Upgrading from Stepper to Servo

Switching to Servos Provides Benefits, Here's How to Reduce the Cost and Challenges

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The customers of machine and robot builder OEMs expect innovative products and solutions that are efficient, flexible and cost effective. Throughput is also a major concern as it directly affects the end user's cost per part. Replacing stepper motors with a servo motion control system can significantly improve all of these factors.

The primary technologies used in applications that require some level of motion control are stepper and servo systems. Steppers and servos have a number of similarities and a couple of key differences.

Steppers and servos are both synchronous motors. The construction of both motor technologies consists of a rotor with permanent magnets and a stator with coiled windings. Both systems operate by applying a DC voltage to the stator windings in a specific pattern that results in movement of the rotor, and both technologies are capable of position and speed control.

The two main differences between stepper and servo systems involve the use of a feedback device and the complexity of the amplifier electronics. A servo by definition is a closed loop system utilizing a feedback device. Steppers are open loop systems with no feedback.

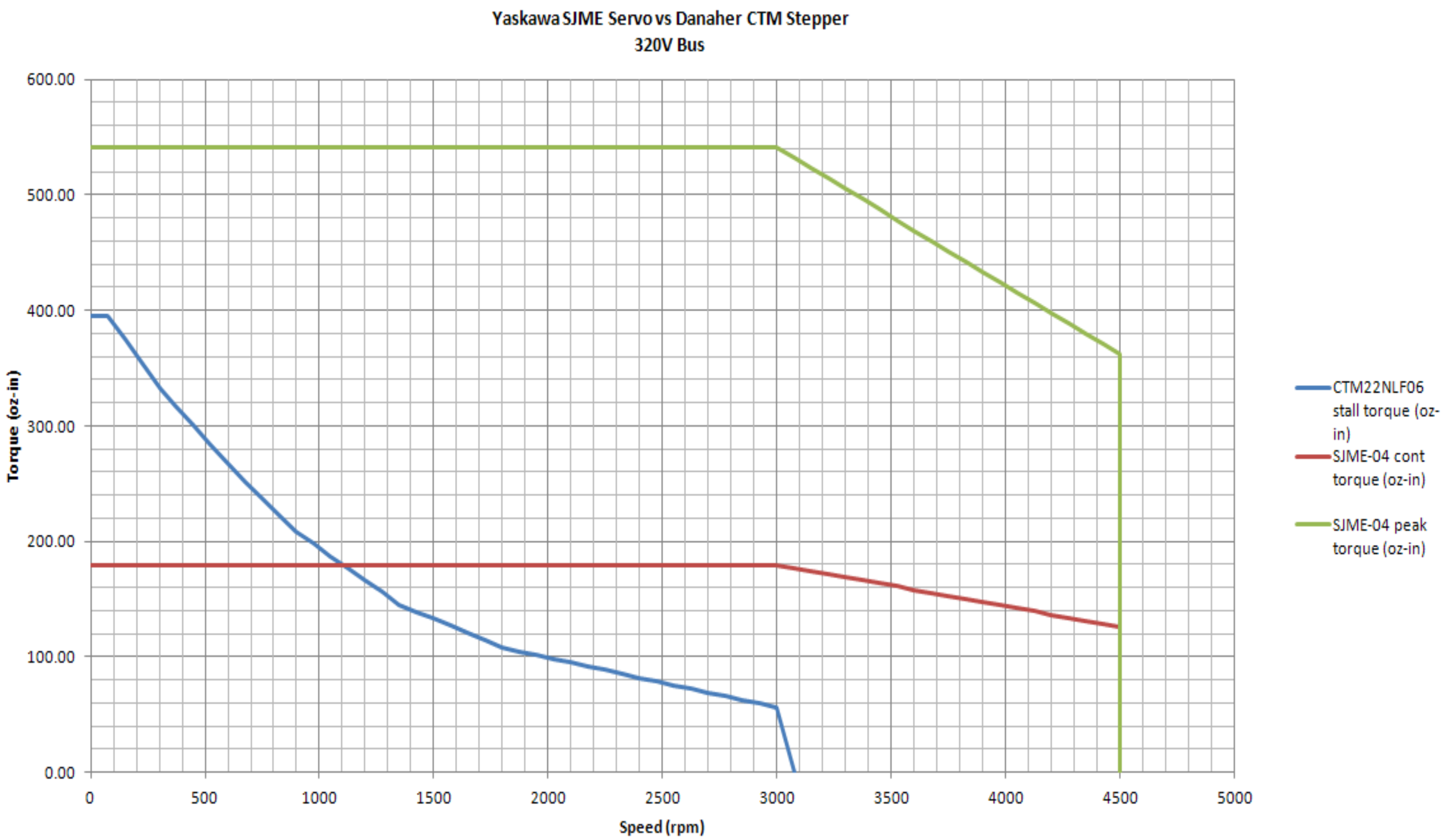
The amplifier electronics utilized in a servo system are typically much more complex than that of a stepper system. While a stepper amplifier simply sends full rated current to each winding set, a servo amplifier regulates the current levels it sends to the motor windings. In a servo system, only the current demanded by the application is used.

Since current is proportional to torque, the control loop in the servo amplifier that regulates current is called the torque loop. The servo amplifier also employs velocity and position control loops. The ability of a servo amplifier to close the torque, velocity, and position control loops ensures that precise control can be maintained. Since a stepper system has no feedback and no control loops, motor stalling can occur when torque demand exceeds available torque at any given speed.

There are also some inherent performance differences between steppers and servos based on motor design. Stepper motors have a larger number of poles and a higher winding inductance than servo motors. As a result, the torque available from a stepper motor drops off much more quickly than that of a servo motor as speed increases, given the same DC bus voltage.

This can be seen in the Figure 1 graph which compares a typical stepper system with the Junma servo system from Yaskawa America. In this example, both motors are of similar size, about 2.3 inches square. The Yaskawa servo is slightly longer due to the feedback device.

Figure 1



Another inherent disadvantage of stepper motors is the existence of two distinct instability regions. There is a low speed region of instability, typically between 100 and 300 full steps per second or 30 to 90 rpm, that results from the excitation of the natural frequency of the motor. When the motor is operated in this region, there will be a large velocity ripple and a potential loss of steps and position.

There is also a mid-range instability that results from the excitation of the natural frequency of the motor. This typically occurs at the speed where motor output torque is ½ of the full running torque of the motor. In Figure 1, the area of mid-range instability for the stepper motor system would be around 1000 rpm. Mid-range instability can cause motor stalling, velocity ripple, and loss of steps and position.

Low speed instability can be minimized through the use of a technique called microstepping, and there are some electronic damping techniques that can minimize the effects of mid-range instability. But the recommended best practice when using stepper systems is to steer clear of operating in these two speed ranges.

Besides the speed range issue, here are some other benefits of upgrading to a servo system.

- **Increased Machine Throughput** – With a servo system, the output torque capacity at higher speeds increases dramatically as can be seen in the speed/torque comparison curve (Figure 1). The additional torque at higher speeds can be utilized to improve the application move profile as shown in Figure 2, where the desired movement is accomplished much more quickly with a servo as compared to a stepper system.

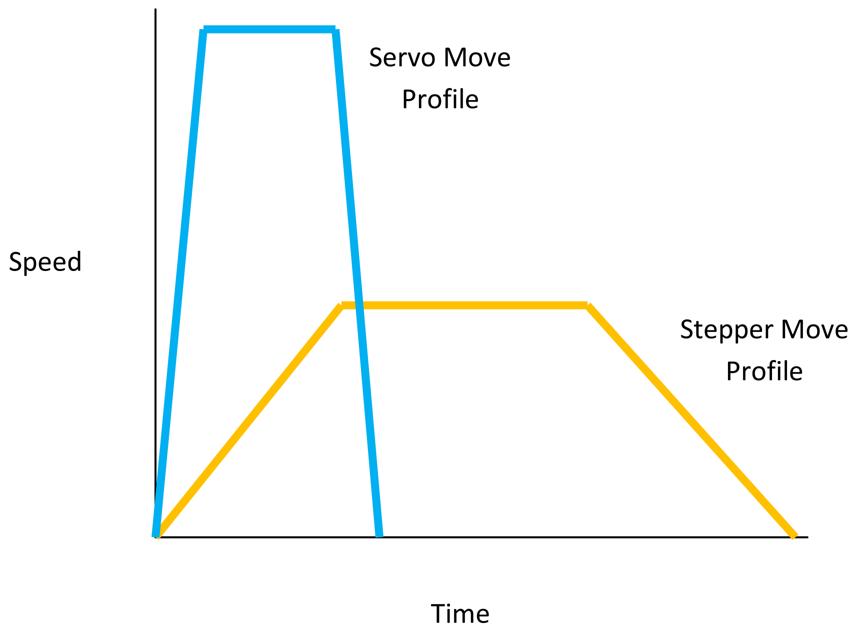


Figure 2

- **Increased Accuracy and Repeatability** – The accuracy of a stepper system is limited by the number of physical full steps per revolution. For example, there are 200 full steps per revolution in a typical 2-phase stepper motor. The repeatability of a stepper system will vary with the amount of frictional load in the system. Because a servo system employs a feedback device, it can achieve much higher levels of accuracy and repeatability. The position control loop in the servo amplifier will assure that the servo gets to the position that has been commanded, regardless of changing conditions.

- **Less Downtime** – Stepper systems are ideal for applications where conditions don't change, but most applications require frequent changes and adjustments. The characteristics of mechanical components can vary with temperature and time, increasing or decreasing frictional loads. Users can introduce loads or duty cycles that fall outside of specifications of the machine. Since stepper motors stall when their rated torque is exceeded, machine throughput can be affected when changing conditions are introduced. Servo systems have the ability to warn the user when changing conditions are introduced. The servo amplifier keeps track of torque, speed, and position via the control loops—and this information can be used to prevent production stoppages.

- **Higher Efficiency and Energy Savings** – A significant amount of energy can be saved with a servo as compared to a stepper system. Stepper systems operate by sending full rated current in sequence to the motor windings while the motor is moving, regardless of the application requirements. Most stepper systems have an idle current reduction setting which allows the current level to be reduced automatically when the motor is not moving, typically to 50% of full rated current. Servo motors only use the current required in the application at any given point in time. Figure 3 shows the amount of current used by a stepper motor during a common move profile: move one direction, dwell, move the other direction. Figure 4 shows the amount of current used by a servo motor for the same move profile. The stepper motor uses full rated current while the motor is moving and uses ½ rated current while the motor is idle. The servo motor uses much less energy because it only uses the current required.

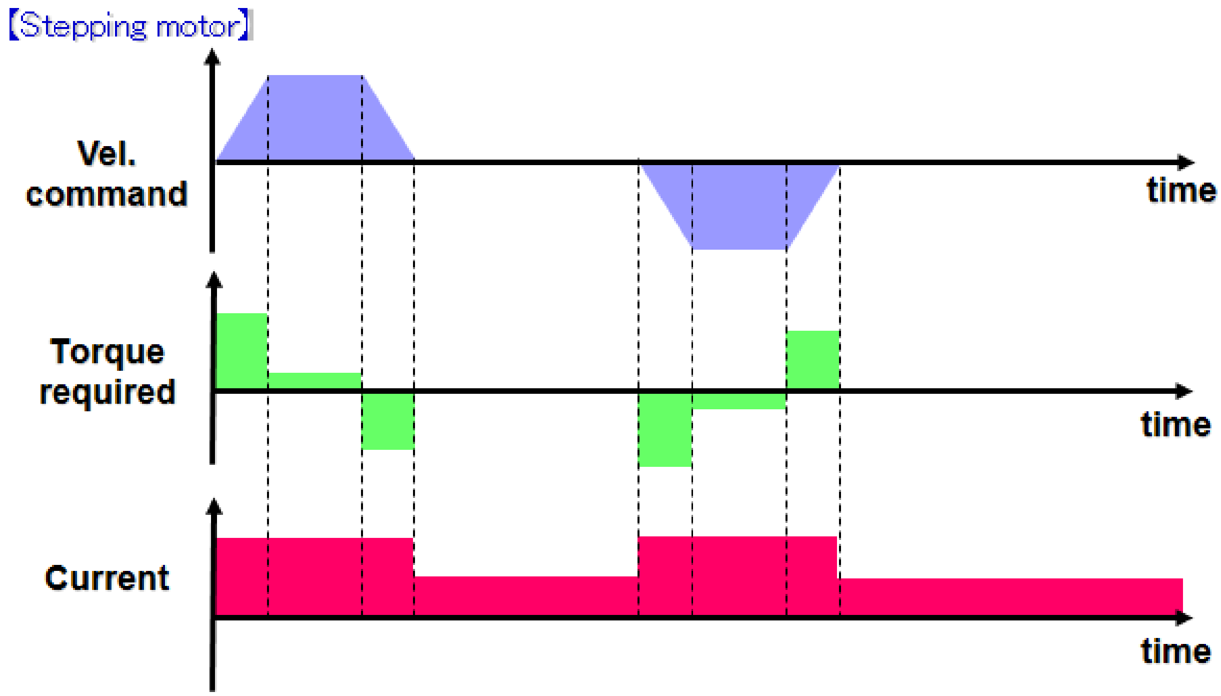


Figure 3

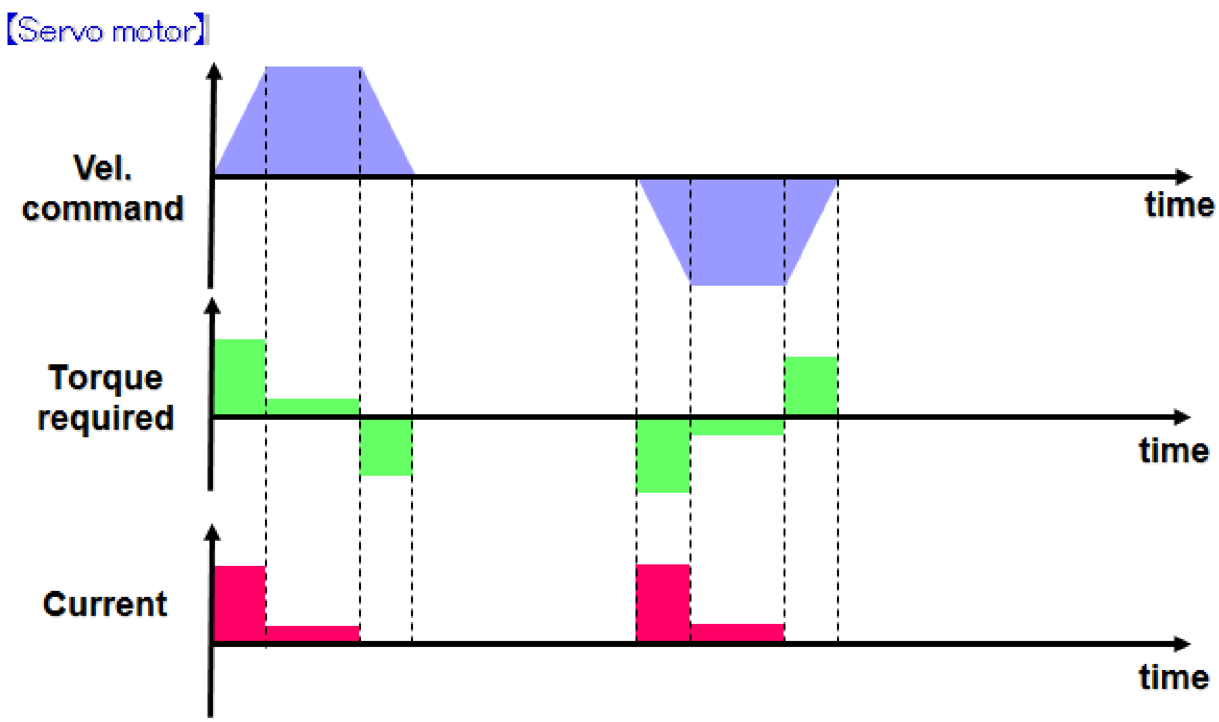


Figure 4

- **Lower Operating Temperature** – Figure 5 shows the amount of heat generated by a stepper and servo motor given the following repeating move profile:
    - Acceleration = 85 ms
    - Constant Velocity = 1000 ms (at 2000 rpm)
    - Deceleration = 85 ms
    - Dwell = 1170 ms
    - Stepper current at dwell = ½ rated stall current of motor
    - Total duration of test = 10 min

  As can be seen, the servo motor maintains a relatively low temperature of 30 deg C, while the stepper motor reaches the much higher temperature of 70 deg C.

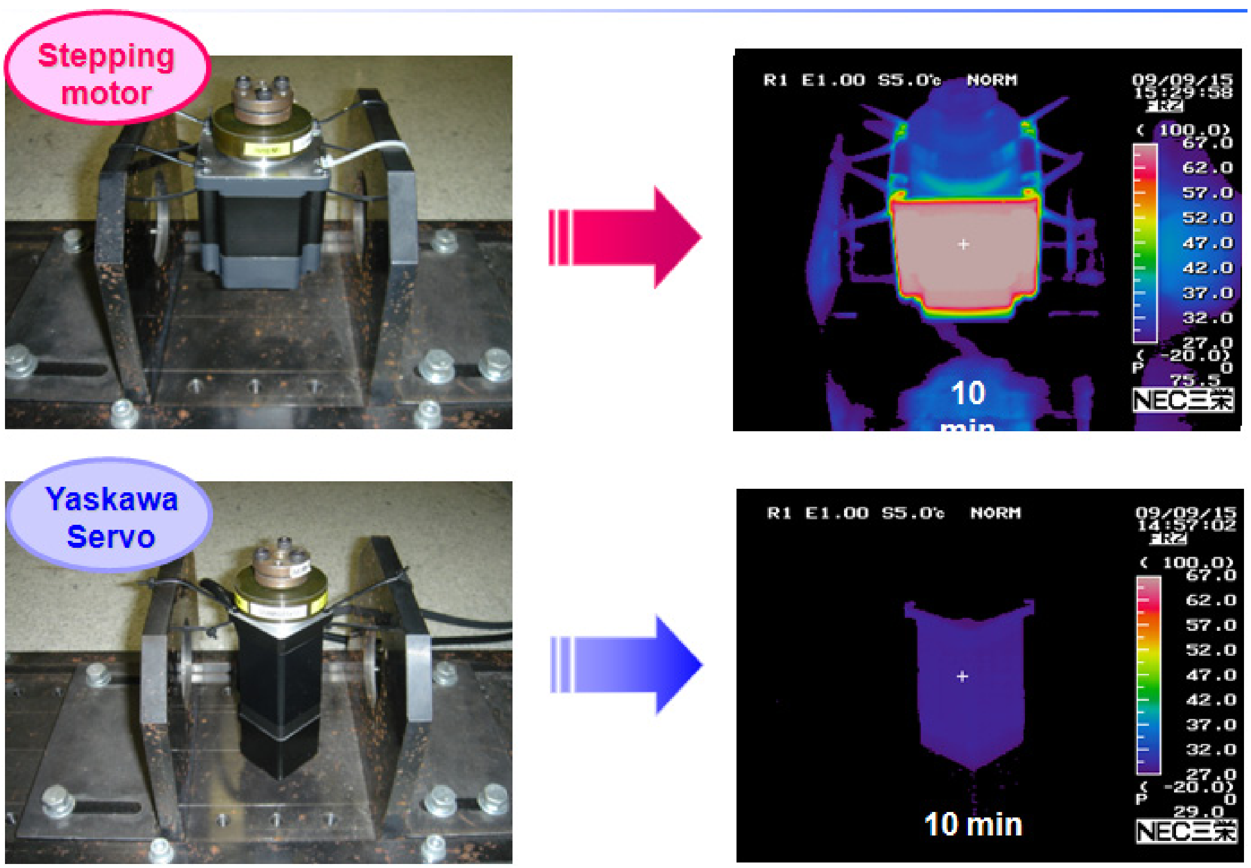


Figure 5

There are also some arguments against upgrading from a stepper to a servo.

- **Cost** – Servo systems are typically more expensive than stepper systems. This is due to the addition of a feedback device and cable on the servo motor system, and more expensive amplifier electronics.
- **Commissioning Time** – Since a servo is a closed loop system with multiple control loops, there is usually additional setup time required for adjustment of tuning gains.
- **Application Requirements** – Some applications don't justify an upgrade to servo technology. In fact, there are applications where a stepper system is a better fit. Stepper systems work best in applications where the conditions are unchanging and predictable.

These arguments can be addressed when evaluating some of the latest servo technologies on the market.

- **Cost** – In recent years, a number of low cost servo options have entered the market. In many cases, the cost adder for a servo over a stepper system isn't significant, as little as 10%.
- **Commissioning Time** – Some servo products, like Yaskawa's Junma servo series, have been designed specifically to replace stepper technology. Part of this design is reducing the effects of servo complexity to the user. With the Junma servo system, load inertia is detected automatically, and adaptive tuning algorithms calculate optimum gains for the control loops without any user interaction. The amplifier comes with a pulse and direction input, so in many instances, the same controller and motion program used with an existing stepper system can be used with the upgraded servo system.
- **Application requirements** – As discussed earlier, the majority of applications have some level of variability. In most cases, upgrading to a servo will allow for higher throughput and will eliminate issues typically seen with steppers like lost steps, stalling, and low and mid-range instability.

If your current machine design currently employs a stepper system, it only makes sense to investigate options for upgrading to a servo system. With today's technology and pricing levels, you can make a significant improvement to your machine design without a major impact to your bottom line.