

An Introduction to Stepper Motors

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Introduction:

A stepper motor is an electric motor that rotates in discrete step increments. The movement of each step is precise and repeatable; therefore the motor's position can be controlled precisely without any feedback mechanism, as long as the motor is carefully sized to the application. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. The position is known simply by keeping track of the input step pulses. It is one of the most versatile forms of positioning systems. They are typically digitally controlled as part of an open loop system, and are simpler and more rugged than closed loop servo systems.

Industrial applications include high speed pick and place equipment and multi-axis CNC machines, often directly driving lead screws or ballscrews. In the field of optics they are frequently used in precision positioning equipment such as linear actuators, linear stages, rotation stages, goniometers, and mirror mounts. Other uses are in packaging machinery, and positioning of valve pilot stages for fluid control systems. Commercially, stepper motors are used in floppy disk drives, flatbed scanners, computer printers, plotters, slot machines, image scanners, compact disc drives and many more devices.

Stepper Motor Advantages and Disadvantages

Advantages:

1. The rotation angle of the motor is proportional to the input pulse.
2. The motor has full torque at stand still (if the windings are energized)
3. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.
4. Excellent response to starting/stopping/reversing.
5. Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
6. The motor's response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
7. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
8. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1. Resonances can occur if not properly controlled.
2. Not easy to operate at extremely high speeds.

Fundamentals of operation:

Energizing a coil winding creates an electromagnetic field with a north and south pole. The magnetic field created by the winding will cause the magnetized rotor to align itself with the magnetic field, since unlike poles attract. The direction of the magnetic field can be altered to create rotation of the rotor.

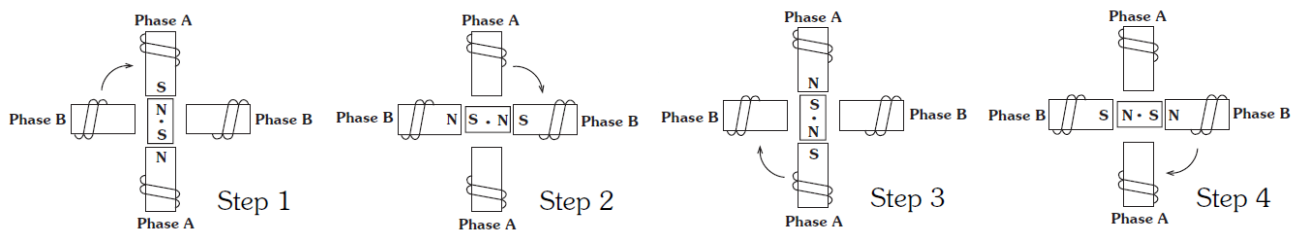


Fig 1. Step sequence for a two-phase motor (Wave Drive)

Fig 1. illustrates a typical step sequence for a two phase motor. In Step 1, phase A is energized; it locks the rotor in the position shown. In Step 2, phase A is turned off and phase B is turned on, the rotor rotates 90° clockwise. In Step 3, phase A is turned on again but with reversed polarity and in Step 4, phase B is turned on with reversed polarity. This sequence completes a full turn of the rotor. Repeating this sequence causes the rotor to rotate clockwise in 90° steps. This is the basic “one phase on” stepping.

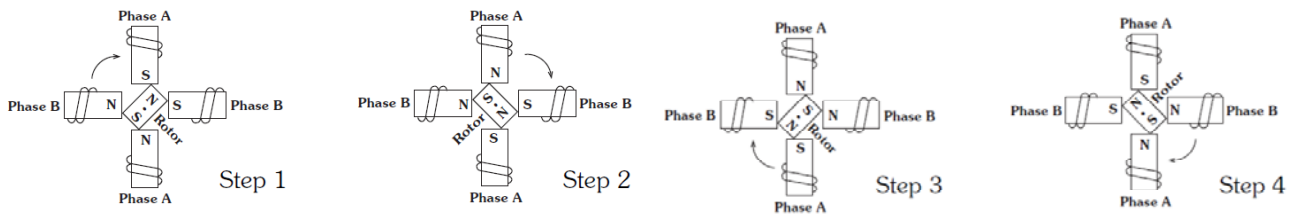


Fig 2. Step sequence for a two-phase motor (Full Step Drive)

Fig 2. Shows a more common “two phases on” stepping where both phases are always energized. The rotor in this stepping mechanism aligns itself between the poles. This stepping method gives 41.4% more torque than “one phase on” stepping but requires twice the input power.

Coil Windings and Stepping Mechanism:

There are two common winding arrangements for the electromagnetic coils: bipolar and unipolar (Fig 4).

The described stepping sequence utilizes the bipolar winding. Each phase consists of a single winding. By reversing the current in the windings, electromagnetic polarity is reversed. A unipolar stepper motor has one winding with center tap per phase. Each section of windings is switched on for each direction of magnetic field. Since in this arrangement a magnetic pole can be reversed without switching the direction of current, the commutation circuit can be made very simple for each winding.

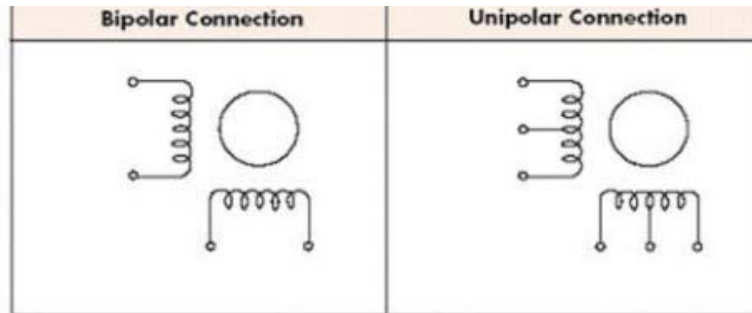


Fig 3. Two common winding arrangements

Aside from the “one phase on” (aka Wave Drive) and “two phases on” (aka Full Step Drive) stepping mechanisms, there are also Half Stepping (1 & 2 phases on) and Microstepping (Continuously varying motor currents). Half Stepping is a driving method that alternates between “two phase son” and “one phase on”. It therefore doubles the steps. Microstepping is a more advance stepping mechanism where the coil windings are no longer fully on or fully off. What is commonly referred to as microstepping is often "sine-cosine microstepping" in which the winding current approximates a sinusoidal AC waveform. Sine-cosine microstepping is the most common form, but other waveforms can be used. Theoretically, this method can position the rotor direction anywhere between phases. As the microsteps become smaller, motor operation becomes smoother. To better understand these mechanisms, Fig. 4 shows the drive currents on 4-phase unipolar stepper motor.

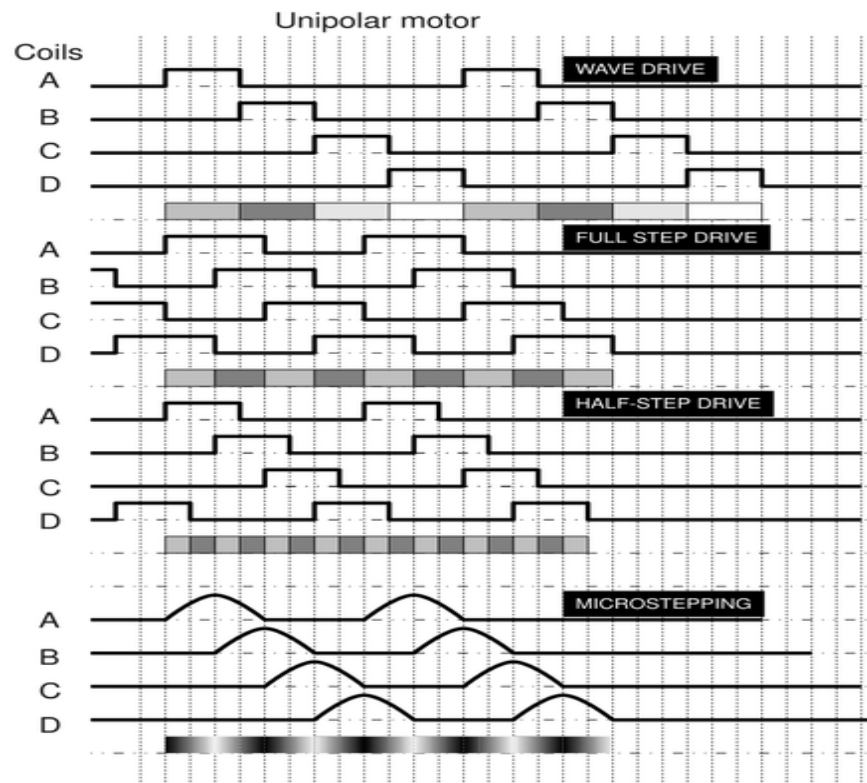


Fig. 4: Drive currents on 4-phase unipolar stepper motor.

Stepper motor Driving and Control:

Stepper motors require some external electrical components in order to run. These components typically include a power supply, logic sequencer, switching components and a clock pulse source to determine the step rate. Many commercially available drives have integrated these components into a complete package. Some basic drive units have only the final power stage without the controller electronics to generate the proper step sequencing. Common drives include Unipolar Drives, Bipolar Drives, L/R Drives, Chopper Drives, Microstepping Drives. This tutorial will not discuss in depth the driving of stepper motor.

Most commercially available stepper motor drivers takes pulses as inputs. The amount of rotation of the stepping motor is proportional to the number of pulses given to the driver. The relationship of the stepping motor's rotation and input pulses is expressed as follows.

$$\theta = \theta_s \times A \quad \left\{ \begin{array}{l} \theta : \text{Rotation angle of the motor output shaft [deg]} \\ \theta_s : \text{Step angle [deg/step]} \\ A : \text{Pulse number [pulses]} \end{array} \right.$$

The speed of the rotation is then proportional to the speed of the pulses. The relationship of the pulse speed (Hz) and motor speed (r/min) is expressed as follows:

$$N = \frac{\theta_s}{360} \times f \times 60 \quad \left\{ \begin{array}{l} N : \text{Speed of the motor output shaft [r/min]} \\ \theta_s : \text{Step angle [deg/step]} \\ f : \text{Pulse speed [Hz]} \\ \quad \text{(Number of pulses input per second)} \end{array} \right.$$

Understanding Stepper Motor Specifications and Speed-Torque Characteristics

Specifications

When choosing a stepper motor for an application, the specifications of the stepper motor must be fully understood. The following table shows a typical list of specification of stepper motors.

Model	Single-Phase 100-115 VAC	Single Shaft	RK566AAE	RK566AAE-N5
		Double Shaft	RK566BAE	RK566BAE-N5
	Single-Phase 200-230 VAC	Single Shaft	RK566ACE	RK566ACE-N5
		Double Shaft	RK566BCE	RK566BCE-N5
①→Maximum Holding Torque		N·m (oz·in)	0.83 (117)	3.5 (30 lb·in)
②→Rotor Inertia J		kg·m ² (oz·in ²)	280×10 ⁻⁷ (1.53)	280×10 ⁻⁷ (1.53)
③→Rated Current		A/Phase	1.4	
④→Basic Step Angle			0.72°	0.144°
⑤→Gear Ratio			—	1:5
⑥→Permissible Torque		N·m (lb·in)	—	3.5 (30)
⑦→Maximum Torque		N·m (lb·in)	—	7 (61)
⑧→Backlash		arc minute (degrees)	—	2 (0.034°)
⑨→Angular Transmission Error		arc minute (degrees)	—	5 (0.084°)
⑩→Permissible Speed Range		r/min	—	0~600
⑪→Power Source			Single-Phase 100-115 VAC+15% 50/60 Hz 4.5 A Single-Phase 200-230 VAC ^{+10%} _{-15%} 50/60 Hz 3.5 A	
⑫→Excitation Mode			Microstep	
Mass	Motor	kg (lb.)	0.8 (1.8)	1.5 (3.3)
	Driver	kg (lb.)	0.85 (1.9)	
Dimension No.	Motor		②	⑩⑥
	Driver		②②	

Fig 5. Typical specifications of stepper motors

1. Maximum Holding Torque

The holding torque is the maximum holding power (torque) the stepping motor has when power (rated current) is being supplied but the motor is not rotating (with consideration given to the permissible strength of the gear when applicable).

2. Rotor Inertia

This refers to the inertia of rotor inside the motor. This is necessary when the required torque (acceleration torque) for the motor needs is calculated.

3. Rated Current

The rated current is determined by motor temperature rise. It is the current value that can flow to the motor coils continuously at motor standstill.

4. Basic Step Angle

The step angle is the angular distance (in degrees) that the motor moves at the input of one pulse from the driver.

5. Gear Ratio

This is the ratio in rotation speed between the input speed from the motor and the speed of the gear output shaft.

6. Permissible Torque

The permissible torque represents the torque value limited by the mechanical strength of the gear when operated at a constant speed. The total torque including acceleration/deceleration torque should not exceed this value.

7. Maximum Torque

This is the maximum torque that can be used instantaneously (for a short time). During acceleration/deceleration, the motor can be operated up to this value.

8. Backlash

The play of gear output shaft when the motor shaft is fixed. When positioning in bi-direction, the positioning accuracy is affected.

9. Angular Transmission Error

Angular transmission error is the difference between the theoretical angle of rotation of the output shaft, as calculated from the input pulse count, and actual angle of rotation.

10. Permissible Speed Range

This is the rotation speed that the motor can be operated at with the gear output shaft.

Torque vs Speed Characteristics

The Speed-Torque graph indicates the characteristic relationship between the speed and torque when the stepping motor is driven. The torque vs speed characteristics are the key to selecting the right motor and drive method for a specific application. These characteristics are dependent upon (change with) the motor, excitation mode and type of driver or drive method. On the graph, the horizontal axis is the speed at the motor's output shaft while the vertical axis is the torque.

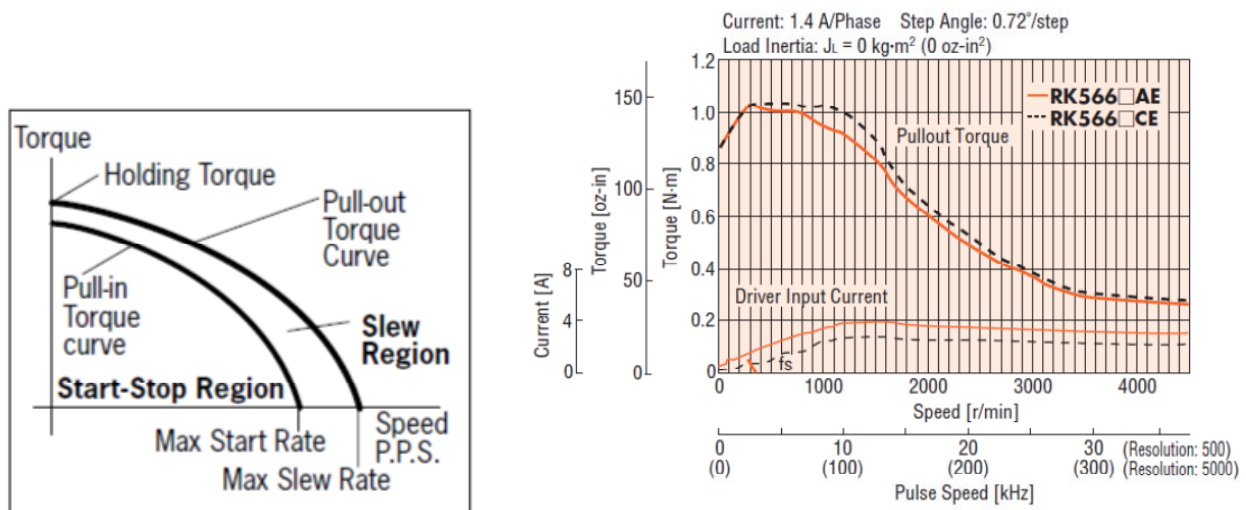


Fig. 6 Typical torque-speed characteristics

1. Maximum Holding Torque

The holding torque is the maximum holding power (torque) the stepping motor has when power (rated current) is being supplied but the motor is not rotating (with consideration given to the permissible strength of the gear when applicable).

2. Pull-in Curve

The pull-in curve defines a area referred to as the start stop region. This is the maximum frequency at which the motor can start/stop instantaneously, with a load applied, without loss of synchronism.

3. Pullout Torque Curve

Pullout torque is the maximum torque that can be output at a given speed. When selecting a motor, be sure the required torque falls within this curve.

4. Maximum Starting Frequency

This is the maximum pulse speed at which the motor can start or stop instantaneously (without an acceleration or deceleration time) when the frictional load and inertial load of the stepping motor are 0. Driving the motor at greater than this pulse speed requires gradual acceleration or deceleration. This frequency drops when there is an inertial load on the motor.

5. Maximum Slew Rate

The maximum operating frequency of the motor with no load applied.

References:

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