Hybrid Stepper Motor Engineering

Hybrid stepper motors provide excellent performance in areas of torque, speed, and step resolution. Typically, step angles for a hybrid stepper motor range from 200 to 400 steps per revolution. This type of motor provides a combination of the best features available on both the PM and VR types of stepper motors.

Permanent magnet and hybrid stepper motors are two types of the most commonly used stepper motors. Sometimes, it's difficult to know which type of stepper motor is the best choice for your project. For this reason, we have provided detailed information to help engineers determine the best motor for their application requirements. Follow our convenient step motor guide to learn the basics of hybrid stepper motor engineering and find out why this type of motor can be so beneficial to your project.

By following the links below, you'll find information on the various aspects of a hybrid stepper motor. The "General Specs" section provides quick reference to the specifications of the hybrid stepper motor in a table format. The "Construction and Operating Theory" section discusses why permanent magnets are imperative for efficient and effective functioning of a step motor. The "Full, Half & Microstepping" section explains these three commonly used excitation modes for step motors. You'll find additional details in the "Vibration and Resonance," "Drivers and Winding Configuration", "Winding Diagram and Switching Sequence", and "Torque and Speed Relationship" sections as well. Choose your subject of interest and start learning more about hybrid stepper motor engineering now.

General Specification

Glossary	Specification
Step Accuracy	±5%
Temperature Rise	80℃MAX
Ambient Temperature Range	-20℃~+50℃
Insulation Resistance	100MΩMIN .DC 500V
Dielectric Strength	AC 500V 1min
Radial Play	20μmMAX. (at 4.4N { 450gf } [Load])
End Play	80μmMAX. (at 4.4N { 450gf } [Load])

The Permanent Magnet in Motors – Construction and Operating Theory

Permanent magnets are a critical element to virtually any modern step motor. Read on to learn how a magnet, properly used, can convert electrical power to physical power and how such a magnet, whether in a PM motor or a hybrid motor, makes a step motor highly efficient and effective.

Hybrid Motor

Figure 1a depicts a 1.8° hybrid step motor. The rotor contains a permanent magnet similar to those found in permanent magnet step motors. Hybrid rotors are axially magnetized, one end polarized north and the other polarized south. Both the rotor and the stator assemblies of hybrid motors have tooth-like projections. These “teeth” align in various configurations during rotation.

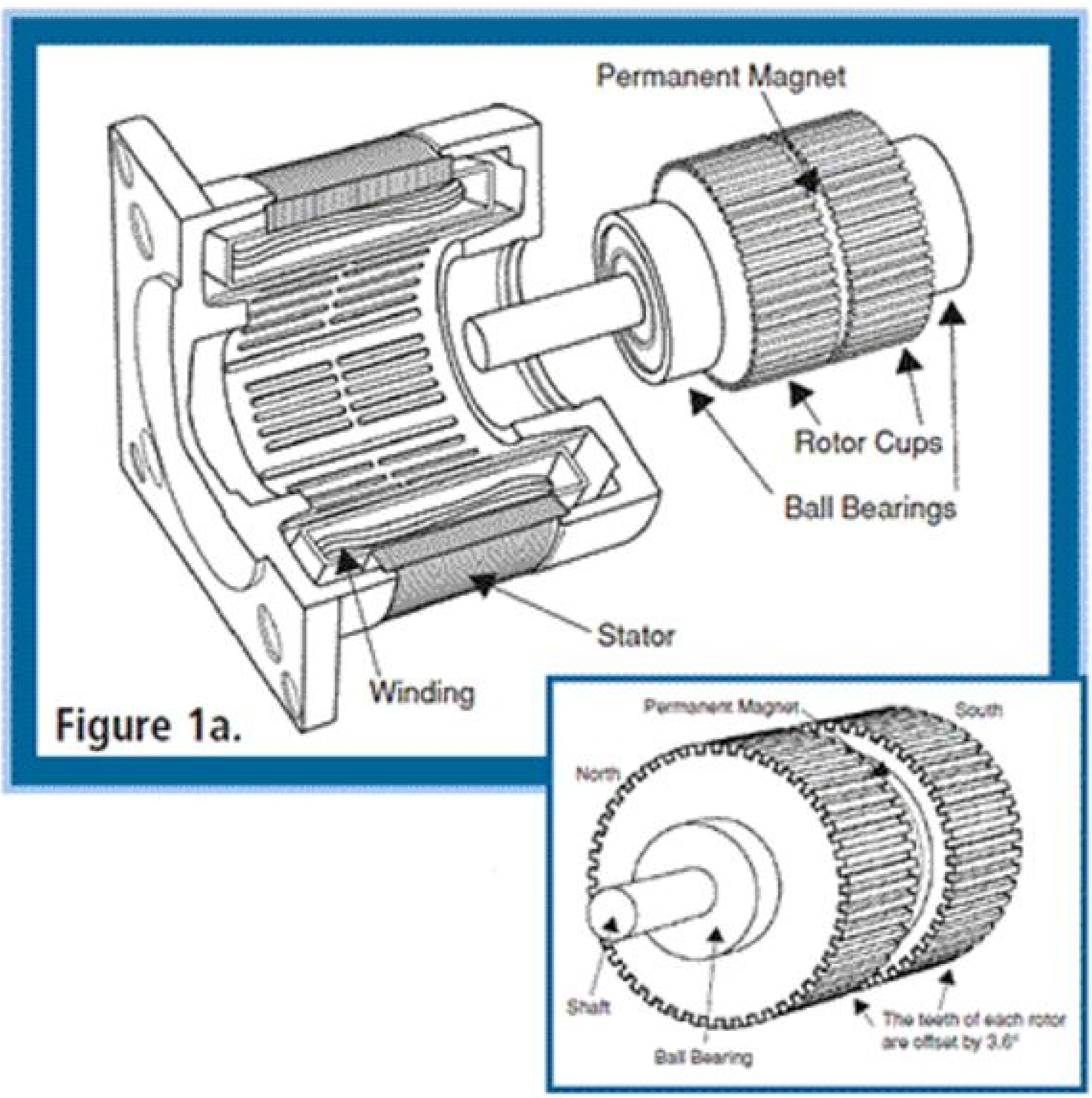


Figure 1a.

To understand the rotor's interaction with the stator, examine the construction of a 1.8° (the most common resolution) hybrid step motor. First, the rotor is composed of two 50-tooth rotor cups enclosing a permanent magnet. The two cups are oriented so that the teeth of the top cup are offset to the teeth of the bottom cup by 3.6°. Second, the stator has a two-phase construction. The winding coils, 90° apart from one another, make up each phase. Each phase is wound so that the poles 180° apart are the same polarity, while the poles 90° apart are the opposite polarity. When the current in a phase is reversed, so is the polarity, meaning that any winding coil can be either a north pole or a south pole.

As shown in fig. 1b below, when phase A is energized, the windings at 12 o'clock and 6 o'clock are north poles and the windings at 3 o'clock and 9 o'clock are south poles. The windings at 12 and 6 would attract the teeth of the magnetically south end of the rotor, and windings at 3 and 9 would attract the teeth of the magnetically north end of the rotor. The desired direction of travel determines the next set of poles to be energized.

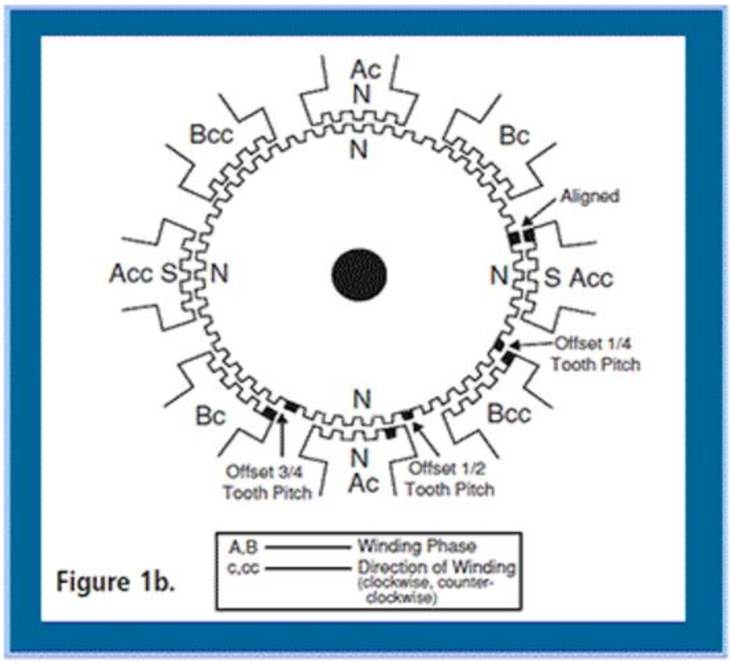


Figure 1b.

The driver controls this phase sequencing. Because there are 50 teeth on the rotor, the pitch between teeth is 7.2°. As the motor moves, some rotor teeth are in alignment with the stator teeth. The other rotor teeth are out of alignment with the stator teeth by 3/4, 1/2 or 1/4 of a tooth pitch. When the motor takes a step, it will move to the next closest position where the rotor and stator teeth are aligned. The rotor will move 1/4 of 7.2°. The motor will move 1.8° with each step.

The motor will move 1.8° with each step.

Permanent Magnet Motor

Figure 2 depicts a permanent magnet type motor, or "PM" motor. The rotor contains a permanent magnet, giving PM type motors their name. Permanent magnet step motors work on the same principles as hybrids but use a slightly different geometry.

The main distinction between a permanent (PM) magnet motor and a hybrid motor is the presence of the tooth-like projections that the hybrid uses to supplement the magnet action and help with rotation. The predecessor of the permanent magnet motor was the variable resistance motor, which did not use permanent magnets to turn the motor and used solely the teeth to achieve the rotating action of the motor. Variable resistance motors were largely replaced when it was realized that a magnet could do the work of the teeth. The realization that using both a magnet and teeth could yield even more accurate results, leading to the hybrid motor, a hybrid of permanent and variable type motors. All motors with permanent magnets have their advantages. The PM motor can be highly effective and is a good choice for people who like permanent magnets but don't need the precision accuracy and expense of a hybrid.

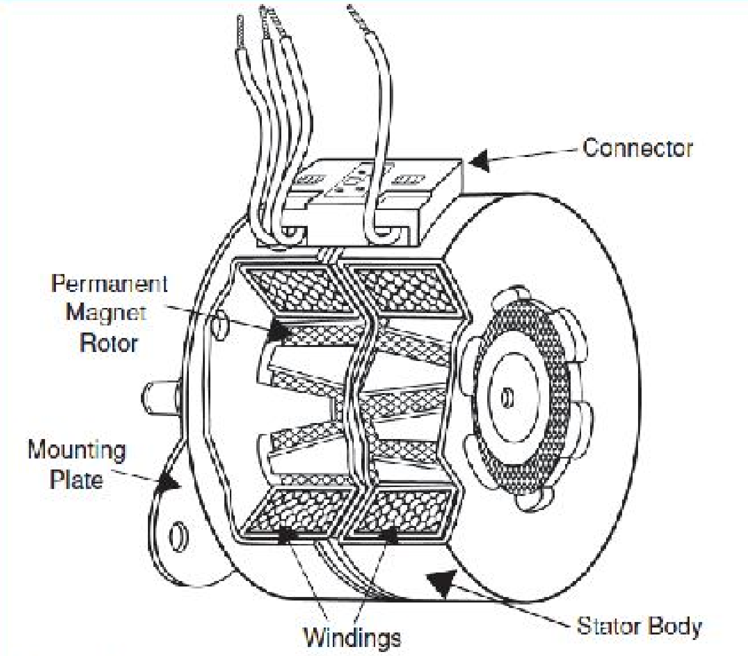


Figure 2.

Rotor/Stator Alignment

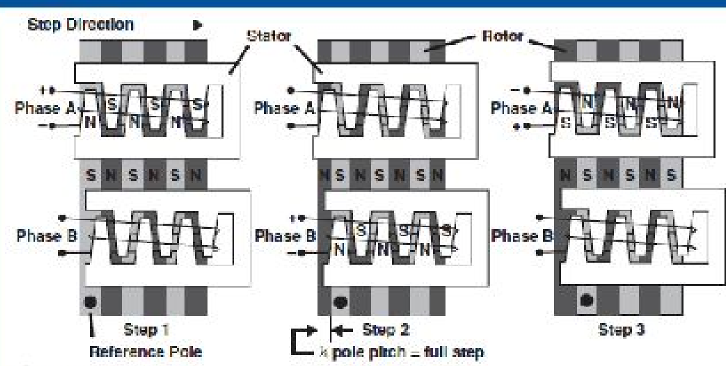


Figure 3.

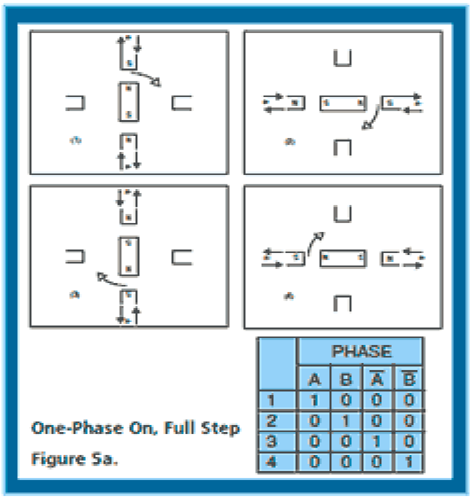
PM rotors are radially magnetized, north and south poles alternating along the circumference of the rotor. A pole pitch is the angle between two poles of the same polarity, north to north or south to south. Both the rotor and the stator assemblies of PM motors are smooth.

The stator sections of the A phase and the B phase are mechanically offset by one quarter pole pitch. Each phase's stator section has projections offset by one half of a pole pitch. As current is passed through the windings a rotating magnetic field is established. The rotor of the permanent magnet motor will move in synchronism with this rotating field. See Fig. 3.

Microstepping, Full Step & Half Step

There are three commonly used excitation modes for step motors; these are full step, half step and microstepping.

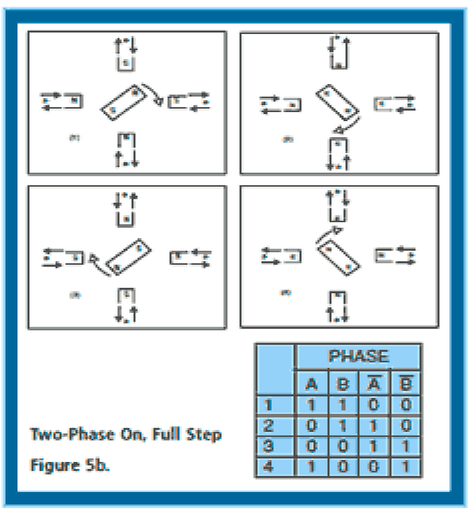
In full step operation, the motor moves through its basic step angle, i.e., a 1.8° step motor takes 200 steps per motor revolution. There are two types of full step excitation modes. In single phase mode, also known as "one-phase on, full step" excitation, the motor is operated with only one phase (group of windings) energized at a time. This mode requires the least amount of power from the driver of any of the excitation modes. See Fig. 5a.



	PHASE			
	A	B	$\bar{A}$	$\bar{B}$
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1

One-Phase On, Full Step

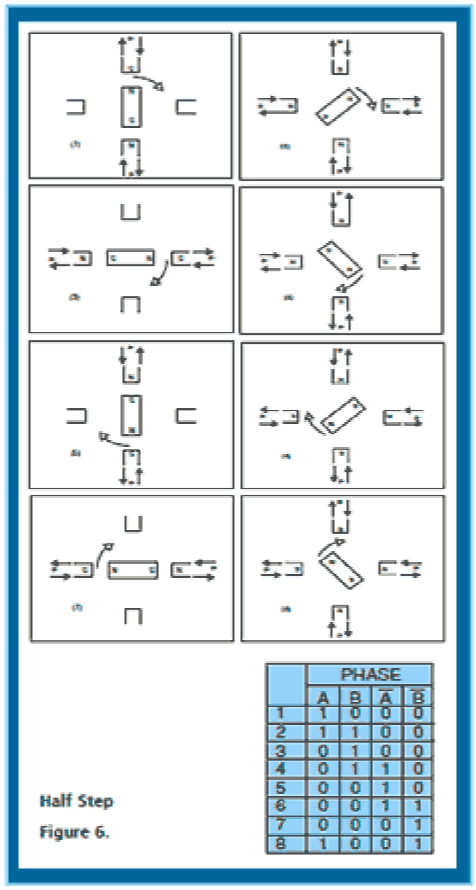
Figure 5a.



	PHASE			
	A	B	$\bar{A}$	$\bar{B}$
1	1	1	0	0
2	0	1	1	0
3	0	0	1	1
4	1	0	0	1

Two-Phase On, Full Step

Figure 5b.



	PHASE			
	A	B	$\bar{A}$	$\bar{B}$
1	1	0	0	0
2	1	1	0	0
3	0	1	0	0
4	0	1	1	0
5	0	0	1	0
6	0	0	1	1
7	0	0	0	1
8	1	0	0	1

Half Step

Figure 6.

Microstepping

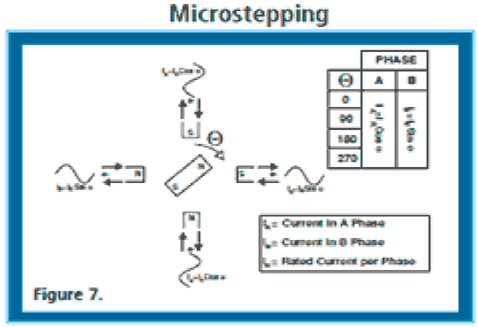


Figure 7.

More on Microstepping

What is the goal of microstepping? Essentially, the goal of this process is to create a motor that runs as smoothly as possible. Due to the nature of step motors, their rotation is not entirely smooth, as the motor is moving “step by step”. Of course, these steps are designed to be moved through rather quickly, so there is usually no particularly detrimental effect on performance, but for those who require smoother resolution, the full step stepper motor may not be quite what is needed.

This is where the microstepper controller comes in. The microstepper controller is a driver that sends pulses to the motor in an ideal waveform for fluid rotation. The idea is for the driver to send current in the form of sinewaves. Two sinewaves that are 90 degrees out of phase is the perfect driver for a smooth motor. If two step coils can be made to follow these sinewaves, it results in a perfectly quiet, smooth motor with no detectable “stepping”.

This is because, in such a case, the two waves work together to keep the motor in smooth transition from one pole to the other. When the current increases in one coil, it decreases in the other, resulting in smooth step advancing and continuous torque output at each position. A normal bipolar stepper driver does not have these smooth wave forms. As a result, the motor transitions are not as smooth. In most applications requiring stepper motors, assuming an ideal driver situation. In reality, the wave forms can deviate significantly, resulting in what is called “resonance”, which is a phenomenon that creates problems for mechanical systems. Microstepping reduces resonance issues by controlling the waves so that this type of deviation does not occur.

A microstepper controller subdivides the motor step angle into multiple divisions to improve control over the motor. This allows for more refined motor work that requires greater motor resolution. Keep in mind that while a microstepper controller may make this refined motion possible, there may be physical limitations in your machinery that affect the motion of the motor in your particular application. That being said, if you are doing precise work for which the threat of resonance is an issue, you definitely want to be looking into the use of a microstepping controller for your motors.

Vibration and Resonance

When a step motor makes a move from one step to the next, the rotor doesn't immediately stop.
The rotor actually passes up its final position (overshoots), then goes past it in the opposite direction (undershoots), then moves back and forth until it finally comes to rest.

We call this "ringing," and it occurs every time the motor takes a step. In most cases, the
motor is commanded to move to the next step before it comes to a rest.

Unloaded, the motor exhibits a fair amount of ringing. This ringing translates into motor vibration. The motor will often stall if it is unloaded or under-loaded, because the vibration is high enough to cause the motor to lose synchronism. Loading the motor properly will dampen these vibrations. The load should require somewhere between 30% to 70% of the torque that the motor can produce, and the ratio of load inertia to rotor inertia should be between 1:1 and 10:1. For shorter, quicker moves, the ratio should be closer to 1:1 to 3:1.

A step motor will exhibit much stronger vibrations when the input pulse frequency matches the natural frequency of the motor. This phenomenon is called resonance. In resonance, the overshooting and undershooting become much greater, and the chance of missing steps is much higher. The resonance range may change slightly due to the damping effect of the load's inertia.

Troubleshooting Vibration and Resonance

A two-phase step motor can only miss steps in multiples of four full steps (equivalent to one tooth pitch or pole pitch). If the number of missing steps is a multiple of four, vibration or overloading may be causing a loss of synchronism. If the number of missing steps is not a multiple of four, an electronics problem is most likely the issue. There are a number of ways to get around resonance. The easiest way is to avoid the resonant speed range altogether. The resonant frequency for a two-phase motor is around 200pps; motors can be started at speeds above the resonant range. Accelerating quickly through the range is recommended if the motor must be started at a speed below the resonance range.

Half stepping and microstepping are also effective means of reducing vibration. Both methods reduce the size of each motor step. When the motor step angle is made smaller, the motor will vibrate less. The motor does not have to travel as far for each step, and less energy will be wasted in overshooting and undershooting. Step motors react differently to different loads. Make sure that the motor is sized properly to the load.

Step Motor Driver and Winding Configurations

Drivers

The basic function of a motor driver is to provide the rated current to the motor windings in the shortest possible time. Driver voltage plays a large part in a step motor's performance. Higher voltage forces current into the motor windings faster, helping to maintain high speed torque.

Two of the most commonly used drivers for step motors types of step motor driver are the following:

Constant current drivers are also known as PWM (pulse width modulated) or chopper drives. In this type of driver, the motor current is regulated by switching voltage to the motor on and off to achieve an average level of current. These drivers operate using a high voltage supply, generating a high driver voltage to motor voltage ratio, giving the motor improved high speed performance.

Constant voltage drivers are also known as, L/R or resistance limited (RL) drivers. In this type of driver, the amount of current a step motor receives is limited only by the resistance/impedance of its windings. For this reason, it is important to match the motor's rated voltage to the voltage of the driver. Constant voltage drivers work best in low speed and low current applications. They become inefficient at high speeds and high current levels. In certain situations, resistors may be placed in series with the motor's windings to allow the motor to be operated using a driver voltage larger than the motor's rated voltage to increase performance at higher speeds.

Driver & Winding Configurations

Step motor drivers can be divided into two types, unipolar and bipolar. All 6 and 8 lead wire motors manufactured by NMB can be configured to be driven by either a bipolar or a unipolar driver, however, 4 lead wire motors can only be run by bipolar drivers.

When trying to decide between a bipolar motor driver and a unipolar motor driver, it's important to have a basic sense of the distinction between each type of motor. In a bipolar stepper motor, there are usually four leads, two pairs of two, with a coil powered by each pair. In a unipolar stepper motor, you normally have two sets of three leads, with each set of three powering a coil with a center tap. In some cases you will find five leads, where the two common center taps are combined. Bipolar stepper motors tend to be less expensive, but unipolar motors perform better at high speeds. Therefore, which type of motor driver and motor you should use will depend largely on the job you need performed. In fact, some of the applications in your project may be better suited to unipolar configurations while others will work best with bipolar considerations. For maximum efficiency, you will want to know all the major distinctions between bipolar and unipolar configurations before choosing a motor and motor driver. Here are some more of the most important differences you will want to consider when selecting your driver and motor.

*Unipolar drivers*can send current through a motor's windings in only one direction. Unipolar drivers tend to achieve better high-speed performance.

Bipolar drivers can send current through a motor's windings in both directions. Step motors can be connected to these drives in several different ways to get different motor performance, making a bipolar drive much more flexible than a unipolar drive.

In a *unipolar winding configuration*, only half the coils of each winding are used at a time. Energizing half of the coils is beneficial because it reduces the winding's inductance. Inductance is an electrical property that fights changes in current flow, particularly at higher speeds. The unipolar winding configuration tends to give better high-speed performance. The disadvantage of this type of configuration is that at lower speeds it tends to give less torque than configurations that use the entire winding. See Fig. 4a.

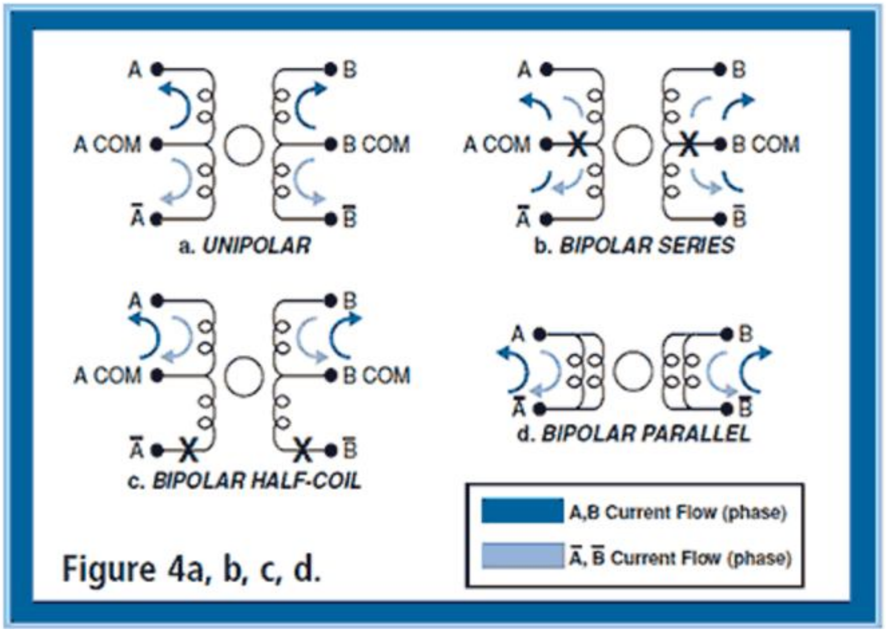


Figure 4a, b, c, d.

In a *bipolar series winding configuration*, both halves of the phase are connected in series. Since the full coil is used, the same motor will produce 40% more torque in the low to mid speed range. Unfortunately, this configuration has four times the inductance of the same motor operated in the unipolar configuration. Although the motor has good low speed torque, the torque will drop off rapidly at high speeds. See Fig. 4b.

A *bipolar half coil winding configuration* can be used to achieve unipolar performance with a bipolar drive. In this configuration, the motor's inductance and low speed torque are less than those in the bipolar series configuration. As in the unipolar configuration, the half coil configuration tends to give better performance at higher speeds. Both 6 and 8 lead wire motors can be connected in the bipolar half coil configuration. See Fig. 4c.

A *bipolar parallel winding configuration* can only be achieved using an 8 lead wire motor or by internal wiring. In a parallel configuration, one half of the winding phase is placed in parallel with the other half. This allows the full winding to be used while keeping the inductance low. This combination allows the bipolar parallel configuration to produce 40% more torque than the unipolar winding configuration while still performing well across a wide range of speeds. However, due to the parallel configuration, the winding resistance is halved and the motor will require 40% more current than the same motor run in a unipolar configuration to produce this increased torque. See Fig. 4d.

Stepper Motor Windings and Winding Configurations

A stepper IC controller, a device which can include commutation logic, an inverter, and a power supply on its chip, is often what is used to control a stepper motor. The current is usually switched with a stepper motor driver IC. These motors allow fairly exact motion and are appropriate for a great many applications. However, how the current supplied by the driver will work with the stepper is dependent upon the winding configuration.

About Stepper Motors and Stepper Motor Windings

A stepper motor usually has four, six, or eight wires with the appropriate number of independent windings. A four lead wire motor is run by a bipolar driver, while the six or eight wire motor can be run by unipolar or bipolar drivers.

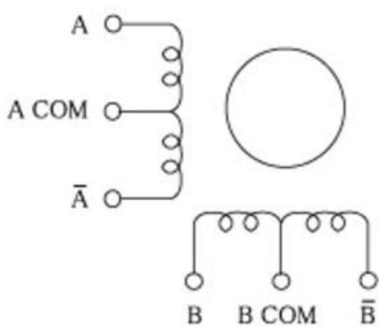
The effect of the unipolar or bipolar driver on the stepper motor is largely manifested in the motor windings. With a unipolar driver, as the name would imply, the current can only be sent through the windings in one direction. This means less flexibility in how you can use the driver, but it offers an advantage when it comes to performance at high speeds. In contrast, the bipolar driver can send current through the windings both ways. This means more ways to connect stepper motors to such a driver, but creates a drop in high speed performance compared to the unipolar driver.

Why is the unipolar winding setup more effective at high speeds? The reason is that only half of the winding coils are used at a time. This reduces inductance, and it is inductance that resists changes in the flow of current at high speeds. However, at lower speeds, you will get less torque from this configuration, so you should use unipolar winding configurations specifically for motors that will be run at high speeds most or all of the time. On the other hand, in the bipolar winding configuration, the full coil is used. This produces more torque at lower speeds, but also causes much more inductance than the motor would experience in the unipolar configuration. This type of setup is much more effective when you have one or multiple motors that will be operating primarily at low to moderate speeds.

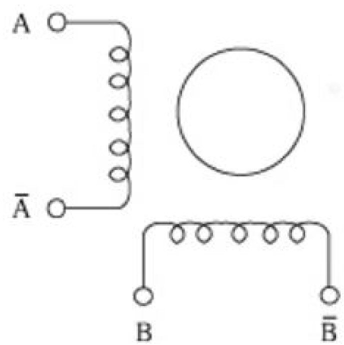
To improve higher speed motor performance with a bipolar winding configuration, you can create a half coil winding configuration with a bipolar driver for a six or eight lead wire motor. This will reduce inductance and improve high speed performance. Another option for keeping the inductance down at high speeds is to create a bipolar parallel winding configuration with an eight lead wire motor. In this configuration, you can make use of the entire winding without seeing a commensurate increase in inductance. The main downside to this type of configuration is that you need an increased amount of current relative to a similar motor run with unipolar winding configuration to get the result you are looking for. Below is a basic winding diagram and switching sequence to give you a visual idea of stepper motor windings.

Winding Diagram

Unipolar



Bipolar



Switching Sequence

Uipolar

Dual

CW Rotation

step	A	B	$\bar{A}$	$\bar{B}$	AB -COM
1	–	–	0	0	+
2	0	–	–	0	+
3	0	0	–	–	+
4	–	0	0	–	+

CW Rotation Facing Mounting End

Bipolar

Dual

CW Rotation

step	A	B	$\bar{A}$	$\bar{B}$
1	+	+	–	–
2	–	+	+	–
3	–	–	+	+
4	+	–	–	+

CW Rotation Facing Mounting End

It should be apparent that the configuration of a stepper motor has applications not only for major industrial projects, but for smaller projects as well. Here are some fun and interesting uses for a stepper, many of which are low speed applications that can benefit from the bipolar winding configuration.

Robot: If you've ever considered building your own robot, pick up some stepper motors. You can use them to create a simple mechanism that can walk, change direction, and pick things up. You can power robot wheels with a motor that generates about 5-10 volts. Keep in mind that you'll want to keep the robot as light as possible, and figure on twice as much torque as you expect you will need.

Automatic Fish Feeder: Take the hassle out of caring for fish by integrating a stepper motor into a device that feeds your fish on your command. Not only will this allow you to go on vacation without having strangers in your home to take care of your fish, it's a cool gadget that can impress friends and serve as a fun conversation piece.

Camera Panning: Having a camera in a room for security doesn't do you that much good if it's only fixed on a single point. This is an area where the right stepper motor can really come in handy. The rotary action and precise angles of a stepper motor are ideal for operating a camera panning system to capture all the action that is happening in a given room.

Turntable: If you're a disc jockey or a vinyl record enthusiast, consider building your own turntable. A stepper motor can provide the rotating action you need to get your turntable moving.

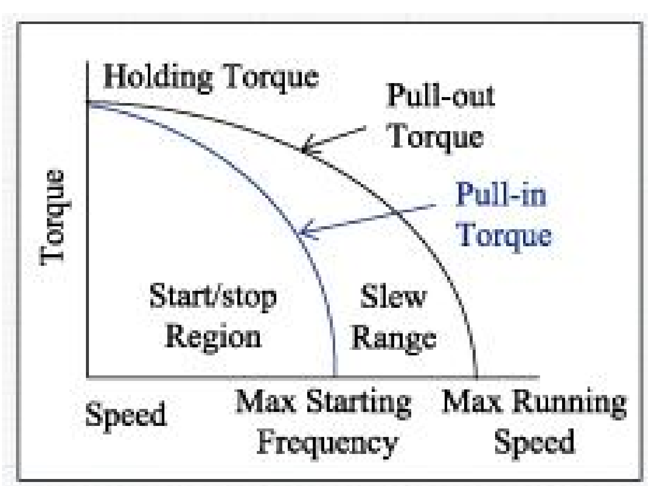
You clearly don't need to understand all of the inner workings of a stepper motor or stepper motor windings in order to use and benefit from this type of motor. Knowing these inner workings, however, can help you get a better understanding of what kind of motor you will need, whether or not a stepper motor is the best bet for your application, and what you can do with this kind of motor to use it most effectively.

Stepper Motor Speed and Torque Relationship

What is Torque for a Stepper Motor?

When you're looking for a stepper motor, you'll often see statistics related to torque. Torque information isn't the only thing you'll be looking at when it comes to selecting your motor, but it is important. Generally, you'll be looking at information regarding how much torque the stepper produces under certain conditions. Before you start examining the different types of torque and the relationship of torque to stepper motor speed, it's important to understand exactly what torque is.

Simply put, torque is rotational force; that is, it's the force used to turn things. This force is measured in pound-feet in the English system, but the international standard is Newton-Meters (or in the case of a small stepper motor, milliNewton Meters (mNm)), meaning the amount of force applied in Newtons times the distance to the center of the rotating object in meters.



Holding Torque - amount of torque that the motor produces when it has rated current flowing through the windings but the motor is at rest.

Detent Torque - amount of torque that the motor produces when it is not energized. No current is flowing through the windings.

Pull-in Torque Curve - Shows the maximum value of torque at given speeds that the motor can start, stop or reverse in synchronism with the input pulses. The motor cannot start at a speed that is beyond this curve. It also cannot instantly reverse or stop with any accuracy at a point beyond this curve.

Stop / Start Region - area on and underneath the pull-in curve. For any load value in this region, the motor can start, stop, or reverse "instantly" (no ramping required) at the corresponding speed value.

Pull-out Torque Curve - Shows the maximum value of torque at given speeds that the motor can generate while running in synchronism. If the motor is run outside of this curve, it will stall.

Slew Range - the area between the pull-in and the pull-out curves, where to maintain synchronism, the motor speed must be ramped (adjusted gradually).

Performance Factors

Torque is proportional to the winding current and the number of turns of wire. To increase torque by 20%, increase the current by about 20%. To decrease the torque by 50%, reduce the current by 50%. Because of magnetic saturation, there is no advantage to increasing the current to more than 2 times the rated current and doing so may damage the motor.

Inductance reduces a stepper motor's high speed torque performance. Inductance is the reason all motors eventually lose torque at higher speeds. Each stepper motor winding has a certain value of inductance and resistance.

The "electrical time constant" is the amount of time it takes a motor coil to charge up to 63% of its rated value. If a stepper motor is rated at 1 amp, after one time constant, the coil will be at 0.63 amps, giving the motor about 63% of rated torque. After two time constants, the current will increase to 0.86 amps, giving the motor about 86% of rated torque.

$$t = L/R$$

Inductance "L" (mH), divided by resistance "R" (&), gives the electrical time constant "t" (ms).

At low speeds, high inductance is not a problem. Current can easily flow into the motor windings fast enough that the stepper motor has rated torque. At high speeds, however, sufficient current cannot get into the winding fast enough before the current is switched to the next phase, thereby reducing motor torque. Increasing the driver voltage can fight this loss of torque at higher speeds by forcing current into the windings of the motor at an increased rate. In summary, the current and the number of coil turns in the windings determine a motor's maximum torque output, while the voltage applied to the motor and the inductance of its windings will affect the speed at which a given amount of torque can be generated.