The Step Motor

Dan Jones

Step motors come in many sizes and shapes. But they all share one item in common—each step motor type moves in discrete-degree steps. They react to a series of voltage pulses supplied by their basic controller, known as an "indexer." The step motor was the first to accept digital pulses, then move or rotate a prescribed amount without any feedback device. All step motors are position devices without the need to use any feedback devices. They operate primarily in an open-loop control scheme.

VR Step Motor

The first appearance of a step motor was in the mid-1920s. It was the variable reluctance (VR) type used in the British Navy as a direction indicator for guns and torpedoes. Figure 1 details six rotor teeth and eight stator teeth. It uses a magnetic attraction process when the windings are energized sequentially A-B-C-D in a simple counter-clockwise direction. The rotor teeth rotate in a clockwise direction by being drawn magnetically to the aligned position. Each voltage pulse move or step is 15 mechanical degrees. The VR step was the most popular step motor in the 1960s and 1970s, as many office equipment machines and numerical controls turned to computer control; it was largely replaced by other step motor types in the 1980s.

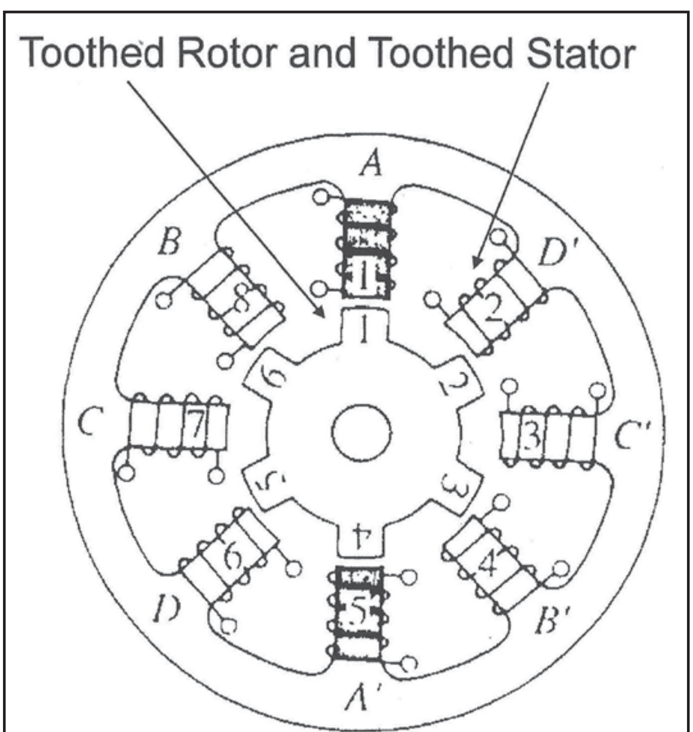

Figure 1 A detail showing six rotor teeth and eight stator teeth of a step motor, which uses a magnetic attraction process when the windings are energized sequentially — A, B, C, D — in a simple, counterclockwise direction.

PM Step Motor

The next step motor to appear was the 4-pole PM step motor that used Alnico magnets. It appeared during World War II and was used as a 4-position switch in military cockpit and other instrumentation packages. It was a 2-phase step motor with four 90° steps-per-revolution. Figure 2 shows the 2-pole rotor magnet and four stator teeth — each with a copper winding and an operating excitation sequence of A-B-A^1-B^1. Its large step angle motion limited its use to very specialized applications. There are some military and space applications that use this motor type with a rare earth rotor magnet.

Can-Stack Step Motor

The availability of the "new" ferrite magnets in the early 1960s led to the development of the can-stack step motor. It combines an inexpensive magnet with multiple poles rotating within two-stator simple toroidal coils surrounded by

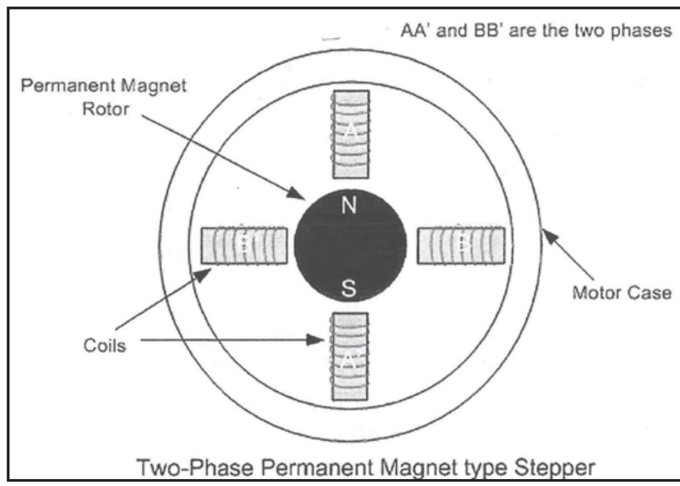

Figure 2 A two-pole rotor magnet and four stator teeth — each with a copper winding and an operating excitation sequence of A, B, A1, B1. There are some military and space applications that use this motor type with a rare earth rotor magnet.

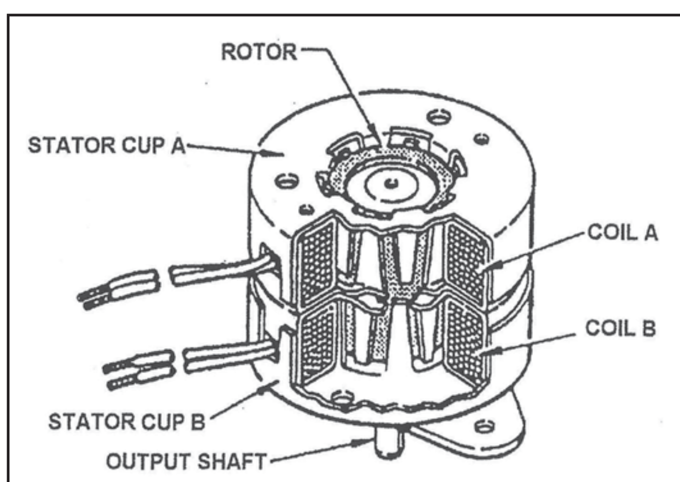

Figure 3 With ready availability of ferrite magnets in 1960s came development of the can-stack step motor. High-volume applications in automobiles and printers use these smaller-sized, cost-effective can-stack step motors.

stamped sheet metal teeth. As shown in Figure 3, the two coil assemblies are offset to achieve alternate N and S magnetic profiles from the all-north top section and the all-south bottom section. The most popular step angle in use for the can-stack step motor is 7.5°. High-volume applications in automobiles and printers use these smaller sized, cost-effective can-stack step motors.

The Hybrid Step Motor

While there are more can-stack motors used in high-volume applications, the hybrid step motor is the workhorse in a myriad of factory, industrial and medical applications. The hybrid step motor is a combination of permanent magnet and variable reluctance motor technology. It was developed in the early 1960s, along with the can-stack step motor, but it immediately differentiated itself as a higher performance step motor. It possesses the highest continuous torque and the best resolution step accuracy of any type step motor.

It is also a two-phase step motor, although there are now both 3-phase and 5-phase hybrid step motors on the market today. The most popular step angle is 1.8° but other step angle operations are available. This motor is a 2-pole permanent magnet—initially Alnico—but later switching to Neodymium-Iron-Boron for improved torque density performance.

Their construction (Fig. 4) is the most complicated of all step motors. The 2-pole, axial-oriented magnet connects to two soft-iron pole pieces with small teeth facing the motor's air gap. The two rotor cups are misaligned with respect to each other by a half-tooth pitch. There are eight major stator teeth with coils and five minor teeth per-motor-stator-tooth-tip facing the air gap. The copper windings are wound on each tooth in bifilar configuration. While the excitation scheme is A-A^{1}-B-B^{1}(2-phase), the magnetic circuit is split with the upper rotor cup (north polarity) magnetically engaging two stator teeth opposite each other (positions 1 and 5) and the lower half of the rotor (south polarity) engaging two other stator teeth (positions 3 and 7). The magnetic circuit is three dimensional due to the polarity difference between the two rotor cups and their flux connections to the stator coils.

Controlling Step Motors

Driving and controlling a step motor in an open-loop configuration (Fig. 5) will provide the user with a simple pulse-and-direction command format. A constant frequency clock will provide signals into an excitation sequence generator or indexer, and then into a 4-transistor drive block to drive the step motor and application load. A counter can count the number of pulses needed to move the load to the desired position. Substitute a microprocessor in place of the clock and sequence generator and counter with a microprocessor and the user possesses the lowest cost electronic positioning system. Add a command function (a larger microprocessor or a digital signal processor (DSP) and a variable pulse rate for starting, slewing and stopping can be created. This system cost is still lower than any position control system. The microprocessor provides the basis for many types of input pulse control such as full step, half step, and micro step strategies. The application motion profile and the position accuracy will determine the desired step motor and control motion strategy. All step motors possess little internal damping capabilities and will "ring" or oscillate around the final position. Figure 5 illustrates an oscillation pattern as a typical step response during a low pulse rate (speed) motion profile.

One can also select different methods for energizing step motor winding. There are two winding hook-ups that are popular. The top approach is the 4-lead bipolar hookup that

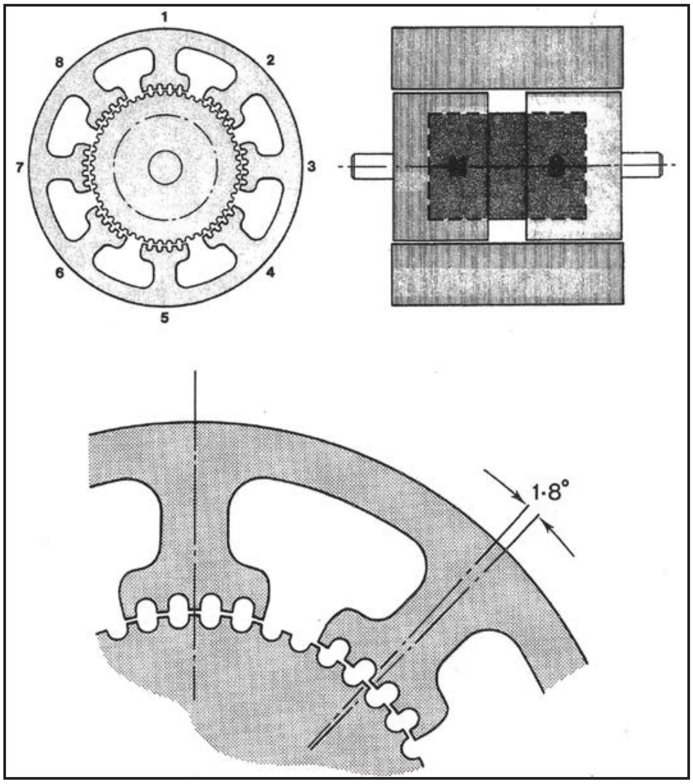

Figure 4 A hybrid (200 step/rev) stepping motor. The detail shows the rotor and stator tooth alignments, and indicates the step angle of 1.8°.

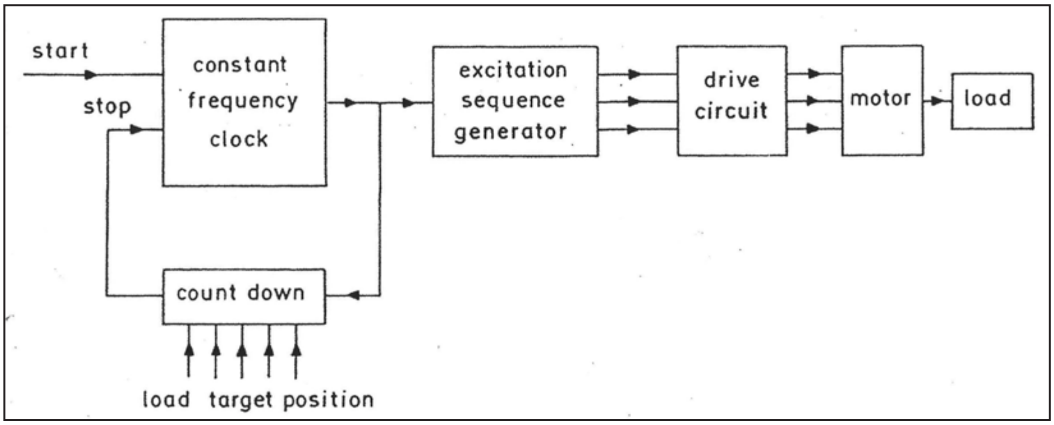

Figure 5 Driving and controlling an open-loop-configuration step motor provides the user with a simple pulse and direction command format.

provides the highest low-speed torque. The second is the 6-lead unipolar hookup for lowest cost, lower torque and higher speed. Many recent step motor controllers can electronically add damping to better control step motor resonances and oscillations. These controllers can also identify a loss of synchronism.

There are many more techniques for driving a step motor, but there is insufficient space in this article to cover them all.

Ins And Outs of Step Motor Performance

The step motor has a unique output torque vs. speed (pulse rate) performance curve. Figure 6 displays a typical curve for a hybrid step motor. There are two major elements in a step motor performance curve, the pull-in and pull-out torque regions. The pull-in torque region is that area of torque and pulse rate (speed) where the step motor can move the load at that commanded pulse rate (speed) within one step. As shown in Figure 6, increasing load inertia reduces pull in the torque region.

The pull-out torque region (cross hatched) area will provide usable torque as long as the step motor is already in controlled motion. The typical motion strategy is to start the step motor in motion at the lower pulse rates and move it using a number of faster pulse rates to move into the pull-out region. This is designated as the pulse rate ramping technique.

Since most applications look at motor shaft speed in rpm, converting a full-step operation of a 1.8° hybrid step motor providing 1,000 pulses-per-second (pps) equals 300 rpm. A typical hybrid step motor will operate at speeds below 4,000 pps or 1,200 rpm. Some special drives can double the step motor speed to 2,400 rpm.

There is another parameter that must be addressed with open-loop control; it is called torque margin. While moving a step motor in the slewing region, any load perturbation could cause the step motor to lose synchronism and drop to zero speed. Step motors do not like load changes— especially increasing load inertias. As a specific pulse rate is commanded, there is a maximum pull-in and pull-out torque rating available. It is displayed as a vertical line upward from the commanded step rate. If just starting a move, one must not have the needed torque approach the pull-in torque load line. If the torque perturbation occurs in the cross hatched region, it is prudent to have a margin of torque available to protect continuous step motor motion. A typical value of torque margin is 60%. Then there would be an extra 40% available to keep the step motor from losing its synchronism. This is a simple example. For longer moves (more pulses), the motion disturbance can be very complicated. All motion is based on timing the pulses at or near peak torque developed per step.

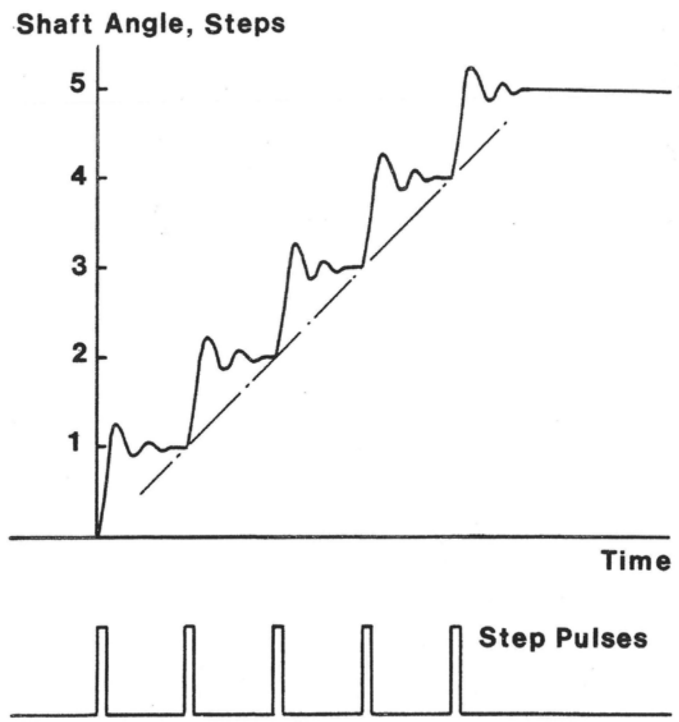

Figure 6 Normal step response to low-frequency, train-of-step command pulses.

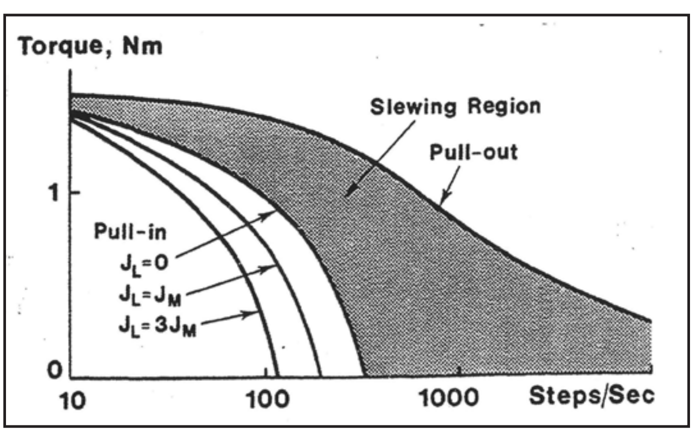

Figure 7 A typical curve for a hybrid step motor. There are two major elements in a step motor performance curve: the pull in, and pull out, torque regions.

Final Comments

As digital devices continued to improve, new developments attached low-count encoders to the step motor shaft to provide a signal that would identify the hybrid step motor's peak torque locations so that the step motor could always supply maximum torque. Further software control algorithms allowed one company to create a 50-pole, brushless PM motor with a 1,000 count optical encoder from a hybrid step motor. Other control innovations added electronic damping and stall detection. While the lower pole count, brushless PM motor continues to grow at a faster pace, the step motor continues to grow as well, driven by its lower cost motion and position solution. **PTE**

Dan Jones received his B.S. degree in electrical engineering from Hofstra University and a M.S. degree in mathematics from Adelphi University. He has since 1962 been a chief engineer and staff engineer with numerous companies. Either as a direct employee or consultant, he has applied his technical skills and experience working on DC motors, step motors, AC motors, brush and brushless motors, electronic drives, and on control systems in applications for the military, industrial, and commercial markets. Jones is a former president of the Association of International Motion Engineers (AIME) and has served on the Board of Directors of the Small Motor Manufacturers Association (SMMA). Jones is now president of Incremotion Associates, a firm combining the capabilities of engineers and marketing focusing on the motion control and power conversion industries.