Step vs. Servo – Selecting the Best

Dan Jones

Over the many years, there have been many technical papers and articles about which motor is the best. The short and sweet answer is—let's talk about the application. More recently a number of papers and articles have appeared that compared each motor's advantages and disadvantages in generic or specific terms. Many times, the methods used to drive and control these motors are not completely described due to the many control schemes available for use. A few articles focus on just the open loop step motor and the closed loop servo motor advantages and disadvantages in a laundry list format. This article is attempting to "drill down" into the reasons why and to describe how it is done.

Basic Control Schemes

There are two major basic control schemes, open loop and closed loop. The open-loop control scheme has no feedback sensor. It utilizes the self-regulation capabilities of the motor (in this case the step motor). The closed-loop scheme feeds back speed, torque and position or any combination of these signals to a comparator that compares the measured sensor's signal output to the command to create an error signal. The error signal is then electronically driven to zero as the servo approaches the final commanded position. A typical set of torque-speed plots is shown in Figure 1. I can illustrate the conventional open-loop step motor's better performance at lower speeds versus the closed-loop servo at higher speeds. But other performance parameters are also important.

Encoders and resolvers are examples of special sensors or feedback devices that measure actual position and/or speed that helps to create the error signal.

Other components can play a major role in the motion system's movement and positioning accuracy. But, before one reviews all elements in a position or servo system, let's review the step and servo motors in more detail.

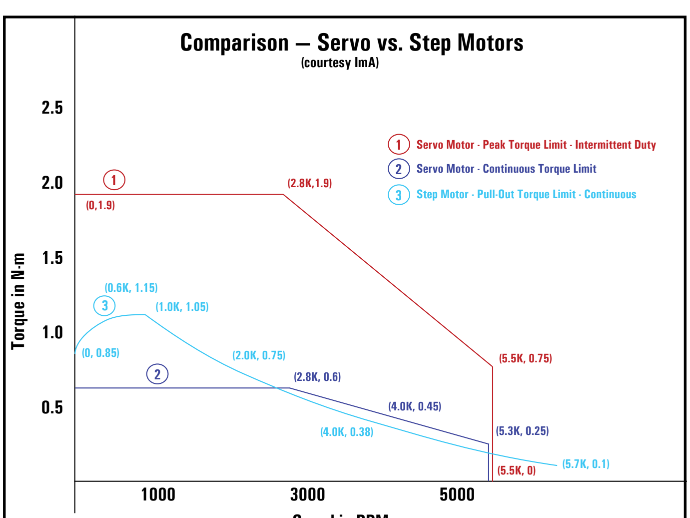

Figure 1 Comparison - Servo vs. Step Motors.

The Hybrid Step Motor

While there are a number of step motor types, the hybrid step motor is the predominant step motor used across a wide range of industrial, medical and automation applications. It possesses a 3-dimensional magnetic circuit with dual 50-tooth magnetic rotor cups, one on each end of the rotor structure (Figure 2). By today's nomenclature, it is a transverse flux motor. The hybrid step motor geometry results in a 1.8 mechanical degree move or step when a single voltage pulse is administered to the step motor windings. Counting the pulses yields the step motor's new position.

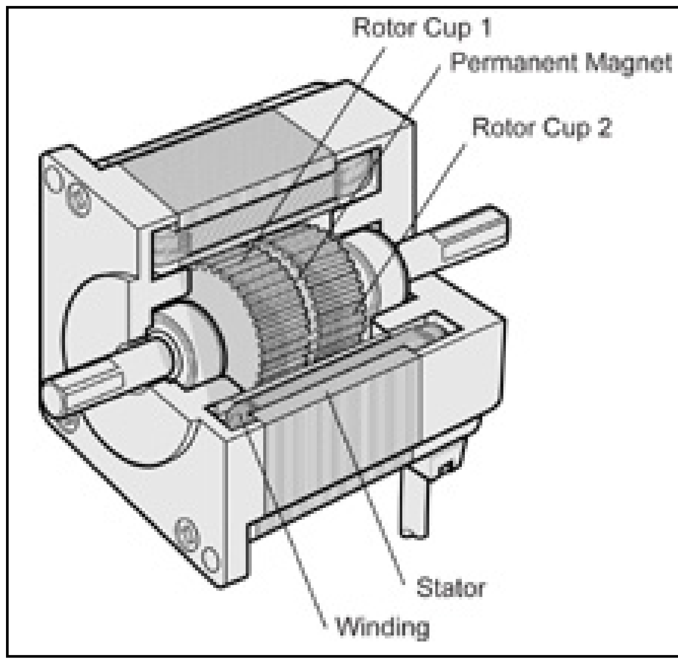

Figure 2 The hybrid step motor.

By definition, the motor is a synchronous, 2-phase, 50-pole brushless permanent magnet (PM) motor. It has a mechanical clearance or air gap of under 2 thousandths of an inch, the smallest of any popular motor type. There is no need for any sensors when operating in a successful open-loop control scheme. The step motor may oscillate and/or resonate around its final position before it settles down. Excessive oscillation could lead to loss of step.

Next in line in popularity is the 5-phase step motor. If the 2-phase hybrid step motor is given a 10 full step command, it will move 18 degrees with a position error of ±0.05 degree unloaded. If the 2-phase step motor moves 10,000 steps, the step error is still ±0.05 degrees. The step error is non-cumulative.

Oriental Motor, a leading supplier of 5-phase step motors, has developed it into an audibly quieter motor. While the rotor is the same for both 2- and 5-phase step motors, there are 8 windings for the 2-phase motor and 10 windings for the 5-phase motor. The 5-phase step motor has a smaller resolution at 0.72 degrees per step (see Figure 3).

Both hybrid step motor types develop more torque than the equivalent sized servo motors below 1,200 full steps per second (about 350 to 400 rpm). Other smaller 2-phase and 5-phase full step hybrid step motors are available; however, the 2-phase, 1.8 degree and the 5-phase, 0.72 degree hybrid step motor are the most popular types. The 5-phase hybrid step motor has the same step accuracy as the 2-phase step motor: ±3% position needs unloaded. The 5-phase step motor is more motion stable that its 2-phase counterpart. Because the 5-phase step motor moves only 0.72 degrees per step, it is nearly impossible for the 5-phase step motor to miss a step due to overshoot or undershoot motion. More will be covered in the drive section.

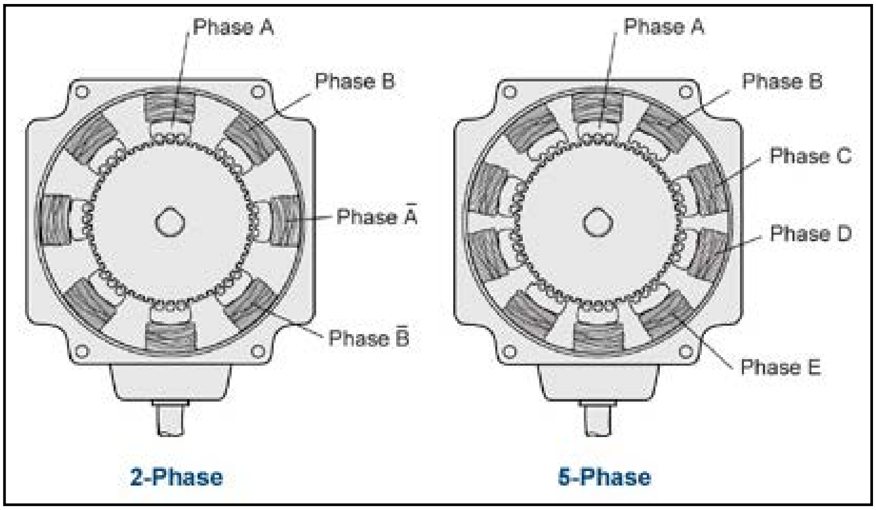

Figure 3 Cutaway view of 2-phase and 5-phase step motors (courtesy Oriental Motor).

Driving & Controlling a Step Motor

Figure 4 shows an open-loop step motor system in block diagram form. The first block diagram is the computer or PLC, the brains of the system. It provides the indexer with the start operating command and the number of pulses that the steps it must move to achieve a required position. The indexer outputs the correct number of pulses and alters the pulse frequency to accelerate, run at a fixed slew speed and then decelerate the step motor and its associated machine load to the commanded position.

The next four system blocks comprise the electronic drive(r). The phase control takes the indexer pulses and

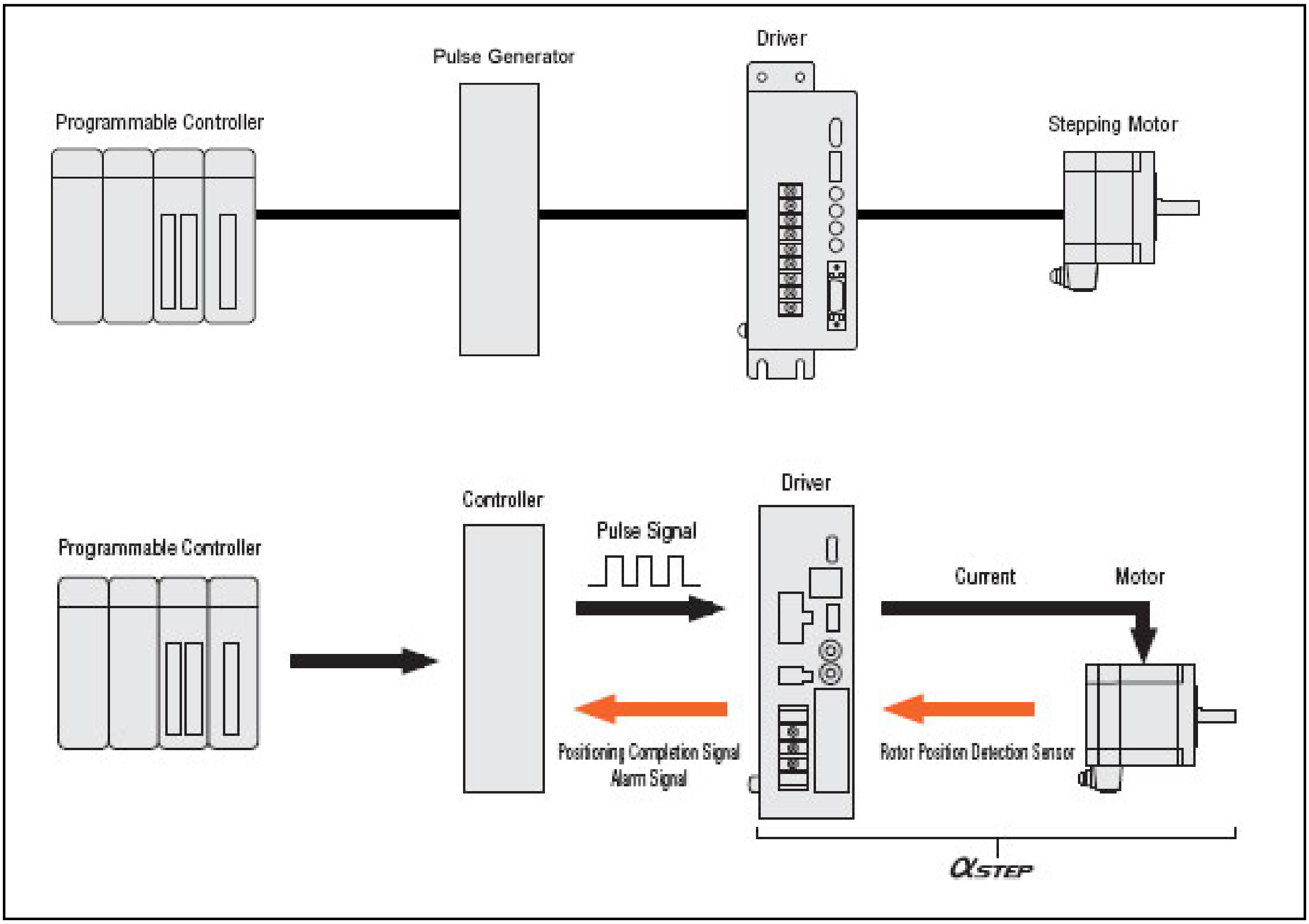

Figure 4 Open loop control of a step motor.

determines which phase or phases are energized in a sequential manner. It is here that any one of four drive sequences can be employed on the computer and indexer inputs. The smaller power supply energizes the various phase control ICs. The phase control logic furnishes the power amplifier with signals used to correctly energize the motor phases. The transistorized power amplifier supplies the higher current and voltage to the step motor from larger power device in order to move the motor and load.

As mentioned previously there are four basic ways to drive an open-loop step motor:

1. Wave Drive (one-phase energized — Full Step)
2. 2 phases on (traditional Full Step)
3. 1–2 phases on (Half Step)
4. Microstep (2-phase vector)

By far the most popular drive topology is the microstepping drive. Microstepping subdivides each full step into a family or series of 8 to 256 microsteps. The discrete full step-by-step motion can be quite spasmodic, particularly at lower speeds.

Microstepping is accomplished by employing pulse width modulation (PWM) to control current to the step motor windings. The driver sends two sine wave voltage waveforms phase shifted 90 degrees one from another. While current is increased in one winding, it is decreased in the other winding phase. The gradual increase in one and decrease in the other results in a much smoother motor current waveform that leads to a more stable run torque profile. However, both torque perturbations and speed ripple are still there but at greatly reduced waveform magnitude.

Now that all the important elements have been identified, how does the engineer combine them to create a successful open-loop step motor system? The starting point is to review the step motor's full step torque-speed (power) performance curve. Next use at least a 30–50% torque margin at the application's specified torque and speed points. Use the pullout torque values. The higher selected torque margin is necessary for load inertia changes and other application variations. Select a microstepping drive (if possible) to reduce resonances or vibrations. Remember, the hybrid step motor does not self-adjust its torque speed and current as the brush and brushless PM motors do. What changes is the developed torque. If the torque needs to rise above the step motor's pull-out torque, the hybrid step motor will lose synchronism and stall. If this happens one must select a larger motor size with more torque and begin the selection again or operate at a much lower speed or frequency. If cost is a major concern, then one must begin the selection process with a hybrid step motor drive using an open-loop drive topology.

Summarizing, the step motor drive system has the following advantages:

- Simpler open-loop drive
- Un-energized detent torque holds final position
- Lower system cost
- Higher shaft torque at lower speeds
- Microstepping smoothes velocity ripple

Disadvantages include:

- Position overshoot and ringing at final position
- Loss of steps while moving at high load or high speed
- limited to speeds below 1,200 rpm
- Lower power efficiency than servo motors
- Can create more internal heat than equivalent sized servos, particularly at higher speeds

The Servo Motor

The typical servo motor is a brushless PM motor with magnets located on the moving rotor. The magnets can be on the rotor hub outside diameter (OD) or buried inside the magnetic rotor hub structure (see Figure 5). The number of magnets in an industrial servo motor can vary from 6 poles to 120-plus poles.

A brushless servo motor is designed to maximize peak torque and fast acceleration capability. The smaller brushless PM servo motors use the NEMA frame sizes (i.e. 17, 23, 34 and 42) as do the hybrid step motors.

The term "servo motor" is not technically correct. The motor by itself has some crude back-EMF signals that can help control speed variations. However, the motor cannot position itself without a set of separate stator coils or an internal resolver or external encoder to provide the needed

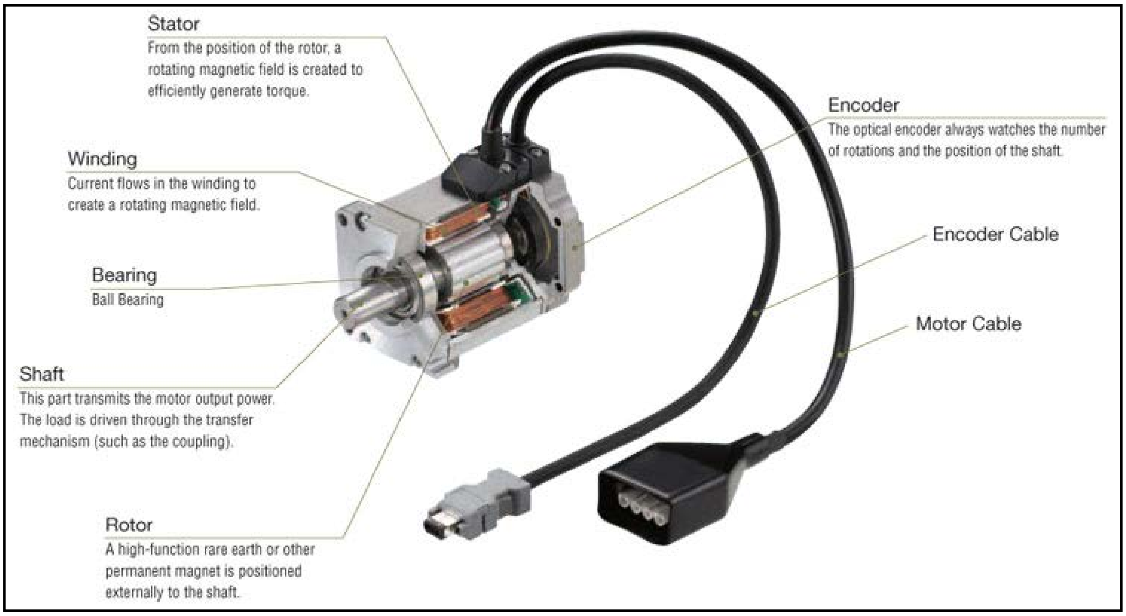

Figure 5 Servo motor construction.

position accuracy for today's 12- to 24-bit encoder position resolution and accuracy used in industrial and factory automation equipment.

The conventional brushless PM motor requires a separate encoder or resolver to provide the necessary feedback sensor signals to control torque, speed and positioning accuracies for servo operation. These extra components increase the overall servo price when compared to the open-loop hybrid step motor. One must use various sensor feedback signals to better stabilize and control the servo motor's motion and positioning requirements. A closed-loop servo control scheme can perform this task better than an open-loop scheme. Any synchronous motor can utilize a servo control scheme. This includes switched reluctance, brush and brushless PM motor and even the hybrid step motor.

Driving & Controlling a Servo Motor

A servo control harnesses several feedback device signals to create a closed-loop or servo control system condition. Position, speed, current/torque are typical closed-loop feedback signals used to develop position, speed and current measurements "on the fly" from the encoder or resolver to be compared to the various command signals. The difference between commanded signals and measured signals creates the analog error signals used to drive and control servo motion to a zero error and its final commanded position. Figure 6 reveals a device diagram at the top and a block diagram below for an analog servo system. The programmable controller (computer or PLC) inputs a series of command signals to the motion controller that also receives the processed feedback signals to create the servo error signals. Potentiometers are used for adjusting the feedback loop gains.

The combination of a 3-phase brushless PM motor, an encoder or resolver with the aforementioned electronic controller provides the following:

Performance Advantages:

- High Torque to Inertia (peak torque)
- Superior position resolution (encoder)
- No major resolution or vibration issues
- Higher shaft speeds
- Lower motor internal losses
- Higher load efficiencies
- Higher power density
- Lower position overshoot
- Wider range of motor frame sizes

Disadvantages include:

- Higher cost
- More complex circuitry
- Tuning feedback gains more complicated
- Feedback gains susceptible to drift (analog servo)
- Can accumulate servo errors

An excellent example is Oriental Motor's NX family of brushless PM motors with a number of servo controls. A high-performance, 20-bit optical encoder is mounted on the motor for carrying out highly accurate positioning operations. A separate reference or home position is used to periodically erase the accumulated servo errors. The NX family is composed of several NEMA frame sizes with continuous power levels covering 50 watts to 750 watts. A tuning algorithm for many application load inertias is used to establish the potentiometer gain settings for each feedback loop. Figure 7 establishes the torque vs. speed performance curve for a 200 watt NEMA size 24 brushless PM motor.

Digital servos are gaining in popularity because they produce a faster response times, simpler ease of auto-tuning and tuning the loop gains. The various loop gains are converted from analog to digital (A to D) signals. All the main control functions are carried out by the microprocessor solving a series of motion equations. Included in its programming is a mathematical model of the servo system that predicts the system's motion behavior.

One of many control strategies is to utilize a PID controller. It can continuously compute the servo error and compensate by varying the Proportional, Integral and Derivative circuit gains. While PID control remains the most popular digital control scheme, there are some others in use depending on the application requirements.

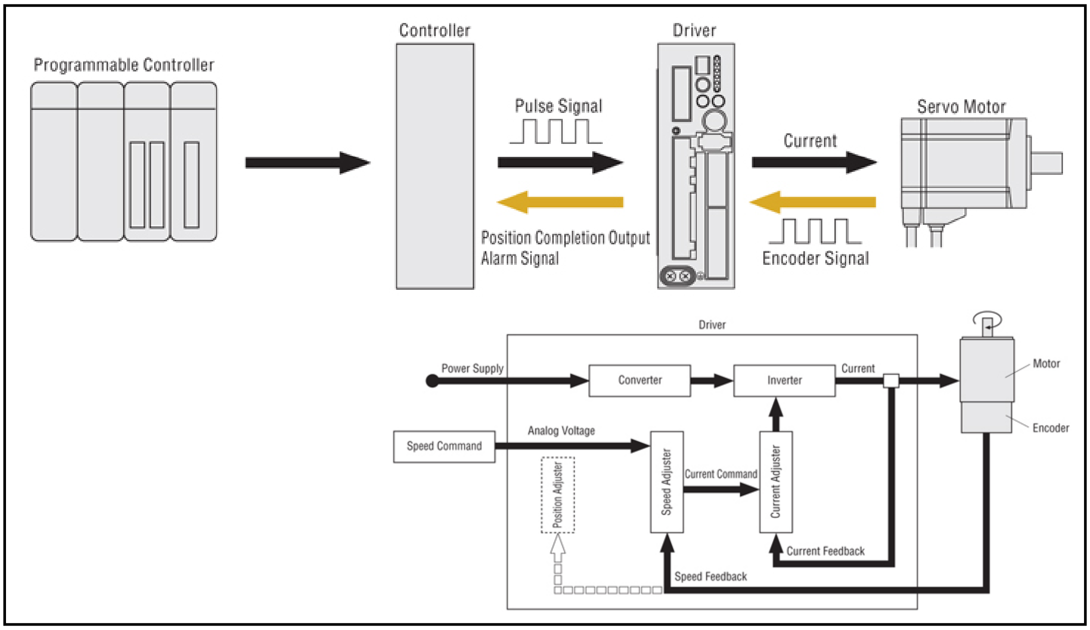

Figure 6 Driving and controlling a servo motor.

Know the Application Needs

Now that the more popular electric motors (step vs. brushless servo) along with their associated drives and controls have been reviewed, the application engineer must develop a profile describing his application needs. The application needs must be matched to the motor's capabilities along with the supporting drive and system requirements.

Sizing

Sizing or selecting a step motor or servo motor requires some mathematical calculations. Most motor manufacturers have developed a computer-based selection program to assist the prospective customer in sizing the application to one of their motors. One selects the servo that best matches the application requirements.

The Oriental Motor Technical Reference supplies the formulas for computing inertia and torque as well as the formulas for selecting the proper step or servo motor. Examples for both step and servo motor selection are liberally included.

It begins with sizing the motor for available space and the motion profile needs. The initial sizing process covers both step and servo motors. Determine what the motion profile looks like. From this profile one can determine the acceleration (and deceleration) requirements. The needed motor speeds can be obtained for repetitive operation. The variable non-repetitive operations require the application engineer to calculate the peak speed and torque and then focus on the motion time.

The available input voltage is set at specific voltages: 120 VAC, 240 VAC rectified to 160 VDC, 320 VDC rectified for all motors typically over 3.35 inches in outside diameter. Smaller sized motors use DC power supplies at 24 VDC, 48 VDC, 72 VDC, 80 VDC and other voltages.

Torque in the form of peak torque for servo motors and pullout torque for step motors is determined by computations using the various formulas found on the internet. One must account for the application mechanism's friction and inertia to establish the total torque during acceleration, slewing and deceleration motion. For example, multiply the acceleration by the total inertia (load + motor) and the results are then tabulated. The list typically includes the supply voltage, rated speed, continuous torque, peak torque and motor size.

The next operation is to tentatively select the motor and confirm its performance vs. application requirements match. For open-loop step motors, apply the needed torque margins, convert the pulses or steps per second into rpm and verify that the selected step motor will more than match the application requirements. The computations for inertia and torque are the same for step motors.

Gathering the various needed performance parameters for both step and servo motor systems will allow the equipment supplier to utilize the various motion companies' selection programs. It will gain some insight into the engineer's application performance requirements. The program can be utilized substituting new performance parameters or contact the motor and drive supplier's application engineer for assistance. This action is the beginning of the road to success. **PTE**

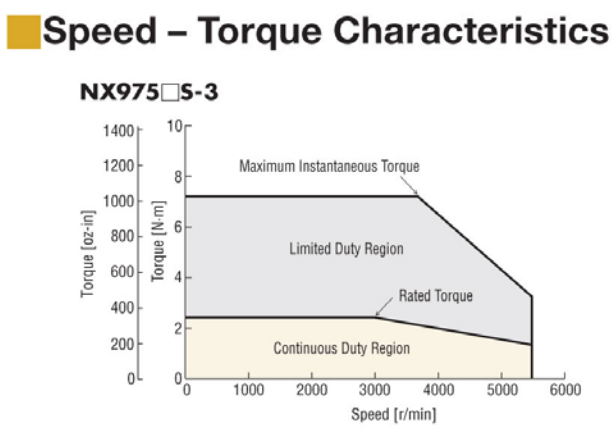

Figure 7 Torque vs. speed performance curve for a 200 watt NEMA size 24 brushless PM motor.

Acknowledgement

The author would like to acknowledge the help supplied to him by the Oriental Motor Engineering Department concerning data and the illustrations for this article.

Dan Jones received his BSEE degree from Hofstra University in 1965 and MS in Mathematics at Adelphi in 1969. He has over 50 years' experience in the design of all types of electric motors and generators from 10 W to 500 kW and has held engineering design, management and marketing management positions at a number of companies. He is recognized as an international authority on electric motors and motion control. He has written 250+ technical articles/papers and held seminars in 10 countries. He is a past member of the board of directors of SMMA and EMERF. In 2014 he received the EMERF Lifetime Achievement Award for "Outstanding Contributions to the Electric Machines Industry." He is a life member of IEEE and a member of ASME.