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# Stepper Motor: A Review on Theory and Fundamentals

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**Abstract**

*Stepper motors are different from all other types of electrical drives and it is also called as step motor. Stepper motor basically follows the principle of discrete control pulse fundamental during its working this is the reason it rotates in discrete steps. On the other hand ordinary electrical a.c and d.c drives are analog in nature and rotate continuously depending on magnitude and polarity of the control signal received. The basic advantage of discrete nature of operation of a step motor makes it easy and suitable for directly interfacing with a computer and direct computer control. These motors are having wide applications in industrial control, specifically for CNC machines, where open loop control in discrete steps are acceptable. These motors can also be adapted for continuous rotation. In this paper we have discussed about the construction, principle, theory and operations of stepper motors.*

**Keywords:** *Stepper motor, electrical drives, discrete control, magnitude, computer control.*

## 1. Introduction

Stepper motor is a special type of electric motor that moves in precisely defined increments of rotor position (Steps). The size of the increment is measured in degrees and can vary depending on the application. Due to precise control, stepper motors are commonly used in medical, satellites, robotic and control applications[1]. There are several features common to all stepper motors that make them ideally suited for these types of applications. They are as under

**High accuracy:** Operate under open loop

**Reliability:** Stepper motors are brushless.

**Load independent:** Stepper motors rotate at a set speed under different load, provided the rated torque is maintained.

**Holding torque:** For each and every step, the motor holds its position without brakes.

Stepper motor requires sequencers and driver to operate. Sequencer generates sequence for switching which determines the direction of rotation and mode of operation.

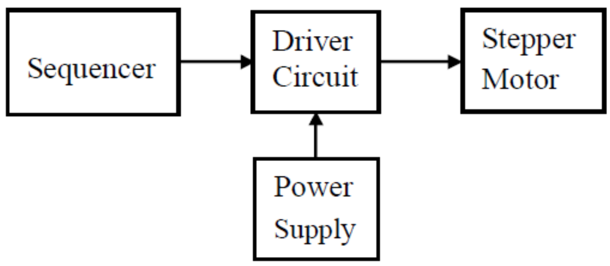


**Figure 1:** Block diagram of stepper motor system

## 2. Types of Stepper Motor

It can be classified into several types according to machine structure and principle of operation as explained by Kenjo in 1984. Basically there are three types

2.1 Variable Reluctance Motor (VRM)

2.2 Permanent Magnet Stepper Motor (PMSM)

2.3 Hybrid Stepper Motor (HSM)

### 2.1 Variable Reluctance Motor (VRM)

It consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current, the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles. Both the stator and rotor materials must have high permeability and be capable of allowing high magnetic flux to pass through even if a low magneto motive force is applied. When the rotor teeth are directly lined up with the stator poles, the rotor is in a position of minimum reluctance to the magnetic flux [2]. A rotor step takes place when one stator phase is deenergized and the next phase in sequence is energized, thus creating a new position of minimum reluctance for the rotor as explained by Kenjo in 1984. Cross section of variable reluctance motor is shown in Figure 2

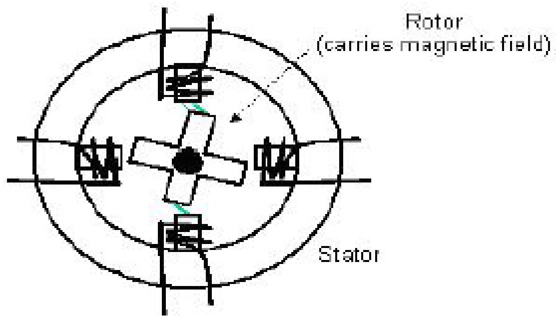


**Figure 2:** Cross section of variable reluctance motor

**2.2 Permanent Magnet Stepper Motor (PMSM)**

A stepper motor using a permanent magnet in the rotor is called a PMSM. The rotor no longer has teeth as with the VRM. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and, because of this the PM motor exhibits improved torque characteristics when compared with the VRM type [1,3]. An elementary PM motor is shown in Figure 3 which employs a cylindrical permanent magnet as the rotor and possesses four poles in its stator. Two overlapping windings are wound as one winding on poles 1 and 3 and these two windings are separated from each other at terminals to keep them as independent windings. The same is true for poles 2 and 4. The terminals marked Ca or Cb denotes common to be connected to the positive terminal of the power supply. When the windings are excited in the sequence A - B - A1 - B1 --- the rotor will be driven in a clockwise direction. The step length is 900 in this machine. If the number of stator teeth and magnetic poles on the rotor are both doubled, a two-phase motor with a step length of 450 will be realized.

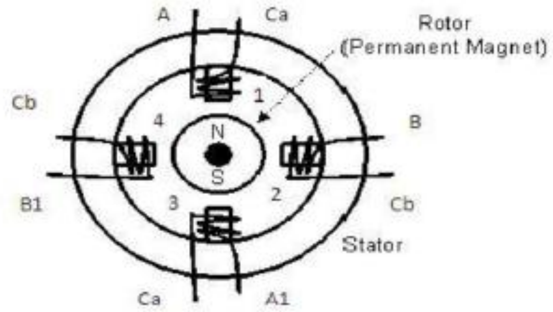


**Figure 3:** Cross section of permanent magnet stepper motor

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**2.3 Hybrid Stepper Motor (HSM)**

The term hybrid is derived from the fact that motor is operated with the combined principles of the permanent magnet and variable reluctance motors in order to achieve small step length and high torque in spite of motor size. Standard HSM have 50 rotor teeth and rotate at 1.8 degree per step. Figures 4 & 5 show a cross section and cut view of two phase HSM. The windings are placed on the stator poles and a PM is mounted on the rotor. The important feature of the HSM is its rotor structure. A cylindrical or disk-shaped magnet lies in the rotor core. Stator and rotor end-caps are toothed. The coil in pole 1 and pole 3 is connected in series consisting of phase A and poles 2 and 4 are for phase B. If stator phase A is excited pole 1 acquires north polarity while pole 2 acquires south polarity [4]. Pole 1 attracts the rotor's South Pole while pole 3 aligns with the rotors north pole.

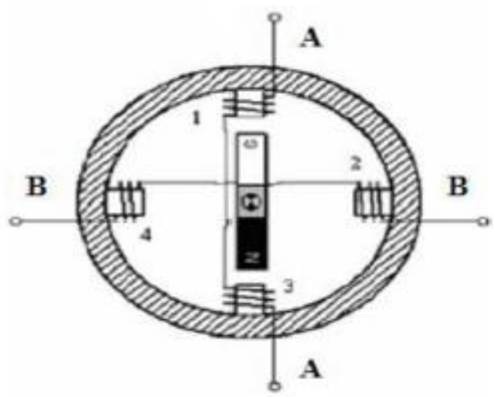


**Figure 4:** Cross section of hybrid stepper motor

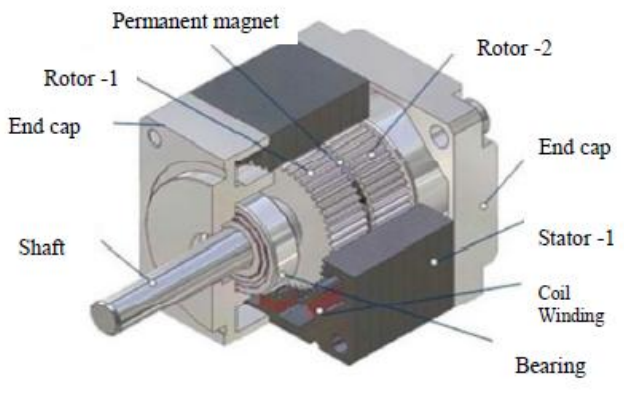


**Figure 5:** Cut view of hybrid stepper motor

When the excitation is shifted from phase A to phase B, in which case the stator pole 2 becomes north pole and stator pole 4 becomes south pole, it would cause the rotor to turn 900 in the clockwise direction. Again phase A is excited with pole 1 as south pole and pole 3 as north pole causing the rotor to move 900 in the clockwise direction. If excitation is removed from phase A and phase B is excited, then pole 2 produces south pole and pole 4 produces north pole resulting in rotor movement of 900 in the clockwise direction. A complete cycle of excitation for the HSM consists of four states and produces four steps of rotor movement. The excitation state is the same before and after these four steps and hence the alignment of stator/rotor teeth occurs under the same stator poles [4,5]. The step length for a HSM and angle through which the rotor moves for each step pulse is known as step angle.

**Table 1:** Mechanical properties of HSM

| Sr. No. | Motor Part | *Material* |
|---|---|---|
| 1. | Shaft | Non magnetic |
| 2. | Magnet | Neodymium iron boron (NdFe)/ |
| 3. | Rotor core | Steel sheet |
| 4. | Stator core | Steel sheet |
| 5. | Coil | Copper |

**Table 2:** Standard step angle of HSM

| Step Angle | *Step Per Revolution* |
|---|---|
| 0.9 | 400 |
| 1.8 | 200 |
| 3.6 | 100 |
| 7.2 | 50 |
| 15 | 24 |

Advantages and disadvantages of HSM are as follows:

a. Advantages

1. Step angle error is very small and non-cumulative.
2. Rapid response to starting, stopping and reversing.
3. Brushless design for reliability and simplicity.
4. High torque per package size.
5. Holding torque at standstill.
6. Can be stalled repeatedly and indefinitely without damage.
7. No extra feedback components required (encoders).

b. Disadvantages

1. Resonance
2. Vibration
3. Torque ripple.

## 3. Comparison of Stepper Motor

The choice of the type of the stepper motor depends on the application Selection of stepper motor depends on torque requirements, step angle and control technique [5].

**Table 3:** Comparison based on advantages and disadvantages

| *Motor Type* | *Advantages* | *Disadvantages* |
|---|---|---|
| Variable reluctance motor | 1. Robust- No magnet<br>2. Smooth movement due to no cogging torque<br>3. High stepping rate and speed slewing capability. | 1. Vibrations<br>2. Complex circuit for control<br>3. No smaller step angle<br>4. No detent torque |
| Permanent magnet stepper motor | 1. Detent torque<br>2. Higher holding torque<br>3. Better damping | 1. Bigger step angle<br>2. Fixed rate torque<br>3. Limited power output and size |
| Hybrid stepper motor | 1. Detent torque<br>2. No cumulative position error<br>3. Smaller step angle<br>4. Operate in open loop | 1. Resonance<br>2. Vibration |

**Table 4:** Comparison based on different phase properties

| *Type of Phases* | *Properties* |
|---|---|
| 2 Phase | 1. Simple driver circuit with low heat dissipation<br>2. Less step error compared to other phases<br>3. Higher accuracy due to more number of stator poles. |
| 3 Phase | 1.Torque ripple is more<br>2. Poor peak torque ratio<br>3. Power transistors are less |
| 4 Phase | 1. Low torque ripple<br>2. Good peak torque ratio |
| 5 Phase | 1. Lower torque ripple<br>2. More expensive controller. |

## 4. Selection of Motor

Stepper motor can be selected based on the following specifications:

**4.1** Electrical specifications include number of phases, step angle, winding voltage, winding resistance/ inductance, holding torque, pull-out torque, maximum slew rate, positional accuracy, temperature rise and power supply & drive circuits.

**4.2** Mechanical specifications includes shaft length & shape, motor length, shape of flange face, lead wire length and connector type.

## 5. Control of Step Motors

In many cases step motors are used for accurate positioning of tools and devices. Precision control over the rotation of the motor is required for these cases. Control of step motors can be achieved in two ways: open loop and closed loop. The open loop control is simpler and more widely used, such a scheme is shown schematically in Fig.13. The command to the pulse generator sets the number of steps for rotation and direction of rotation. The pulse generator correspondingly generates a train of pulse [6]. The Translator is a simple logical device and distributes the position pulse train to the different phases. The amplifier block amplifies this signal and drives current in the corresponding winding. The direction of rotation can also be reversed by sending a direction pulse train to the translator. After receiving a directional pulse the step motor reverses the direction of rotation.

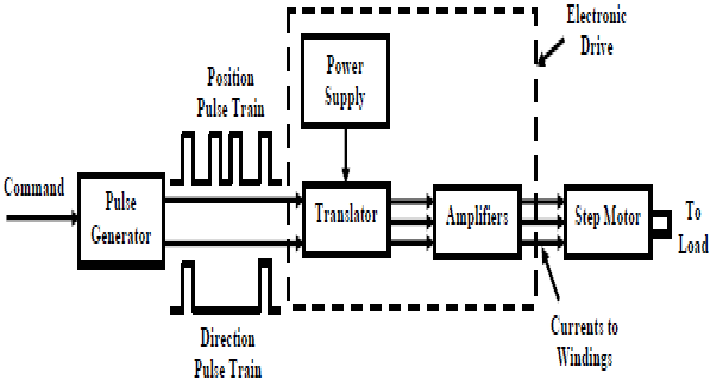


**Figure 6:** Open loop control of a stepper motor

The major disadvantage of the open loop scheme is that in case of a missed pulse, there is no way to detect it and correct the switching sequence. A missed pulse may be due to malfunctioning of the driver circuit or the pulse generator. This may give rise to erratic behaviour of the rotor. In this sequel the closed loop arrangement has the advantage over open loop control, since it does not allow any pulse to be missed and a pulse is send to the driving circuit after making sure that the motor has rotated in the proper direction by the earlier pulse sent. In order to implement this, we need a feedback mechanism that will detect the rotation in every step and send the information back to the controller. Such an arrangement is shown in Fig. 14. The incremental encoder here is a digital transducer used for measuring the angular displacement.

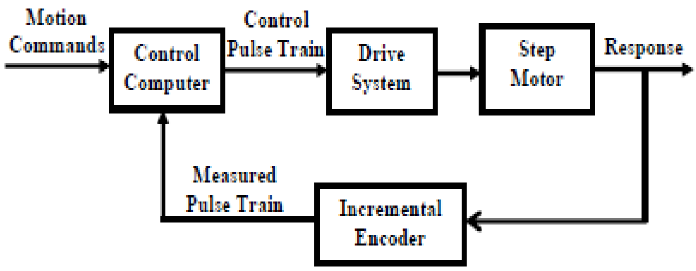


**Figure 7:** Feedback control of a stepper motor

## 6. Different Modes of Excitation

Different types of excitation schemes of the stepper motor are:

6.1 Full step
6.2 Half step
6.3 Micro step

### 6.1 Full step excitation mode

Full step excitation mode is achieved by energizing both windings while reversing the current alternately. Essentially one digital input from the driver is equivalent to one step. If two phases of the hybrid stepper motor are excited, the torque produced by the motor is increased, but the power supply to the motor is also increased. This can be an important consideration for applications, where the power available to drive the motor is limited.

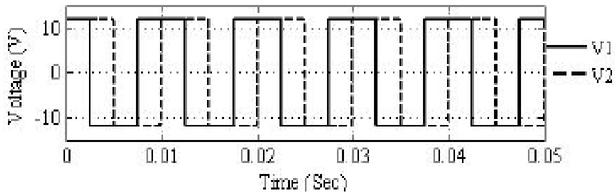


**Figure 8:** Full step excitation

### 6.2 Half step excitation mode

In half step mode, the drive alternates between two phases ON and a single phase ON. Half step sequence is shown in Figure 9. This increases the angular resolution, but the motor also has less torque (approx 70%) at the half step position (where only a single phase is ON) []. This may be mitigated by increasing the current in the active winding. The advantage of half step is that it reduces the vibration.

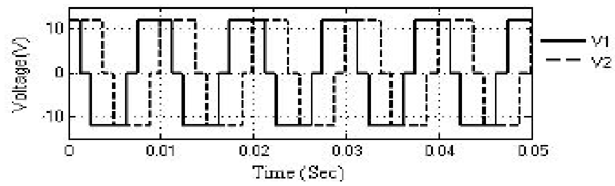


**Figure 9:** Half step excitation

### 6.3 Micro step excitation mode

The full step length of a stepper motor can be divided into smaller increments of rotor motion known as micro step by partially exciting several phase windings and micro step sequence is shown in Figure 10. Micro step is typically used in applications that require accurate positioning and a fine resolution over a wide range of speeds. The major disadvantage of the micro step drive is the cost of implementation due to the need for partial excitation of the motor windings at different current levels [7]. The merits as below

1. Micro step is a way of moving the stator flux of a stepper motor more smoothly than in full or half step drive modes.
2. Less vibration making noiseless step.
3. Makes smaller step angles and hence better positioning is possible.
4. In many applications micro step increases system performance.
5. Micro step diminish the oscillation.

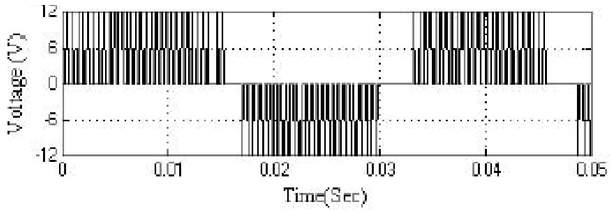


**Figure 10:** Micro step excitation

### 7. Characteristics of stepper motor

The construction features between the various types of SM are different, but their behaviors are similar. Some additional characteristic details about HSM are given below:

### 7.1 Static Characteristics

**1) Torque Angle curve:** The torque increases, almost sinusoidal with angle from equilibrium position as shown in Figure 11. S is the step angle (deg) and M is the maximum angle.

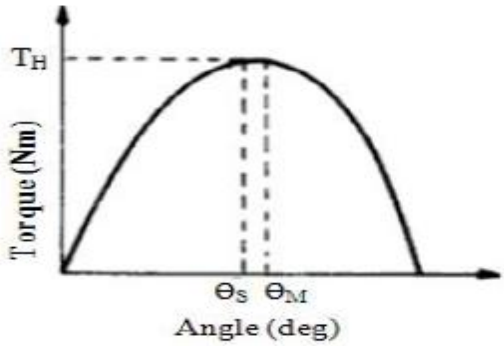


**Figure 11:** Torque- angle curve of stepper motor

**2) Holding torque (TH):** It is the maximum load torque which the energized step per motor can withstand without slip from position.

**3) Detent torque (TD):** It is the maximum load torque which an unenergized step per motor can withstand without slipping and is also known as cogging torque. It is due to residual magnetism and about 5 -10% of holding torque. Detent torque is typically fourth harmonic torque as shown in Figure 12.

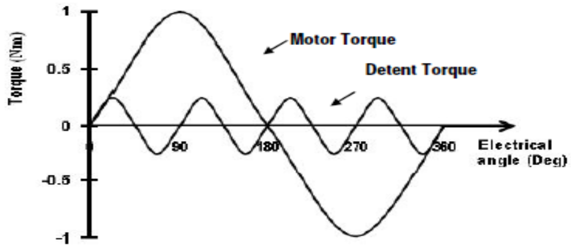


**Figure 12:** Torque and detent torque profiles of stepper motor

### 7.2 Dynamic characteristics

Torque versus speed relationship of a stepper motor is shown in Figure 13. The two curves are the pull-in torque and the pull-out torque curve and intermediately pull-out region is called the slewing curve.

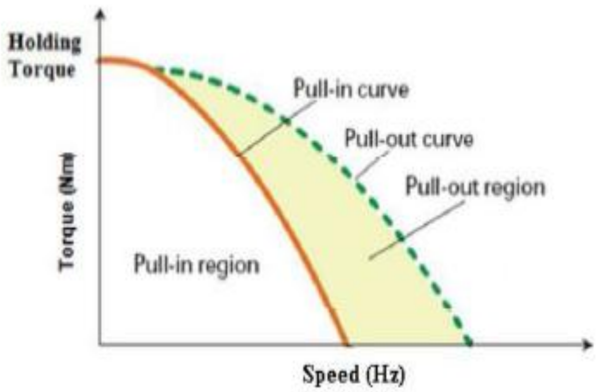


**Figure 13:** Torque Vs Speed curves of stepper motor

The pull-out torque versus speed curve represents the maximum friction-torque load that a stepping motor can drive before losing synchronism at a specified stepping rate with the magnetic field and motor stall. The pull-in torque versus speed curve represents the maximum frictional load at which the stepper motor can start without failure of motion when a pulse train of the corresponding frequency is applied. The pull-in torque depends on the inertia of the load connected to the motor. The pull-in region is defined as the maximum control frequency at which the unloaded motor can start and stop without losing steps. The pull-out region is defined as the maximum frequency at which the unloaded motor can run without losing steps and is alternatively called the maximum pull-out rate.

### 8. Conclusion

Step motors find wide applications as an electrical actuator. It can be readily interfaced with a computer and can be controlled for rotation at a very small angle, or a precisely determined speed. Step motors nowadays can deliver large torque also. These are the reasons step motors are gradually replacing conventional a.c. and d.c. motors in many cases. The constructions, principles of operation and driving schemes used for step motor have been discussed in this lesson. Both the open loop and close loop control schemes for position control of step motors have been elaborated. The torque characteristics of a step motor is distinctly different from conventional motors and nonlinear in nature. As a result it is not possible even to develop a linearised transfer function model of a step motor (a practise that is common for a.c. and d.c. servomotors). This is possibly a major hindrance for modelling and simulation of systems with step motor drives.

### References

1. C.W. de Silva: *Control Sensors and Actuators*, Prentice Hall, New Jersey, 1989
2. T. Wildi: *Electrical Machine Drives and Power Systems*
3. D. Austin, Generate stepper-motor speed profiles in real time, article in Embedded Systems Programming' January 2005.
4. D. W. Jones, Control of Stepper Motors, sections 5.2.10, 10.8, 10.9 and 10.10 of the *Handbook of Small Electric Motors* edited by W. H. Yeadon and A. W. Yeadon, McGraw-Hill, 2001.
5. P.C. Sen, "Principles of Electric Machines and Power Electronics," Second Edition, John Wiley & Sons, USA, 1997.
6. Guru Hiziroglu, "Electric Machinery and Transformers, Third Edition, Oxford University Press, USA, 2001.
7. Theodore Wildi, "Electrical Machines Drives, and Power Systems," Prentice Hall, Ohio, 2006.