

EMPOWERING PROPER SELECTION OF MOTOR TECHNOLOGY

By Mike Lefebvre

While there is no shortage of available electric motor technologies, an initial narrowing of the field for electronics industry applications will often direct attention to several types: *permanent magnet (PM) brush-commutated DC servo motors, brushless DC servo motors, and hybrid stepper motors*. Insights into how each type generally compares with the others can help lighten the evaluation burden and ultimately contribute to proper selection for an application.

As is true with any theoretical exercise comparing and contrasting competing technologies, generic information should always be taken with a grain of salt. Generalizations about motor characteristics may be typical, useful, and preliminarily necessary, but should never be considered absolute. There will always be exceptions and lines may blur, especially since motor solutions often can be recommended and engineered to overcome apparent “deficiencies” perceived in a particular technology.

Nevertheless, as practical starting points in matching motor to application needs, basic selection factors abound to help guide whether a motor type can measure up.

MOTOR DYNAMICS

All *PM brush-commutated and brushless DC servo motors* operate by converting electrical energy into mechanical energy through the interaction of two magnetic fields. One field is produced by a permanent magnet assembly; the other field is produced by an electrical current flowing in the motor windings. The relationship between these two fields results in a torque that tends to rotate the rotor. As the rotor turns, the current in the windings is commutated, or switched, to produce a continuous torque output.

Conventional brush-commutated DC motors use brushes (typically graphite with metal content) as part of the commutation process, while brushless motors achieve commutation electronically via a permanent-magnet rotor, wound stator, and rotor-position sensing scheme.

Hybrid stepper motors combine the operating principles of two distinct step motor types (permanent magnet and variable reluctance). One or more pairs of laminated stacks featuring many sets of teeth along the outside diameter are positioned on the rotor shaft. A permanent magnet between each stack within a pair creates a north pole and south pole along the axis.

Hybrid steppers (like all stepper motors) convert electrical pulses into mechanical movements. Whereas conventional brush or brushless DC motors rotate continuously, a stepper motor, when pulsed, rotates (or “steps”) in fixed angular increments.

Step size, or step angle, will be determined by the number of teeth, motor construction, and type of drive scheme used for control. The most commonly specified step resolution is 1.8° (200 steps per revolution) resulting from 50 pole pairs generated by 50 teeth on each rotor lamination.

‘YARDSTICKS’ FOR COMPARISON

The various motor technologies invite comparisons and users can take advantage of key “yardsticks” to help choose among types. Some of the factors to consider at the outset:

- **Type of Load.** *Brush and brushless DC servo motors* can accommodate a wide range of loads, whether loads are constant, variable, high intermittent peak, or unpredictable. *Hybrid stepper motors* are less tolerant of overload conditions; in fact, high peak loads can cause missed steps and stalls. Stepper types should be specified for applications only where near constant or predictable torque loads can be anticipated.

- **Relative Physical Size and Power Density.** High thermal impedance in *PM brush DC motors* (due to windings located on the armature, or rotor), creates a less efficient thermal path

and diminished rate of heat dissipation. A larger brush motor may therefore be necessary compared to a brushless motor to achieve a given continuous output torque. This larger motor size may be offset by the potential elimination of associated drive electronics.

Lower thermal impedance in *PM brushless DC motors* (windings located in the stator) delivers a more efficient thermal path and higher rate of heat dissipation, which offers the potential for a smaller motor to achieve a given continuous output torque.

Even though *hybrid steppers* exhibit thermal paths similar to those of brushless DC motors, steppers must be sized to accommodate “worst-case” peak loading, which can require a relatively large package. Since steppers are good at delivering high torque at low speed, they offer the potential to eliminate the need for a gearbox, yielding an overall smaller or more convenient package size.

- **Case Heating.** For a given motor size and load point, *brushless DC motors* tend to run at lower internal temperatures than the other two types, due to the higher thermal impedance levels in *brush* types and the continuous drawing of full current for hybrid steppers. (Steppers are typically designed and applied to draw full current constantly.)

Steady-state case temperature for PM brush-commutated DC motors is often significantly less than the winding temperature; case temperature for brushless models often corresponds with the winding temperature; and steppers will run hot relatively constantly..

- **Typical Speed.** *PM brush-commutated DC motors* should generally be operated in excess of 1,000 rpm to prevent brush particle accumulation in the slots between commutator segments, which could result in shorting. Recommended operating speeds above 10,000 rpm are atypical, due to limitations inherent in brush-commutator systems. Speeds below 1,000 rpm can be realized with a gearbox.

High rotational speeds for *brushless DC motors* often will be limited only by the mechanical integrity of the rotor construction, speed-related internal losses, and bearing

selection. Speeds in excess of 10,000 rpm (and even much higher) are possible (with appropriate designs) and speeds below 1,000 rpm can be handled with a gearbox or directly, depending on drive capabilities.

Because of their high pole count, *hybrid steppers* are generally selected for low-speed operation, usually below 1,000 rpm. Usable torque begins to drop off quickly in this range, although specifying a low impedance winding may slightly increase the maximum speed. Notable benefits: Torque capability is quite high at low speeds and steppers further can tolerate operation at multiple speeds through wide ranges.

- **Efficiency.** Gearboxes and brush-and-contact resistance can lower the efficiency of *brush DC motors*. Improvements may be gained from ironless motor construction and precious metal brushes, although subsequent tradeoffs in power density and life can be expected.

Gearboxes and drive electronics will likewise decrease efficiency in *brushless DC motors*, although slotless construction techniques can help compensate by reducing cogging, hysteresis, and viscous losses.

Hybrid steppers represent the least efficient among these motor types, because of continuous current draw.

- **Holding Torque Capability.** Whether *brush* or *brushless*, an unenergized motor's ability to hold a load will depend on its cogging and friction torque, which usually are low. Holding capacity can be increased using a gear reducer to amplify the holding torque reflected to the load. For superior holding capacity installation of brakes is recommended.

An unenergized *hybrid stepper's* ability to hold a load depends on its detent torque, which is similarly low. But since step motors are designed to operate continuously at full current, they can produce high holding torques indefinitely.

- **Susceptibility to Position Loss.** *Brush and brushless DC motors* applied to positioning applications exhibit low susceptibility to position loss, which can be attributed to feedback

devices in a closed loop servo system. By contrast, *hybrid steppers* typically will be applied in an open loop system without a feedback device, rendering them susceptible to position loss. A solution: Specify an encoder for applications demanding position verification.

- **Audible Noise.** Primary sources of audible noise in *brush DC motors* can include armature imbalance, bearings, and brushes yielding moderate overall noise levels. Primary sources in *brushless DC motors* include rotor imbalance and bearings for lower overall noise levels. (Noise in both motor types increases when a gearbox is introduced.) Solutions such as rotor balancing and appropriate bearing and brush material selection can be employed to reduce noise.

In *hybrid steppers* audible noise arises from vibration (caused by resonances) and bearings to create low to high overall noise levels. These levels can be improved by avoiding operating speeds that lead to resonances or instabilities and introducing alternate drive schemes (such as microstepping).

- **Electrical Noise.** For *brushless DC* and *hybrid stepper motors* less electrical noise is generated compared with *brush DC motors*, due to the nature of the mechanical commutation system in brush motors. Noise can be mitigated in brush types by adding suppression devices and filters and appropriately selecting brush materials.

- **Life Expectancy.** In general, *brushless* and *hybrid stepper motors* will serve much longer than *brush-commutated DC motor* types. (This represents one of the greatest practical advantages for these motor types.)

Life expectancy for *brush-commutated DC motors* is limited primarily by the life of the brushes, bearings, and gearbox. Life expectancies in the range of 2,000 to 5,000 hours of operation are common (although actual service life can vary greatly, depending on the motor design and operating current, voltage, speed, and other conditions).

For *brushless DC* and *hybrid stepper motors* life expectancies rise much higher (in excess of 10,000 hours) and will be limited essentially by bearing life and related radial and axial loads, temperature, and environment.

- **Ease of Integration.** *Brush DC motors* are relatively simple to engineer into an application, in part because commutation is performed mechanically without requiring additional components. These motor types can be driven directly by a DC power supply, including a battery, and more advanced drive and control schemes can be integrated for functionality beyond basic operation.

Applying *brushless DC* and *hybrid stepper motors* can be somewhat more complex. Drive electronics for electronic commutation will be required for both types, although “onboard” solutions can help simplify the job for system designers.

With all the many selection factors to consider and particular application requirements to satisfy, we recommend this course of action: Partner with an experienced engineering resource. The expertise can help point the way, remove doubts, and enable a motor’s full potential to be realized.

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