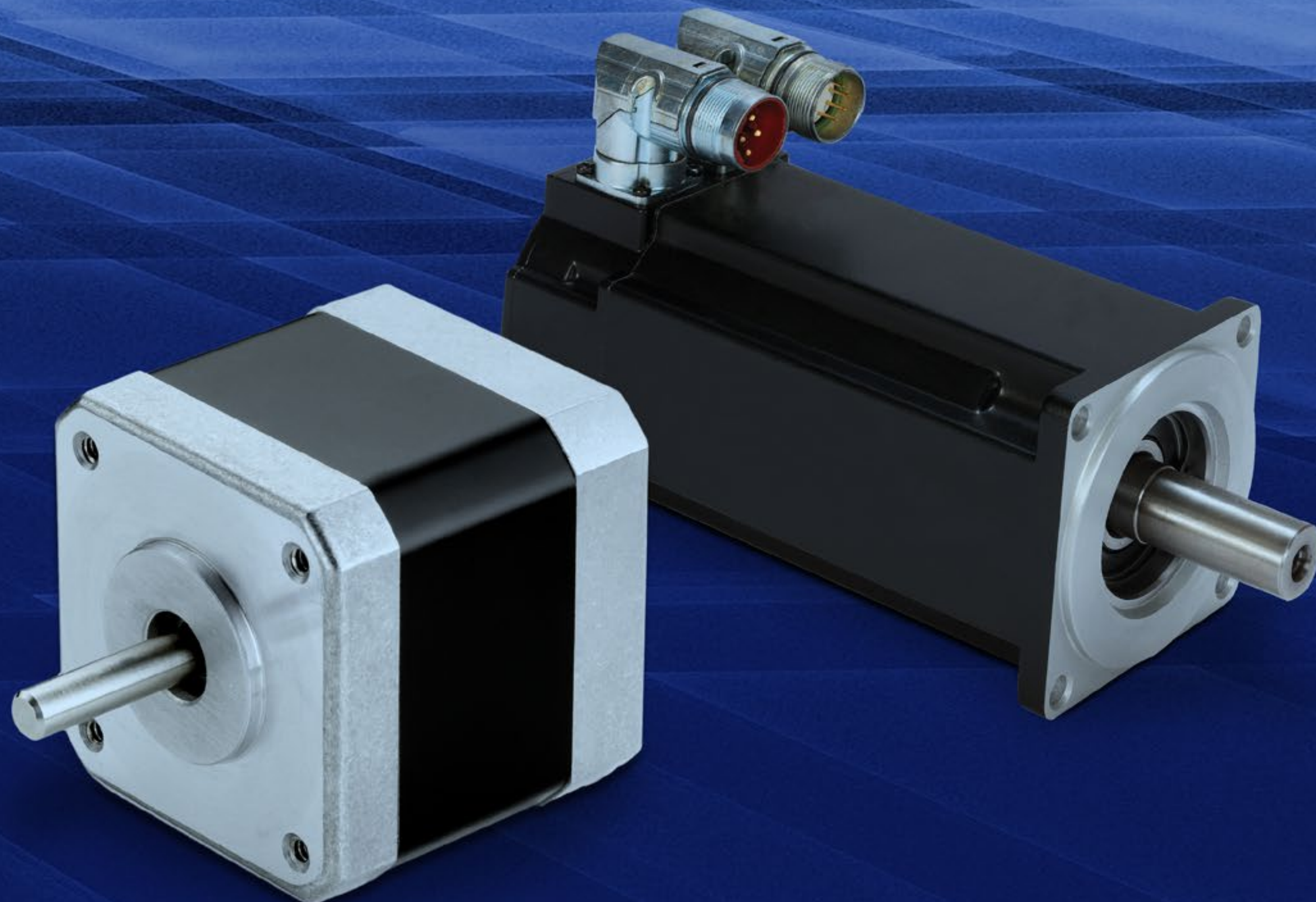


Stepper Motor or Servo Motor:

Which Should It Be?

KOLLMORGEN

Each technology has its niche, and since the selection of either stepper or servo technology affects the likelihood of success, it is important that the machine designer consider the technical advantages and disadvantages of both to select the best motor-drive system for an application.

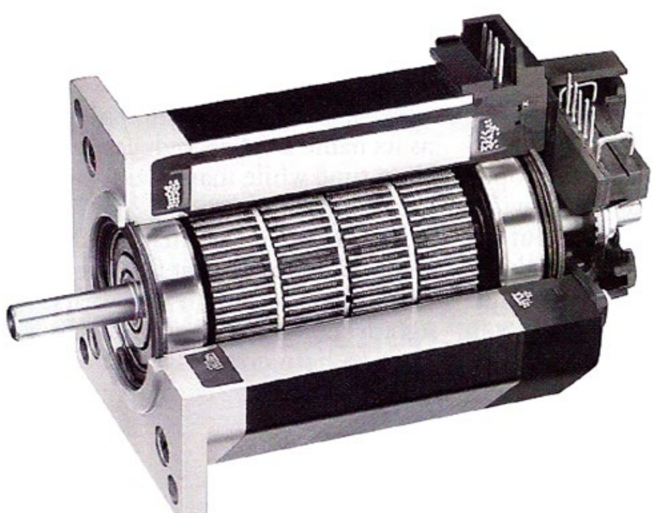
Machine designers should not limit utilization of steppers or servos according to a fixed mindset or comfort level, but should learn where each technology works best for controlling a specific mechanism and process to be performed.

Today's digital stepper motor drives provide enhanced drive features, option flexibility and communication protocols using advanced integrated circuits and simplified programming techniques. The same is true of servo motor systems, while higher torque density, improved electronics, advanced algorithms and higher feedback resolution have resulted in higher system bandwidth capabilities as well as lower initial and overall operating costs for many applications.

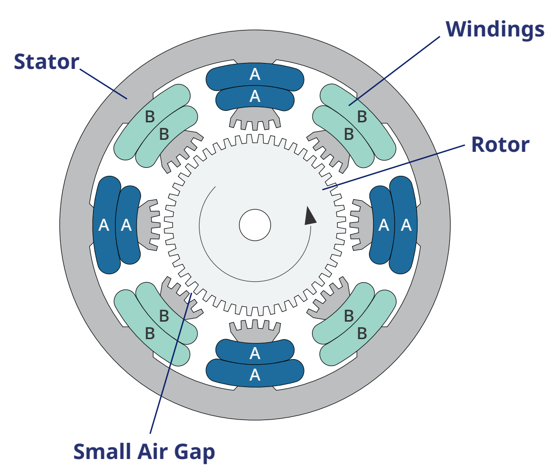
This article presents an overview of stepper and servo capabilities to serve as selection criteria between the two technologies. A thorough understanding of these technologies will help you achieve optimum mechatronic designs to bring out the full capabilities of your machine.

STEPPER MOTOR SYSTEM OVERVIEW

Stepper motors have several major advantages over servo systems. They typically cost less, have common NEMA mountings, offer lower-torque options, require less-costly cabling, and their open-loop motion control simplifies machine integration and operation.



STEPPER CONSTRUCTION



TORQUE AND SPEED CONSIDERATIONS

The issue of whether to use a stepper or servo is dictated by the application in most cases. Steppers are typically sized at twice the continuous requirement for additional acceleration and deceleration torque capability or for a specifically required peak torque.

In contrast, servo motors are generally sized for the application's specific velocities and torques, maximum intermittent acceleration/deceleration, holding torque (if applicable), and equivalent RMS continuous torque requirements over the complete motion profile.

In general, if an application requires high-throughput, high-speed and high-bandwidth capability for disturbance correction, and/or high rpm with or without tight coordination between axes, servo motors are the best option. If point-to-point position performance and rpm requirements are modest (as a function of the process loads and expected disturbances), steppers may be a better choice. Additionally, when the loads are within reason, a stepper's ability to hold position—using holding torque with power and detent torque without power—can be an advantage.

Speed-torque curves highlight the difference between stepper and AC permanent magnet servo motors of equal volume (Figure A). Steppers typically generate higher continuous torque at lower speeds than servo motors. However, servo motors produce intermittent peak torques in this same low-speed range and produce peak and continuous torques over a much wider and higher speed range.

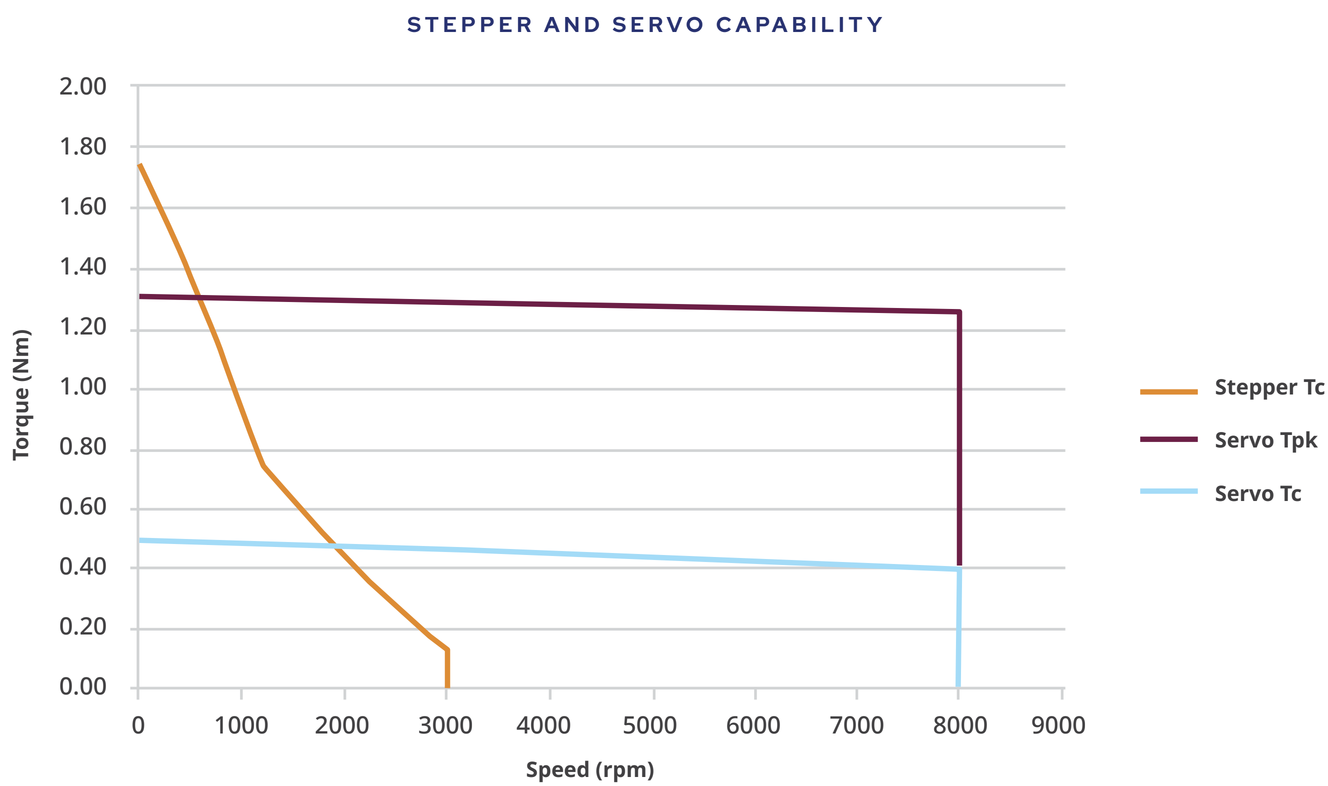


***Figure A:** Performance curve comparison with approximately same volume.*

Example applications that stepper systems fulfill well are automated machine axes for adjustment and setup, as well as video axes for inspection. Steppers are especially ideal for these types of axes because they tend to be easier to design into control systems and are initially less expensive to set up. When an axis for a given setup can be physically locked into place, they are less expensive to operate (for example, enabling optional on/off reduced power mode). Additionally, when properly applied, steppers are less prone to issues because of their simplistic open-loop control, which only requires winding-to-drive matchup versus the motor-to-drive-to-mechanism tuning required for feedback circuits in a closed-loop system.

STEPPER DRIVES

Newer design techniques have improved stepper motor performance through utilization of built-in feedback; end-of-move damping for reduced settling times while maximizing accuracy; soft-start to reduce jerk on power-up; anti-resonance modes for optimizing torque, stability and noise reduction (audible or otherwise); idle current reduction for reduced motor heating during standstill; and easily controlled operation modes between full-step, half-step and microstepping.

Although most properly sized steppers are extremely accurate when running open-loop in the selected step mode, built-in feedback provides additional precision without the cost of an external feedback device. With the reduction of step size to increase resolution, Microstepping techniques result in smoother torque and motion, at low speeds and higher speeds.

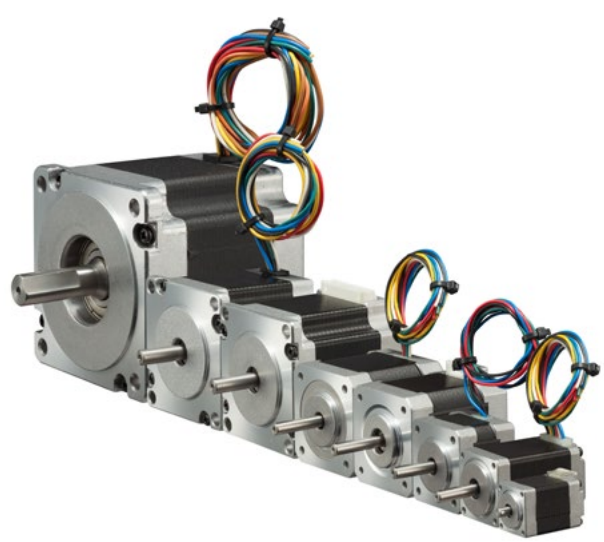
MODERN STEPPER DEVELOPMENTS

Modern steppers are available in larger power ratings than earlier-generation steppers. Newer design techniques have led to smaller air gaps, stronger magnets, physically larger magnets and oversized rotors.

Increasing the rotor's diameter and inertia—while retaining the stepper motor's same frame size and winding—generates more torque per unit volume. Of course, the larger rotor inertia can also affect acceleration and deceleration times for a given application, but this method opens up more applications to a given stepper frame size by effectively decreasing the ratio of the load (J_load) to the motor rotor (Jm) inertia. Generally, stepper motor systems are sized with a J_load:Jm of less than 30:1, but with slower accelerations and decelerations and advanced microstepping operation, inertia ratios of 200:1 are achievable.

With stall detection now being handled electronically within today's modern stepper drives, external feedback is usually not required for the pulse-shaft synchronization. However, optional feedback devices are utilized for position confirmation (open-loop) or position correction due to component misalignment, noise and/or lost pulse (position) information. Depending on the stepper drive, a stepper motor with dynamic feedback will have less velocity ripple and use less power than open-loop equivalents and will have higher residual torque at low speeds than an equivalent three-phase servo motor.

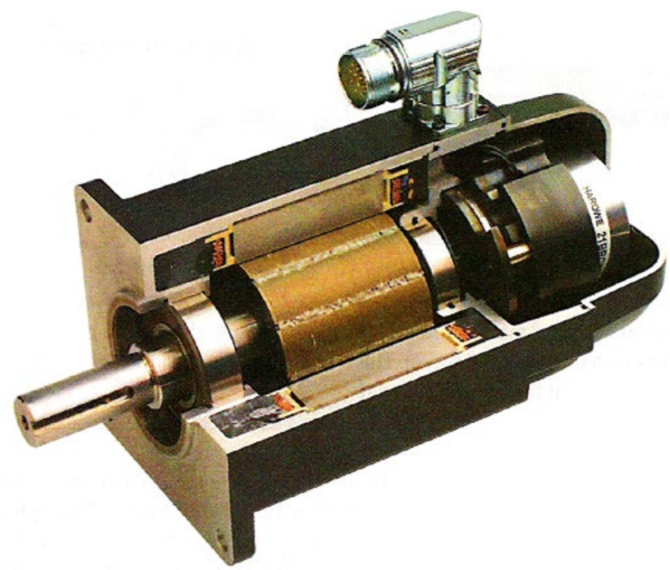
Stepper motor applications requiring feedback can approach the cost of a servo system, and what may be an operational advantage in one application may be a disadvantage in another. To make the right choice, designers must carefully judge the work to be performed. Often, closed-loop stepper systems do not compete well technically against lower-priced servo motor systems, so the pros and cons of both types should be carefully considered with regard to the specific application.



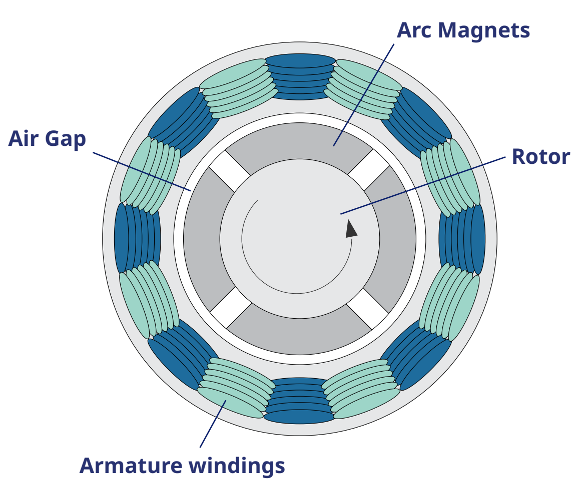
PMX stepper motors offer performance and design flexibility in a high torque-to-cost package.

SERVO MOTOR SYSTEM OVERVIEW

Servo motors have several distinct advantages over steppers. They can generate high torque over a wide speed range on demand and are available in wider torque ranges and higher voltages (up to 480 Vac). They respond to disturbances with a torque much greater than their continuous capability while using only the power required to accomplish the commanded motion. And they are compact. Steppers typically operate under 75 volts with higher voltage capability available.



SERVO CONSTRUCTION



SERVO DRIVES

Motor-drive compensation, often referred to as tuning or comp, was once a bane of the setup process for servo users but is now, for the most part, history. Today, the newest digital servo drive technologies have enhanced software and hardware capabilities for an improved user experience and offer remarkable compensation flexibility. In fact, some servo systems automatically configure the motor, drive and feedback, and tune themselves as well. Servo drives that tune themselves automatically adapt to the given motor-drive-mechanism without a decrease in performance and with little need for further fine-tuning of the control loops.

TORQUE AND SPEED CONSIDERATIONS

Although servo motors are designed to run at high speeds, they can accurately run at extremely low speeds under very precise control—even down to 1 rpm and below—with proper preparation. When properly utilized, steppers are accurate and are usually a more economical solution for low-speed applications of less than 1,000 rpm. However, above 1,000 rpm, a stepper motor's torque begins to fall off as the result of magnetic circuit time constants and core losses.

In contrast, servo motors with comparable torque do not start to fall off until around 2,000 to 4,000 rpm or more (Figure B). Direct drive servo applications powering high-inertia loads typically use speeds below 1,000 rpm, while the typical servo application with a mechanically advantaged drive train will use any speed within the motor's working envelope of capability.

With a required speed range between 1,000 and 3,000 rpm, the optimum motor technology may be determined by such application requirements as horsepower, peak torque at speed, continuous RMS torque, repeatability and source voltage.

At stall (low speeds < 50 steps/second or 15 rpm) or when holding a load with no movement, stepper motors—especially those with oversized rotors—can produce more torque than servos for a given frame size, although newer servo motor designs are catching up. With that torque capability, steppers can produce extremely accurate and stiff low-speed motion without the need for a gearbox or other mechanical advantage.

In contrast, direct drive servo motors with higher pole count and high-resolution feedback are often used in industrial process applications requiring typical velocities of less than 1,000 rpm without a mechanical advantage such as a gearhead.

When a stepper motor is at rest, it uses continuous energy and there is absolutely no movement unless overloaded. When the motor is not powered, its detent torque capability for some applications can be used to hold position.

In contrast, a servo motor is never at rest when enabled due to constant closed-loop error correction, during which it only uses the energy required to maintain its commanded position. The constantly varying position-loop error causes the servo's output shaft to move back and forth—although this should not be noticeable—while continuously looking for minimum error.

This continuous back-and-forth actuator motion is called "hunting," similar to another term, "dither," a purposely induced actuator movement—for example, in a valve actuation to continuously overcome potential issues of stiction. The physical displacement during hunting typically involves only a few feedback counts relative to the total resolution. Movement that is unnoticeable in most applications can be unacceptable in others. Higher-resolution feedback devices reduce the typical hunting delta while lowering the risk of axis instability.

Where repeatability and resolution are an issue—traditionally servo motor territory—steppers may now be considered. The application requirement for stepper systems is that the load must be predictable or subject to only small external forces and disturbances, where tight coordination between axes is not necessary. Steppers running open-loop can save an initial cost of greater than 20% to 30% over comparable servo solutions.

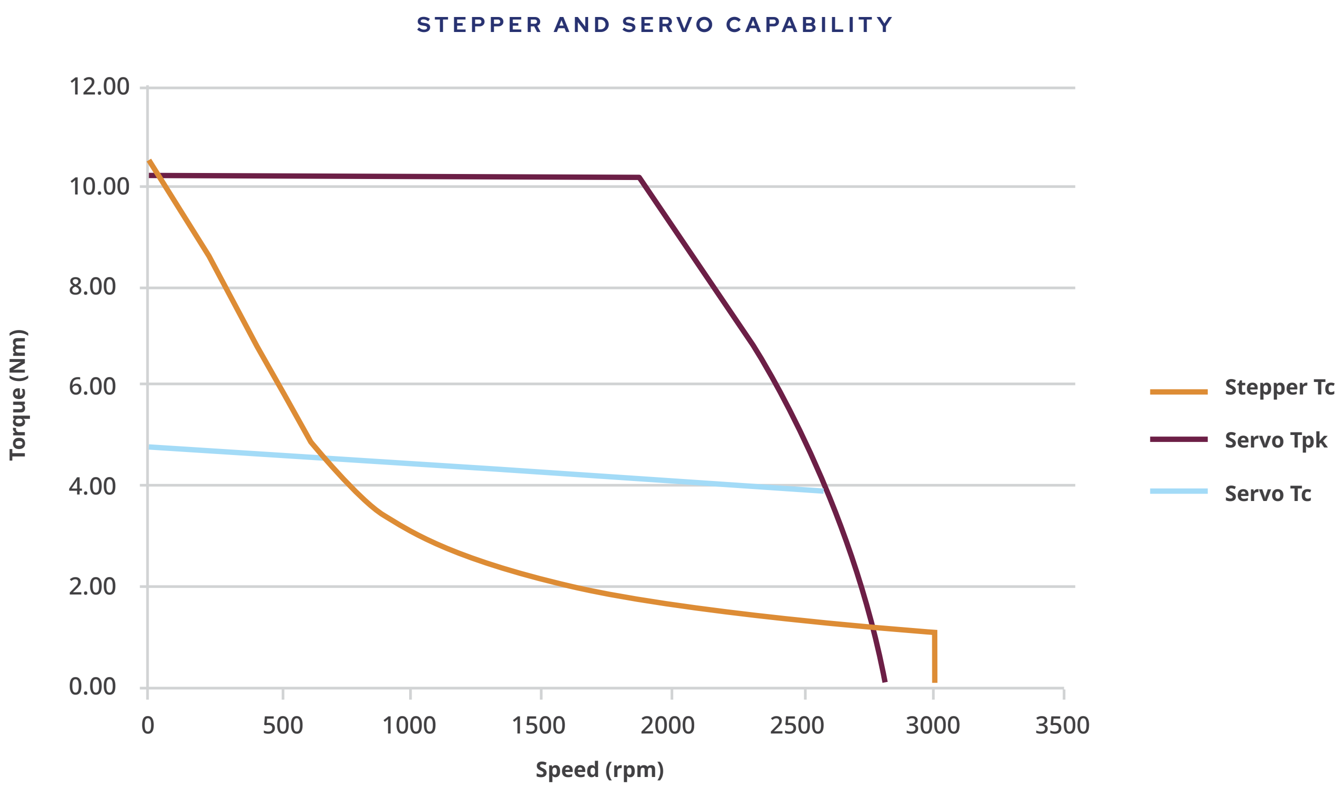


Figure B: *Performance curve comparison with similar volume and speed capability.*

SELECTION CRITERIA

TORQUE PERFORMANCE

When evaluating comparable speed-torque curves, designers should select the motor that provides the higher torque value at the speeds required. For the same price, most designers prefer to use servo motors. For constant or variable loads, servo systems can recover from overload conditions where stepper systems cannot. Steppers provide a lot of torque in a small package at speeds under 1,000 rpm, while servo motors can handle torque requirements at speeds below and well above 1,000 rpm.

INERTIA MATCHING

Determining the system's load inertia can help with technical selection of motor technology. As a rule of thumb, steppers usually do not exceed a 30:1 ratio of load inertia to motor inertia (J_load:Jm). In contrast, direct drive servo systems with high-resolution feedback and no compliance (except for the driven steel), can run at a 200–300:1 ratio and higher with quick response times relative to previous feedback technologies.

In the past, typical servo motor systems requiring quick response times and high acceleration or deceleration required a load-to-rotor inertia ratio in the range of 1:1 to 5:1, which later moved to a range of 1:1 to 8–10:1.

Today, a servo system that has the highest available feedback resolution, with minimal compliance and/or backlash, can obtain 1–20:1 and higher inertia ratios for many applications. The higher range ratios deliver the best operational efficiency with little additional risk. Higher inertia ratios become increasingly dependent upon the application, not only relative to the desired machine specification and performance but also in relation to the mechanism's compliance and backlash. For direct drive systems, the required stiffness often demands larger shafts and bearings, and even the compliance of the machine fixture/stand holding the motor comes into play.

AKM™ servo motors give designers the flexibility to quickly co-engineer modifications to fit specific applications. They are available in 8 frame sizes with over 500,000 standard configurations.

COORDINATION OF AXES

Applications requiring coordination between axes can benefit from servo-controlled systems due to their tight synchronization and high bandwidth capability, which allows for fast correction against sensed disturbances and/or command changes. Properly sized open-loop stepper motor systems will stay in sync without any confirmation feedback, but they are limited to point-to-point moves with only the possibility of sequential or pseudo coordination between the commanded axes. In a stepper system where the lower speeds and position within microsteppping capability is satisfactory, point-to-point coordinated motion is possible. 3D printers are an example of this coordinated motion capability. If tighter coordinated or synchronized motion is required then a servo system should be considered.

CABLING AND MOTOR-DRIVE ADJUSTMENTS

One change that improves reliability and maintenance in servos has been the reduction in the number of wires necessary between the power and feedback devices.

Manufacturers have taken much of the guesswork out of tuning (compensation of the motor-drive-mechanism) in closed-loop systems and timing of system maintenance. Automated or calculated tuning techniques and built-in diagnostic programs help simplify these requirements for the user. In addition, most servo drives can use traditional step and direction inputs that have been used to interface to steppers for many years. Servos utilizing this capability are in an operational position mode that eliminates the potential loss or addition of commanded motor steps.

This brings us to one of the most common issues with stepper motor systems when run on the threshold of their capability: the loss and/or addition of motion steps relative to the number of commanded steps. The problem is most noticeable during acceleration and/or deceleration. The loss of steps typically results from too large inertia affecting acceleration or from higher-than-desirable friction. In contrast, the addition of steps typically results from noise or too large inertia affecting deceleration. Due to the accumulation of the added and lost motion steps, it can take hours before a given manufacturing tolerance is exceeded.

Nonetheless, stepper motors are still simpler, having fewer wires to connect and minimal motor-drive adjustments to get a system up and running.

ACCURACY AND RESOLUTION

Stepper systems have a difference between their theoretical and actual resolution. For example, a two-phase, full-stepping, 1.8° step-angle motor has 200 possible positions in one revolution (360°/1.8°), but whether or not this is actually achieved depends on how the motor was sized for the application. The same is true of half-stepping and microstepping motor drive modes. A 1.8° microstepper, although specified as having ten microsteps per each full step, cannot necessarily find every microstep position.

Additionally, several commanded microsteps may be required before there is enough torque buildup to overcome friction and load inertia. In a real-world situation, the motor could easily jump one or more microsteps beyond the number commanded and stabilize there. When positioning-resolution requirements need to exceed 200 steps per revolution, steppers may utilize a feedback encoder to achieve upwards of 1,000 steps per revolution. With reasonable preparation, five-phase motors and microstepping motors can also improve on the steps per revolution.

Servo motor resolution is theoretically infinite, but system positioning with closed-loop operation depends primarily on the resolution of the feedback device—whether a sine encoder, resolver or a digital (TTL) encoder. Today's high-resolution feedback devices can approach between 2^{21} (i.e., 2,097,152) to 2^{28} (i.e., 268,435,456) counts per motor revolution, plus optional multi-turn capability (typically up to 4,096 turns). Multi-turn capable feedback devices are available for the absolute position of an axis on machine power-up, eliminating the homing cycle on each machine power-up; however, a multi-turn option can limit total available feedback resolution.

REPEATABILITY

Servo motors are extremely repeatable because they run closed-loop. But steppers can be just as repeatable in many applications, especially when running in one direction. However, when an idle current reduction (ICR) mode is utilized and/or the load increases (such as during direction reversal), the situation changes when exceeding the stepper's capability. Similar to how a gearbox must take up backlash, the stepper must catch up to the system command. During the first move in a new direction, motor accuracy is affected because the stepper is overcoming inertia and friction effects of the load. Once that happens, the system regains its specified repeatability, but it may have lost or gained actual position steps over those commanded.

INPUT POWER

A stepper motor is equivalent to an inductor in series with a resistance, and as a result the current that produces torque requires time to rise. This time limits the speed for a given voltage, so increasing the motor's speed in a given application may require higher voltages.

A servo system works similarly, but working within its capability envelope the drive's control loops will present the required voltage and current to the servo motor to meet the demand of the load relative to its command and feedback error. In contrast, when a servo motor system is forced to work outside its operational envelope, even for a millisecond, it is no longer under control and thus not operating as a servo.

CONCLUSION

Stepper and servo technologies both have important roles to play in today's mechatronic machine designs. However, once the advantages and disadvantages of servo and stepper motor systems are clearly understood, especially relative to the process or work to be performed, the best selection for a given application becomes much clearer.

Assuming the desired process can be accomplished with either a stepper or servo motor solution—meeting the application's repeatability, accuracy and flexibility requirements for present and future needs—the remaining considerations would likely be environment, life expectancy, operating noise and energy utilization.

When specific requirements allow for either technology, discernment and foresight can guide the final selection with regard to the considered working process or job to be performed, possible future needs, and the designer's machine experience.

APPLICATION ATTRIBUTES FOR STEPPER VS. SERVO

Application Requirements	Stepper	Servo
Highest Torque Density	✓	
Largest Torque and Speed Range		✓
Open-Loop (typical)	✓	
Low Voltage (<75 volts)	✓	✓
Medium Voltage	Possible	✓
High Voltage (400-480+ Volts)		✓
Low Speed (up to 1,000 rpm)	✓	✓
Medium Speed (1,000 – 3,000 rpm)	Possible	✓
High Speed (> 3,000 rpm)		✓
High Torque at Low Speed (< 1,000 rpm)	✓	✓
High Bandwidth Response Times		✓
Point-to-Point (simple / modest)	✓	✓
Point-to-Point (coordinated)	Possible	✓
Coordination Between Axes	Pseudo	✓
Highest Acceleration / Deceleration		✓
Hold Position Without "Hunting"	✓	
Detent Torque	✓	
Inertia Loads up to 30:1 (J_load:Jm)	✓	Possible
Inertia Loads up to 200:1 (J_load:Jm)	Possible	DD+(R/L)*
Fast Corrections Against Disturbances / Commands		✓
Peak Torques Available > Continuous Capability		✓
Highest Resolution		✓
Highest Input Voltage Range		✓
Simplest Integration	✓	
Ideal for Fixed Loads	✓	
Highest Product Throughput		✓
Highest Efficiency		✓

*DD=Direct Drive, R= Rotary, L=Linear

About the Author

Hurley Gill is senior applications/systems engineer at Kollmorgen located in Radford, VA. He's a 1978 Engineering graduate of Virginia Tech who has been engaged in the motion control industry since 1980.

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