AMS ADVANCED MICRO SYSTEMS, INC. ams2000.com

Stepper Motor System Basics

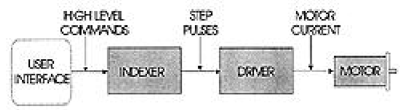
BACK

INTRODUCTION

Motion Control, in electronic terms, means to accurately control the movement of an object based on either speed, distance, load, inertia or a combination of all these factors. There are numerous types of motion control systems, including; Stepper Motor, Linear Step Motor, DC Brush, Brushless, Servo, Brushless Servo and more. This document will concentrate on Step Motor technology.

In Theory, a Stepper motor is a marvel in simplicity. It has no brushes, or contacts. Basically it's a synchronous motor with the magnetic field electronically switched to rotate the armature magnet around.

A Stepping Motor System consists of three basic elements, often combined with some type of user interface (Host Computer, PLC or Dumb Terminal):



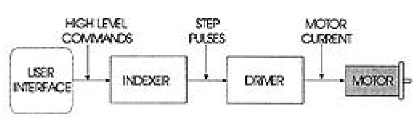
The Indexer (or Controller) is a microprocessor capable of generating step pulses and direction signals for the driver. In addition, the indexer is typically required to perform many other sophisticated command functions.

The Driver (or Amplifier) converts the indexer command signals into the power necessary to energize the motor windings. There are numerous types of drivers, with different current/amperage ratings and construction 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 electromagnetic device that converts digital pulses into mechanical shaft rotation. Advantages of step motors are low cost, high reliability, high torque at low speeds and a simple, rugged construction that operates 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.

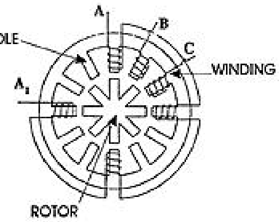
TYPES OF STEPPER MOTORS

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.



VARIABLE RELUCTANCE

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 .



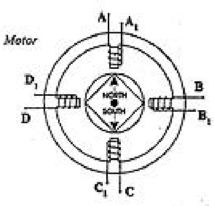
Variable Reluctance Motor

The variable reluctance motor in the above illustration has four "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.

PERMANENT MAGNET

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, such as a line printer print wheel positioner.

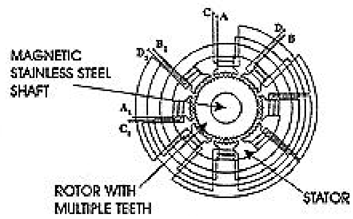
Permanent Magnet Motor



Unlike the other stepping motors, the PM motor rotor has no teeth and is designed to be magnetized at a right angle to it's 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

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 1.80 step angles. Other hybrid motors are available in 0.9ºand 3.6º 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.

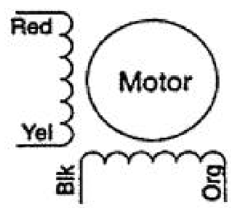


Hybrid Motor

MOTOR WINDINGS

UNIFILAR

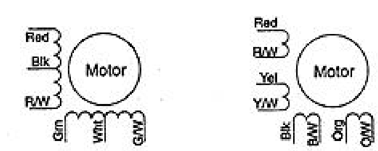
Unifilar, as the name implies, has only one winding per stator pole. Stepper motors with a unifilar winding will have 4 lead wires. The following wiring diagram illustrates a typical unifilar motor:



4 Lead Unifilar Motor

BIFILAR

Bifilar wound motors means that there are two identical sets of windings on each stator pole. This type of winding configuration simplifies operation in that transferring current from one coil to another one, wound in the opposite direction, will reverse the rotation of the motor shaft. Whereas, in a unifilar application, to change direction requires reversing the current in the same winding.



6 and 8 Lead Bifilar Wound Motors

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.

STEP MODES

Stepper motor "step modes" include Full, Half and Microstep. The type of step mode output of any motor is dependent on the design of the driver.

FULL STEP

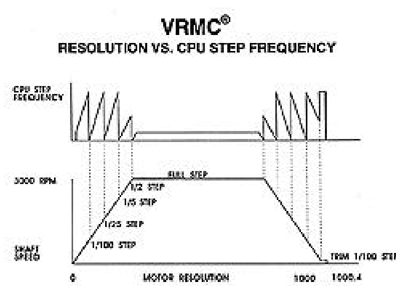
Standard (hybrid) stepping motors have 200 rotor teeth, or 200 full steps per revolution of the motor shaft. Dividing the 200 steps into the 360º's rotation equals a 1.8º full step angle. Normally, full step mode is achieved by energizing both windings while reversing the current alternately. Essentially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

HALF STEP

Half step simply means that the motor is rotating at 400 steps per revolution. In this mode, one winding is energized and then two windings are energized alternately, causing the rotor to rotate at half the distance, or 0.9º's. (The same effect can be achieved by operating in full step mode with a 400 step per revolution motor). Half stepping is a more practical solution however, in industrial applications. Although it provides slightly less torque, half step mode reduces the amount "jumpiness" inherent in running in a full step mode.

MICROSTEP

Microstepping is a relatively new stepper motor technology that controls the current in the motor winding to a degree that further subdivides the number of positions between poles. AMS microsteppers are capable of rotating at 1/256 of a step (per step), or over 50,000 steps per revolution.



Microstepping is typically used in applications that require accurate positioning and a fine resolution over a wide range of speeds.

MAX-2000 microsteppers 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 using "on-motor-pole" synchronization. At the completion of a coarse index, the target micro position is trimmed to 1/100 of a (command) step to achieve and maintain precise positioning.

DESIGN CONSIDERATIONS

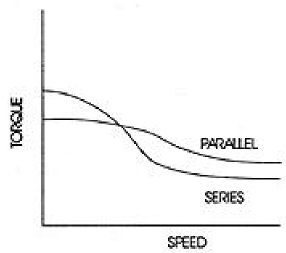
The electrical compatibility between the motor and the driver are the most critical factors in a stepper motor system design. Some general guidelines in the selection of these components are:

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 similarly the reverse is true.

SERIES, PARALLEL CONNECTION

There are two ways to connect a stepper motor; in series or in parallel. A series connection provides a high inductance and therefore greater performance at low speeds. A parallel connection will lower the inductance but increase the torque at faster speeds. The following is a typical speed/torque curve for an AMS driver and motor connected in series and parallel:



Series vs. Parallel Motor Connection

DRIVER VOLTAGE

The higher the output voltage from the driver, the higher the level of torque vs. speed. Generally, the driver output voltage should be rated higher than the motor voltage rating.

MOTOR STIFFNESS

By design, stepping motors tend to run stiff. Reducing the current flow to the motor by a small percentage will smooth the rotation. Likewise, increasing the motor current will increase the stiffness but will also provide more torque. Trade-offs between speed, torque and resolution are a main consideration in designing a step motor system.

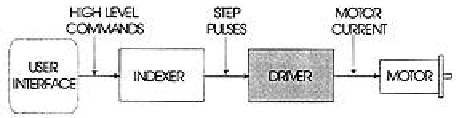
MOTOR HEAT

Step motors are designed to run hot (50º-90º C). However, too much current may cause excessive heating and damage to the motor insulation and windings. AMS step motor products reduce the risk of overheating by providing a programmable Run/Hold current feature.

DRIVER TECHNOLOGY OVERVIEW

The stepper motor driver receives low-level signals from the indexer or control system and converts them into electrical (step) pulses to run the motor. One step pulse is required for every step of the motor shaft. In full step mode, with a standard 200 step motor, 200 step pulses are required to complete one revolution. Likewise, in microstepping mode the driver may be required to generate 50,000 or more step pulses per revolution.

In standard driver designs this usually requires a lot of expensive circuitry. (AMS is able to provide equal performance at low cost through a technology developed at AMS known as VRMC®; Variable Resolution Microstep Control).



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 inductance. The lower the inductance, the faster the current gets to the winding and the better the performance of the motor. To reduce inductance, most types of driver circuits are designed to supply a greater amount of voltage than the motors rated voltage.

TYPES OF STEP MOTOR DRIVERS

For industrial applications there are basically three types of driver technologies. They all utilize a "translator" to convert the step and direction signals from the indexer into electrical pulses to the motor. The essential difference is in the way they energize the motor winding. The circuit that performs this task is known as the "switch set."

UNIPOLAR

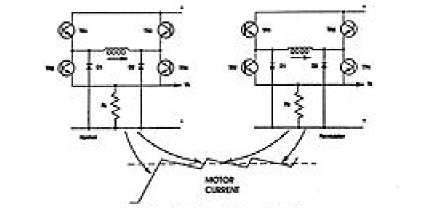
The name unipolar is derived from the fact that current flow is limited to one direction. As such, the switch set of a unipolar drive is fairly simple and inexpensive. The drawback to using a unipolar drive however, is it's limited capability to energize all the windings at any one time. As a result, the number of amp turns (torque) is reduced by nearly 40% compared to other driver technologies. Unipolar drivers are good for applications that operate at relatively low step rates.

R/L

R/L (resistance/limited) drivers are, by today's standards, old technology but still exist in some (low power) applications because they are simple and inexpensive. The drawback to using R/L drivers is that they rely on a "dropping resistor" to get almost 10 times the amount of motor current rating necessary to maintain a useful increase in speed. This process also produces an excessive amount of heat and must rely on a DC power supply for it's current source.

BIPOLAR CHOPPER

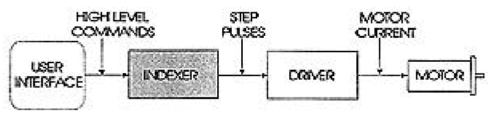
Bipolar chopper drivers are by far the most widely used drivers for industrial applications. Although they are typically more expensive to design, they offer high performance and high efficiency. Bipolar chopper drivers use an extra set of switching transistors to eliminate the need for two power sources. Additionally, these drivers use a four transistor bridge with recirculating diodes and a sense resistor that maintains a feedback voltage proportional to the motor current. Motor windings, using a bipolar chopper driver, are energized to the full supply level by turning on one set (top and bottom) of the switching transistors. The sense resistor monitors the linear rise in current until the required level is reached. At this point the top switch opens and the current in the motor coil is maintained via the bottom switch and the diode. Current "decay" (lose over time) occurs until a preset position is reached and the process starts over. This "chopping" effect of the supply is what maintains the correct current voltage to the motor at all times.



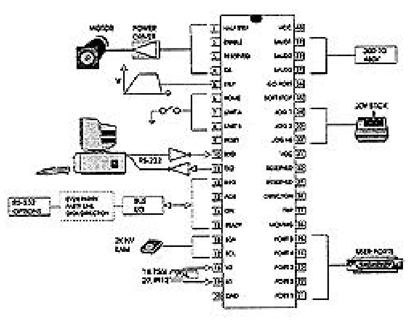
Bipolar Chopper Driver Switch Circuit

INDEXER OVERVIEW

The indexer, or controller, provides step and direction outputs to the driver. Most applications require that the indexer manage other control functions as well, including acceleration, deceleration, steps per second and distance. The indexer can also interface to and control, many other external signals.



Microprocessor based indexers 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 indexer:



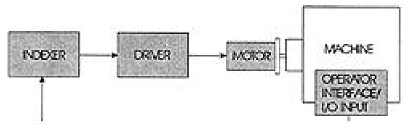
SMC-C24 Step Motor Control I.C.

Communication to the indexer is either Bus-based or through an RS-232/ RS-422 serial port. In either case, the indexer is capable of receiving high level commands from a host computer and generating the necessary step and direction pulses to the driver.

The indexer 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.

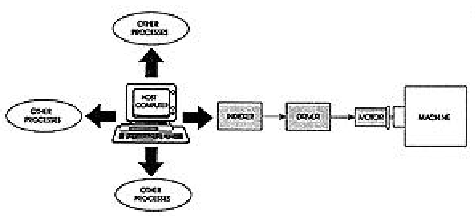
STAND-ALONE OPERATION

In a stand-alone mode the indexer can operate independent of the host computer. Once downloaded to the non-volatile memory motion programs can be initiated from various types of operator interfaces, such as a keypad or switch, or through the auxiliary I/O inputs. A stand-alone stepper motor control system is often packaged with a driver and/or power supply and optional encoder feedback for "closed loop" applications that require stall detection and exact motor position compensation.



INTEGRATED CONTROL

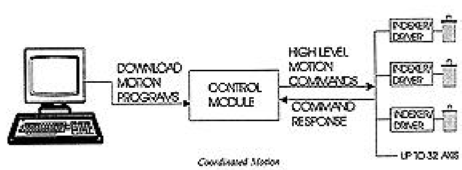
Integrated control means the indexer is embedded within the complete system and accepts commands from the host computer "on-line" throughout the entire motion process. Communication, operator interface and the I/O functions are designed as separate elements of the system. Control and management of the motion sequence is done by the host computer. In this case the indexer acts as an intelligent peripheral. CNC (computer numerical control) applications are well suited for integrated control because the data input is "dynamic", or changing frequently.



MULTI-AXIS CONTROL

Many motion applications have more than one motor to control. In such cases a multi-axis control system is available. A PC Bus step motor controller card for example, may have up to four indexers mounted on it; each one connected to a separate driver and motor. In a serial communication mode, up to 32 axis can be controlled from a single communication port and/or I/O channel.

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 central processor. AMS provides a variety of single board or modular level controllers for these types of operations.



In multi-axis applications that do not require simultaneous motion, where only one motor moves at a time, it is possible to "multiplex" the step and direction pulse from one indexer to multiple drivers.