

Stepper Motor System Basics (Rev. 5/2010)

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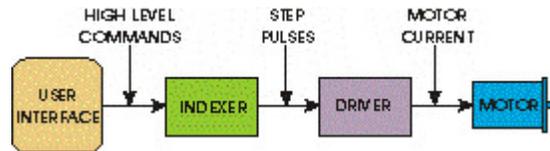
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1. STEPPER MOTOR SYSTEMS OVERVIEW

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.



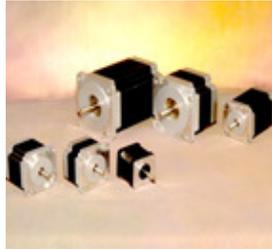
[Example Indexer: IBC-400](#)

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/ampere 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.



[Example Driver: DR-38M](#)

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.



[Example Step Motors: AM Series](#)

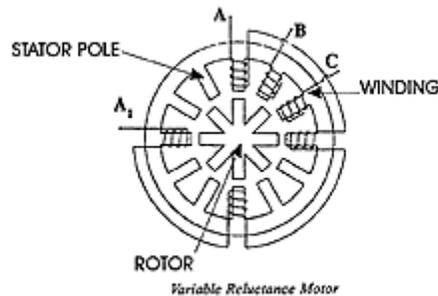
2. STEPPING MOTORS

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.

VARIABLE RELUCTANCE

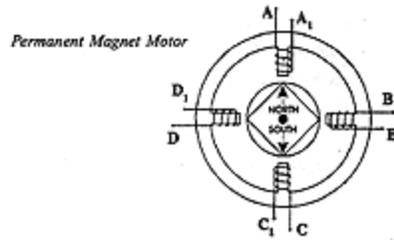
The variable reluctance motor does not use a permanent magnet. As a result, the motor rotor can move without constraint or "detent" torque. This type of construction is good in non industrial applications that do not require a high degree of motor torque, such as the positioning of a micro slide .



The variable reluctance motor in the above 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.

PERMANENT MAGNET

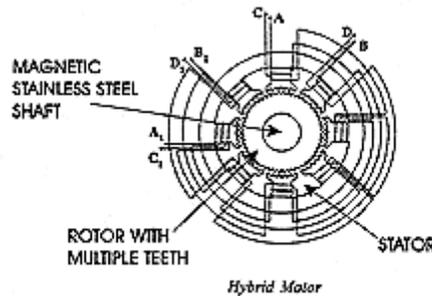
The permanent magnet motor, also referred to as a "canstack" motor, has, as the name implies, a permanent magnet rotor. It is a relatively low speed, low torque device with large step angles of either 45 or 90 degrees. It's simple construction and low cost make it an ideal choice for non industrial applications,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



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

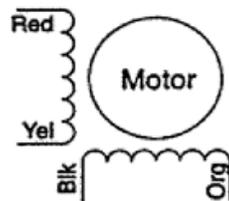
Hybrid motors combine the best characteristics of the variable reluctance and permanent magnet motors. They are constructed with multi-toothed stator poles and a permanent magnet rotor. Standard hybrid motors have 200 rotor teeth and rotate at 1.80 step angles. Other hybrid motors are available in 0.9° 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.



MOTOR WINDINGS

UNIFILAR

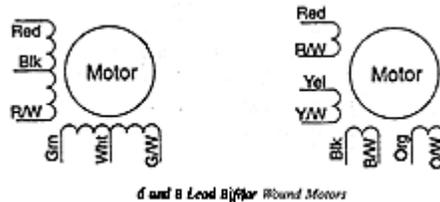
Unifilar, as the name implies, has only one winding per stator pole. Stepper motors with a unifilar winding will have 4 lead wires. The following wiring diagram illustrates a typical unifilar motor:



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.



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

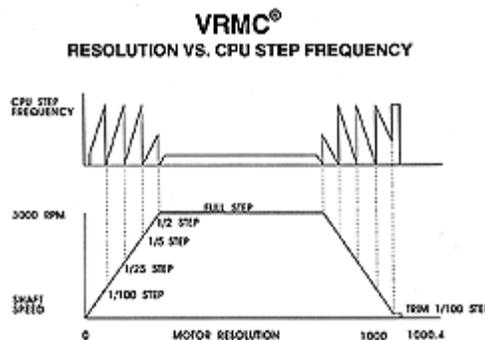
Standard (hybrid) stepping motors have 200 rotor teeth, or 200 full steps per revolution of the motor shaft. Dividing the 200 steps into the 360° rotation equals a 1.8° full step angle. Normally, full step mode is achieved by energizing both windings while reversing the current alternately. Essentially 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 0.9°. (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 technology controls the current in the motor winding to a degree that further subdivides the number of positions between poles. AMS microstep drives are capable of rotating at 1/256 of a step (per step) which corresponds to 51200 steps per revolution (for a 1.8° step angle motor).



Microstepping 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 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.



[MAX-410 and MAX-420 with VRMC.](#)

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 lower torque at higher speeds.

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

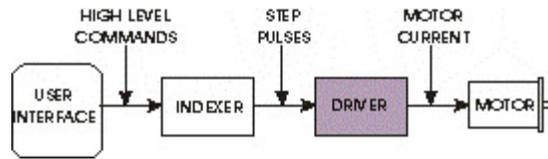
Step motors are designed to run hot (50°-90° C). However, too much current may cause excessive heating and damage to the motor insulation and windings. AMS step motor products reduce the risk of overheating by providing a programmable Run/Hold current feature.

3. DRIVERS

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.

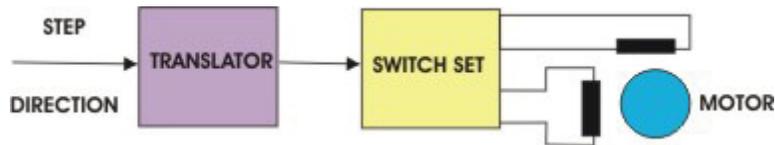
In standard driver designs this usually requires a lot of expensive circuitry. (AMS is able to provide equal performance at low cost through a technology developed at AMS known as VRMC®; Variable Resolution Microstep Control).



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 the effects of inductance, most types of driver circuits are designed to supply a voltage greater than the motor's 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

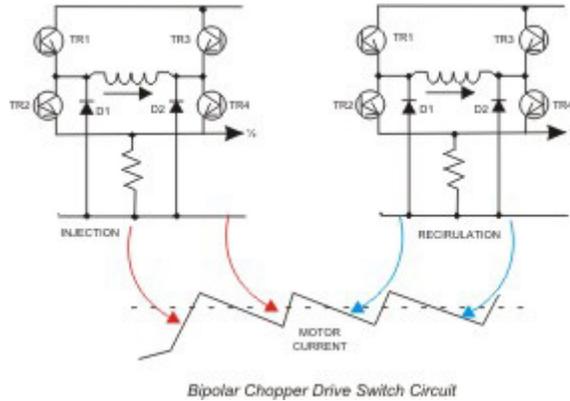
The name unipolar is derived from the fact that current flow is limited to one direction. As such, the switch set of a unipolar drive is fairly simple and inexpensive. The drawback to using a unipolar drive however, is its limited capability to energize all the windings at any one time. As a result, 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 its current source.

BIPOLAR CHOPPER

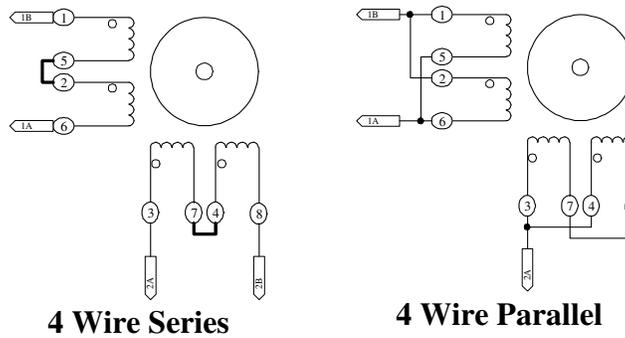
Bipolar chopper drivers are by far the most widely used drivers for industrial applications. Although they are typically more expensive to design, they offer high performance and high efficiency. Bipolar chopper drivers use an extra set of switching transistors to eliminate the need for two power sources. 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.



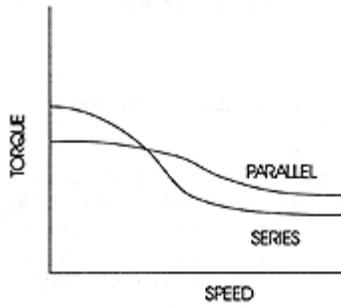
[Example: Chopper Drives with built-in Power Supply](#)

MOTOR WIRING CONFIGURATIONS

Stepping motors typically come with 4,6 or 8 leads. With respect to wiring a motor to the driver, let us first consider bipolar drives. The driver will typically feature 4 connections to connect the motor: a + and – connection for each of the 2 phases. Wiring up a 4 lead motor is therefore straightforward. When using bifilar motors with 8 leads, the coils can either be connected in series or in parallel as shown in the diagrams.

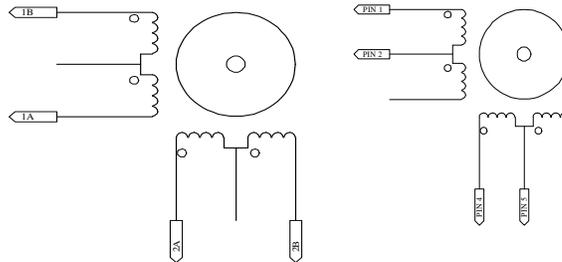


A series connection provides a high inductance and therefore greater performance at low speeds. A parallel connection will lower the inductance but increase the torque at faster speeds. The following is a typical speed/torque curve for an AMS driver and motor connected in series and parallel:



Series vs. Parallel Motor Connection

In case of a six lead motor, the performance at higher speeds can be improved by using the below 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.



6 Wire Motor

6 Wire, Half Winding

Unipolar drivers, as described previously, do not have the capability to reverse the current flow. In order to make the motor operate as desired, the 2 center taps of a 6 lead motor (see diagram “6 Wire Motor”) are connected to the supply voltage. By simply switching either of the end taps to GND, the driver can generate a current in either direction within the coil. As a result, only 1/2 of the coil will be operated at a given time.

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 it is decisive to ensure that this current is not exceeded. This implies that the current of the drive must be restricted to this or any lower value. Many drives allow limiting the current either by potentiometer, DIP switches or by soft setting for example through the indexer. As step motors tend to run hot it is advisable to use a current that is as low as possible while still maintaining reliable operation of the application. This means that in many applications the actual maximum phase current used will be lower than that allowed by the motor manufacturer. This will help to maximize the lifetime of motor and driver hardware.

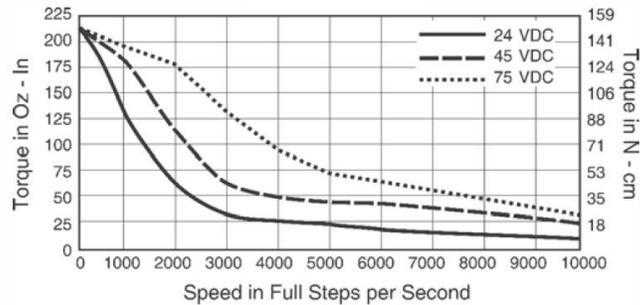
In case of a bifilar motor, the wiring configuration needs to be taken into account. The allowable current in a series configuration is half that of the parallel connection.

4. POWER SUPPLY

VOLTAGE

The higher the output voltage from the driver, the higher is the level of torque versus speed. You can think of the voltage as the driver of the current. The higher the voltage, the faster will the current in the windings reach its new

target value from one step to the next. Therefore it is conceivable why a higher voltage will result in better speed performance.



The torque versus speed behavior varies strongly 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. When selecting a motor for your application, make sure that it is capable of delivering adequate torque at your target speeds of operation. 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 section “Motor Wiring Configurations” in the Chapter “Drivers”.

The voltage applied to the step motor should be higher than the rated motor voltage. It is common to use a voltage that is 3 to 25 times the rated motor voltage. As an example, for a motor that is rated at 3.7V, supply voltages in the range of 11V to 92V are typical. Again, the higher the voltage, the better the performance will be.

Note that 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 sudden increase in current demand. 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 tend to be attractive due to their price competitiveness. An important consideration in the design of such power supplies is the buffering capacitor. It needs to be adequately sized to provide the required 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 and the stepping mode you are planning to use it in. Full step mode, where both phases are on all the time at maximum current, requires more current than microstepping modes. 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.

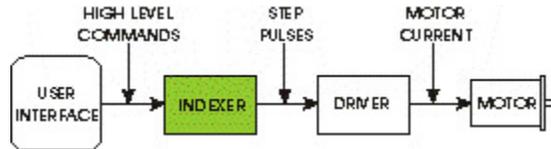
Typically a power supply capable of delivering ½ or more of the peak phase current should be sufficient. For example, if you are using a motor with a maximum phase current of 4A per phase and assuming the drive is set to this maximum value, a power supply capable of delivering 2A or more will be adequate in most applications.

When connecting several drives / motors to one power supply, the current draw for all drives need to be added together to yield the requirement for the power supply.

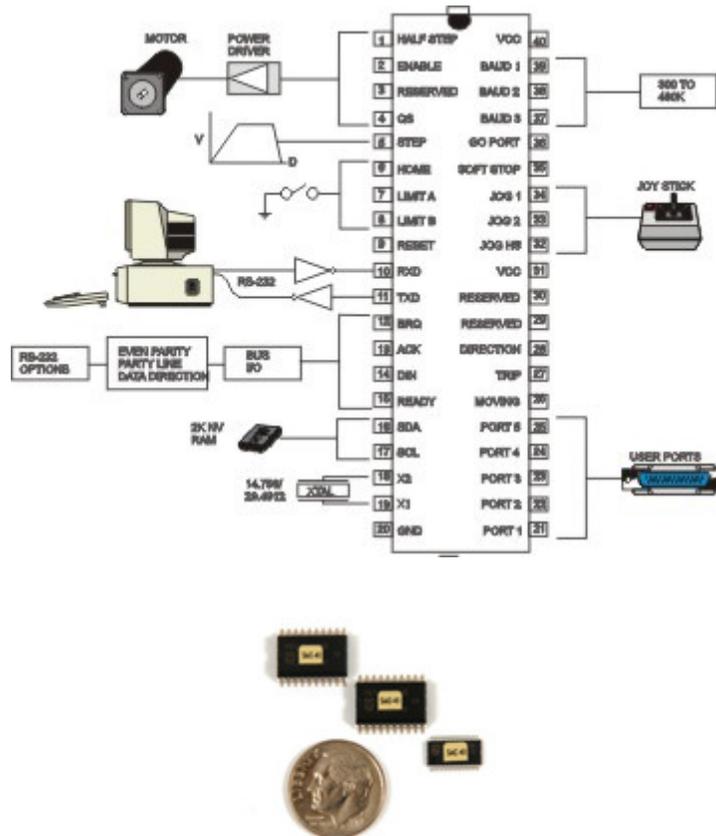
5. INDEXERS

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:



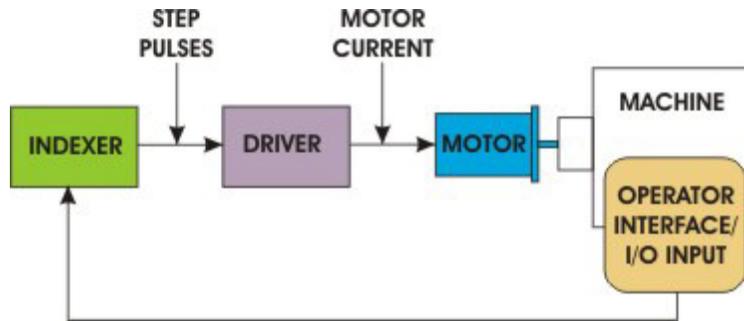
Example: Indexer SMC-40

Communication to the indexer is either Bus-based or through an RS-232/ RS-422 / USB 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.

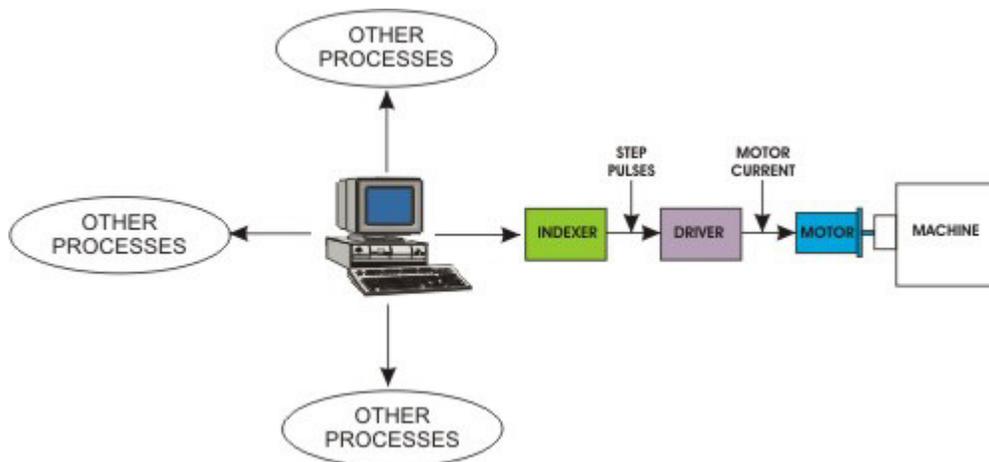
STAND-ALONE OPERATION

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.



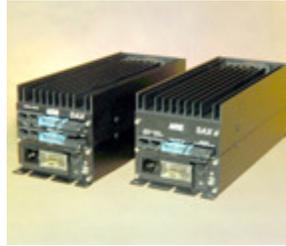
INTEGRATED CONTROL

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.



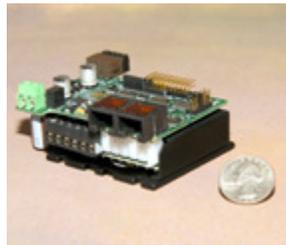
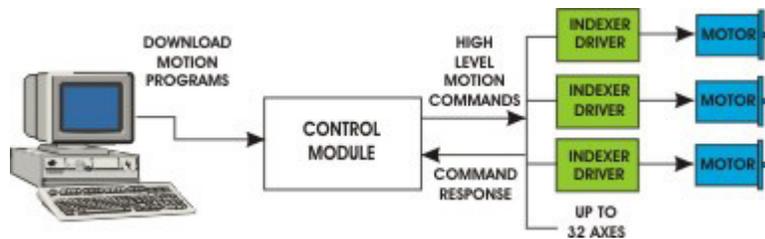
MULTI-AXIS CONTROL

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.



[Example: Multi-axis Control: DAX](#)

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.



[Example: Indexer / Driver with Encoder Feedback mSTEP-407](#)

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.