Comparing Open Loop and StepSERVO™ Closed Loop Stepper Systems

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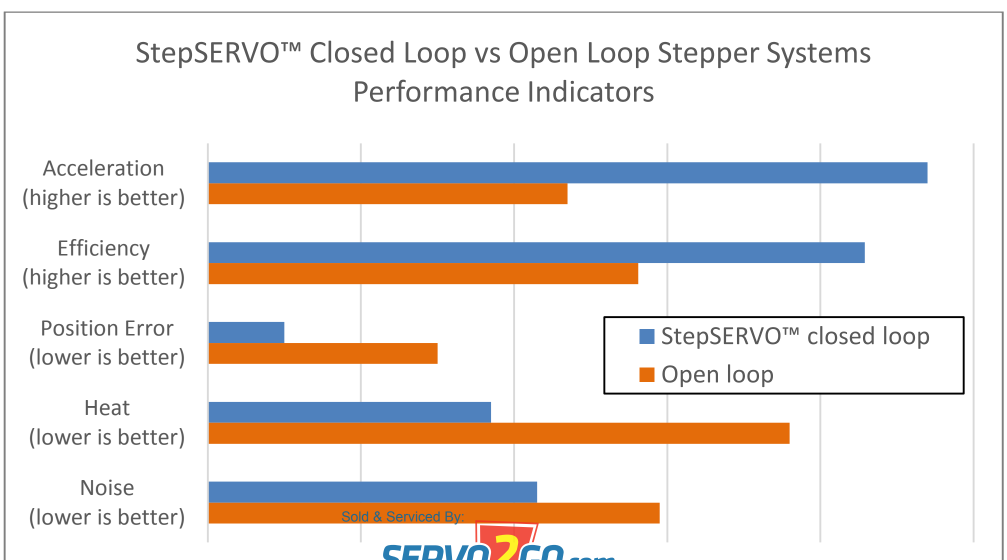
Abstract

What if…you could make a step motor faster? And quieter? While saving energy?

Introduction

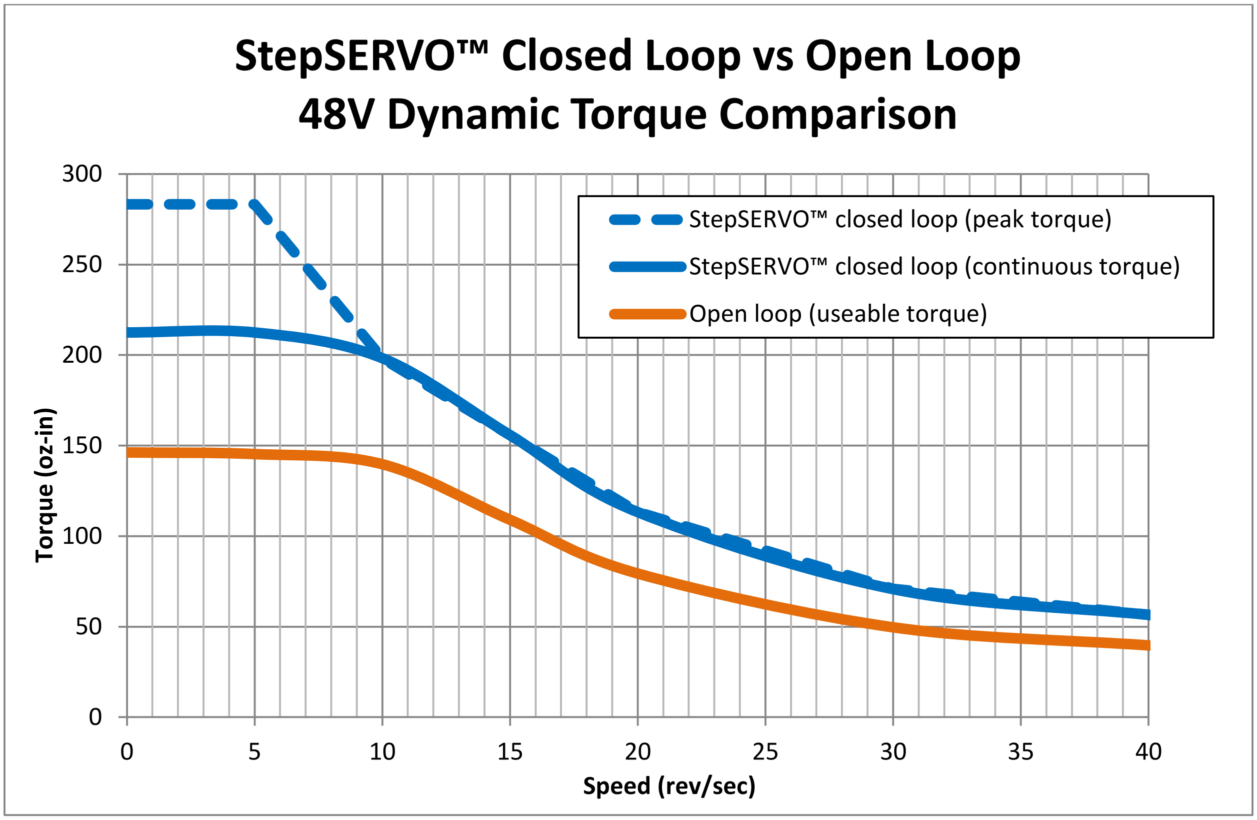
The simplicity and low cost of step motors have made them popular in the automation business for decades. Like most technologies, they've steadily advanced to better compete with other forms of motion control. Low cost transistors and logic chips enabled manufacturers to build PWM or "chopper" drives that dramatically extended the usable speed range. Then cheap, compact microcontrollers led to microstep drives that provided finer resolution and smoother, quieter motion. Further increases in compute power and advances in algorithms resulted in anti-resonance and electronic damping that further enhanced machine throughput. Ever decreasing chip sizes and increasing efficiency of MOSFET power transistors allowed the drive electronics to be integrated into the motor itself. Integrated step motors now represent one of the highest growth segments of the motion control industry.

The latest exciting development in stepper technology has been the application of low cost, high resolution feedback devices and advanced digital signal processing to close the loop on stepper motion, resulting in the efficient and high performance StepSERVO™ closed loop stepper system. Here we compare the benefits of StepSERVO™ closed loop stepper systems to traditional open loop stepper systems.

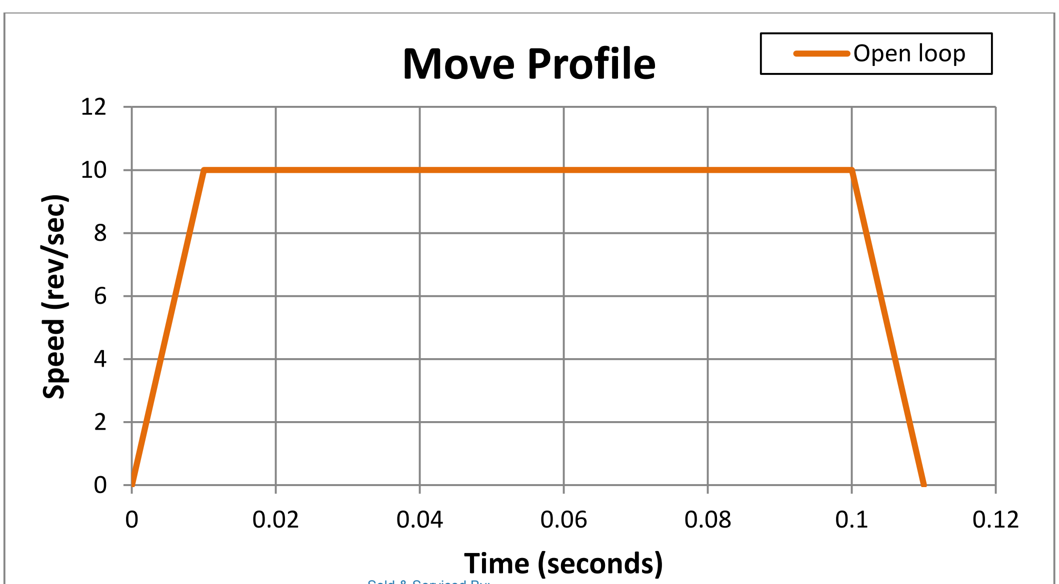


Acceleration & Cycle Time

The torque curves below show the peak and continuous torque of a StepSERVO™ closed loop stepper system and the useable torque of a typical open loop stepper system.

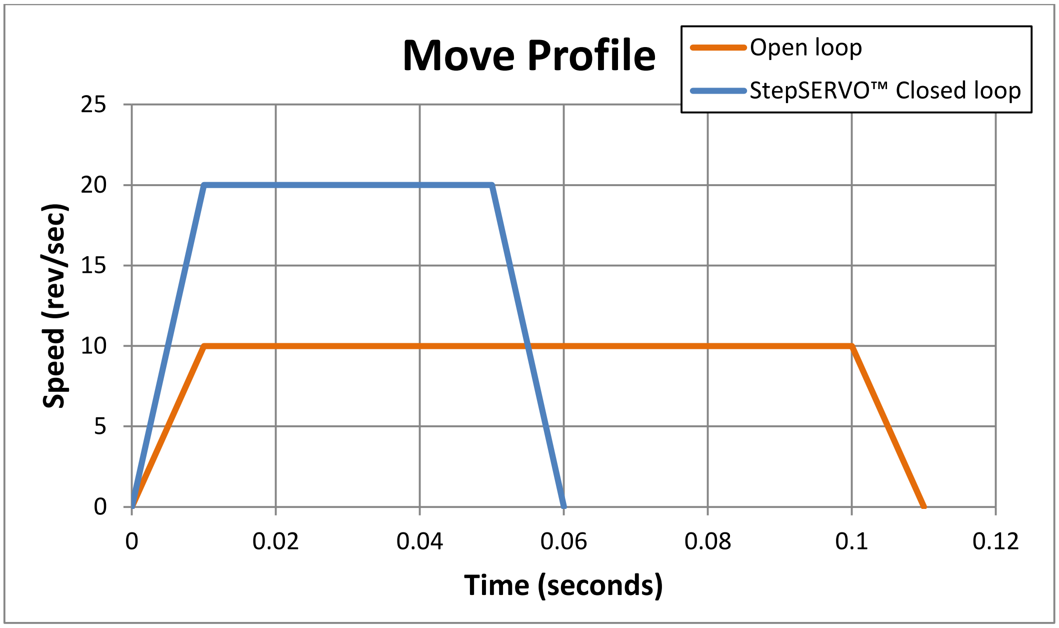


To compare acceleration rates, equally sized open loop and StepSERVO™ closed loop stepper systems were used with an external inertial load of 460 g-cm^2. The open loop system was able to achieve a maximum acceleration rate of 1000 rev/sec^2 up to 10 rev/sec, where the flat portion of the torque curve above ends. For a move distance of one revolution, the move profile looked like this:

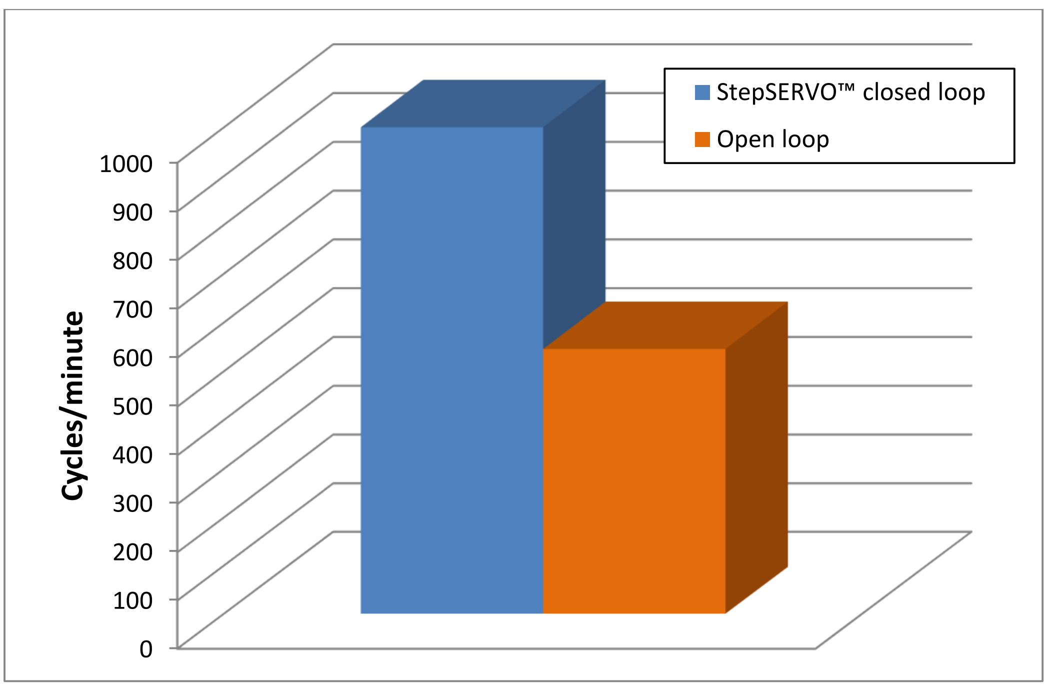


Move duration was 110 milliseconds.

The StepSERVO™ closed loop stepper system produced much higher peak torque and higher torque at higher speeds than the open loop stepper system, which allowed us to drive the same load at an acceleration rate of 2000 rev/sec^2 and to a speed of 20 revs/sec. By doing so, the move duration was reduced to 60 milliseconds.



With the faster move, we are able to achieve nearly double the cycles/minute. For anyone building a high throughput machine, the StepSERVO™ closed loop system has a clear advantage.



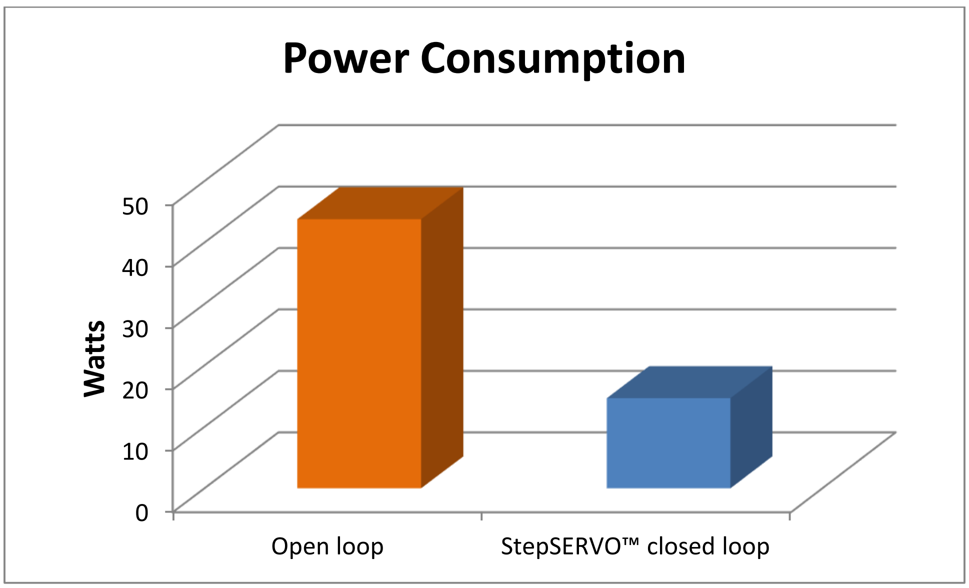
Efficiency:

To measure the relative efficiency of an open loop versus a StepSERVO™ closed loop system, we ran both systems side by side, with the same move profile and same load inertia. Both systems had the same rotor inertia and were operated from identical 48VDC power supplies while we measured the average power into each system.

Move parameters:

- Accel = 100 rev/sec2
- Decel = 100 rev/sec2
- Distance = 5 rev
- Speed = 10 rev/sec
- Dwell time = 0.1 sec

The average power consumption of the open loop stepper system was 43.8 watts, while the StepSERVO™ closed loop system consumed only one third as much: 14.2W.



Accuracy

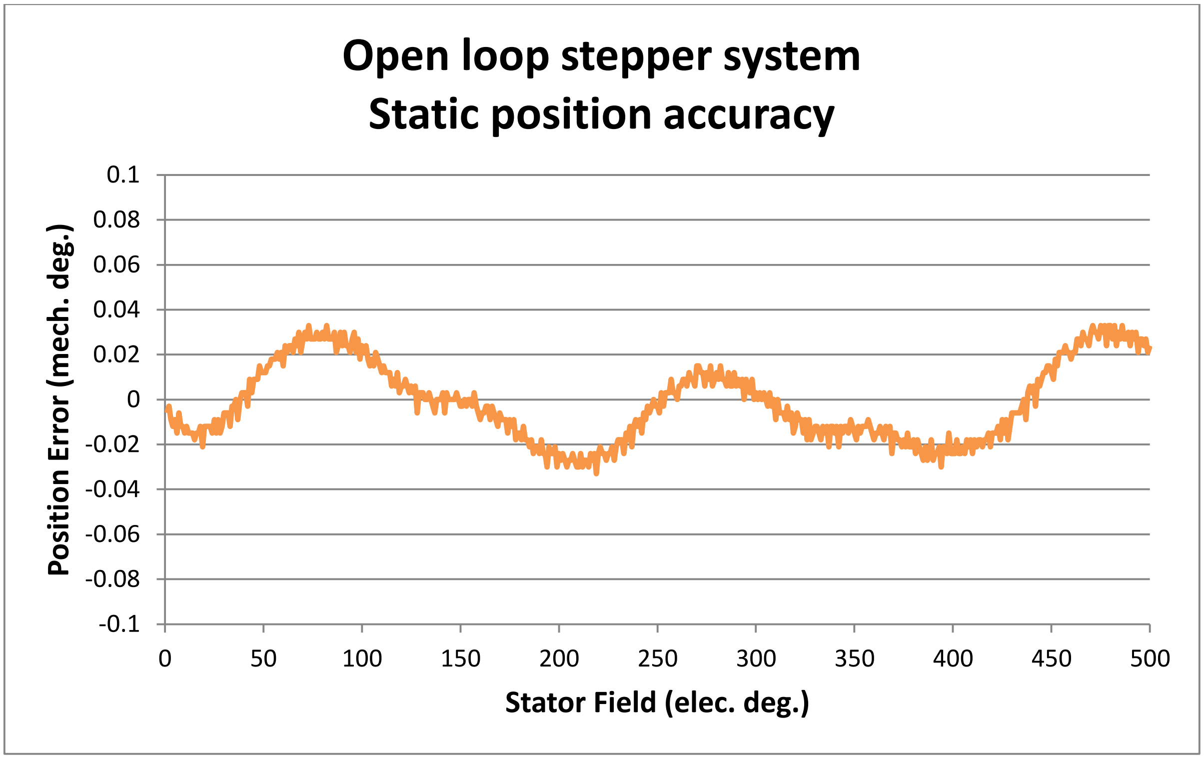
Step motors are prized for their ability to precisely position loads without a feedback mechanism or closed loop control system. This inherent precision is owed to the fact that hybrid step motors have toothed rotors and stators that create an electromechanical gearing system to increase the resolution. For every turn of the shaft, the stator field is rotated 50 times. When the stator field is moved 90° (one full step) the motor shaft moves by just 1.8°.

If the stator field is rotated at a constant rate from a precise quartz crystal clock, the average open loop velocity is nearly perfect, with near 0% speed variation.

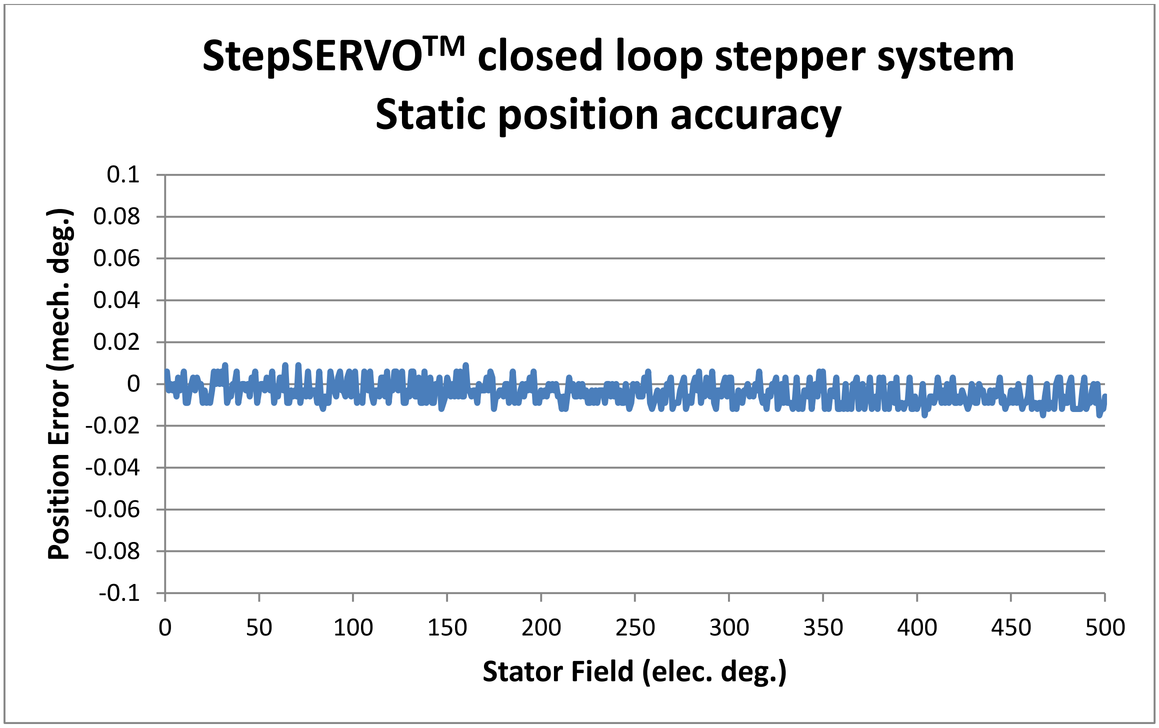
Static Positioning Accuracy

But how accurate is the positioning? According to the specification of a typical 1.8° hybrid step motor, the device can position within ±0.09°. The factors affecting this positional accuracy are the precision to which the stator and rotor components are punched and assembled, the concentricity of the air gap, and the current balance of the two phases as provided by the drive electronics.

This chart illustrates the actual position error measurement of an open loop step motor using a high resolution measurement system. The pattern repeats every electrical cycle (400 steps at 20,000 steps/rev).

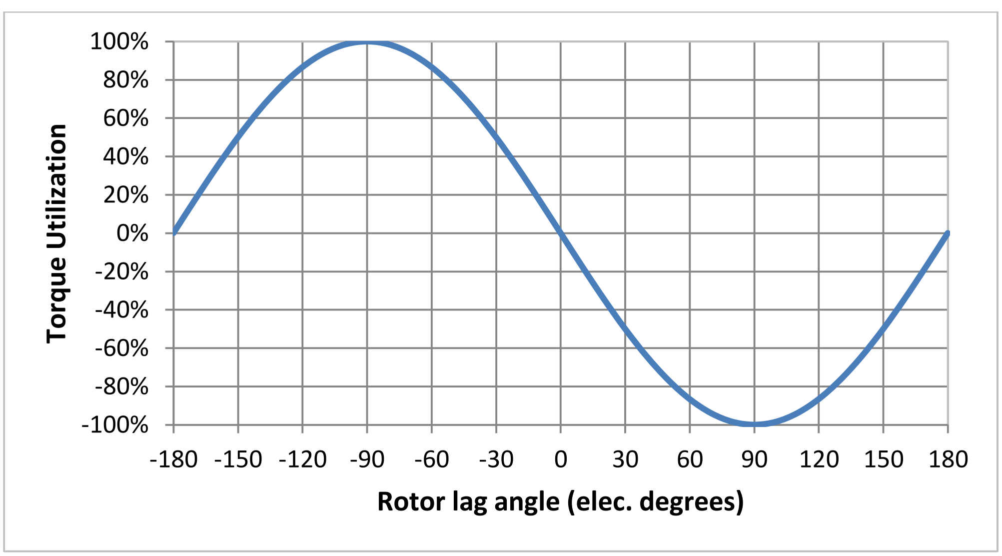


In the case of the StepSERVO™ closed loop system, any errors in the motor electromechanics or the drive electronics are compensated for by closing the servo position loop around feedback from the high resolution encoder. If the encoder is perfect, the expected error is ±1 encoder count, or 1/20000th of a revolution (.018°). The chart below illustrates the actual position error measurement of the StepSERVO™ closed loop stepper system using the same high resolution measurement system.



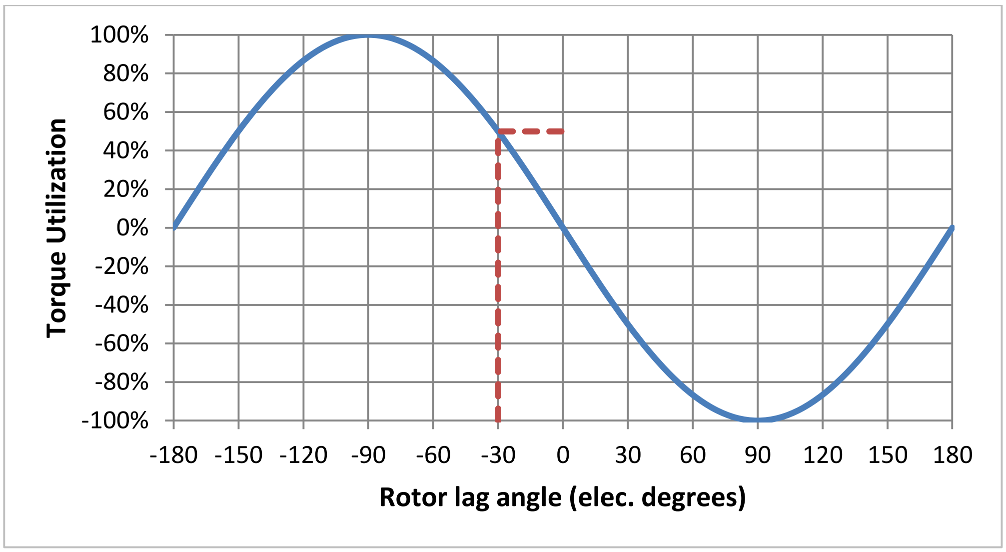
Dynamic Positioning Accuracy

The data we've provided so far references static positional accuracy: the motor has arrived at its intended position and stopped moving. What if you need the motor to be at an exact position while it is still moving? "On-the-fly" positioning applications like labeling and scanning require such precision. To determine positional accuracy at speed, we must consider both the inherent electromechanical errors shown above, plus the rotor lag angle. When a step motor is driven open loop, the stator field is rotated by the driver, and (if the laws of physics are not violated by expecting more torque than the motor can deliver) the rotor follows. The torque produced is a function of the difference between the electrical angles of the stator and rotor, called lag angle. This follows a mostly sinusoidal relationship as shown below.



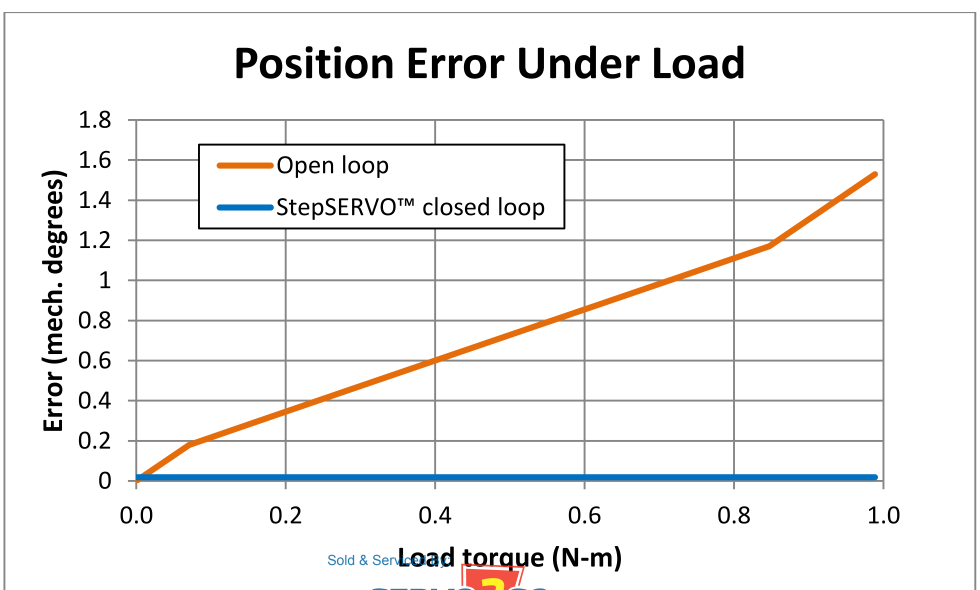
If we accelerate the motor hard and use, say, 50% of the available torque, we can calculate the lag angle using the arcsine function to determine that the rotor will lag behind the intended position by 30 electrical degrees (0.6° at the shaft) during acceleration.

$$\theta = \frac{\sin^{-1}(T)}{50} = \frac{\sin^{-1}(0.50)}{50} = \frac{30°}{50} = 0.6°$$



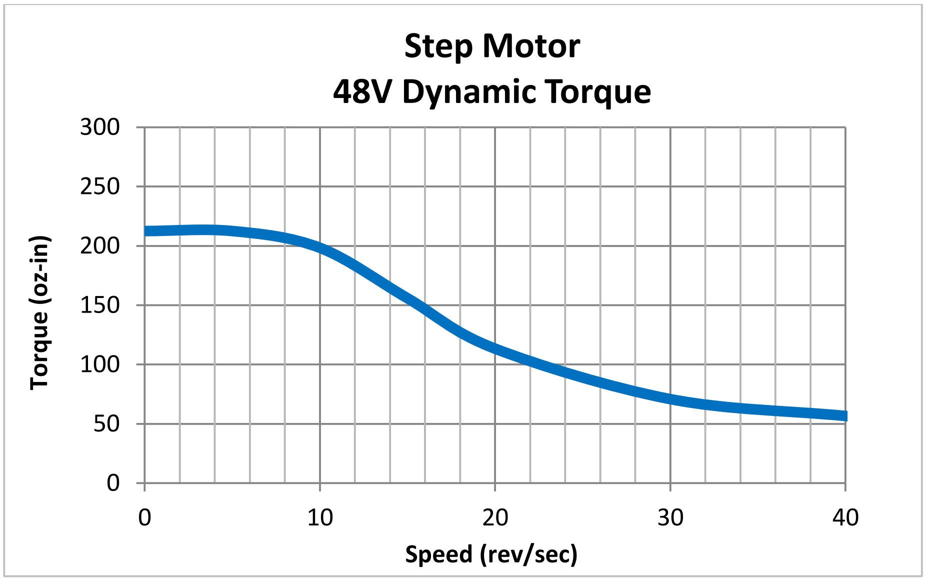
A properly tuned StepSERVO™ closed loop stepper system continuously adjusts for load demand, and generates torque by advancing the stator field rather than allowing the rotor to lag. This technology minimizes dynamic position errors.

Static position accuracy will be similarly affected if an open loop system experiences a static torque load, which would be present in a vertical positioning application. We measured this error in the lab, comparing the same open loop and StepSERVO™ closed loop systems, and present the results below.



Heating

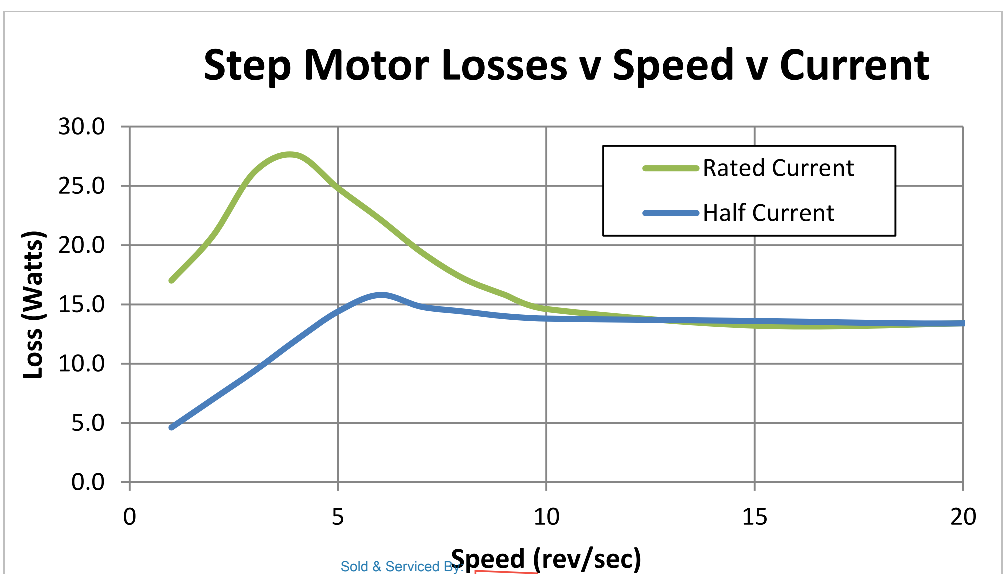
Open loop steppers are simple beasts. Set the drive for the motor's rated current and it will do its best to put that current into the motor at all times, whether the resulting torque is needed or not. At higher speeds, where the drive does not have enough voltage to overcome the motor's inductance and back emf, the current and torque begin to fall, as seen in the speed torque curve below.



Since step motor windings have resistance, the power lost in the stator is proportional to the square of the winding current:

$$P_{loss} = i^2R$$

In addition to the i^2R, or "copper losses", step motors also create heat from "iron losses" that arise from the effects of the reversing magnetic field and high frequency voltage modulation that is used to control winding current. The chart below compares the losses of a typical motor at the rated current and at one half the rated current.

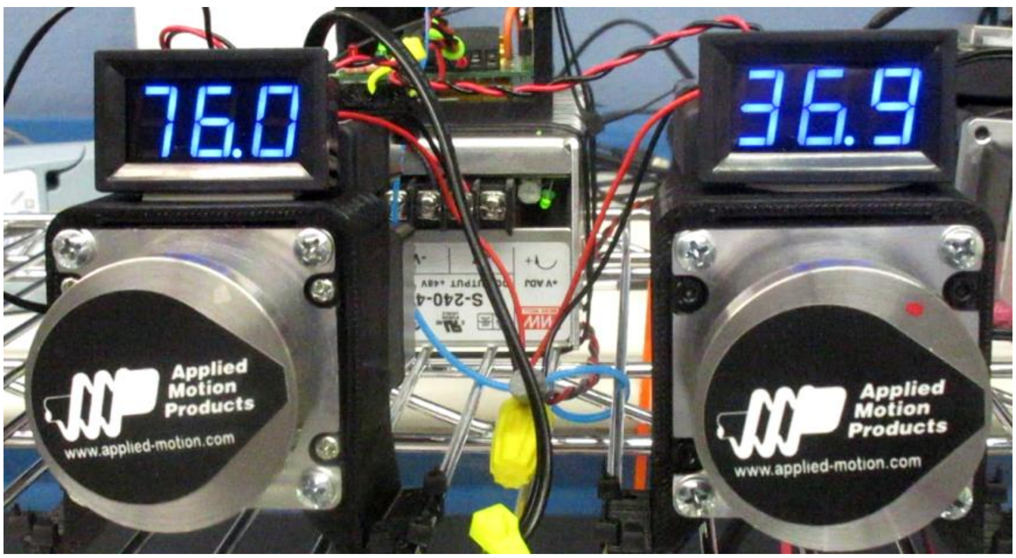


Because motor losses depend on winding current, it is advantageous to apply only the current that is needed to drive the load, and that's exactly what a StepSERVO™ closed loop stepper system does. To demonstrate the difference between the two technologies in a practical manner, we ran open loop and StepSERVO™ closed loop stepper systems side by side. Both systems were commanded to continuously execute the same move.

Move parameters:

- Accel = 100 rev/sec2
- Decel = 100 rev/sec2
- Distance = 5 rev
- Speed = 10 rev/sec
- Dwell time = 1 sec

Both motors were driving inertial loads of 460 g-cm^2, which is equal to their rotor inertia. After running the test for 30 minutes, the case temperature of the open loop stepper system rose to 76°C while the StepSERVO™ closed loop stepper system was running cool at just 36.9°C.

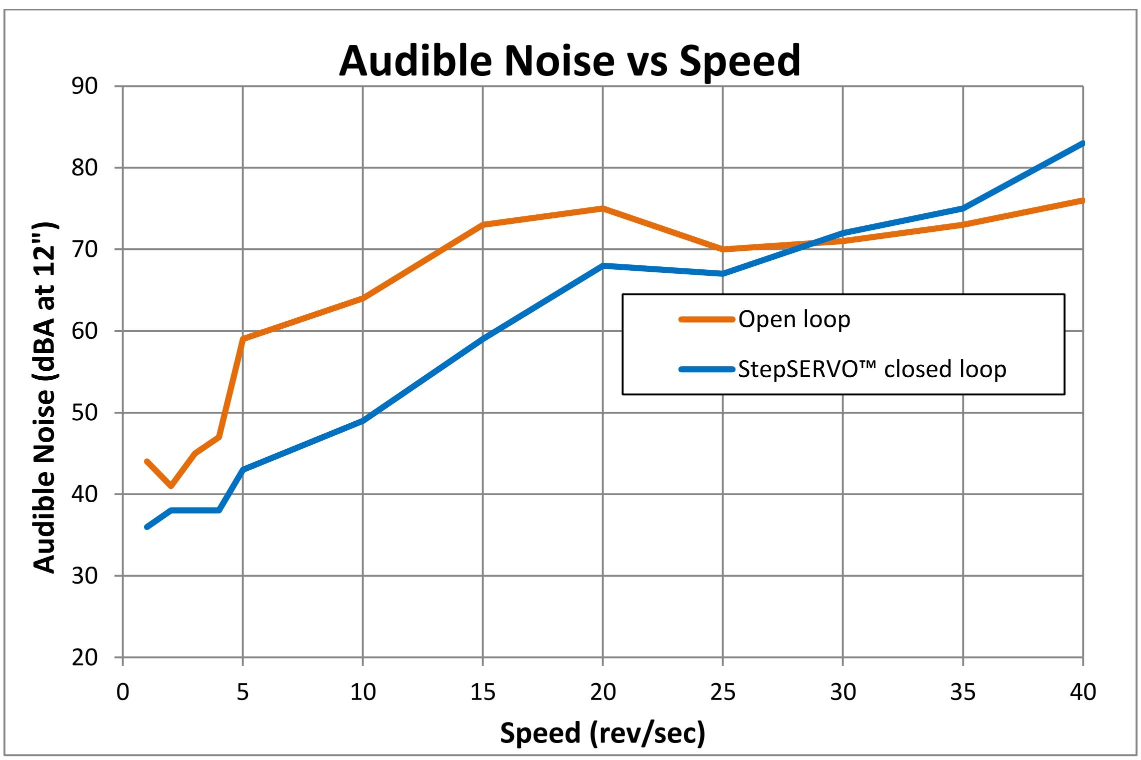


Noise

Step motors are known to make a bit of audible noise. That's partly due to the high electrical frequency and rapid flux changes in the stator teeth. Another contributing factor is that open loop stepper systems operate the motor at full rated current regardless of load. StepSERVO™ closed loop systems, on the other hand, supply the motor with just enough current to control the load. To compare the two, we measured the acoustic noise of each system in a soundproof chamber.

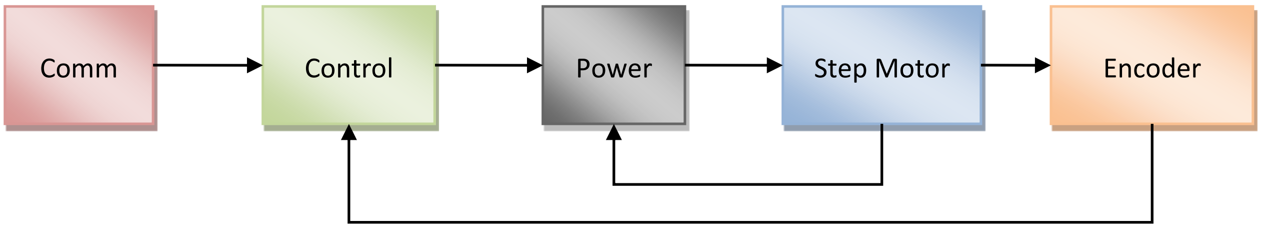
Measuring Acoustic Noise

At speeds in the range of 0 to 20 revs/second, the StepSERVO™ closed loop system is dramatically quieter. At high speeds, the motor impedance prevents both systems from achieving the rated winding current, so the noise is about the same.



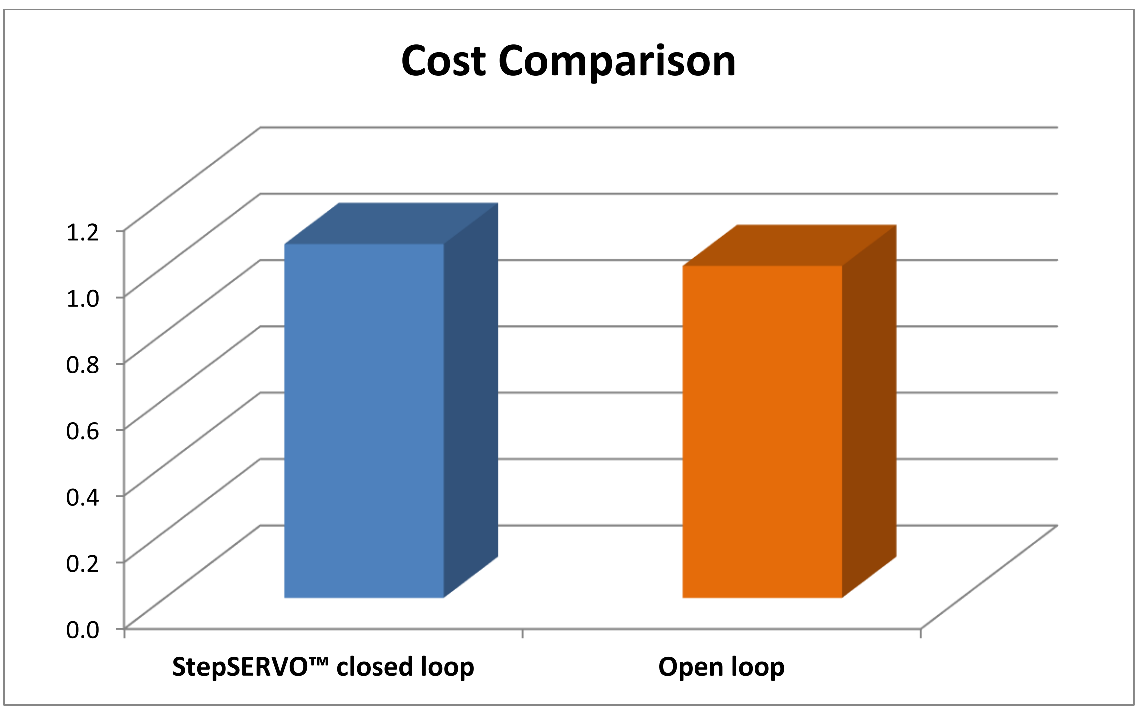
Cost

An integrated step motor system consists of five components: the step motor, a feedback device, control electronics, power electronics and communication.



The motor, power amplifier and communication costs generally will not increase by going closed loop. The control electronics may require a bit more CPU power or memory to servo the motor and the firmware will certainly cost more to develop and maintain. Servo systems also require tuning software. Much of the cost difference between an open loop and a StepSERVO™ closed loop stepper system lies in the closed loop system's requirement for a high resolution, accurate feedback device to provide real time position and velocity data to the servo loop.

The net result is that StepSERVO™ closed loop systems cost slightly more than open loop systems but make up the difference with higher performance and more efficient operation.



Conclusion

Having compared the acceleration, accuracy, efficiency, heating, noise and cost of open loop stepper systems to the new StepSERVO™ closed loop stepper system technology, we can conclude that the slight increase in cost of the StepSERVO™ closed loop system is easily justified by the many benefits. The energy savings and increased throughput of the StepSERVO™ closed loop system easily pay for themselves, while secondary benefits like lower operating temperatures and reduced acoustic noise can be game changers in many applications.

Steppers have come a long way from the early days of voltage drives and full stepping, and StepSERVO™ closed loop stepper systems assure that step motors will continue to be a cornerstone of the motion control industry for years to come.