Stepper Motor or Servo Motor: Which should it be?

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Each technology has its niche, and since the selection of either of these technologies for a given application affects its chance of success, it is important for the machine designer to select the best motor-drive system for the application, while considering the technical advantages and disadvantages of both.

It is all about utilizing these technologies with balance to achieve the desired process performance for a given machine design while balancing cost versus the capability of the required mechanism.

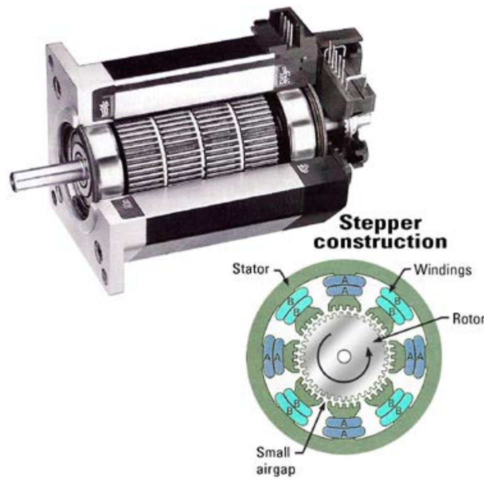
Machine designers shouldn't limit utilization of steppers or servos by a predetermined mindset or comfort level, but learn where each technology works best for controlling a specific mechanism and process to be performed.

This article presents an overview of different baseline capabilities for selection criteria between stepper and servo technology. A thorough understanding of these technologies will help generate the best and most efficient mechatronic designs to bring forth the full capability of a machine.

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, algorithms, and higher feedback resolution have resulted in higher system Bandwidth (BW) capabilities, and lower initial and overall operating costs for many applications.

Stepper Motor System Overview

Stepper motors have several major advantages over servo systems. They are typically lower cost, have common NEMA mountings, offer lower torque options, require less costly cabling, and their open loop motion control component makes machine integration simplistic and provides ease-of-use to end users.



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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 for twice their continuous requirements for additional acceleration and/or deceleration torque capability or for a required peak torque.

In contrast, servo motors are generally sized for the specific application velocities and torques for maximum intermittent acceleration/deceleration, holding torque (if applicable), and continuous RMS 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 (PM) 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-higher speed range.

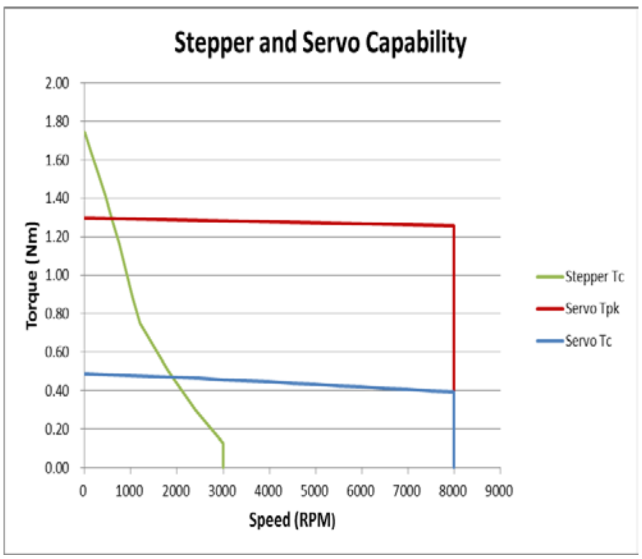


Figure A: *Performance Curve Comparison with approximately same volume.*

Automated machine axes for adjustment and setup as well as video axes for inspection, are applications that stepper systems fulfill well. Steppers are especially ideal for these type axes because they tend to be easier to design into control systems and less expensive on initial setup. When an axis for a given setup can be locked into place they are less expensive to operate (e.g. optional ON/OFF reduced power mode). Additionally, when properly applied, steppers are less prone to failure because of their simplistic open-loop control, which only requires winding-to-drive match-up versus motor-drive-to-mechanism tuning required with feedback circuits of a closed-loop system.

Stepper Drives

Newer design techniques have improved step motor performance by the 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 (IRC - 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 running open loop in the selected step mode, built-in feedback provides additional precision without the cost of an external feedback device. Microstepping techniques result in smoother torque and motion at low speeds and greater resolution at high speeds with the reduction of step size from full-step/half-step.

Modern Stepper Developments

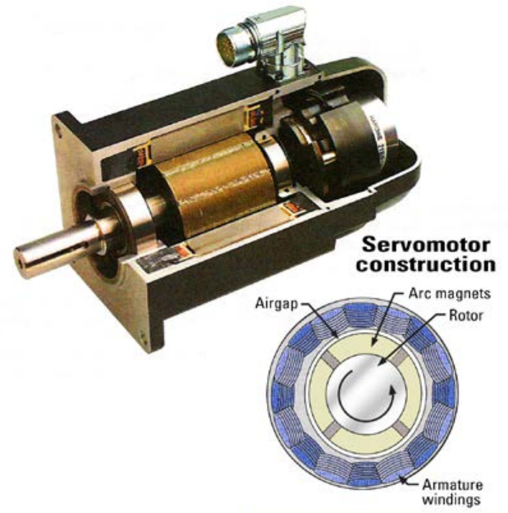
Modern steppers are available in larger power ratings than earlier generation steppers. Newer design techniques have led to smaller airgaps, stronger magnets, physically larger magnets and rotor oversizing. Increasing the rotor's diameter generates more torque per unit volume. For this technique, the physical frame size and winding of the step motor stays the same while the rotor's diameter and inertia are increased. Of course, the larger rotor inertia can affect acceleration and deceleration times for a given application; but this method opens up more applications to a given stepper frame size by the effective decreased ratio of the load (J_load) to motor rotor (Jm) inertia. Generally, step 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, optional feedback devices are typically utilized for position correction due to component misalignment, noise, and/or lost pulse (position) information. A step motor with feedback, depending on the stepper drive, 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. Thus, the designer must use discernment in regard to the work to be performed because step 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. Closed-loop stepper systems do not technically compete well against the lower priced servo motor system; so the pros and cons of both type systems should be carefully considered for the application.

PMX step motors offer performance and design flexibility in a high torque-to-

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 and use only the power required to accomplish the commanded motion and are compact.



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Servo Drives

Motor-drive compensation often referred to as tuning or comp, once considered the bane process of servo users is, for the most part, history. Today, the newest digital servo drive technologies have enhanced software and hardware capabilities for 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 (less than 1,000 rpm). However, above 1,000 rpm, a stepper motor's torque begins to fall off, 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 are typically found utilizing speeds < 1000 rpm, while typical servo applications with a mechanically advantaged drive train are likely to be found using any speed within its working envelope of capability.

With a required speed range between 1,000 to 3,000 rpm, the motor type that should be used may be determined by such application requirements as horsepower, peak torque at speed, continuous (RMS) torque and repeatability.

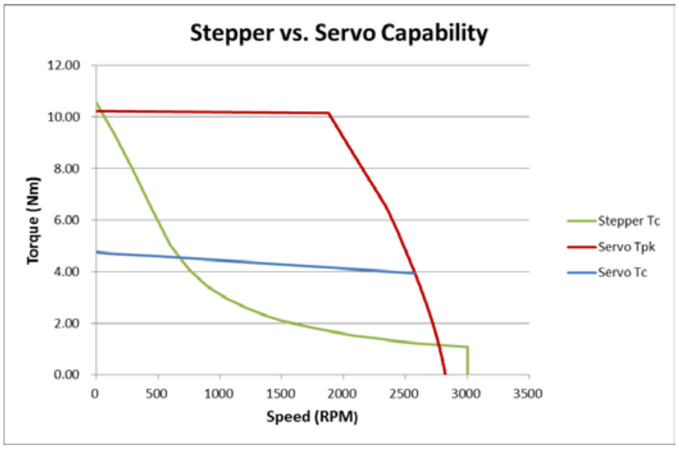

Figure B: *Performance Curve Comparison with similar volume and speed.*

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

In contrast, Direct Drive servo motors with higher pole count and high-resolution feedback are often utilized for industrial process applications requiring typical velocities of less than 1000 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), and when not powered its detent torque capability can be used to hold position.

In contrast, a servo motor is never at rest when ON, due to the constant closed loop error correction, while only using 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 (though it 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 (e.g. valve to continuously overcome the issues of stiction). The physical displacement during hunting, typically involves only a few feedback counts, relative to the total resolution: what is unnoticeable in most applications, can be unacceptable in others (higher resolution feedback devices reduce the typical hunting delta).

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

Torque Performance

Regarding torque, designers should select the motor that provides the higher value at the speeds required, from comparable speed-torque curves. 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 give a lot of torque in a small package, under 1,000 rpm. In contrast, servo motors can handle torque requirements below and well above 1,000 rpm.

Inertia Matching

Determining the system's load inertia can help technical selection. 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 the driven steel), can run 200-300:1 (J_load : Jm 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 and/or deceleration required a load to rotor inertia ratio in the range of 1:1 to 5:1, which later moved to the range of 1:1 to 8-10:1.

Today a servo system that has the highest available feedback resolution and minimal compliance and/or backlash, can obtain, 1-15:1 and higher inertia ratios for many applications. These 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, 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 flexibility to quickly co-engineer modifications to fit applications. (Available in 8 frame sizes, over 500,000 configurations.)

Coordination of Axes

Applications requiring coordination between axes can benefit from servo-controlled systems due to their tight synchronization and high BW capability which allows for fast correction against signal disturbances and/or command changes. Properly sized open-loop step motor systems, will stay in sync without any confirmation feedback, but are limited to point-to-point moves with only the possibility of sequential or pseudo coordination between the commanded axes.

Cabling & 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 servo tuning (motor-drive-mechanism compensation) of the closed-loop system and determining when a system needs maintenance. Automated or calculated tuning techniques and built-in diagnostic programs help simplify this requirement 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 a position mode that eliminates the potential loss or addition of commanded motor steps.

This brings us to one of the most common issues with step motor systems when run on the edge 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 higher-than-desirable friction. In contrast, the addition of steps typically results from noise or to too large inertia (affecting deceleration). Due to the accumulation of the additional (+) and loss (-) motion steps, it can take hours before some manufacturing tolerance is exceeded.

Nonetheless, step motors are still simpler having fewer wires to connect with minimal amounts of motor-drive adjustment 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 may have 200 possible positions in one revolution (360°/1.8°), but whether or not it's 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, though specified as having ten microsteps per each full step, cannot necessarily find any position within 0.18°.

Additionally, several commanded microsteps may be required before there is enough torque build-up 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 1000 steps/rev. Five-phase motors and microstepping motors (with caution) can also improve on the steps/rev.

Servo motor resolution is theoretically infinite, but in closed-loop operation, system positioning depends primarily on the resolution of the feedback device be it a sine encoder, resolver or a digital (TTL) type encoder. Today's high resolution feedback devices can approach between 2^{21} [2,097,152] to 2^{28} [268,435,456], counts per motor revolution, plus the optional multi-turn capability (typically up to 4096 turns). Multi-turn capable feedback devices are available for an axis' absolute positon on machine power-up eliminating the initial axis power-up homing cycle.

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 (e.g. as during direction reversal) and exceeds the capability of the stepper the situation changes. Similar to how a gearbox must take up backlash, the stepper must catch up to 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 step 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 (for whatever reason) outside its operational envelope, even for a millisecond, it is no longer under control and thus, not operating as a servo.

Detailed Conclusion on Next Page

Conclusion

Both technologies are a clear choice 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, with the repeatability, accuracy and flexibility requirements, for present and future needs, the remaining considerations would likely be environment, life expectancy, operating noise, and/or energy utilization.

When specific requirements allow for either technology, one should utilize discernment and foresight, with the specific knowledge of 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**	**Application Requirements**	**Stepper**	**Servo**
Highest Torque Density	✓		Detent Torque	✓	
Largest Torque and Speed Range		✓	Inertia Loads up to 30:1 (J_load : Jm)	✓	Possible
Open-Loop (typical)	✓		Inertia Loads up to 200:1 (J_load : Jm)	Possible	DD+(R / L)*
Low Speed (up to 1000 rpm)	✓	✓	Fast Corrections Against Disturbances / Commands		✓
Medium Speed (1000 - 3000 rpm)	Possible	✓	Peak Torques Available > Continuous Capability		✓
High Speed (> 3000 rpm)		✓	Highest Resolution		✓
High Torque at Low Speed (< 1000 rpm)	✓	✓	Highest Input Voltage Range		✓
High Bandwidth (BW) Response Times		✓	Simplest Integration	✓	
Point-to-Point (simple / modest)	✓	✓	Ideal for Fixed Loads	✓	
Coordination between Axes	Pseudo	✓	Highest Product Through-Put		✓
Highest Acceleration / Deceleration		✓	Highest Efficiency		✓
Hold Positon without 'Hunting'	✓		* R= Rotary, L=Linear		

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