Step Motor

What Is A Step Motor?

A step motor is a digital device, like a computer, in that digital information is processed to accomplish an end result, in this case, controlled motion. It is reasonable to assume that a step motor will faithfully follow digital instructions just as a computer is expected to. This is the distinguishing feature of a step motor.

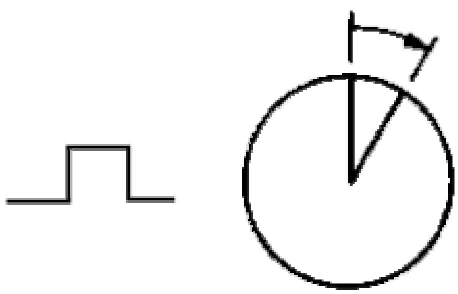

Figure 1: One Pulse Equals One Step

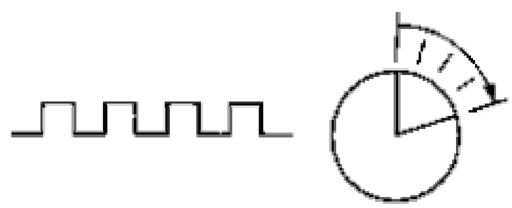

Figure 2: Pulse Count Equals Step Count

In essence, step motors are electrical motors that are driven by digital pulses rather than a continuously applied voltage. Inherent in this concept is open-loop control, wherein a train of pulses translates into so many shaft revolutions, with each revolution requiring a given number of pulses. Each pulse equals one rotary increment, or step (hence, step motors), which is only a portion of one complete rotation.

Therefore, counting pulses can be applied to achieve a desired amount of shaft rotation. The count automatically represents how much movement has been achieved, without the need for feedback information, as would be the case in servo systems.

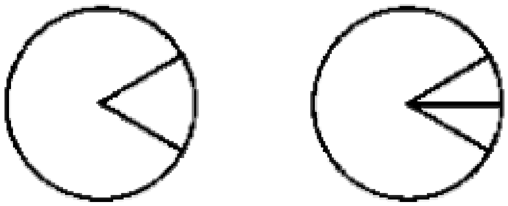

Figure 3

Precision of a step motor controlled motion is determined primarily by the number of steps per revolution; the more steps, the greater the precision. For even higher precision some step motor drivers divide normal steps into half-steps or micro-steps. Accuracy of the step motor is a function of the mechanical precision of its parts and assembly. Whatever the error that may be built into a step motor, it is noncumulative. Consequently, it can be negligible.

How Do They Work?

A step motor is an electromagnetic, rotary actuator, that mechanically converts digital pulse inputs to incremental shaft rotation. The rotation not only has a direct relation to the number of input pulses, but its speed is related to the frequency of the pulses.

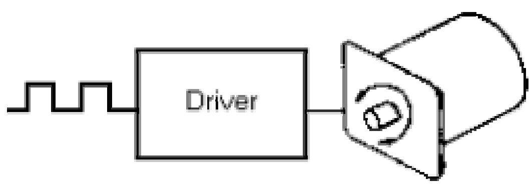

Figure 4: Motor With Driver

Between steps, the motor holds its' position (and its' load) without the aid of clutches or brakes. Thus a step motor can be precisely controlled so that it rotates a certain number of steps, producing mechanical motion through a specific distance, and then holds its load when it stops. Furthermore, it can repeat the operation any prescribed number of times. Selecting a step motor and using it advantageously depends on three criteria: desired mechanical motion, speed, and the load.

With the appropriate logic, step motors can be bi-directional, synchronous, provide rapid acceleration, stopping, and reversal, and will interface easily with other digital mechanisms. They are further characterized as having low rotor moment of inertia, no drift, and a noncumulative positioning error.

Generally step motors are operated without feedback in an open-loop fashion and sometimes match the performance of more expensive DC Servo Systems. The only inaccuracy associated with a step motor is a noncumulative positioning error measured in % of step angle.

Basic Types: Variable Reluctance, Permanent Magnet, Hybrid

Variable Reluctance (VR) - VR motors are characterized as having a soft iron multiple rotor and a wound stator. They generally operate with step angles from 5 degrees to 15 degrees at relatively high step rates, and have no detent torque (detent torque is the the holding torque when no current is flowing in the motor). In Figure 5, when phase A is energized, four rotor teeth line up with the four stator teeth of phase A by magnetic attraction. The next step is taken when A is turned off and phase B is energized, rotating the rotor clockwise 15 degrees; Continuing the sequence, C is turned on next and then A again. Counter clockwise rotation is achieved when the phase order is reversed.

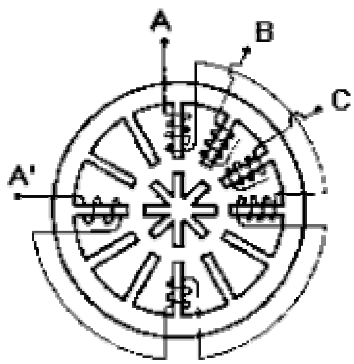

Figure 5: Variable Reluctance Motor

Permanent Magnet (PM) - PM motors differ from VR's by having permanent magnet rotors with no teeth, and are magnetized perpendicular to the axis. In energizing the four phases in sequence, the rotor rotates as it is attracted to the magnetic poles. The motor shown in Figure 6 will take 90 degree steps as the windings are energized in sequence ABCD. PM's generally have step angles of 45 or 90 degrees and step at relatively low rates, but they exhibit high torque and good damping characteristics.

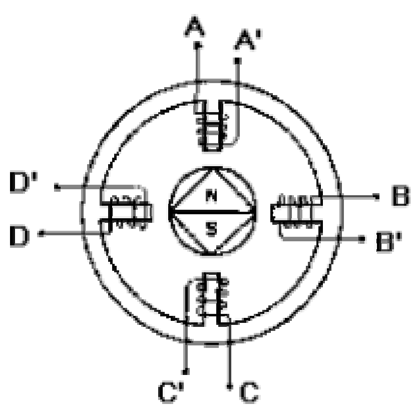

Figure 6:Permanent Magnet Motor

Hybrid - Combining the qualities of the VR and the PM, the hybrid motor has some of the desirable features of each. They have high detent torque and excellent holding and dynamic torque, and they can operate at high stepping speeds. Normally, they exhibit step angles of 0.9 to 5 degrees. Bi-filar windings are generally supplied (as depicted in Figure 7), so that a singlesource power supply can be used . If the phases are energized one at a time, in the order indicated, the rotor would rotate in increments of 1.8 degrees. This motor can also be driven two phases at a time to yield more torque, or alternately one then two then one phase, to produce half steps or 0.9 degree increments.

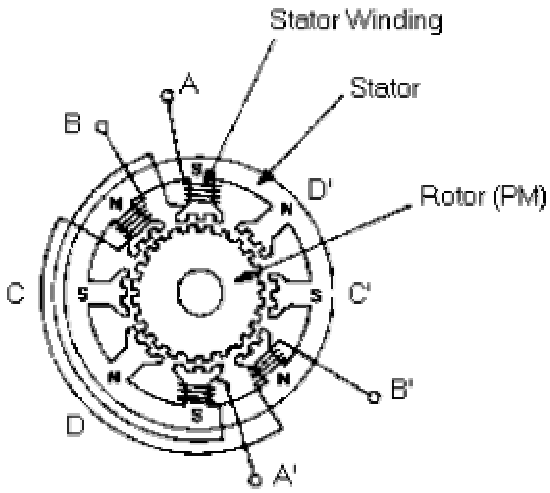

Figure 7: Hybrid Motor

Where Are They Used?

Although the step motor has been overshadowed in the past by servo systems for motion control, it now is emerging as the preferred technology in more and more areas. The major factor in this trend is the prevalence of digital control, and the emergence of the microprocessor.

Today we have many step motor applications all around us. They are used in printers (paper feed, print wheel), disk drives, photo-typesetting, X-Y plotters, clocks and watches, factory automation, aircraft controls, and many other applications. Ingenuity and further advances in digital technology will continue to extend the list of applications.

How Are They Controlled?

Amount, speed, and direction of rotation of a step motor are determined by appropriate configurations of digital control devices. Major types of digital control devices are: Motor Drivers, Control Links, and Controllers. These devices are employed as shown in Figure 8. The Driver accepts clock pulses and direction signals and translates these signals into appropriate phase currents in the motor. The Indexer creates the clock pulses and direction signals. The computer or PLC (programmable logic controller) sends commands to the indexer.

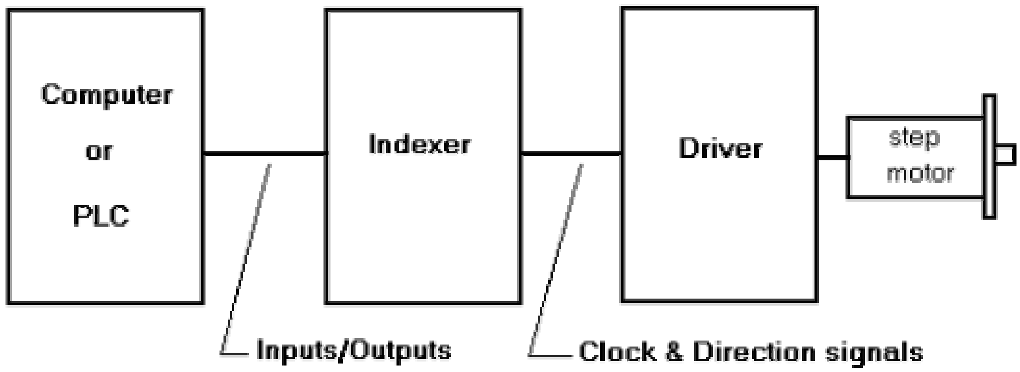

Figure 8: Typical Step Motor System

How To Select A Step Motor Driver

A step motor driver provides precisely controllable speed and positioning. The motor increments a precise amount with each control pulse easily converting digital information to exact incremental rotation without the need for feedback devices such as tachometers or encoders. Because the system is open loop, the problems of feedback loop phase shift and resultant instability, common with servo drives, are eliminated.

Load characteristics, performance requirements, and mechanical design including coupling techniques must be thoroughly considered before the designer can effectively select the most suitable motor and driver combination for an application. The following factors must be considered in order to obtain an optimum solution.

1. Parameters to be considered:
   a) Distance to be traversed.
   b) Maximum time allowed for a traverse.
   c) Desired detent (static) accuracy.
   d) Desired dynamic accuracy (overshoot).
   e) Time allowed for dynamic accuracy to return to static accuracy specification (settling time).
   f) Required step resolution (combination of step size, gearing, and mechanical design).
   g) System friction: All mechanical systems exhibit some frictional force. When sizing the motor, remember that the motor must provide torque to overcome any system friction. A small amount of friction is desirable since it can reduce settling time and improve performance.
   h) System inertia: An object's inertia is a measure of its resistance to changes in velocity. The larger the inertial load, the longer it takes a motor to accelerate or decelerate that load. The speed at which the motor rotates is independent of inertia. For rotary motion, inertia is proportional to the mass of the object being moved times the square of its distance from the axis of rotation.
   i) Speed/Torque characteristics of the motor: Torque is rotational force (in ounce-inches) defined as a linear force (in ounces) multiplied by a radius (in inches). When selecting a motor/drive, the capacity of the motor must exceed the overall requirements of the load. The torque any motor can provide varies with its speed. Individual speed/torque curves should be consulted by the designer for each application.
   j) Torque-to-inertia Ratio: This number is defined as a motor's rated torque divided by its

rotor inertia. This ratio (measurement) determines how quickly a motor can accelerate and decelerate its own mass. Motors with similar torque ratings can have different torque-to-inertia ratios as a result of varying construction.
k) Torque Margin: Whenever possible, a motor drive that can provide more torque than is absolutely necessary, should be specified. This torque margin allows for mechanical wear, lubricant hardening, and other unexpected friction. Resonance effects can cause the motor's torque to be slightly lower at some speeds. Selecting a motor drive that provides at least 50% margin above the minimum required torque is ideal. More than 100% may prove too costly.

2. Calculation: Measurement of inertia, friction and work loads reflected to motor.
a) In an open loop step motor drive system, the motor does not "know" if excessive inertia or friction has made the motor lose or gain one or more steps, thus affecting the positional accuracy.
b) Load inertia should be restricted to no more than four times motor rotor inertia for high performance (relatively fast) systems. A low performance system can deliver step accuracy with very high inertia loads, sometimes up to ten times rotor inertia. System friction may enhance performance with high inertia loads.
3. Experimentation: Tailoring
a) Experimentation for motor sizing is almost always necessary because of dynamic changes in system friction and inertia, (load anomalies) that are difficult to calculate. Motor resonance effects can also change when the motor is coupled to its load.

Types of Drivers

Bilevel Drivers

The basic function of a motor driver is to provide the rated motor phase current to the motor windings in the shortest possible time. The bilevel driver uses a high voltage to obtain a rapid rate of current rise time in the motor windings. When the appropriate operating current level is reached, the driver turns off the high voltage and sustains the current level from a low voltage supply. Hence, the term bilevel. While the motor is stepping, the high voltage drives the current into the windings, supplying more of the required current as the stepping rate increases. This low-high-low voltage switching scheme results in higher efficiency and lower cost than that obtainable from choppers and other more exotic schemes. Also, bilevel drivers do not have motor heating problems or RFI and EMI problems associated with chopper type drivers. Bilevel drivers can only drive motors in the half-step or full-step mode.

L/R Drivers

Step motors driven by L/R drivers produce low to moderate performance. That is, full rated running torque is provided only at low to moderate speeds, resulting in limited power output. However, the speed and power output may be entirely adequate for some low speed applications. Resistance limited, or L/R drivers use dropping resistors to match the motor to the power supply. These resistors are usually placed in series with the common leads of the motor. Their resistance should be calculated based upon the motor phase current and voltage ratings. When moderate to high torque and speed are required, L/R driver circuits are rather inefficient. Considerable heat may be generated in resistors that are part of the circuitry involved, and the power supply and resistors may be rather bulky. These factors must be taken into account before selecting the type of driver to be used.

In more successful L/R driver applications performance requirements are low enough (i.e. low speed operation) to preclude the need for dropping resistors altogether. In these applications, the motor phase voltages often range from 5 to 35 volts with correspondingly low to very low phase currents. These applications make up the bulk of the practical uses for L/R drivers.

PWM (Chopper) Drivers

PWM (pulse width modulated) drivers are also known as chopper or constant current drivers. These drivers use a single high voltage supply. The motor current is regulated by switching output transistors on and off to achieve an average level of current. These drivers have advantages and disadvantages. The most outstanding feature of chopper drivers is the ability to drive motors in a microstep mode (see next section). The disadvantages of chopper drives is that they produce EMI and RFI and often have motor heating problems.

Modes

There are three commonly used excitation modes; full-step, half-step, and micro-step

FULL-STEP

In full step operation, the motor steps through the normal step angle e.g. 200 step/revolution motors take 1.8 steps while in half step operation, 0.9 steps are taken. There are two kinds of full-step modes. Single phase full-step excitation is where the motor is operated with only one phase energized at-a-time. This mode should only be used where torque and speed performance are not important, e.g. where the motor is operated at a fixed speed and load conditions are well defined. Problems with resonance can preclude operation at some speeds. This mode requires the least amount of power from the drive power supply of any of the excitation modes. Dual phase full-step excitation is where the motor is operated with two phases energized at-a-time. This mode provides good torque and speed performance with a minimum of resonance problems. Dual excitation, provides about 30 to 40 percent more torque than single excitation, but does require twice the power from the drive power supply.

HALF-STEP

Half-step excitation is alternate single and dual phase operation resulting in steps one half the normal step size. This mode provides twice the resolution. While the motor torque output varies on alternate steps, this is more than offset by the need to step through only half the angle. This mode has become the predominately used mode by Anaheim Automation because it offers almost complete freedom from resonance problems. Motors can be operated over a wide range of speeds and used to drive almost any load commonly encountered.

MICRO-STEP

In the micro-step mode, a motor's natural step angle can be divided into much smaller angles. For example, a standard 1.8 degree motor has 200 steps/revolution. If the motor is micro-stepped with a 'divide-by-10', then each micro-step would move the motor 0.18 degrees and there would be 2,000 steps/revolution. Typically, micro-step modes range from divide-by-10 to divide-by-256 (51,200 steps/rev for a 1.8 degree motor). The micro-steps are produced by proportioning the current in the two windings according to sine and cosine functions. This mode is only used where smoother motion or more resolution is required.

Where to get it?

You can get it from free from some old printers, or check the following websites:
http://www.linengineering.com
http://www.anaheimautomation.com