Step Motors & Drives

The typical step motor system consists of a step motor and a drive package that contains the control electronics and a power supply. The drive receives step and direction signals from an indexer or programmable motion controller, which may be an integrated part of the drive. The drive logic determines the correct current level for each phase of the motor and the power amplifiers generate and maintain the proper current loads. The power supply provides the necessary voltages from the AC or DC power source.

Advantages of step motor systems include:

- Inherently a digital device, number of pulses determine distance, frequency determines speed
- Cost efficient, simple designs
- Drift free
- Non-cumulative error
- Brushless design for reliability and simplicity
- Maintenance free, bearings lubricated for life
- High torque per package size, high acceleration and power rates
- Stable at zero speed
- Holding torque at standstill (high stiffness)
- Can be stalled repeatedly without damage
- No extra feedback components required (encoders can be added for additional advantages)
- Bi-directional operation

Step Motor Technology

Step motors are electromechanical, rotary, incremental actuators that convert digital pulses into mechanical shaft rotation. The amount of shaft rotation is directly proportional to the input pulses generated and the speed of the rotation is relative to the frequency of the pulses. Most microprocessors, timing/counting logic, or even switch or relay closures can generate the pulses used in a stepper system. The step driver acts to convert the logic pulses by sequencing power to the stepper windings; generally, one supplied pulse will yield one rotational step of the motor.

Step Motor Construction

The three most popular types of step motors are the variable reluctance (VR), permanent magnet and the hybrid. The hybrid step motor is by far the most popular. While a variety of step angles are available, the most common and popular is the 200 step per revolution, which is commonly referred to as a 1.8 degree step motor.

Variable Reluctance Step Motors

The general construction for a variable reluctance step motor is shown in Figure 13. There is a stator assembly consisting of an insulated lamination stack with coils wound around the teeth. The stator assembly is positioned within a housing, or main frame, so that its location is secured. The rotor assembly consists of a steel magnetic core, a steel shaft, and bearings. The rotor assembly is positioned in the center of the stator, both radially and axially. The rotor is supported by end frames or bearing supports.

When a stator phase is energized, the soft-iron rotor is electro-magnetically attracted to the stator poles. A rotor tooth attempts to align with the nearest energized stator pole. A rotor step takes place when one stator phase is de-energized and the next phase in the sequence is energized. To reverse the direction of rotation, the stator poles would be energized in the reverse sequence.

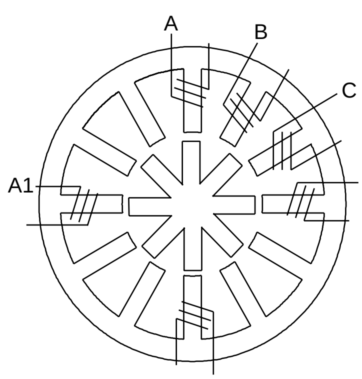


Figure 13: Variable Reluctance Step Motor

Permanent Magnet Step Motors

The permanent magnet (PM) step motor is shown in Figure 14. Permanent magnet motors differ from VR's by having a permanent magnet rotor with no teeth, which is magnetized perpendicular to its axis. The stator consists of two stamped steel cups with diagonally shaped teeth facing the rotor. Coils of wire are wrapped around each of the stator cups.

By energizing the phases in sequence, the rotor will rotate as it follows the changing magnetic field. In this example, the motor's step will be 90 degrees. Typical steps for PM motors are 45 and 90 degrees. They step at relatively low rates, but exhibit high torque and good damping characteristics.

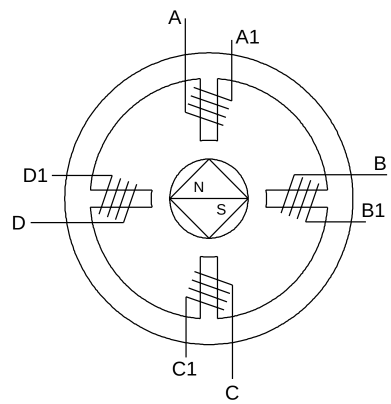


Figure 14: Permanent Magnet Step Motor

Hybrid Step Motors

Combining the qualities of both the VR and PM, the hybrid step motor has multi-toothed stator poles and a magnet encased within a multi-toothed rotor. These types of motors exhibit high detent torque, excellent static and dynamic torque, and can achieve high stepping rates. Normally, hybrids are designed for 0.9, 1.8, and 3.6 degrees per step.

Refer to Figure 15. The motor shown has two windings on each stator pole so that the pole can be either a magnetic north or south, depending on the direction of current flow. Hybrid step motors can achieve a wide range of torque values by altering the length and diameter of the motor.

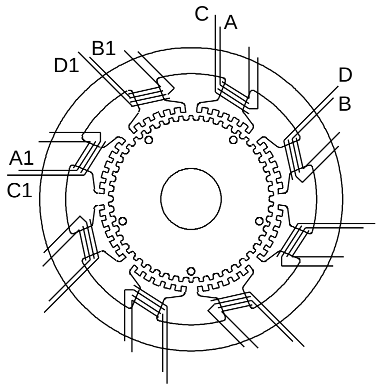


Figure 15: Hybrid Step Motor

Hybrid step motors consist of just five basic components, with the bearings being the only contacting part. The rotor consists of a permanent magnet, often with rare earth properties, located between the top and bottom half of the rotor stacks. The two stacks are similar to the VR step motor, with the magnet being placed between the two stacks. The two stacks are offset from each other by one-half tooth pitch. The stacks are made up of a series of laminations, each with 50 teeth on the circumference. This creates 50 natural detent positions on the rotor. Each of the detent positions will be maintained even without power being applied. Dividing 360 degrees by the 50 natural positions on the rotor yields a mechanical step angle of 7.2 degrees. For this reason, motion will be seen ± 3.6 degrees when energizing or de-energizing the motor. By changing the number of stator and rotor teeth, the step angle of the rotor will change. Typical step angles are 0.9°, 1.8°, and 3.6°.

Step motors are manufactured with single, double, and triple stack rotors on a single shaft. The number of stacks on a motor will be a determining factor in the maximum torque output of the motor. Typically, a three stack rotor will have approximately 2.5 to 3 times the static torque of a single stack rotor motor.

Step Motor Windings

There are two phases, or windings, in a typical step motor. The windings of the motor are located in the stator. This allows for optimum heat dissipation and lower inertia than DC brush type motors. There are two types of windings used in step motors, unifilar and bifilar.

Unifilar Winding

A unifilar winding refers to the winding configuration of a step motor where each stator pole has one set of windings; the motor will only have four lead wires. See Figure 16 for winding configurations. This winding configuration can only be driven by a bipolar drive design.

Bifilar Winding

A bifilar winding refers to the winding configuration of a step motor where each stator pole has a pair of windings, and the motor will have either 6 or 8 lead wires, depending on the termination, see Figures 17 and 18 respectively. This type of winding can be driven by either a unipolar or bipolar drive design.

Stepping Modes

In both the unipolar and bipolar drive, current for both phases is controlled in a four-state sequence. This sequence, multiplied by the 50 rotor teeth, creates the 1.8 degree step angle or 200 step per revolution motor. Switching the current on and off to the two phases of the stator windings creates a rotating electromagnetic field. The number of times that switching takes place controls the shaft position of the motor. The frequency of the switching controls the velocity of the motor shaft. The permanent magnet rotor will rotate in fixed mechanical increments to maintain rotor and stator tooth alignment. Reversing the basic switching sequence causes the motor shaft to reverse direction. Maintaining current flow at standstill results in zero speed stability and shaft stiffness.

There are three types of step modes a stepping motor can operate in: full-step, half-step, and microstep.

Full-Step Mode

The term full step means that for each digital pulse received from the drive, the shaft will rotate 1.8 mechanical degrees. For one complete shaft revolution, the driver must give 200 digital pulses.

In full-step, the motors have a tendency to oscillate with each step. This condition is most visible at low speeds, below one revolution per second. A resonant condition (loss of torque) may

FULL STEP ø SEQUENCE (BIPOLAR)

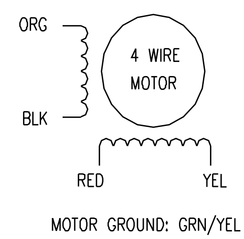
CW ROTATION ↓ / CCW ROTATION ↑

	ORG	BLK	RED	YEL
STEP \ PHASE	A	Ā	B	B̄
1	+	–	–	+
2	+	–	+	–
3	–	+	+	–
4	–	+	–	+
1	+	–	–	+

HALF STEP ø SEQUENCE (BIPOLAR)

CW ROTATION ↓ / CCW ROTATION ↑

	ORG	BLK	RED	YEL
STEP \ PHASE	A	Ā	B	B̄
1	+	–	–	+
2	+	–	0	0
3	+	–	+	–
4	0	0	+	–
5	–	+	+	–
6	–	+	0	0
7	–	+	–	+
8	0	0	–	+
1	+	–	–	+



\+ = POSITIVE CURRENT FLOW
– = NEGATIVE CURRENT FLOW

Figure 16: 4-Lead Unifilar Step Motor Wiring for Bipolar Driver

PHASE SEQUENCE (UNIPOLAR)

CCW ↓ / CW ↑

STEP	RED	GRN	WHT/RED	WHT/GRN	COM
1	–	–	0	0	+
2	0	–	–	0	+
3	0	0	–	–	+
4	–	0	0	–	+

COMMON: BLK & WHT

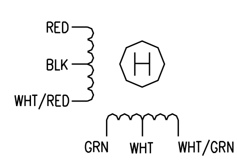
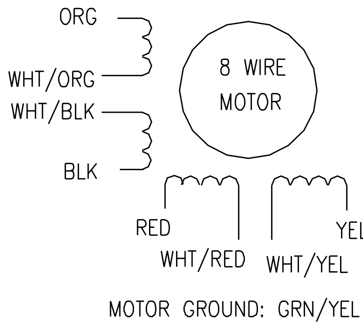


Figure 17: 6-Lead Step Motor Wiring

FULL STEP Ø SEQUENCE (BIPOLAR)				
SERIES	ORG	BLK	RED	YEL
	WHT/ORG & WHT/BLK (COM)		WHT/RED & WHT/YEL (COM)	
PARALLEL	ORG & WHT/BLK	BLK & WHT/ORG	RED & WHT/YEL	YEL & WHT/RED
STEP \ PHASE	A	$\bar{A}$	B	$\bar{B}$
1	+	–	–	+
2	+	–	+	–
3	–	+	+	–
4	–	+	–	+
1	+	–	–	+

CW ROTATION ↓   CCW ROTATION ↑



HALF STEP Ø SEQUENCE (BIPOLAR)				
SERIES	ORG	BLK	RED	YEL
	WHT/ORG & WHT/BLK (COM)		WHT/RED & WHT/YEL (COM)	
PARALLEL	ORG & WHT/BLK	BLK & WHT/ORG	RED & WHT/YEL	YEL & WHT/RED
STEP \ PHASE	A	$\bar{A}$	B	$\bar{B}$
1	+	–	–	+
2	+	–	0	0
3	+	–	+	–
4	0	0	+	–
5	–	+	+	–
6	–	+	0	0
7	–	+	–	+
8	0	0	–	+
1	+	–	–	+

CW ROTATION ↓   CCW ROTATION ↑

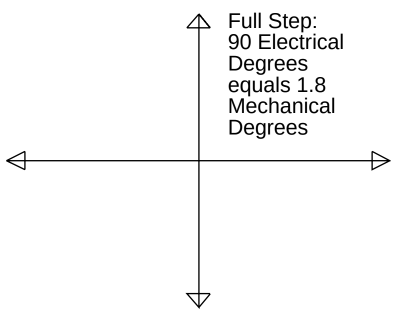
FULL STEP Ø SEQUENCE (UNIPOLAR)						
	ORG	BLK	RED	YEL	WHT/ORG & WHT/BLK	WHT/RED & WHT/BLK
STEP \ PHASE	A	B	C	D	A COM	B COM
1	–	0	–	0	+	+
2	0	–	–	0	+	+
3	0	–	0	–	+	+
4	–	0	0	–	+	+
1	–	0	–	0	+	+

CW ROTATION ↓   CCW ROTATION ↑

NOTE:
1. SHAFT ROTATION VIEWED FROM MTG END.
2. 0 = OFF OR OPEN
3. + = POSITIVE CURRENT FLOW
4. – = NEGATIVE CURRENT FLOW
5. COM = COMMON CONNECTION

Figure 18: 8-Lead Step Motor Wiring

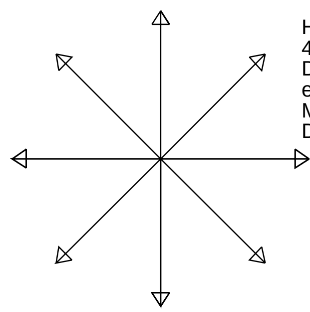
be observed. System mechanics, inertia, and friction will determine the exact resonant frequency characteristics. There are two electronic solutions to solving the problems associated with resonance in a stepping motor system: half stepping, and microstepping.



Full Step:
90 Electrical
Degrees
equals 1.8
Mechanical
Degrees

Half-Step Mode

The term half step means that instead of moving the 1.8 degrees per digital pulse, the motor shaft will move half that distance. Modifying the switching sequence from two windings on to a sequence of two windings on, one winding off, two on, etc. will create 400 steps per revolution. Reducing the distance the rotor moves reduces the overshoot or ringing, and therefore the resonance problem. Since there are times when only one winding is energized, the torque output of the motor can be reduced by up to 30%. To compensate, the drive electronics must increase the current in the energized winding.



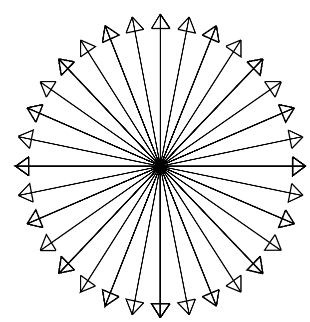
Half Step:
45 Electrical
Degrees
equals 0.9
Mechanical
Degrees

Microstepping Mode

Problems can occur with full-step systems. They include rough operation at low speeds, operating speeds that cause the motor to oscillate wildly, and limited resolution. The rough low speed operation of a full-step system frequently jars the mechanical system to which it is attached, and therefore has limited application on machinery requiring smooth operation.

Forbidden operating speeds below 1 rev/sec force system designers to accelerate the motor instantly to some “base” speed to avoid this velocity region. This instantaneous acceleration also prohibits smooth mechanical motion. The limited resolution of these systems (usually 200 or 400 steps/revolution) may also necessitate gearboxes or reduction transmissions to achieve the desired position resolution. There is a technique, however, that overcomes the low speed and limited resolution problems associated with step motors. It is known as microstepping.

Microstepping systems use the same hybrid step motor (usually 200 full steps/rev) and precise current control to position the motor’s rotor at a location in-between the normal full-step positions. While full-step drives produce coil currents that are either “on” or “off”, microstepping drives proportion the current smoothly between the motor’s coils, or phases. Instead of turning one phase “off” and another “on” to produce motion, a microstepping system slowly changes the currents in each phase. If the phase currents are held at intermediate values, the rotor maintains an intermediate position. This position is very repeatable.



Microstep:
Electrical
Degrees
equals 90
over # of
steps,
Mechanical
Degrees
equals 1.8
over # of
steps

Full-step systems apply square waves of current to the motor’s phases to rotate the motor. This square wave current causes jerky motion of the motor. Microstepping systems will apply a precise sinusoidal current so the motor moves smoothly without jerking. The frequency of these currents determines

Technical Reference

the rotational speed of the motor. The frequency of the current can be easily increased or decreased to accelerate or decelerate the motor.

Microstepping systems can easily accelerate and decelerate through velocities that would cause resonance or position loss in a conventional full-step system. The application of precise sinusoidal currents causes the rotor to move smoothly from one pole of the motor to the next, without stopping or oscillating. There are applications where the increased position resolution of microstepping is not needed, but the acceleration and resonance control is.

The ability to run smoothly at any speed produces another benefit. Microstepped systems can accelerate from zero velocity to the desired speed linearly. They can also decelerate smoothly to a stop. Conventional full-step systems must “jump” to a base speed, than accelerate to the desired velocity. They must also decelerate to the base speed and then instantly stop. Again, this can cause unwanted vibration and shock.

Microstepping Resolution

Microstepping systems are true incremental motion control systems. Each pulse that is sent to the microstepping driver commands the motor to move one microstep. The number of microsteps per full step is determined by the digital circuitry (usually a microprocessor) in the drive. This number of microsteps per full step multiplied by the number of full steps per revolution yields the number of microsteps per revolution. See Figure 19.

Position and Velocity Control

The desired position of a microstep system is, therefore, proportional to the number of pulses sent to the drive. For example, 50,000 pulses sent to a 25,000 step/rev system would cause the motor to rotate 2 revolutions. This distance is highly repeatable, as the number of microsteps per full step is fixed by the drive’s digital electronics and the motor’s full-step resolution is a function of internal lamination design. Component drift over time and temperature changes do not cause the system to mis-position.

The velocity of the rotor is proportional to the frequency of the applied pulse stream. A 25 kHz pulse train will cause a 25,000 step/rev system to rotate at 1 rev/sec. This is not subject to drift and the long-term velocity stability is equal to the stability of the pulse train (usually crystal controlled).

Step Motor No-Load Positional Accuracy Definition

The locations where the rotor and stator teeth naturally align are at every 1.8° of angular motion for a 200 step per revolution step motor. These full steps are stable points of motion. Full step errors for the Turbo step motors are less than ±2%.

The half pitch alignments of the rotor and stator teeth are unstable points of motion. Half-step errors are usually less than ±2%. Half-step motion quality is amplifier dependent.

Microstepping angular positions are within ±5% error. Sine wave peak errors normally occur at the quarter step positions.

Worst case microstep angular position error = ±5% of 1.8° = 0.09°
Worst case full step angular position error = ±2% of 1.8° = 0.036°

For a 200 steps/rev (1.8°/full step) step motor:

$$\% \text{ Error} = \frac{\text{Absolute Value [Perfect Position – Measured Position]} * 100}{1.8}$$

Performance Factors

One of the most important aspects affecting motor performance is the driver circuit design. The driver design factors include power delivery to the mo-

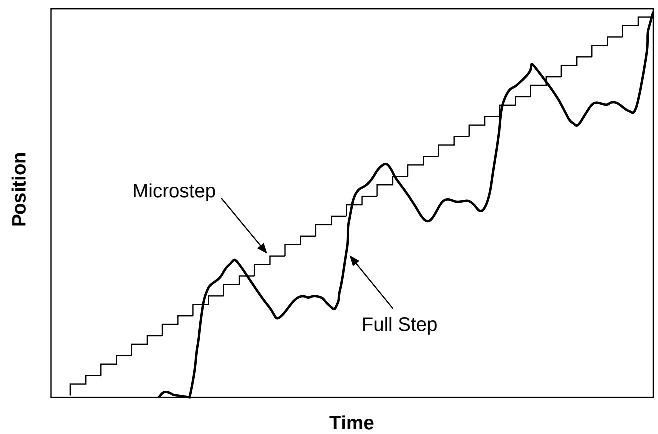


Figure 19: Motor Settling Time

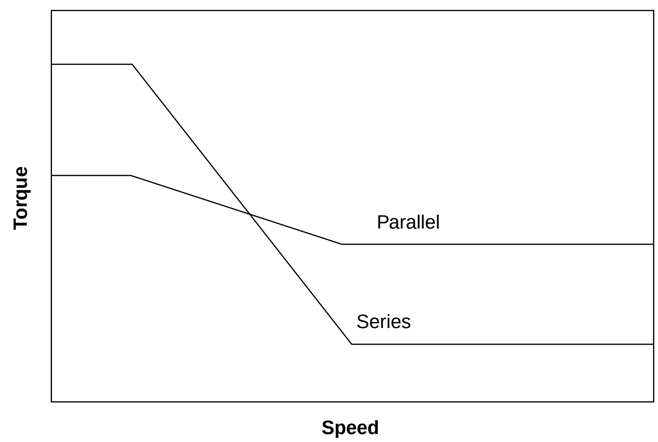


Figure 20: Motor Performance per Connection Method

tor, efficiency, and power dissipation. The basic objective of the driver circuitry is to provide a high voltage to move current into and out of the motor windings at the pulse transition, and to provide a low voltage to sustain only the correct current during the steady state portion of the current pulse.

General Guidelines

- **Driver Output Voltages**: Higher voltage will provide better high-speed torque.
- **Motor Inductance**: Higher inductance provides better low speed torque, but limits high-speed torque. Lowering the inductance gives the reverse.
- **Smoothness of Operation**: Decreasing the motor current by 10% below rated will provide smoother operation. Increasing current 10% will produce more torque, but will cause the motor to run "stiffer".
- **Motor Connection Method**: (Series or Parallel) Connecting a motor in series results in 4 times the inductance as compared to a parallel connected motor. The result is that a series connection will provide better low speed performance and less heating, while a parallel connection will provide better high-speed performance, and will create more heating. For a comparison of performance for Series and Parallel Connections, see Figure 20.
- **Motor Heating:** It is normal for a step motor to run hot, 50°C to 90°C. The maximum allowable temperature of the motor is normally specified by the motor manufacturer, and is dependent on the insulation system of the motor.

Disc Magnet Stepper Motors

The step motor differs from that of the DC and BLDC motor in so far as it generates a large number of stable positions within one revolution. This originates from the principle of construction: a two phase motor using a rotor with a magnet of one pole pair has four stable positions per rev., whereas a two phase motor with 50 pole pairs has 200 stable positions and, therefore, makes 200 full steps/rev.

The number of commutations per rev depends on the number of steps/rev of the motor. Every electrical commutation provokes a variation of the magnetic flux, and each flux variation generates iron losses. In a stepper motor with many commutations per rev these iron losses cannot be neglected. It is for this reason that step motors of conventional design are not intended for high speed, rapid movements.

The disc magnet stepper motor, on the other hand, is the only step motor to offer exceptional dynamic behavior. This technology, developed by API Motion and for which a patent was granted, fully exploits newly available materials like rare earth magnets, which in conjunction with an innovative concept have produced exceptional results.

The standard test for disc magnet stepper motors

The high quality level offered by API Motion is assured by testing and checking throughout the manufacturing process. These tests follow a standard quality plan and well established procedures.

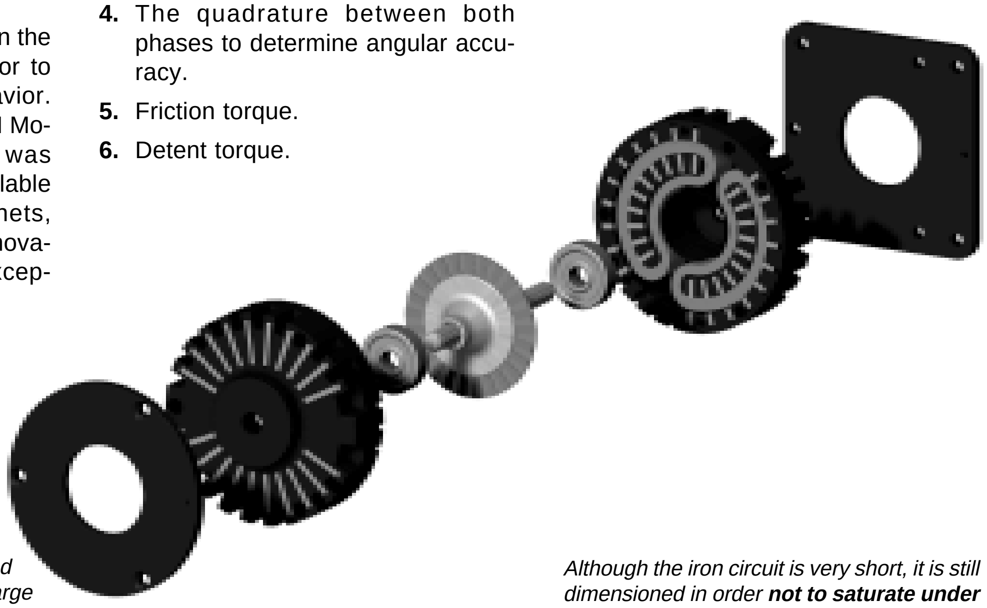
The following motor parameters are checked against the values given in the catalog or in their specification, at a temperature of 20/25°C.

100% test:

1. The resistance of each winding.
2. Back-EMF of each phase to determine their holding torque and any difference between them.
3. Phase changes of back-EMF periods over one revolution.
4. The quadrature between both phases to determine angular accuracy.
5. Friction torque.
6. Detent torque.

Specific tests:

Tests of other parameters and/or following other criteria may be done according to customer needs. They are then part of the customer specification and are noted on a quality control document.



The Rotor
*The rotor as the heart of this technology consists of a rare earth magnet in the shape of a thin disc. API Motion's know-how and experience has allowed us to optimise the magnetic circuit, and to axially magnetize the disc with a large number of pole pairs. Compared to traditional two phase PM step motors this gives a higher number of steps/rev. Unlike other motor technologies, the rotor does not require an additional iron structure to obtain flux variations; therefore **rotor inertia is very low**. It is capable of exceptional accelerations, which, together with a high peak speed, make this motor technology suitable for fast incremental motion.*

Furthermore, the low rotor inertia favors high starting frequencies which save time during the first step. Therefore, certain movements can be executed without having to generate an acceleration ramp.

The Magnetic Circuit
*The C-shaped magnetic circuit is very short. Unlike the hybrid motor the iron volume is not used as a structural support but optimised strictly in view of the magnetic induction. Each elementary circuit is made of SiFe laminations; their low volume assures minimum iron losses from hysteresis and eddy currents. Thus **very high peak speeds** can be achieved; even at 10,000 steps/s iron losses will not cause an excessive temperature rise.*

*For the user this means **a very high power output** from a small motor size, e.g. up to 50 W for the 52 mm Ø x 33 mm motor size.*

*Although the iron circuit is very short, it is still dimensioned in order **not to saturate under boost conditions**. For the customer this may allow the use of a smaller size motor and boosting it during acceleration or braking. This results in a higher torque to inertia ratio.*

*Contrary to other step motor technologies, with disc magnet motors there is no magnetic coupling between the phases. Each phase is entirely independent. Thus its geometry can be adapted to obtain a truly **sinusoidal function of torque vs rotor position**, and a value of **detent torque** which is **very small** compared to holding torque. These are prime conditions with microstep operation, if **high positioning accuracy** is needed on any microstep.*

Drive Technologies

The basic function of a step motor drive is to receive input signals from an indexer and translate them into power to energize the motor windings. The design of the drive circuit is one of the most important aspects of a stepping motor system. Overall, system performance is dependent upon the capabilities of the drive to supply the required voltage and amperage (power) to the motor.

When a step motor is running, the flow of current through the windings is critical for optimal speed and torque. Winding inductance must be overcome to inject current into the winding. While an infinite number of drive circuits can be devised to create a lower inductive time constant, they all fall into three basic categories: L/R, bi-level, or chopper.

With each method, a supply voltage greater than the motor's rated voltage is used to decrease the current rise time in the motor windings. Each method has a different approach to current level control.

L/R Drives

This design was the basis for older drive designs, and is still used on some existing drives. It allows for full and half-step operation, but does not permit variable control of current level and requires a resistor between the supply voltage and motor to limit current. While this method is simple and inexpensive, it is also very inefficient due to the power losses from the resistor.

Bi-Level Drives

Bi-level drives use two voltages, one high and one low. When each winding is energized, it initially receives the higher voltage to build up the current faster. At an appropriate time, based on a current sensing circuit, the high voltage is turned off and the lower voltage is applied for the remainder of the step. This eliminates the resistor of the L/R scheme, but is somewhat more expensive to design and build.

Constant Current Chopper Drives

The constant current chopper (switching or PWM) drive uses a high voltage source to lower the current rise time in the motor windings. The drive maintains an acceptable current level by switching ("chopping") the voltage on and off at high frequencies. This method is called Pulse Width Modulation (PWM). These drives maintain relatively constant currents to the motor at all speeds, therefore they offer excellent performance. These are more costly and complex than L/R drives. However, in addition to improved motor performance, they allow use of such features as closed loop control, microstepping, current boost, and mid-range stabilization.

Unipolar vs. Bipolar

Step motor stator poles need to alternately change magnetic polarity. This polarity change is accomplished by changing the direction of the current flow. In a unipolar motor, each stator pole has two windings, each of which creates the two magnetic poles. With a unipolar drive, the center tap of each winding is used and connected to the power source. Switching either end of the winding to ground then controls current flow. This is often referred to as a four-phase motor when operated in this configuration.

The bipolar motor has only one winding, and reversing the direction of the current flow from the driver creates each pole. In a bipolar drive, the direction of current flow through the winding will be controlled. The bipolar drive is more expensive, but it provides a 60% increase in torque because all the copper in the windings is utilized. Bipolar drives use full bridge drive circuits to supply a bi-directional current to each phase winding.

Indexer Technology

An essential part of every motion control system is the controlling device. In its simplest form, an INDEXER must provide step and direction outputs to the driver inputs for motion to be performed using a step motor. In many applications, the indexer is required to have functions other than the basic drive outputs. These may include:

- A data communication interface
- Additional inputs and outputs to control or monitor other functions in a machine or process
- Motion program storage
- The circuitry to interface with a feedback device for closed-loop control

Given the flexibility of microprocessors, they are typically the devices of choice in the design of an indexer. There are two configurations of indexer: stand-alone and as part of a control system.

Stand-Alone

In a stand-alone configuration, the motion control system provides all the control functions and the I/O required to control the process. The system is initially programmed and then operates "stand-alone" without the need for data or other control signals.

Control System

In a control system approach, the motion controller is a single element within the complete system. The system usually includes other elements such as:

- A host device such as a computer or PLC
- Operator interface device
- Analog and digital inputs/outputs

Practical Microstepping

- High microstepping resolutions, (25,000 or 50,000 steps per revolution), require very fast pulse rates to achieve upper speeds. For example: If the microstep resolution is 25,000 steps per revolution, and you desire to run at a top speed of 1,800 RPM, then the pulse source must be capable of generating 750,000 pulses per second. Before selecting a step resolution, ensure that the pulse generating device is capable of producing step rates high enough to achieve the top speed that you desire.
- Encoders can be used to determine if final position has been achieved, and with the electronics as found in API Motion indexers, position correction can be accomplished. The standard incremental encoder provided by us provides 4,000 counts per shaft revolution. This does not mean that your step resolution cannot be greater than 4,000 steps per revolution. It merely means that if you are using an encoder for closed-loop positioning, a “deadband window” would exist whereby it is not possible to account for actual in-between microsteps.
- Increasing the step resolution decreases the torque available per microstep. The torque available for each microstep is determined as follows: **Torque per microstep = Motor holding torque X Sin (90°/ Microsteps per step)**. If the resolution is 10,000 steps per revolution, and you are using a 100 ounce inch motor, then each microstep will produce a torque change of 3.1 oz.-in. If you were to increase the resolution to 50,000 steps per revolution, then each microstep will produce a torque change of only 0.63 oz.-in.

If the friction of the load is 3 oz.-in. with a resolution of 10,000 steps per revolution, you would expect an immediate response to your command to move one step. If you increase the resolution to 50,000 steps per revolution, it may take 5 microsteps to be commanded before the torque builds to a level high enough to move the load. This effect is sometimes referred to as “Empty Stepping” and can be overcome if motor sizes and step resolutions are properly selected.

Microstep Resolution

From the wide range of available microstep resolutions, you can usually find the right one for your application. For many applications this makes designing your motion control system easier, as you do not have to adjust formulas for an inexact resolution. Some of the common microstep resolutions and their uses are shown in the chart.

Step Resolutions	Step Mode	Motion Type	Scale
200	Full	Linear	English or Metric
400	Half	Linear	English or Metric
1000	Micro	Linear	English or Metric
2000	Micro	Linear	English or Metric
5000	Micro	Linear	English or Metric
10000	Micro	Linear	English or Metric
12800	Micro	Rotary	English-to-Metric
18000	Micro	Rotary	Degrees
20000	Micro	Linear	English or Metric
21600	Micro	Rotary	Arc Minutes
25000	Micro	Linear	English
25400	Micro	Linear	English-to-Metric
25600	Micro	Rotary	Degrees
36000	Micro	Rotary	Degrees
50000	Micro	Linear	English or Metric
50800	Micro	Linear	English-to-Metric

General Requirements

Motion requirements, load characteristics, coupling techniques and electrical requirements need to be understood before the system designer can select the best motor/drive for the application. While not a difficult process, several factors need to be considered when determining an optimal solution. A good system designer will adjust the characteristics of the elements under his control to meet the application requirements. Some of these elements may include the motor, drive, power supply selection and type of mechanical transmission such as gearing or load weight reduction through the use of alternative materials. Some of these relationships and parameters are described in the following.

Inertial Loads. Inertia is a measure of an object's resistance to a change in velocity. The larger an object's inertia, the greater the torque that is required to accelerate or decelerate it. Inertia is a function of an object's mass and shape. A designer may wish to select an alternative shape or low density material. Depending on the level of torque available in a selected system, the acceleration and deceleration times may need to be increased.

For the most efficient operation the system coupling ratio (gear ratio) should be selected so that the reflected inertia of the load to the motor is equal to or greater than (but less than 10 times) the rotor inertia of the motor. The system design may require that inertia be added or subtracted by selecting different materials or shapes of the loads. It should be noted that the reflected inertia is reduced by the square of the gear ratio and the speed is increased by the gear ratio.

Frictional Loads. All mechanical systems exhibit some frictional force. The designer must be able to predict elements causing friction within his system. These elements may be in the form of bearing drag, sliding friction, system wear or the viscosity of an oil filled gear box (temperature dependent). A motor must be selected that can overcome any normal system friction and still provide the torque necessary to accelerate the inertial load. Some friction is desired, however, since it can reduce settling time and improve performance.

Positioning Resolution. The positioning resolution required by the application may have an effect on the type of transmission used or drive selection. For example a lead screw with 5 threads per inch on a full-step drive provides 0.001 inch/step; in half step, 0.0005 inch/step; with a microstep resolution of 25400 steps/rev, 0.0002 mm/step.

Torque. When sizing a step motor system, the designer must calculate the maximum torque demand for the application. This will usually be the total torque required during the acceleration portion of the motion. Since the available torque of a step motor decreases as speed increases, the application may have an effect on the type of transmission selected. A torque margin or design safety factor can be utilized to make sure the step motor system will deliver more torque than is absolutely required. The design safety factor accommodates mechanical wear, extra loads, lubrication hardening, and other extraordinary factors. A design with a large excess of torque, however, may cause the mechanical system to resonate. A design safety factor in the range of 1.25 to 2.5 is recommended.

Resonance Characteristics. Since a step motor system is a discrete incremental positioning system, it is subject to the effect of resonance. When the system is operated at its natural frequency it may begin oscillating. Primary resonance frequency is typically around one revolution per second. This resonance oscillation will cause a loss of effective torque and may result in loss of synchronism (stall condition of the motor).

Settling time and resonances can best be dealt with by dampening the motor's oscillations through mechanical or electronic means. Mechanically, a friction or viscous damper may be mounted on the motor to smooth out the motion. Alternately, API Motion offers several step motor drive products with electronic damping capability.

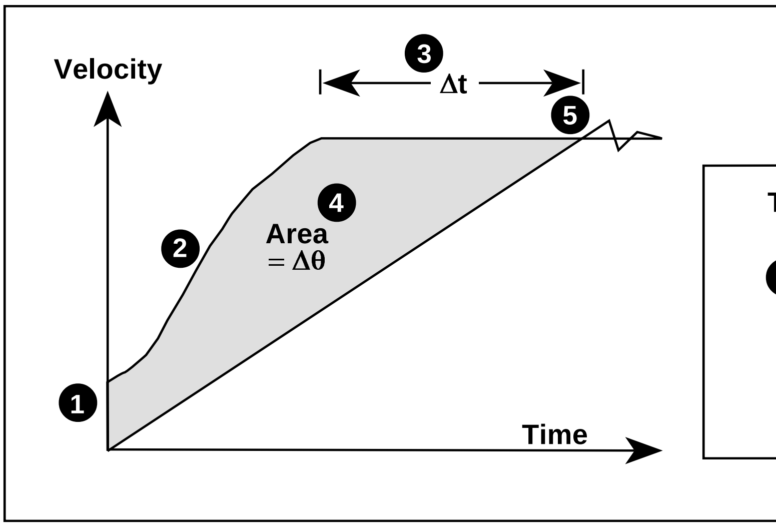
Some methods for changing or reducing resonance points within a stepper system are as follows:

- Utilize half-step or microstepping techniques
- Change system inertia
- Accelerate through resonance speed ranges (jump start or the setting of a minimum start/stop frequency)
- Correct coupling compliance

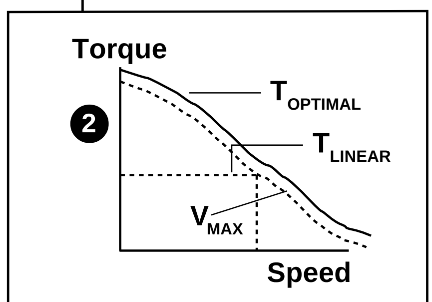
Optimized System Ramping

API Motion has developed an optimized non-linear ramping technique to provide distinct advantages over both linear and sinusoidal methods. Our technique provides the ability to maximize step motor performance throughout its speed range, which allows us to extend the useful speed range.

Optimal Non-Linear Vs. Linear Ramping



Speed/Torque Curve
For Typical Step Motor



Advantages

Five major advantages of our Optimal Non-Linear Ramping (illustrated above) are:

1. **Base Speed.** A base speed allows us to bypass low speed ranges where problems with resonance can occur.

2. **Optimal Ramping.** The acceleration rate is continuously changed as a function of speed. This can result in over 80% utilization of the motor's available torque across its speed range. The $T_{OPTIMAL}$ curve illustrates this advantage over T_{LINEAR} (inset Speed/Torque Curve). Because the Optimal Non-Linear Ramping maximizes the use of the motor's available torque, the user is not required to continuously change the acceleration rate to optimize performance (linear).

3. **Reduced Acceleration Times.** At speeds of 10 RPS and greater, we provide 30-60% faster acceleration to final velocity (**Δt**), than standard linear ramping.

4. **More Distance, Less Time.** The shaded area in the curve represents the extra distance (**Δθ**) traveled during the same amount of time, resulting in increased machine throughput.

5. **Jerk-Free Motion.** Once a step motor gets to maximum velocity, there is a tendency for jerk resulting in overshoot and velocity variations. The resulting overshoot can cause stalling of the step motor and is much more pronounced with linear ramping. Jerk-free motion will also prevent potential damage to mechanical components.

Some Questions and Answers

1) **Q:** *Why do step motors run hot?*
A: There are two basic reasons. First, full current flows through the motor windings even at standstill. Secondly, PWM drive designs tend to make the motor run hotter. Motor construction, such as lamination material and riveted rotors, will also affect heating.

2) **Q:** *What are safe operating temperatures?*
A: Motor case temperatures up to 90 degrees C will not cause thermal breakdowns. Motors should be mounted where operators cannot come into contact with the motor case.

3) **Q:** *What can be done to reduce motor heating?*
A: Many drives feature a "reduce current at standstill" command or jumper. This reduces current when the motor is at rest but without position loss.

4) **Q:** *What does the absolute accuracy specification mean?*
A: This refers to inaccuracies (non-cumulative) resulting from machining of the motor.

5) **Q:** *How can the repeatability specification be better than that of accuracy?*
A: Repeatability indicates how precisely a previous position can be re-obtained. There may be an inaccuracy associated with a given position, but if the inaccuracy is repeatable, the same position is reached each time.

6) **Q:** *Will motor accuracy increase proportionately with the resolution?*
A: No, the basic absolute accuracy and hysteresis of the motor remain unchanged.

7) **Q:** *Can I use a small motor on a large load if the torque requirement is low?*
A: Yes, however, if the load inertia is more than ten times the rotor inertia, cogging and extended ringing at the end of the move will be experienced.

8) **Q:** *How can end of move "ringing" be reduced?*
A: Friction in the system will help dampen this oscillation. Acceleration/deceleration rates could also be increased. If start/stop velocities are used, lowering, or eliminating them will help.

9) **Q:** *Why does the motor stall during no load testing?*
A: The motor needs inertia roughly equal to its own inertia to accelerate properly. Any resonances developed in the motor are at their worst in a no load condition.

10) **Q:** *Why is motor sizing important? Why not just use a larger motor?*
A: If the motor's rotor inertia is the majority of the load, any resonances may become more pronounced. In addition, productivity would suffer, as excessive time would be required to accelerate the larger rotor inertia.

11) **Q:** *What are the options for eliminating resonance?*
A: Adding inertia will lower the resonant frequency. Friction would tend to dampen the modulation. Start/stop velocities higher than the resonant point could be used. Changing from full-step to half-step operation will help. Mini-stepping and microstepping also minimize resonant vibrations.

12) **Q:** *Why does the motor jump at times when it is turned off?*
A: This is due to the rotor having 50 teeth and therefore 50 natural detent positions. Movement can then be $\pm$ 3.6 degrees, either direction after power is removed.

13) **Q:** *Do the rotor and stator teeth actually mesh?*
A: No, an air gap is very carefully maintained between the rotor and the stator.

14) **Q:** *Does the motor itself change if a microstepping drive is used?*
A: The motor is still the standard 1.8 degree stepper. Microstepping is accomplished by proportioning currents in the drive. Higher resolutions result.

15) **Q:** *A move is made in one direction, and then the motor is commanded to move the same distance but in the opposite direction. The move ends up short, why?*
A: Two factors could influence the results. First, the motor does have magnetic hysteresis that is seen on direction changes. This is approximately 0.03 degrees. Secondly, any mechanical backlash in the system to which the motor is coupled could also cause loss of motion.

16) **Q:** *Why are some motors constructed as eight lead motors?*
A: This allows greater flexibility. The motor can be run as a six lead motor with unipolar drives. And with bipolar drives, the windings can be connected in either series or parallel.

17) **Q:** *What advantage do series or parallel connection windings give?*
A: With the windings connected in series, low speed torque is maximized. However, this also gives the most inductance so performance at higher speeds is lower than if the windings were connected in parallel.

18) **Q:** *Can a flat be machined on the motor shaft?*
A: Yes, but the motor must be disassembled to do this. Care must be taken to not damage the bearings, the stator windings, and the rotor during disassembly and re-assembly.

19) **Q:** *How long can the motor leads be?*
A: For bipolar drives, 100 feet and unipolar designs, 50 feet. Shielded, twisted pair cables are required.

20) **Q:** *Can specialty step motors; explosion proof, radiation proof, high temperature, low temperature, vacuum rated, or waterproof ratings be provided?*
A: API Motion is willing to quote on most requirements with the exception of explosion proof.

21) **Q:** *What are the options if an explosion proof motor is needed?*
A: Installing the motor in a purged box could be investigated or use one of our explosion-proof servo motors.