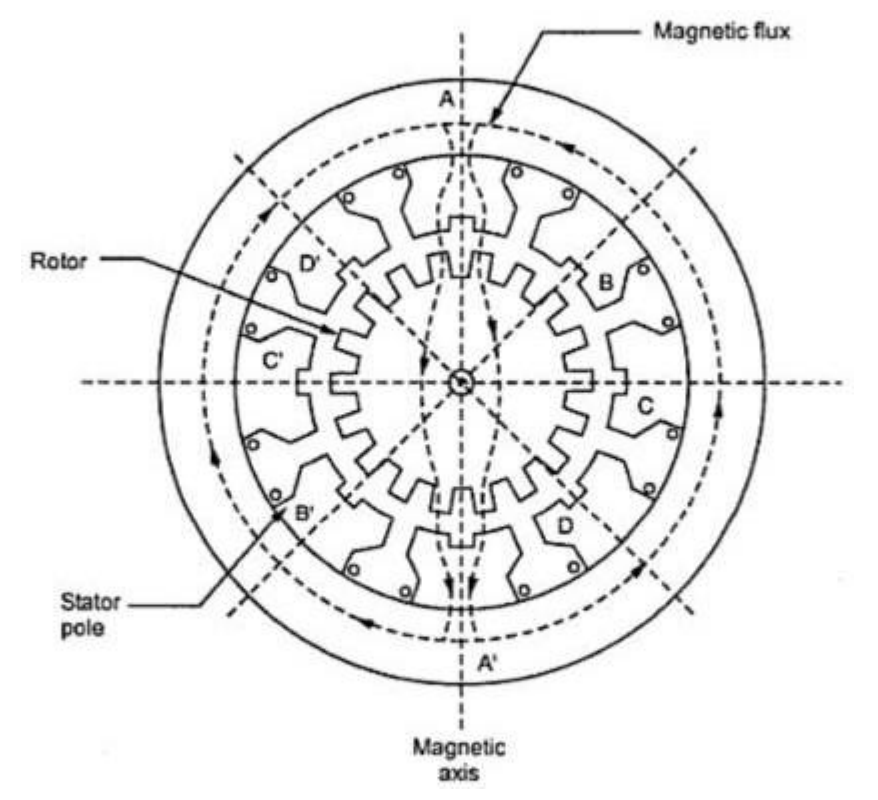


**Fig. 5.8.4 Reduction gear stepper**

With this arrangement, the step angle reduces to 5. By successive excitation of coils A-A', B-B', C-C; and D-D', the rotor makes 72 steps to complete one revolution. The general relationship between step angle , number of stator phases q and rotor poles or teeth $N_r$ remains same as,

$\alpha_s = 360^o/mN_r$

By choosing different combinations of number of rotor teeth and stator phases, any desired step angle can be achieved.

**Multistack Stepper Motor**

As mentioned earlier, these are used to obtain small step size, typically ranging between 2 to $15^o$.

In a m stack motor, the motor is divided into a m number of magnetically isolated sections called stacks, along its axial length. The m stacks of stator have a common frame while the rotors are mounted on a common shaft. The stators and rotors have the same number of poles (teeth). The stator poles in all m stacks are aligned while the rotor poles are shifted by (1/m) of the pole pitch from one another. All the stator windings in a stator stack are excited simultaneously hence each stator stack forms a phase. So number of stator phases is equal to number of stator stacks. Generally three stack stepper motors are used. The Fig. 5.8.5 shows the arrangement in three stack stepper motor along with shifting of the rotor poles by (1/3) of the pole pitch from one another.

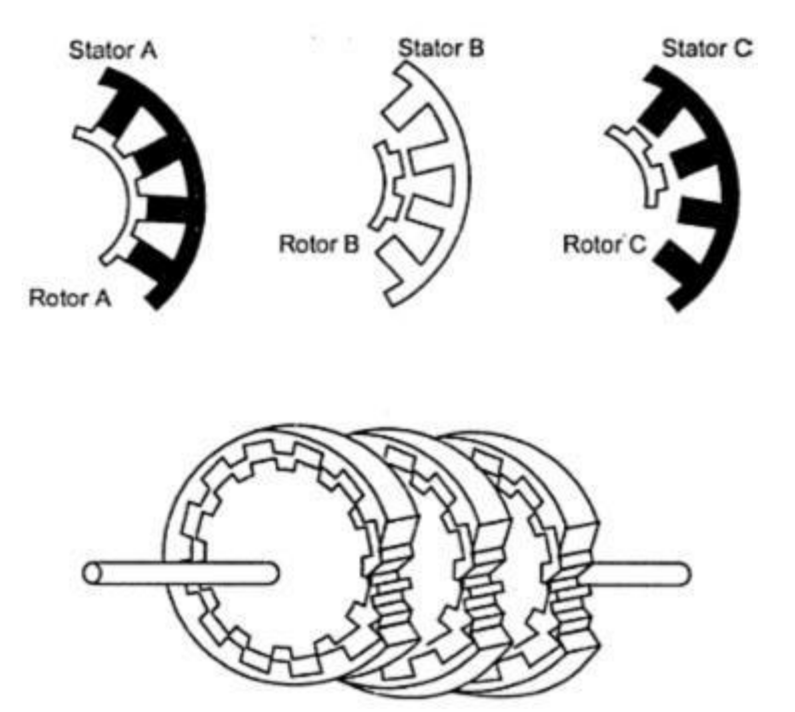


**Fig. 5.8.5 Reduction gear stepper**

The Fig.5.8.6 shows the cross sectional view of a three stack, three phase variable reluctance motor. In each stack, the stator and rotor laminations have 12 poles. The poles of the stator are in one line while the rotor poles are offset from each other by one third of the pole pitch.

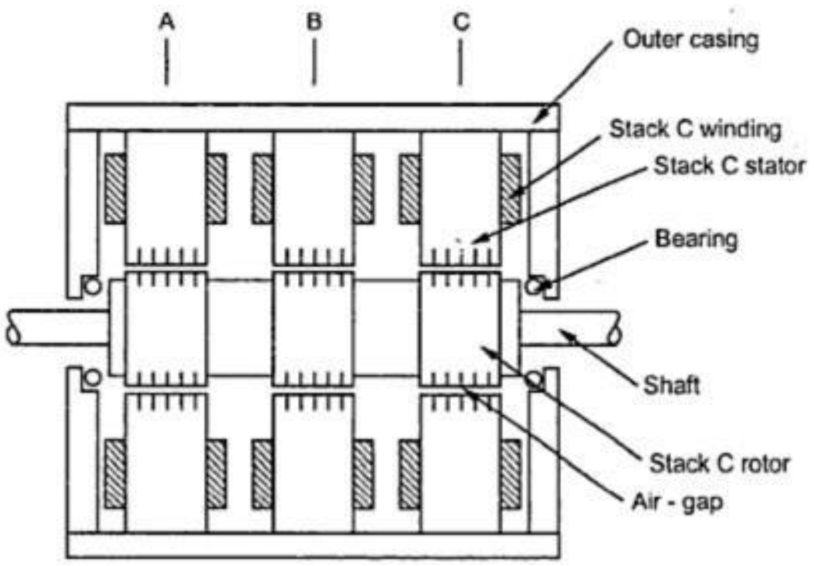


**Fig. 5.8.6 Cross sectional view of 3 stack variable reluctance**

The various windings in one stack are energized simultaneously. When phase A of stator is excited then rotor poles of stack A get aligned with the stator poles. But due to offset, rotor poles of stack B and C do not align. Now if phase A is de-energized and phase B is energized, rotor poles of stack B get aligned with the stator poles. Thus, rotor moves by one third of pole pitch. When B is de-energized and C excited, rotor further moves by one third of pole pitch so that rotor poles of stack C get aligned with the stator poles.

If m is the number of stacks i.e. phases and N be the rotor poles then the step angle is given by,

$\boldsymbol{\alpha_s = 360^o/mN_r}$

In the case discussed above, m = 3 and N = 12 hence the step angle is,

$\boldsymbol{\alpha_s = 360^o/(3 \times 12) = 10^o}$

An alternative design where the rotor stacks are aligned and stator stacks are offset also is used in practice.

**Advantages of Variable Reluctance Motor**

The variable reluctance stepper motor has following advantages.

1. High torque to inertia ratio
2. High rates of acceleration.
3. Fast dynamic response
4. Simple and low cost machine
5. Efficient cooling arrangement as all the windings are on stator and there is no winding on rotor.

**Hybrid Stepper Motor**

The hybrid stepper motor uses the principles of the permanent magnet and variable reluctance stepper motors. In the hybrid motors, the rotor flux is produced by the permanent magnet and is directed by the rotor teeth to the appropriate parts of the air gap. The permanent magnet is placed in the middle of the rotor. It is magnetized in the axial direction. Each pole of the magnet is surrounded with soft-toothed laminations.

The construction of hybrid stepper motor is shown in the Fig. 5.8.7

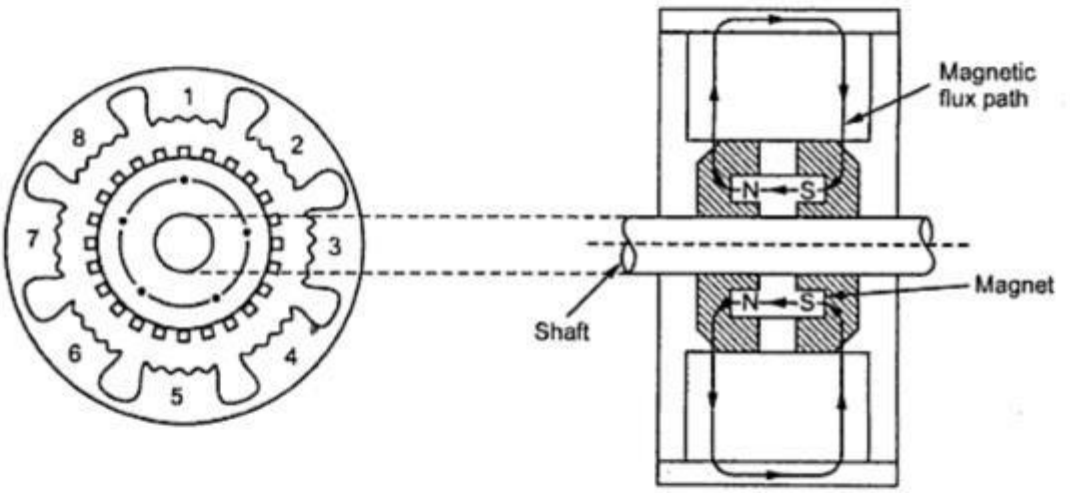


**Fig. 5.8.7 Hybrid Stepper**

The main flux path is from the north pole of the magnet, into the end stack, across the air gap through the stator pole, axially along the stator, through the stator pole, across the air gap and back the magnet south pole via other end stack.

There are usually 8 poles on the stator. Each pole has between 2 to 6 teeth. There is two phase winding. The coils on poles 1, 3, 5 and 7 are connected in series to form phase A while the coils on poles 2, 4, 6 and 8 are connected in series to form phase B. The windings A and B are energized alternately.

When phase A carries positive current, stator poles 1 and 5 become south and 3 and 7 become north. The rotor teeth with north and south polarity align with the teeth of stator pole 1 and 5 and 3 and 7 respectively. When phase A is de-energized and phase B is excited, rotor will move by one quarter of tooth pitch.

The torque in a hybrid motor is produced by interaction of the rotor and the stator produced fluxes. The rotor field remains constant as it is produced by the permanent magnet. The motor torque $T_m$ is proportional to the phase current.

Following are the main advantages of the hybrid stepper motor.

1. Very small step angles upto $1.8^o$
2. Higher torque per unit volume which is more than in case of variable reluctance motor.
3. Due to permanent magnet, the motor has some detent torque which is absent in variable reluctance motor.