Stepper Motor System Basics

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1. STEPPER MOTOR SYSTEM OVERVIEW

Motion Control is the process of accurately controlling the movement of an object, based on speed, distance, load, inertia or a combination of all these factors. There are numerous types of motion control systems, including: Stepper Motors, DC Brushed and Brushless Motors, Servo Motors, and more. This document will concentrate on Step Motor technology.

Stepper motors are a marvel of simplicity; they have no brushes or contacts for commutation, like DC motors. Instead, it's a synchronous motor with electronically-switched magnetic fields which rotate the armature magnets.

A Stepping Motor System consists of three basic elements, often combined with some type of user interface (such as a host computer or PLC [Programmable Logic Controller]):
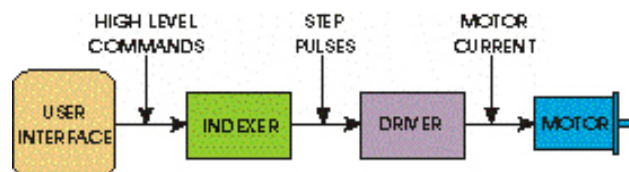
The **User Interface** provides a series of high-level motion commands. These guide the controller (or indexer) to generate the motion signals implied by those commands which the driver amplifies to drive the step motor.

The **Indexer** (or controller) is a subsystem which interprets high-level motion commands and generating motion primitives (step pulses and direction signals) for the driver. In addition, the controller typically performs other sophisticated command functions based on commands, current status, or real-time inputs.

The **Driver** (or Amplifier) converts the controller command signals into current levels necessary to energize the motor windings. There are numerous types of drivers, with various current/amperage ratings and technology. Not all drivers are suitable to run all motors, so when designing a Motion Control System the driver selection process is critical.

The **Step Motor** is an electromechanical device that converts drive waveforms into mechanical shaft rotation. Advantages of step motors are low cost, high reliability, high torque at low speeds, simple rugged construction, and operation in almost any environment. The main disadvantages in using a step motor is the resonance effect often exhibited at low speeds, and decreasing torque with increasing speed.

Example Step Motors: AME Series

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2. STEPPING MOTORS

TYPES OF STEPPER MOTORS

There are basically three types of stepping motors; variable reluctance, permanent magnet and hybrid. They differ in terms of construction based on the use of permanent magnets and/or iron rotors with laminated steel stators.

The variable reluctance motor does not use a permanent magnet. As a result, the motor rotor can move without constraint or "detent" torque. This type of construction is good in non industrial applications that do not require a high degree of motor torque, such as the positioning of a micro slide.

The variable reluctance motor in the right illustration has three "stator pole sets" (A, B, C,), set 15 degrees apart. Current applied to pole A through the motor winding causes a magnetic attraction that aligns the rotor (tooth) to pole A. Energizing stator pole B causes the rotor to rotate 15 degrees in alignment with pole B. This process will continue with pole C and back to A in a clockwise direction. Reversing the procedure (C to A) would result in a counterclockwise rotation.

The permanent magnet motor, also referred to as a "canstack" motor, has, as the name implies, a permanent magnet rotor. It is a relatively low speed, low torque device with large step angles of either 45 or 90 degrees. It's simple construction and low cost make it an ideal choice for non industrial applications.

Unlike the other stepping motors, the PM motor rotor has no teeth and is designed to be magnetized at a right angle to its axis. The above illustration shows a simple, 90 degree PM motor with four phases (A-D). Applying current to each phase in sequence will cause the rotor to rotate by adjusting to the changing magnetic fields. Although it operates at fairly low speed the PM motor has a relatively high torque characteristic.

Hybrid motors combine the best characteristics of the variable reluctance and permanent magnet motors. They are constructed with multi-toothed stator poles and a permanent magnet rotor. Standard hybrid motors have 200 rotor teeth and rotate at 1.8° step angles. Other hybrid motors are available in 0.9° and 3.6° step angle configurations. Because they exhibit high static and dynamic torque and run at very high step rates, hybrid motors are used in a wide variety of industrial applications where exact positioning and speed are critical.

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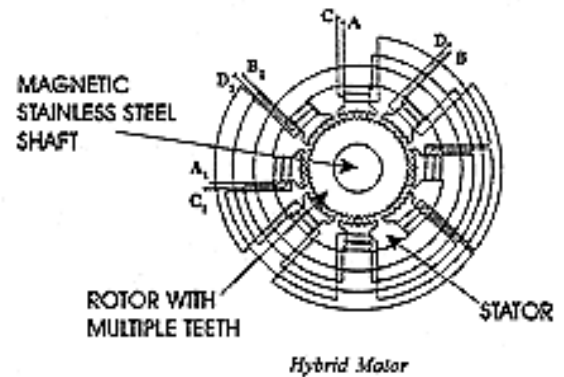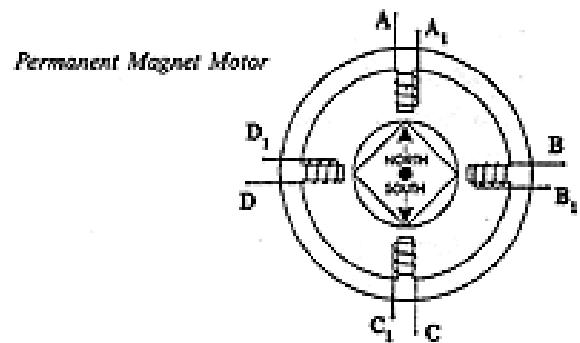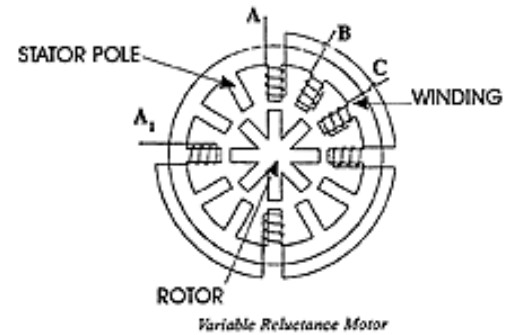
MOTOR WINDINGS

Unifilar-wound motors have only one winding per stator pole. Stepper motors with a unifilar winding will have 4 lead wires. The following wiring diagram illustrates a typical unifilar motor.

Bifilar-wound motors have two identical sets of windings on each stator pole. This type of winding configuration simplifies operation in that switching current (commutating) from one coil to the one wound in the opposite direction, will reverse the rotation of the motor shaft. Whereas, in a unifilar application, to change direction requires reversing current within the same winding.

The most common wiring configuration for bifilar-wound stepping motors is 8 leads because they offer the flexibility of either a series or parallel connection. There are however, many 6-lead stepping motors available for series-connection applications.

The most commonly available stepper motor is the unifilar hybrid with 1.8° full steps. There is more information on motor winding types (4, 6 or 8-lead motors) and their tradeoffs in the driver section.
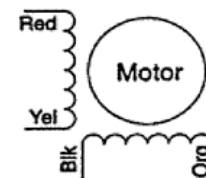
4 Lead Unifilar Motor
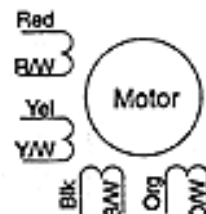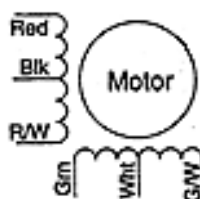
6 and 8 Lead Bifilar Wound Motors

ADDITIONAL MOTOR CONSIDERATIONS

The electrical compatibility between the motor and the driver are critical factors in a stepper motor system design. Some general guidelines are:

INDUCTANCE

Stepper motors are rated with a varying degree of inductance. A high inductance motor will provide a greater amount of torque at low speeds and lower torque at higher speeds.

MOTOR "STIFFNESS"

By design, stepping motors tend to run "stiff" – meaning the default pattern of torque during motion appears stiff and jumps from one step to another (depending upon motion rate, current, etc). Reducing the current flow to the motor by a small amount can smooth the rotation and increasing the motor current could increase the stiffness but will also provide more torque. Trade-offs between speed, torque, step mode and resolution are a main consideration in designing a step motor system.

MOTOR HEAT

Step motors are designed to run hot (50º-90º C max). However, too much current may cause excessive heating and damage to the motor insulation and windings. AMS motion control products reduce the risk of overheating by providing a programmable Run/Hold current feature, which reduces drive current during periods where motion is not needed.

3. DRIVERS

DRIVER TECHNOLOGY OVERVIEW

A stepper motor **driver** receives low-level signals from a controller/indexer and converts them into electrical winding currents to run a stepper motor. One step pulse into the driver is required for every step of the motor shaft. In full-step mode, with a standard 200 step motor it takes 200 step pulses to complete one revolution; in half-step mode it would take 400. In microstepping modes the driver would be generate many more step pulses per revolution – 16X mode would require 3200 steps and 256x mode would require 51,200!
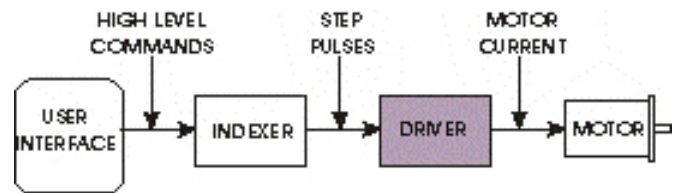
It is generally accepted that increasing microstepping accuracy is limited to about 16x microstepping, but greater microstepping can continue to improve smoothness in slower motion situations.

Speed and torque performance of the step motor is based on the flow of current from the driver to the motor winding. The factor that inhibits the flow, or limits the time it takes for the current to energize the winding, is known as motor winding inductance. The lower the inductance, the faster the current gets to the winding and the better the performance of the motor. To reduce the effects of motor inductance, most drivers are designed to supply a voltage much greater than the motor's "rated" voltage. The higher the applied voltage, the higher the maximum speed of the system at maximum step rate.

TYPES OF STEP MOTOR DRIVERS

For industrial applications there are several types of driver technologies. They all utilize a "translator" to convert the step and direction signals from the controller into electrical pulses to the motor – this translator converts then amplifies the signal to generate the required winding currents. The essential difference is in the way they energize the motor windings.

UNIPOLAR

The name unipolar is derived from the fact that current flow is limited to one direction for each motor drive signal, and as such it necessarily requires a unipolar stepper motor (see motor types). Because of the simplicity of switching current in one direction, the unipolar drive is fairly simple and inexpensive. The drawback to using a unipolar drive, however, is its limited capability to energize all windings at one time. As a result, the number of amp-turns (torque) is reduced by nearly 40% compared to other driver technologies. Unipolar drivers are acceptable for low step rates and lower torque.

BIPOLAR

Bipolar chopper drivers are by far the most widely used drivers for industrial applications. Although they are typically more expensive to design, they offer high performance and high efficiency. Bipolar chopper drivers use an extra set of switching elements to eliminate the need for two power sources; a "chopping" effect is utilized to maintains the correct current drive to the motor during all drive stages and through microstepping modes.

DRIVER AND MOTOR WIRING CONFIGURATIONS

Stepping motors typically come with 4, 6, or 8 leads. With respect to wiring a motor to the driver, let us only consider bipolar drives (AMS supplies only bipolar drivers and driver-controller systems). The driver will typically feature 4 connections to connect the motor: an A and B connection for each of the 2 phases – each phase output pair is independent – so wiring up a 4-lead unifilar motor is therefore straightforward.

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For bipolar (bifilar-wound) motors, there are more options for connection. When driving with standard drivers to bifilar motors with 8 leads, the coils can either be connected in series or in parallel, as shown right. A series connection provides a high inductance and therefore greater performance (higher torque) at low speeds. A parallel connection will lower the inductance but increase the torque at higher speeds. The following is a typical speed/torque curve for an AMS driver and motor connected in series and parallel:

In case of a six-lead motor, the performance at higher speeds can be improved by using the half-winding configuration. This comes at the price of reduced torque at lower and mid range speeds. However, due to the reduced inductance, performance at higher speeds is improved.

Six-lead motors were used most commonly with unipolar drivers, which used currents from the center lead of each phase to alternate ends of the winding – this method only uses half the motor winding at any one time. To get maximum torque on one, drive the ends of the winding and insulate (don't connect) the center taps.
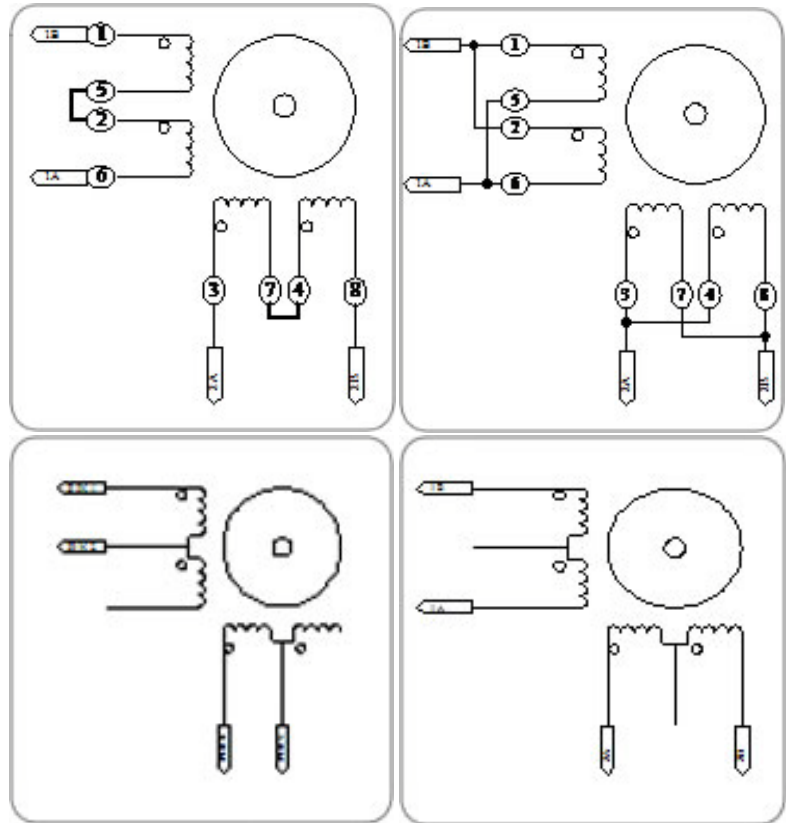
PHASE CURRENT

An important parameter in the selection or design of the driver is the current it sends through the coils of the motor. The current specified for the motor is the maximum current that is allowable per phase. To avoid damage to the motor, ensure that this current is not exceeded. Many drives allow limiting the current either by potentiometer, DIP switches, or by soft setting through the controller. Because stepper motors run hot it is advisable to use a current that is as low as possible while still maintaining reliable motion. This means that in many applications the maximum phase current set can and will be lower than that allowed by the motor or driver specs. This will help to maximize the

lifetime of motor and driver hardware.

Note that many drivers and driver/controller systems have *Automatic Idle Reduction feature*, which can reduce the drive current during idle or 'hold' situations automatically to a lower drive current than during standard motion. Some systems provide independent idle-current and run-current settings, others set idle current as a percentage of run current, and still others cut off current during idle (zero current). Each situation requires consideration of idle/hold current requirements.
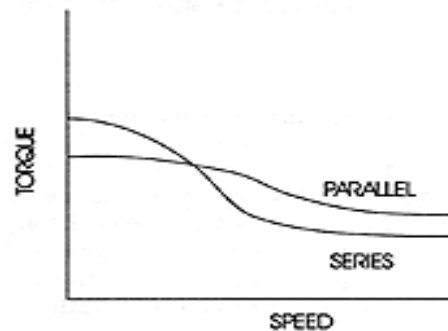
Series vs. Parallel Motor Connection
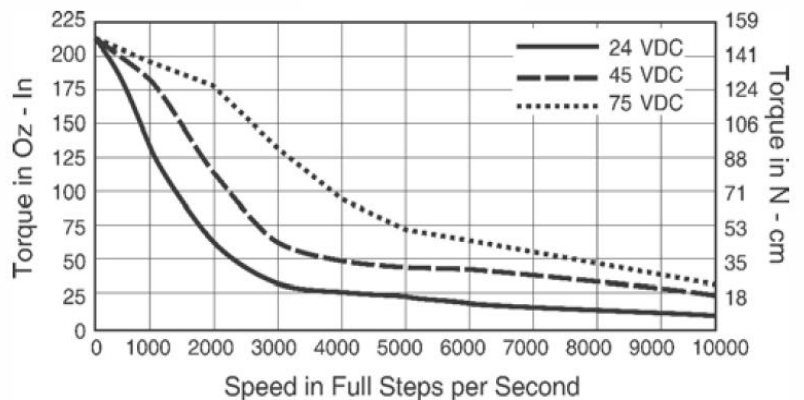
4. CONTROLLER (INDEXER)

CONTROLLER OVERVIEW

The controller block provides step and direction outputs to the driver. Most applications require that the controller manage other control functions as well, including acceleration, deceleration, steps per second and distance. The controller can also interface to and control, many other external signals.
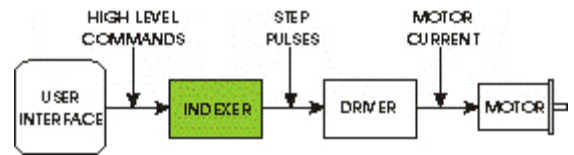
Microprocessor based controllers offer a great deal of flexibility in that they can operate in either stand-alone mode or interfaced to a host computer. The following illustration highlights the elements of a typical AMS controller function: Communication to the controller is either Bus-based or through an RS-232/ RS-422 / USB serial port. In either case, the controller is capable of receiving high level commands from a host computer and generating the necessary step and direction pulses to the driver.

The controller includes an auxiliary I/O for monitoring inputs from external sources such as a Go, Jog, Home or Limit switch. It can also initiate other machine functions through the I/O output pins.

STEP MODES

Controller and driver can utilize different "step modes" to synthesize the multiple waveforms needed to drive the motor. These include Full, Half and Microstepping. The type of step mode output available is dependent on the design of the driver (and is usually coordinated with the controller/indexer).

FULL STEP

Standard (hybrid) stepping motors have 200 rotor teeth, or 200 full steps per revolution of the motor shaft. Dividing the 200 steps into the 360° rotation equals a 1.8° full step angle. Normally, full step mode is achieved by energizing both windings while reversing the current alternately. One digital input from the controller to the driver is equivalent to one motor step.

HALF STEP

In Half step mode, one winding is energized and then two windings are energized, causing the rotor to rotate half the distance, or 0.9°. Utilization of overlapping drive currents in this mode provides slightly less torque but makes the torque application smoother. It results in 400 input steps to the driver to achieve a single revolution of the same example 200-step 1.8° motor.

MICROSTEP

Microstepping technology controls the current in the motor winding more completely, to more accurately emulate a set of SINE and COSINE waveforms – which would be the most efficient and smoothest drive method, if possible. Microstepping controllers instead chop the current to further subdivide the number of positions between poles, and use each subdivision to implement an intermediate winding current. AMS microstepping drivers and drive systems are capable of implementing microstepping from ¼ up to 1/256 of a step (for each controller step), which in the case of the MAX family at 1/256 corresponds to 51,200 steps per revolution (for a 1.8° step-angle motor).

Microstepping provides more accurate positioning of a step motor in addition to added smoothness in motion, and is typically used in applications that require accurate positioning and a fine resolution over a wide range of speeds.

MAX-410/MAX-420 microstep drives integrate state-of-the-art hardware with "VRMC" (Variable Resolution Microstep Control) technology developed by AMS. At slow shaft speeds, VRMCs produces high resolution microstep positioning for silent, resonance-free operation. As shaft speed increases, the output step resolution is expanded for quicker operation.

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STAND-ALONE OPERATION

In stand-alone mode a controller can operate independent of any host computer. Motion programs, once downloaded to the controller permanent memory, can be initiated and controlled from various types of operator interfaces, such as a keypads, switchs, or sensors. A stand-alone stepper motor control system is sometimes packaged with a position encoder feedback for closed loop applications which require stall detection and exact motor position compensation.
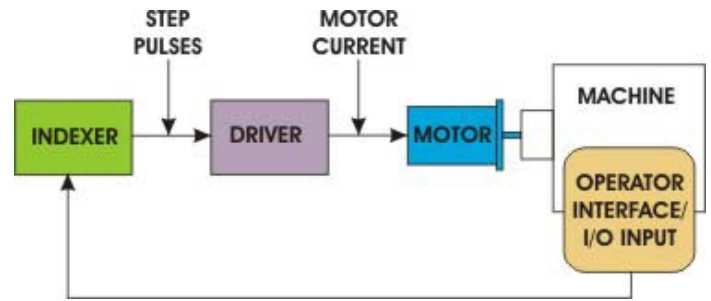
INTEGRATED CONTROL

Integrated control describes a system where the controller is embedded within a larger system and accepts commands from a host computer controlling the entire motion process. Communication, operator interface, and I/O functions can be designed as separate elements of the system. Control and management of the motion sequence is done by the host computer. In this case the controller acts as an intelligent peripheral. Many dynamic or variable process applications are well suited for integrated control, as well as multi-axis applications.
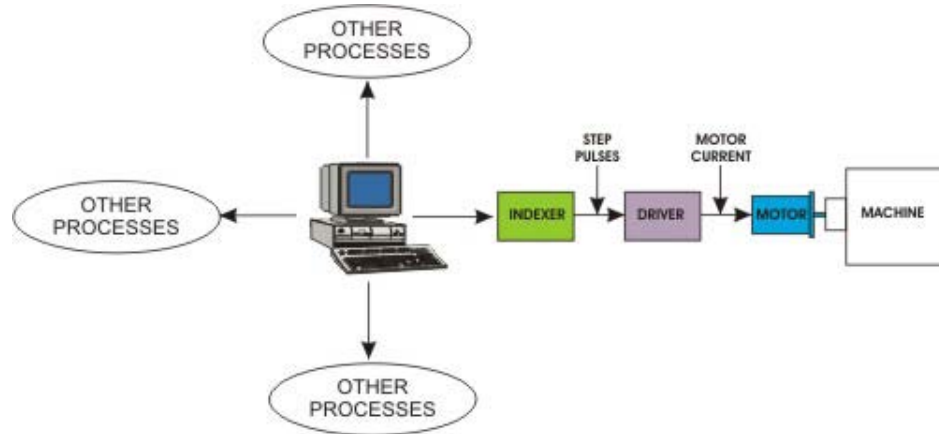
MULTI-AXIS CONTROL

Many motion applications have more than one motor to control. In such cases a multi-axis control system can be created. A host-based system can easily be constructed with AMS interfaces and driver/controller units that may have up to 32 controller/drivers; each one connected to a separate motion axis.
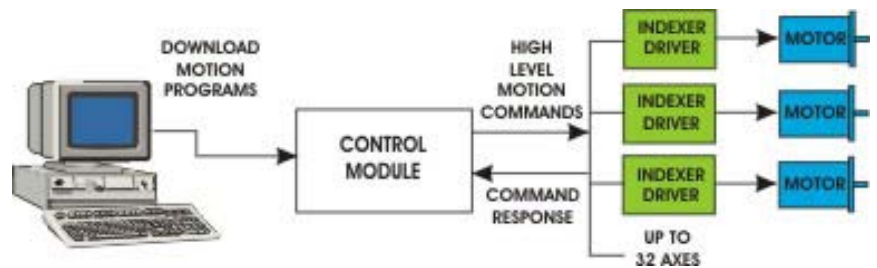
Some applications require a high degree of synchronization, such as circular or linear interpolation. Here, it may be necessary to coordinate the movement with a specific coordinated motion system to achieve these requirements.

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5. POWER SUPPLY

VOLTAGE

The higher the output voltage from the driver, the higher is the maximum speed from any specific motor. The higher the voltage, the faster the current in the windings will reach its new target value from one step to the next, overcoming the inherent inductance value of the winding and building the magnetic field in the rotor. So, a higher voltage will result in better speed performance.

The relationship between torque and speed varies greatly across stepping motors. Parameters such as the inductance of the coils and their resistance play an important role. The higher the inductance, the worse the performance will be at higher speeds, but the better the torque at lower speeds.

When selecting a motor for your application, make sure that it is capable of delivering adequate torque at your target speeds of operation. The most powerful and efficient motor would be the hybrid bipolar model. But, if you are using bifilar motors with 6 or 8 leads, you may be able to optimize performance by selecting either the series or parallel configuration as explained in the *Motor Wiring Configurations* section of the *Drivers* chapter.

The voltage applied to the step motor should be higher than its rated motor voltage; it is common to use a motor drive voltage that is 3 to 25 times higher. As an example, for a motor that is rated at 3.7V, motor supply voltages in the range of 11V to 92V are typical. Again, the higher the voltage, the better the performance will be. But, never drive a motor past its absolute maximum voltage rating (insulation rating).

Again, the rated motor voltage does not represent the maximum voltage that can be applied to the motor. In fact, the motor will normally not operate properly at the rated motor voltage.

TYPE

Unregulated power supplies are best suited for step motor applications. Their behavior is superior to other power supplies, such as switching power supplies, especially in situations where there is a wildly variable change in current demand. Note also that stepper motor drivers utilize a 'chopping' mechanism that requires much higher peak currents spread out to make lower average currents, and thus requires higher instantaneous peak currents. These instances can occur in step motor applications, depending on usage. Nevertheless, switching power supplies are also successfully used in many step motor applications. They are attractive due to their price competitiveness. An important consideration in the design of such power supplies is the addition of a buffering capacitor – it provides the peak current needed, allowing the supply to be rated closer to the average current. Capacitors should be adequately sized to provide peak current during the response time of the power supply.

AMPERAGE

The current capability is another key parameter in selecting an appropriate power supply. The current rating is determined by the choice of motor, driver, and the stepping mode you are planning to use it in. Full step mode, where both phases are on maximally at full current, requires more current than microstepping modes do. Also, the current draw strongly depends on the voltage. The higher the voltage, *the less current* will be required from the power supply to achieve a given phase current in the windings of the motor.

Typically a power supply capable of delivering maximum supply current at ½ or more of the 'peak phase current' should be sufficient. For example, if you are using a motor with a maximum peak phase current of 4A per phase is set, then a power supply capable of delivering 2A or more will be adequate in nearly all applications.

When connecting several drives and motors to one power supply, the current draw for all drives need to be added together to yield the requirement for the power supply. Further, any equipment that shares a single power supply should be wired individually to the supply (without sharing intermediate wiring) to reduce ground voltage offsets and other signal and power interactions.