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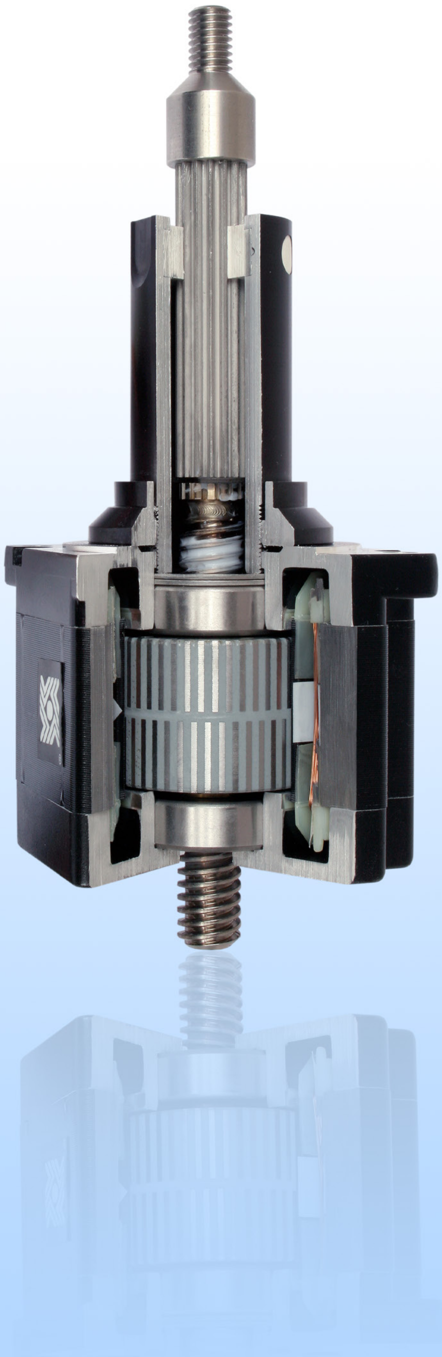
Factors that Influence Performance

Stepping Motors & Actuators

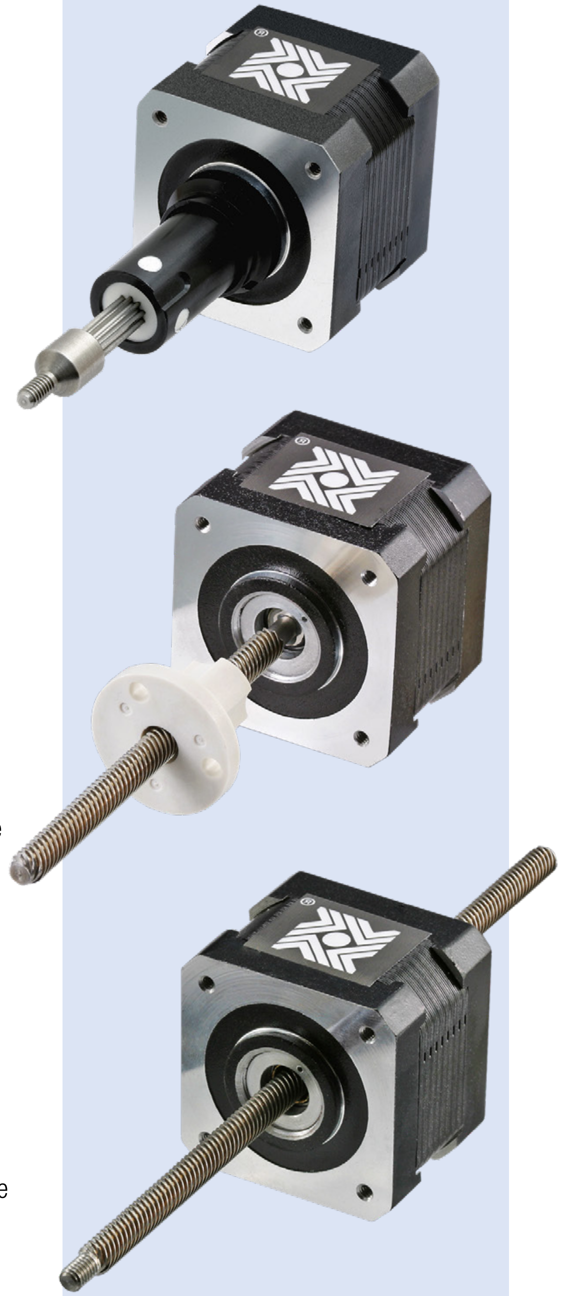


This paper discusses some methods of testing Stepper Motors and Stepper Linear Actuators; information about the typical types of Stepper Drives; and the effects of various applied voltage levels and of reduced levels of phase current for these motors.

There are various parameters to consider when selecting a Rotary Stepper Motor or a Stepper Linear Actuator for a particular motion control application. The following lists many key items to consider:

- Speed range required
- Desired rotary or linear step resolution and step accuracy
- Maximum loading in each direction
- Type of load (frictional, inertial, mechanical spring, shock load, or combinations of these)
- Orientation of the motor's rotary or linear axis
- Mechanical alignment
- Type of drive that will be used (typically a Chopper Drive or an L/R Drive)
- Desired step mode (full, half, quarter, eighth, etc.)
- The use of acceleration and/or deceleration ramping
- Duty cycle: the operational *on* (energized) time relative to any *off* (or reduced power) time
- Levels of *Operating Current* and *Hold Current* relative to the rated current
- Maximum voltage / current capabilities of the Drive
- Applied power supply voltage (relative to the rated voltage of the motor)
- Environmental conditions

Suppliers of Rotary Stepper Motors provide *speed versus torque* performance curves of their various motors, while suppliers of Stepper Linear Actuators provide *speed versus force* performance curves of their various actuators, in addition to the characteristics and mechanical dimensional specifications.



Size 17 Single Stack Stepper Linear Actuators are available in Captive, External Linear and Non-Captives shafts.

Rotary Stepper Motors

Typically published is a graph of the maximum Pull-Out Torque at various step rates throughout a usable speed range for each type of rotary stepper. Measurement of Pull-Out Torque at each speed level is accomplished by running the motor at the designated speed and increasing the rotary load until the maximum operational output torque is obtained just at the point of stalling.

For Stepper Motors this torque is typically listed in units of Newton-centimeters and/or ounce-inches. The speed is usually listed in *full* or *half steps* per second. For these motors the typical rotary *full step* angles are either 0.45°, 0.9°, 1.8°, 3.75°, 7.5°, 15°, or 18°.

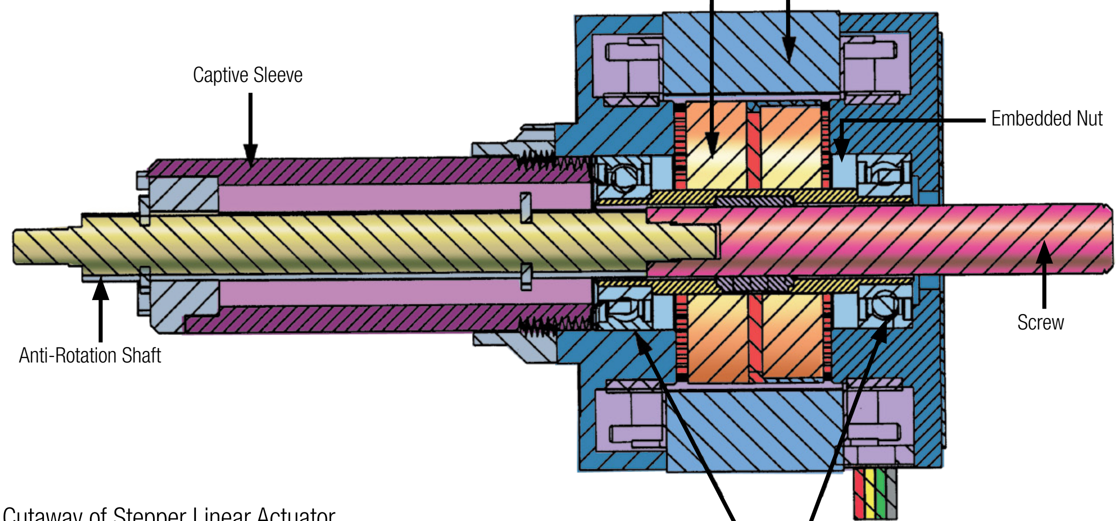


Figure 1. Cutaway of Stepper Linear Actuator.

Stepper Linear Actuators

Typically published is a graph of the maximum Pull-In Force at various step rates throughout a usable speed range for each type of actuator. One method of measuring the Pull-In Force at each speed level is by orienting the actuator axially vertical, output screw/shaft upward, in a test fixture. The actuator is then cycled in each linear direction at the designated speed and the applied dead-weight loading is incrementally increased until the maximum operational output force is obtained just at the point of stalling. This is typically performed without any acceleration or deceleration ramping of the speed.

For Stepper Linear Actuators this force is usually listed in units of Newtons, Ounce-Force, or Pound-Force. The speed is commonly listed in *full* or *half steps* per second. For these actuators the internal rotary *full step* angles are typically the same as the Rotary Steppers and the output linear resolution is based upon the combination of *full step* angle and the pitch of the lead screw or ball screw.

The type of electronic Drive used to operate the motors or actuators can be a very significant factor in their *speed versus torque* or *speed versus force* performance.

In addition, the settings used with these Drives and/or the magnitude of the source voltage into the Drives can affect the overall performance of Stepper Motors and Stepper Linear Actuators.

The Drive settings can include the “Run” current, the “Hold” current, the Step Mode (i.e. full, half, quarter, eighth, sixteenth, etc . . .), and any acceleration and deceleration ramp profiles.

L/R Drives are Constant Voltage Drives

Constant Voltage, referred to as a L/D Drive, is an induction/resistance type of stepper drive. For normal continuous operation of a stepper motor or actuator in a room temperature environment the output voltage (measured at the motor leads) is set to the motor’s rated coil voltage.

One of the world’s smallest linear actuators, Size 8 Single Stack Stepper Linear Actuator, occupies a minimal 0.8” (21mm) space. Available in 3 designs: Captive, Non-Captive (shown above) and External Linear.

In the example performance graph for a Rotary Stepper Motor (Figure 2) this is shown as the 1:1 voltage ratio curve. As a result the available output torque drops off relatively quickly within a narrow speed range, mainly due to the winding inductance and back-emf of the stepper motor.

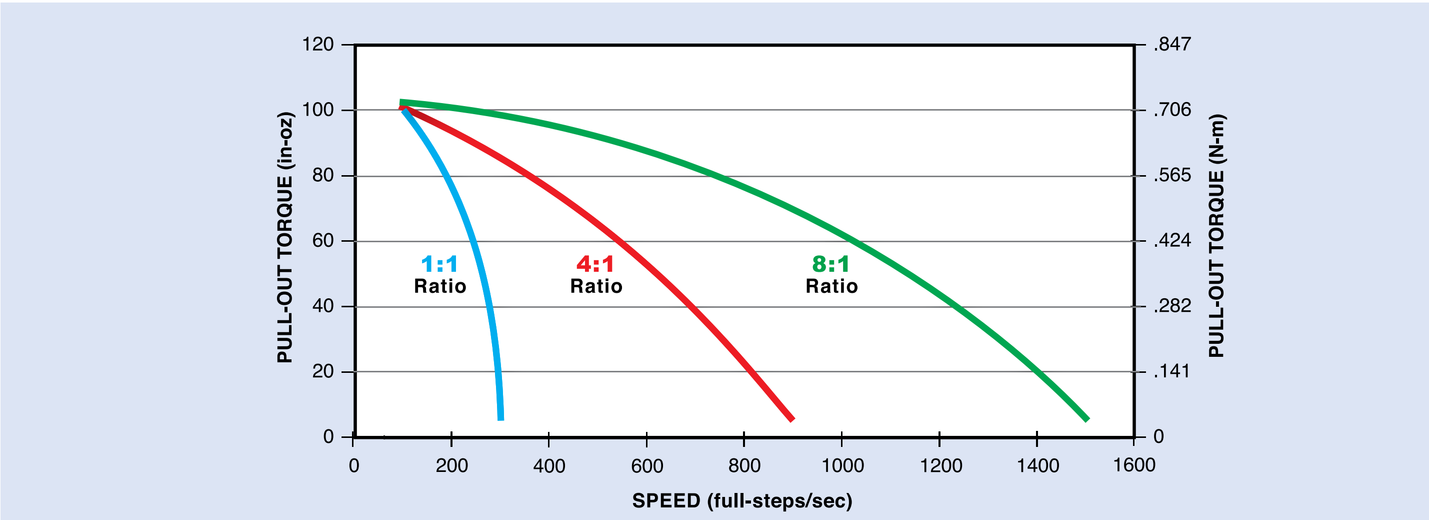


Figure 2. Example of the relative effect of the source-to-coil voltage ratio on motor performance using a Chopper Drive.

Chopper Drives are Constant Current Drives

The chopper type of stepper Drive is a Constant Current drive. The name relates to its output current control technique which can rapidly turn a relatively high source voltage (as compared to the motor's rated coil voltage) on and off – typically *chopping* – at frequencies above the audible sound range.

For normal continuous operation of a stepper motor or actuator in a room temperature environment the output current of this drive is set to the motor's rated phase current.

In the example performance graph for a Rotary Stepper Motor, see Figure 2, two voltage ratio curves (4:1 and 8:1) show the relative improvements as compared to an L/R Drive (1:1 voltage ratio). Other ratios will produce correspondingly proportional performance up to approximately 12:1 above which there would be increasingly diminishing returns.

The available output torque remains relatively higher over a wider speed range mainly due to the higher source voltage helping to overcome the effects of the motor's inductance and back-emf.

Effects of Current Starving a Stepper Motor or Stepper Linear Actuator

Output torque of a Rotary Stepper Motor, and similarly the output force of a Stepper Linear Actuator, is proportional to the ampere-turns. Within the lower speed range the output voltage level of an L/R Drive, or the output current level setting of a Chopper Drive, would be the major factor influencing the output torque or the output force.

Therefore setting the output voltage of an L/R Drive to values below the motor's rated coil voltage or setting the output current of a Chopper Drive to values below the motor's rated phase current will, in effect, current starve the motor resulting in reduced output torque or output force levels.

At relatively higher speed ranges the ratio of the source voltage to motor rated coil voltage becomes a large factor because of the higher frequency dependent coil impedance (due to inductance) and the higher back-emf. Higher voltage ratios help allow the coil current to quickly rise to the set level during the relatively smaller pulse widths of each step as the step frequency increases.

Conditions of Current Starving these Motors

Rotary output torque or linear output force can be further reduced due to internal losses from the friction of the internal plain bearings or pre-loaded ball bearings. There can be production build variations, bearing pre-load variation, and variations in the mechanical stack-up of tolerances.

- Rotary output torque or linear output force can also be reduced due to internal losses from the rotary detent torque. High Torque motors or actuators containing rotors with relatively high energy permanent magnets, and thus having higher rotary detent torque, will typically produce less torque / force when current starved than standard stepper motors or actuators under equivalent conditions.
- Rotor inertia, being another fixed value per motor type and size, will impede the performance of these motors during accelerations and decelerations (i.e. any changes in the operational velocity).
- For Stepper Linear Actuators there can be additional losses in output force due to the mechanical drag torque in the rotary-to-linear conversion components (lead screw nut interface) which becomes a larger percentage loss factor when the actuators are operated under current starved conditions.
- There can be a possible reduction in the motor's step accuracy depending upon the external loading characteristics.
- Typically there will be a greater performance variation from motor to motor due to the internal losses being larger and highly variable factors when stepper motors or actuators are under powered.
- There also can be several beneficial aspects for some specific low-load applications such as a softer step response, reduced audible noise, less vibration, and a reduction in resonance.

The Size 17 Double Stack Stepper Linear Actuator delivers force of up to 75 lbs. Available in 3 designs: Captive, Non-Captive and External Linear (shown above).

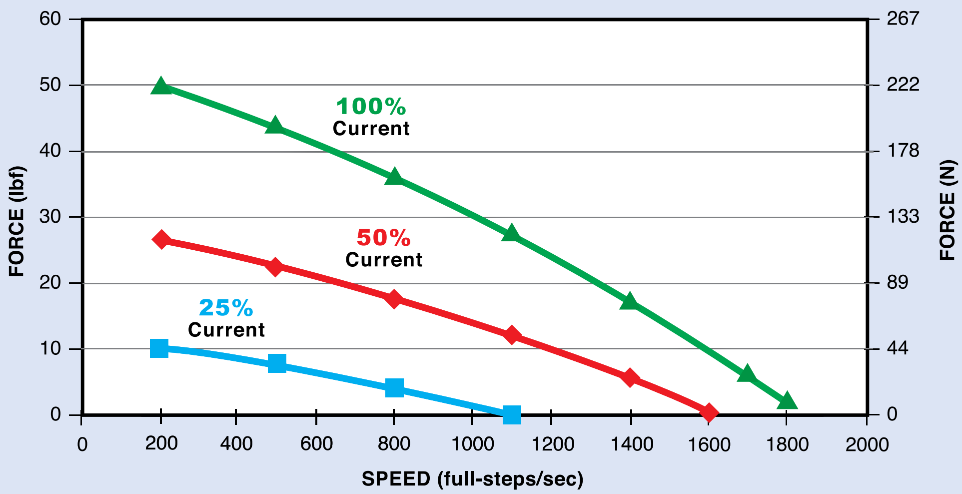


Figure 3. Example of current starving a Hybrid Size 17 Double Stack Linear Actuator (percentages are relative to the continuous-duty rated current.)

To further discuss the performance effects of internal losses when current starving a Rotary Stepper Motor we can make use of percentages. As an example let's consider just one of the contributors of internal loss – the total drag torque of the two internal ball bearing assemblies relative to the available generated torque. In this example imagine that we might be able to obtain a special Rotary Stepper Motor containing ideal friction-free (zero drag torque) ball bearings – even under typical pre-loading.

Let's say this theoretical motor could produce 100 in-oz of output torque at 500 full-steps per second when operated at its full rated current. At this speed when driven at half of the rated current level and at one quarter of the rated current level this theoretical motor then produces 50 in-oz of torque and 25 in-oz of torque respectfully.

To now build this theoretical motor into a standard production motor let's assume that installing and pre-loading a set of actual real-world ball bearings yields a total drag torque of 10 in-oz at this rotary speed of 500 full-steps per second. When operated at full rated current the drag torque of these bearings (internal losses within the motor) is 10% of the total available torque. However, when operated at half of the rated current these same internal losses become 20% of the available torque. When operated at one quarter of the rated current these internal losses can then become 40% of the available output torque.

Conclusion

There are many factors to consider when choosing Stepper type motors and actuators for motion control systems. Particularly important are: the choice of Stepper Drive type, the selection of motor coil rated voltage, and the proper levels of "Run" and "Hold" current for the application.

The Size 17 Double Stack Stepper Linear Actuator with integrated IDEA™ Drive is fully programmable and RoHS Compliant. Available in 3 designs: Captive (shown above), Non-Captive and External Linear.