By Chuck Lewin, Performance Motion Devices Inc

CHOOSING THE RIGHT MOTOR CAN MAKE ALL THE DIFFERENCE FOR YOUR SYSTEM.

Motoring to success

For many motion engineers, motor selection plays a central part in the search for improved system performance. Knowing which motor to use in a given application improves the cost, performance, and simplicity of your machine-design process (**Table 1**).

Motion control is the art and science of precisely controlling the position, velocity, and torque of a mechanical drive. Motion-control systems comprise a numerical controller that performs path generation, such as a DSP; an amplifier; and a motor (**Figure 1**). You can optimize each element of this loop for cost and performance, but not all elements are necessary for all motor types. Different motors require different electronic feedback and controls, affecting the cost and performance of your entire system.

Positioning-control systems most often employ step motors, dc-brush motors, and brushless-dc (permanent-magnet) motors. All electric motors use electromagnetic fields to create torque. You can construct motors to create torque along a rotating axis or on a plane giving linear motion. However, whether the motor is rotary or linear does not affect the fundamentals of how torque, or force, is created.

STEP MOTORS

Step motors are self-positioning and thus do not require an encoder, although sensitive applications often add an encoder that can detect a "stall" during motion. Step motors are usually constructed with no magnetic material in their rotor (the part of the motor that rotates) or their stator (the part that is connected to the motor frame). So, step motors are not only made in high volume, but are also inexpensive. Step motors are also brushless, meaning that there is no direct electrical/mechanical contact to the rotor. Such construction eliminates problems that can occur with mechanical brush or metal commutators, such as arcing or physical degradation. Finally, step motors produce a high torque for a given size and weight.

Despite these advantages, step motors have drawbacks. The most significant disadvantage is that they create noise that is often audible and induce vibrations that can disturb the load. Microstepping techniques or even mechanical dampers can reduce vibration, but these methods seldom completely eliminate the problem. Another significant limitation of step motors is that they have low high-end speeds. For most systems, you can expect a maximum of 5000 rpm. And the torque that is available from a step motor drops significantly at higher velocities. Finally, step motors are generally unavailable in power ranges greater than several hundred watts. The most common NEMA (National Electrical Manufacturers Association) motor sizes for step motors are 17, 23, and 34.

Figure 2 shows typical waveforms to drive a step motor. Step motors are multiphase devices, meaning that they must electronically drive two or more motor coils to create motion. Even if the motion controller you are using is "unaware" of this activity, because it outputs a step and direction signal, the amplifier converts these digital signals into a set of correctly sequenced signals to each coil of the motor. Most step motors have two coils or phases, although more exotic configurations, such as three- and five-phase motors, exist.

Few engineers think of

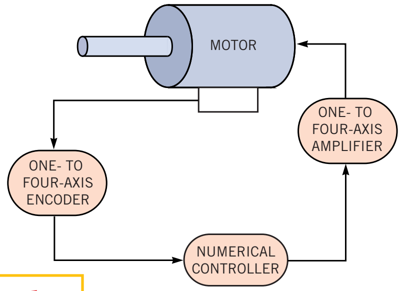


Figure 1 Motion-control systems comprise a numerical controller that performs path generation, such as a DSP; an amplifier; and a motor.

TABLE 1–BEST MOTORS FOR OPTIMIZING COST, PERFORMANCE, AND SIMPLICITY

Desired characteristic	Motor	Comments
Low cost	Step or dc brush	Brushless-dc-motor costs are decreasing but are still greater than step-motor or dc-brush-motor costs in most applications.
Smooth operation (minimal noise or vibration)	Brushless dc or dc brush	You can make brushless-dc motors smoother using high-performance commutation techniques, such as sinusoidal commutation.
High-speed operation	Brushless dc or dc servo	Step motors are not generally suitable for applications beyond 5000 rpm.
High-torque-to-size ratio	Brushless dc or step	Over the full velocity spectrum, brushless motors are superior to step motors, whose torque drops off at higher speeds.
Ease of use	Step	Servomotors require no feedback and no servo tuning.
Single-phase operation (lower amplifier cost)	DC servo	Step and brushless-dc motors are multiphase devices requiring more than one amplifier circuit per motor.

step motors as devices that require "commutation," but this term does apply. In the world of step motors, the commutation techniques that the amplifiers employ have special names, such as "full-step," "half-step," or "microstep" drives. These names refer to the number of power levels that you apply to each motor coil during an electrical cycle. A full-step drive uses an "all-on" or "all-off" technique; a half-step drive can separate the torque level into all-off, halfway-on, and all-on levels); and a microstep drive can generate a more or less sinusoidal signal. The more the waveform resembles a sinusoid, the smoother and more precise the degree of control.

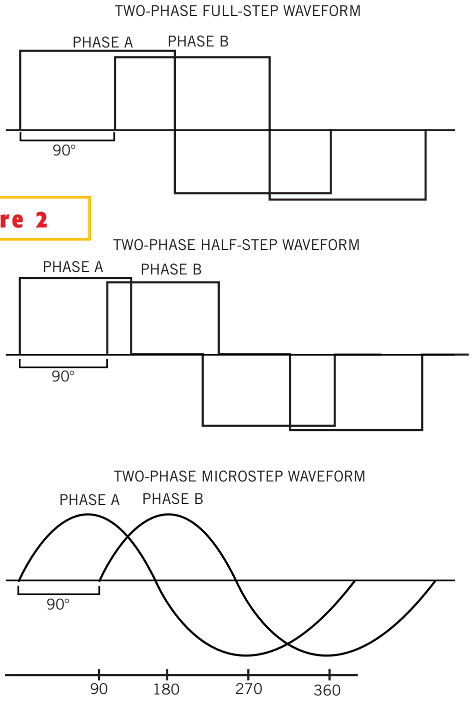
Whatever drive method a motor uses, it moves forward or backward by advancing the drive waveform electrically forward or backward. A "full" step means one 90-electrical-degree movement. Step motors are usually constructed with 1.8 mechanical degrees per full electrical step (or 90 electrical degrees). Therefore, a 1.8° stepper would have 200 full steps per mechanical motor rotation.

If a motor uses a microstepping scheme, you can easily calculate your positioning resolution—not accuracy, which this article will later cover—by multiplying the microsteps per full steps by the degrees-per-full-step rating. Thus, if you use a microstep drive with 64 microsteps per full step, and you use a step motor with 200 full steps per motor rotation, you will be able to move to 12,800 commandable positions per motor rotation. However, with step motors, accuracy and resolution differ, because step motors are neither perfectly linear nor perfectly stiff. Thus, the position you command may not match the theoretical position to which you want your motion system to go.

DC-BRUSH MOTORS

You can use dc-brush motors in a variety of applications that require positioning and in simpler applications, such as speed or torque control. High-volume everyday items, such as hand drills and kitchen appliances, use a dc servomotor known as a universal motor. DC-servo motors are inexpensive; in many cases, their prices are comparable with those of step motors.

Figure 2



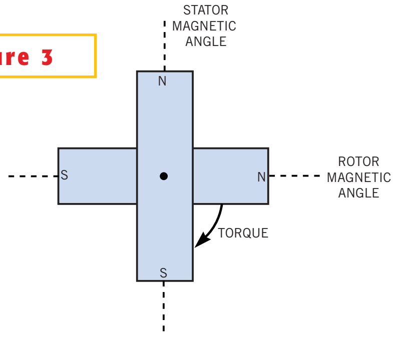
Typical waveforms for driving a two-phase step motor include full-step, half-step, and microstepping.

By itself however, a dc-brush motor has no sense of position. You must connect it to an encoder for use in positioning applications. The encoder provides the position feedback, which connects to a controller. The controller, in turn, generates an output command using a PID (proportional, integral, derivative) algorithm or a similar servo scheme.

DC-brush motors are available in powers as great as more than 1 kW. They can operate at 10,000 rpm and even higher. DC servomotors are smooth and relatively quiet. However, dc-brush motors have two primary disadvantages. The first is that they require a mechanical device to commutate the motor. The brushes can wear out or cause electrical arcing that generates EMF (electromotive force). The second disadvantage is that they have a relatively low torque output for a given size, because current drives through coils on their rotors. From a thermodynamic standpoint, the rotor is not "anchored" to the motor frame. Therefore, you can remove from the coil only a limited amount of the total amount of energy, in turn limiting the available torque output.

DC-brush motors require a single bipolar signal (positive as well as negative voltage) to drive it forward or backward. Give it a positive voltage, and the motor spins in the positive direction and vice versa. So, this type of motor is commutated internally by mechanical contacts that continually distribute the current to the different motor coils, depending on the rotor angle. This technique keeps the rotor electrical/magnetic angle a consistent 90° from the stator electrical/magnetic angle, thereby creating the maximum torque for a given magnetic field (**Figure 3**).

Figure 3



Keeping the rotor electrical/magnetic angle a consistent 90° from the stator's electrical/magnetic angle creates the maximum torque for a given magnetic field.

BRUSHLESS-DC MOTORS: OVERACHIEVERS

Brushless-dc motors have been gaining in popularity in the last several years because, for many applications, they provide a "no-compromise" approach to servo control. Brushless-dc motors are relatively smooth and quiet and require no mechanical brushes for commutation. In addition, they drive the torque-generating current through the stator, which is directly connected to the motor case, allowing heat to be rapidly dissipated. In turn, brushless-dc motors can generate high torque for a given package size. Brushless-dc motors are available in a variety of power ranges up to more than 1 kW, and you can operate them at very high speeds. Some motors reach beyond 30,000 rpm.

Despite these important advantages, brushless motors have several disadvantages. Like dc-brush motors, they have no sense of position and thus require a position encoder. They are also more expensive than dc-servo or step motors, because they require rare-earth magnetic materials to generate torque. Further, brushless-dc motors must be commutated externally, increasing the complexity of the controls and requiring the installation of Hall sensors or equivalent phasing tracks on the optical encoder disk.

Hall sensors typically perform commutation. These signals provide digital reference signals that allow the controller to excite each of the three motor-phase coils at the right time based on the shaft angle of the motor. **Figure 4** shows typical commutation waveforms for brushless-dc motors.

Sinusoidal commutation is a higher performance commutation method that has become popular in the last 10 years. The technique uses the motor's position encoder or a resolver to generate continuously varying sinusoidal signals. The motor-drive signals are phased 120 electrical degrees apart. Sinusoidal commutation results in smoother motion without Hall-boundary discontinuities, which otherwise can cause servo-stability problems.

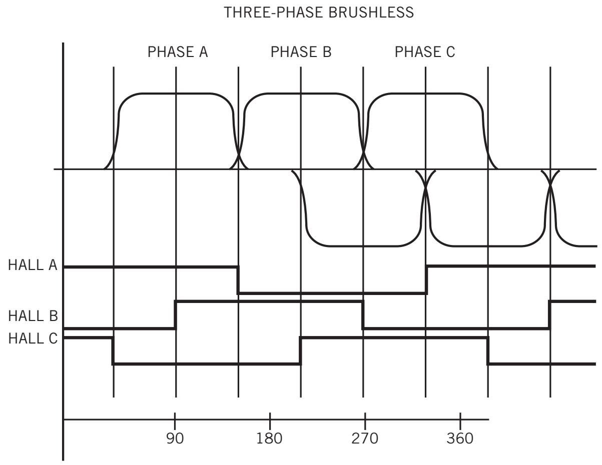


Figure 4 A three-phase brushless-dc motor uses Hall-based and sinusoidal-drive waveforms.

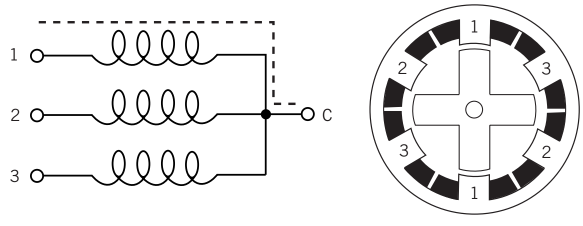


Figure 5 The switched-reluctance motor is usually a four-lead motor with three driven coils and a common high-voltage supply lead.

SELECTING THE RIGHT MOTOR

Before starting a motion-control project, view your system requirements as a whole, factoring in the cost of the motor as well as the control system. Also, factor in your own comfort level working with more control-intensive technologies, such as PID/servo control and external commutation.

The last 15 years have brought two "new" motor types to the scene to impact the world of positioning motion control: variable-, or switched-reluctance, also known as vernier motors, and ac-induction motors.

The switched-reluctance motor is hardly new. Its use dates back to 1838 when it first found use in locomotives. However, it has recently found new popularity due to its low cost, high efficiency, and variable-speed-drive capability. The switched-reluctance motor uses no magnets and is usually a four-lead motor with three driven coils and a common high-voltage supply lead. Commutation is somewhat complicated because the stator and rotor have a different number of poles, most commonly six and four (**Figure 5**). Vibration and noise can also be problems, unless you use more complicated waveforms. Most modern controls can handle these complications, but therein lies the catch. When you add the electronics required to make a switched-reluctance motor perform in positioning applications, the motor becomes expensive. So for the moment, switched-reluctance motors will find use in consumer applications, in which their low cost, variable speed, and high efficiency can seriously challenge their nearest competitor, the ac-induction motor.

The ac-induction motor represents another crossover from the nonpositioning world to the positioning world. It has been the workhorse "plug-it-into-the wall-and-watch-it-spin" motor for much of the past century. Like the switched-reluctance motor, it has no magnets, but unlike the switched-reluctance motor, a simple sinusoid controls it. For positioning applications, a three-lead, three-coil motor configuration is most commonly used, similar to a brushless-dc motor. However, unlike a brushless-dc motor, you use the more complicated Flux vector control to manage an ac-induction motor in a positioning mode. Again, by the time you add an encoder, the cost of the system increases enough that this motor has only marginal advantages, if any, in positioning applications.

Off-the-shelf motion chips, also called motion processors, are IC-based controllers that let users talk in a universal motion language on the "front end," while managing all the motor-specific phasing and signaling on the "back end." A good example is the MC2340 motion processor from Performance Motion Devices (**Figure 6**). This off-the-shelf motion processor provides standard motion features, such as s-curve profile generation and PID with feedforward servo loop and target breakpoints. However, it also provides onboard sinusoidal commutation for brushless dc motors. To use this product, you simply specify the number of encoder counts per motor rotation, and the chip handles commutation and pulse-width-modulation signal generation. Other versions of this same family provide output signals for dc and step motors.□

Figure 6 The off-the-shelf MC2340 motion processor from Performance Motion Devices provides standard motion features, such as s-curve profile generation and PID with feedforward servo loop and target breakpoints.

Author's biography

Chuck Lewin is president of Performance Motion Devices Inc. He has worked in motion control for 12 years and has designed DSP-based motion systems for eight years. He has written more than 50 articles providing practical, application-oriented advice on the implementation of motion-control systems.