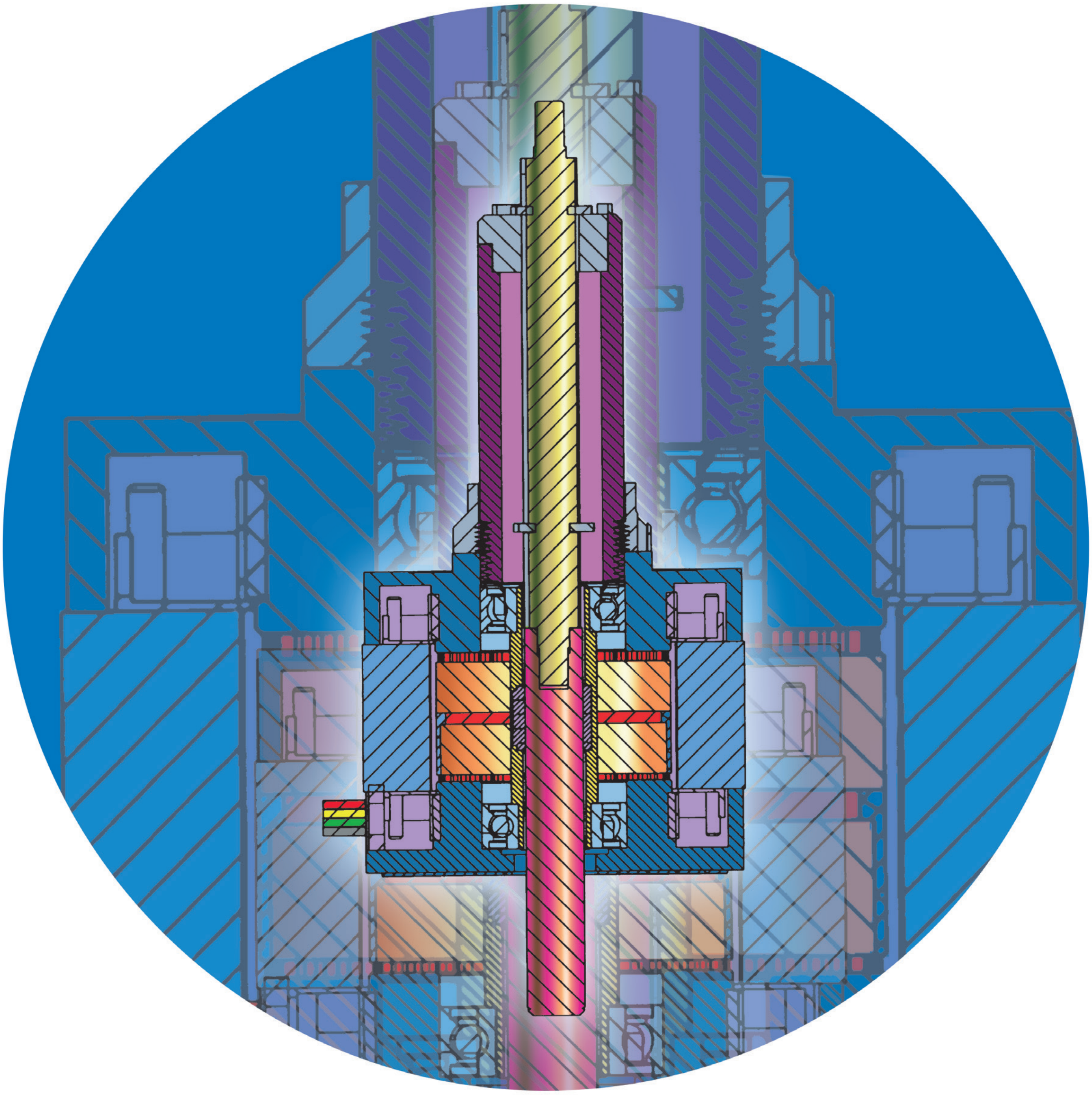
Stepper Motor Linear Actuators 101



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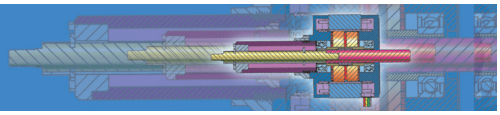


Suppose you, as an engineer, are tasked to design a machine or part of a machine that requires precise linear positioning. How would you go about accomplishing this? What is the most straightforward and effective method?

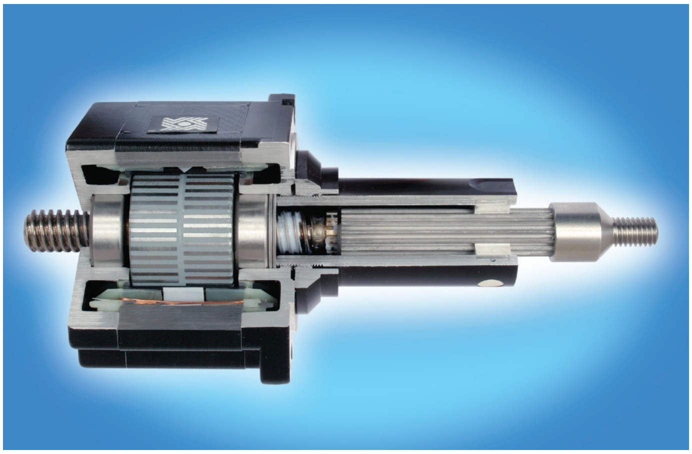
When students are trained in classic mechanical engineering, they are taught to construct a system using conventional mechanical components to convert rotary into linear motion. Converting rotary to linear motion can be accomplished by several mechanical means using a motor, rack and pinion, belt and pulley, and other mechanical linkages. The most effective way to accomplish this rotary to linear motion, however, is within the motor itself.

What Exactly Is a Stepper Motor-Based Linear Actuator?

A linear actuator is a device that develops a force and a motion through a straight line. A stepper motor-based linear actuator uses a stepping motor as the source of rotary power. Inside the rotor, there's a threaded precision nut instead of a shaft. The shaft is replaced by a lead-screw. As the rotor turns (as in a conventional stepper motor), linear motion is achieved directly through the nut and threaded screw. It makes sense to accomplish the rotary to linear conversion directly inside the motor, as this approach greatly simplifies the design of rotary to linear applications. This allows high resolution and accuracy ideal for use in applications where precision motion is required.

Stepper Motor Basic Components

Why use a stepper motor instead of a conventional rotary motor? Unlike other rotary motors, steppers are unique in that they move a given amount of rotary motion for every electrical input pulse. This makes steppers a perfect solution for use in positioning applications. Depending on the type of stepper motor, our motors can achieve resolutions from 18 rotational degrees per step to 0.9 rotational degrees per step. This unique "stepping" feature coupled with the characteristics of the lead screw provides a variety of very fine positioning resolutions



How Does the Stepper Motor Work?

Permanent magnet stepper motors incorporate a permanent magnet rotor, coil windings, and a steel stator capable of carrying magnetic flux. Energizing a coil winding creates an electromagnetic field with a NORTH and SOUTH pole as shown in figure 1.

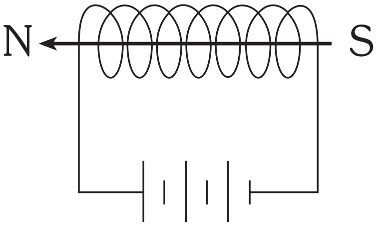
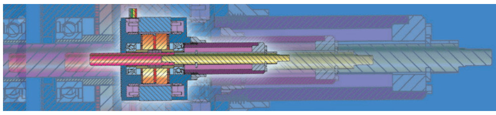


Figure 1. Magnetic field created by energizing a coil winding

The stator conducts the magnetic field and causes the permanent magnet rotor to align itself to the field. The stator magnetic field can be altered by sequentially energizing and de-energizing the stator coils. This causes a "stepping" action and incrementally moves the rotor resulting in angular motion.



"One-Phase On" Stepping Sequence

Figure 2 illustrates a typical step sequence for a simplified 2 phase motor. In step 1, phase A of the 2 phase stator is energized. This magnetically locks the rotor in the position shown, since unlike poles attract. When phase A is turned off and phase B is turned on, the rotor moves 90° clockwise. In step 3, phase B is turned off and phase A is turned on but with the polarity reversed from step 1. This causes another 90° rotation. In step 4, phase A is turned off and phase B is turned on, with polarity reversed from step 2. Repeating this sequence causes the rotor to move clockwise in 90° steps.

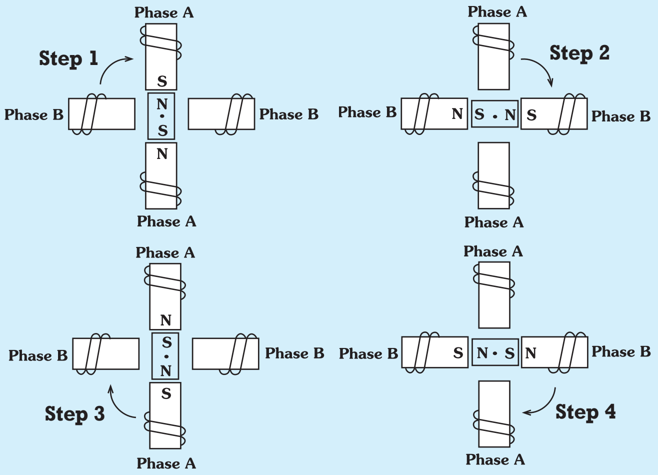


Figure 2. "One Phase On" stepping sequence for two phase motor

"Two-Phase On" Stepping Sequence

A more common method of stepping is "two phase on" where both phases of the motor are always energized. However, only the polarity of one phase is switched at a time, as shown in Figure 3. With two phase on stepping, the rotor aligns itself between the "average" north and "average" south magnetic poles. Since both phases are always on, this method provides 41.4% more torque than "one phase on" stepping.

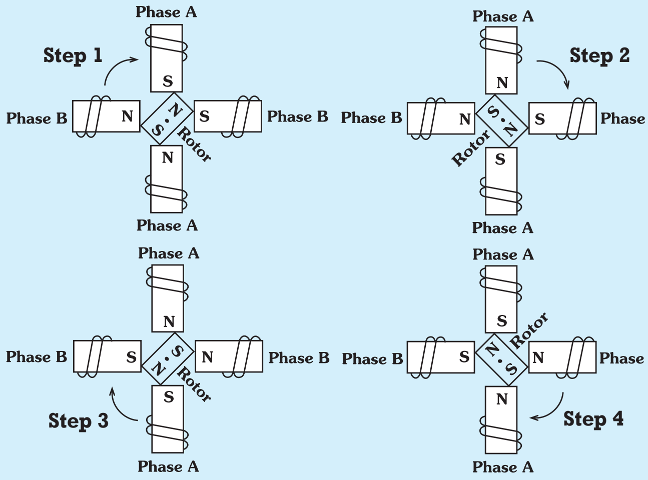


Figure 3. "Two Phase On" stepping sequence for two phase motor

Lead Screw

The acme lead screw is a special type of screw that provides a linear force using the simple mechanical principle of the inclined plane. Imagine a steel shaft with a ramp (inclined plane) wrapped around it. The mechanical advantage (force amplification) is determined by the angle of the ramp which is a function of the lead, pitch, and diameter of the screw.

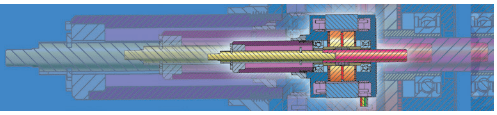
Lead – The axial distance a screw thread advances in a single revolution

Pitch – The axial distance measured between adjacent thread forms

The threads of the lead-screw allow a small rotational force to translate into a large load capability depending on the steepness of the ramp (the thread lead).

A small lead (more threads per inch) will provide a high force and resolution output. A large lead (fewer threads) will provide a lower force, but a correspondingly higher linear speed from the same source of rotary power.

Examples of different thread configurations:
Finer threads will provide higher force but lower speeds;
Coarse threads will provide higher speeds but lower force.



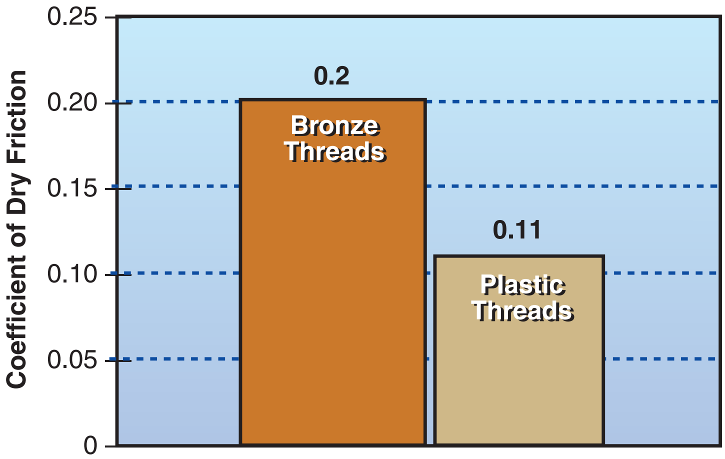
INTEGRATED NUT

Of equal, if not greater importance to the lead screw is the nut that drives the screw. This nut is often imbedded in the rotor of the stepping motor, which makes this actuator configuration unique from other rotary to linear techniques. The traditional nut material is a bearing grade bronze which lends itself to the required machining of the internal threads. Bronze is a traditional compromise between physical stability and lubricity. Compromise, however, is the key word since it excels at neither.

FRICTION CONSIDERATIONS

A much better material for a power nut in the linear actuator is a lubricated thermoplastic material. With the evolution of new engineered plastics, the screw threads may now travel with a lower overall coefficient of friction. This is illustrated below in Figure 4.

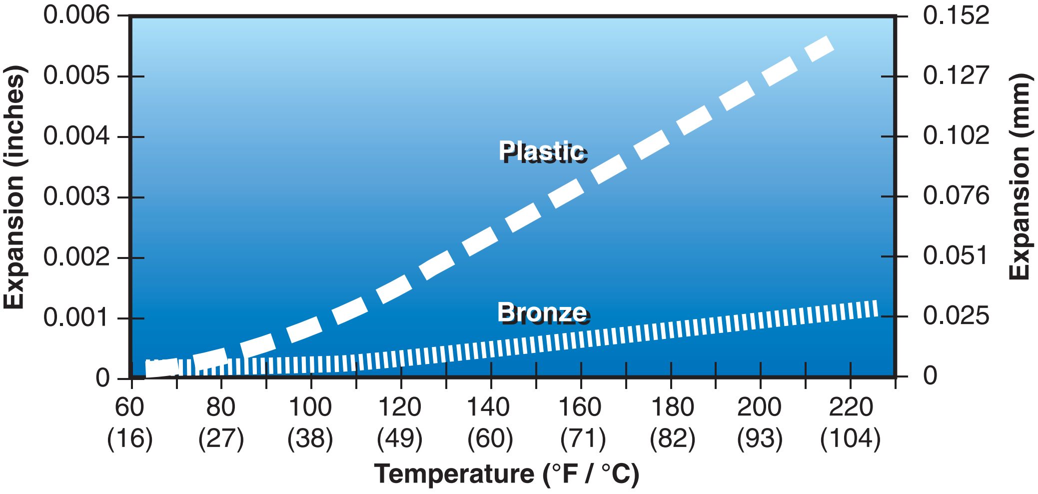
Figure 4. **FRICTION EFFECTS**
Comparative friction of stainless steel on select rotor materials



THERMAL CONSIDERATIONS

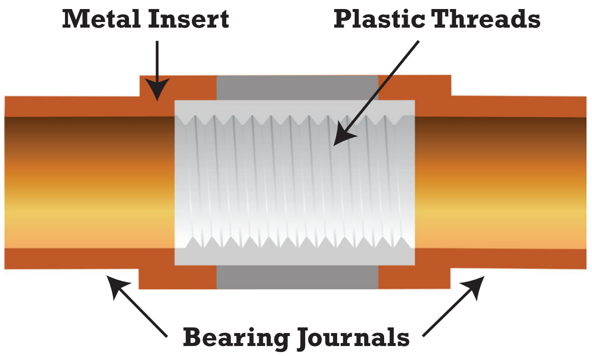
Given the data, it was clear that a plastic drive nut provides the lower coefficient of friction when compared with bronze. Unfortunately, as good as the plastic is for threads, it is not stable enough for the bearing journals of a hybrid motor, which are critical in the hybrid motor design. Under a continuous full load condition, plastic bearing journals can expand as much as 0.004-in., where brass will expand only 0.001-in. This is illustrated in Figure 5. In order to achieve the high performance characteristics of the stepper motor, the design must maintain a stator-to-rotor airgap of only a few thousandths of an inch. This tight design requirement demands thermally stable bearing journals.

Figure 5. **THERMAL EFFECT**
Linear thermal expansion for 1-inch (25.4 mm) samples



By injection molding plastic threads within a brass rotor assembly, both characteristics of low friction and high bearing journal stability is achieved (see figure 6).

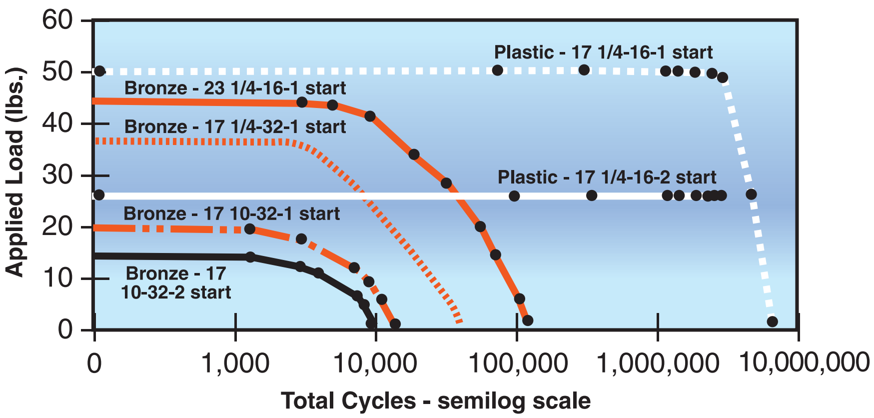
Figure 6. **POWER NUT CONFIGURATION**
Embedded in Permanent Magnet Rotor



Effects on Actuator Life

The result is a product with quiet operation, higher efficiencies, and higher life expectancies. Motor life is improved by 10 to 100 times over the traditional bronze nut configuration, as illustrated in the life test chart in figure 7.

Figure 7. **LIFE TEST: BRONZE vs PLASTIC**
Nuts used in Size 17 and 23 Hybrid Linear Actuators



Extending Actuator Life

With proper application consideration, Haydon Kerk linear actuators deliver up to 20 million cycles. Ultimately, motor fatigue and resultant life are determined by each customer's unique application.

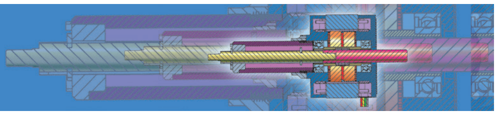
There are some general guidelines that should be understood in order to insure maximum life. Ultimately, to determine an actuator's performance in a given system it's best to perform testing in the final assembly in "field conditions" or in a setting that closely approximates those conditions.

Since a stepper has no brushes to wear out, its life usually far exceeds that of other mechanical components of the system. If a stepper does fail there are certain components which are likely to be involved. Bearings and lead-screw/nut interface (in linear actuators) are typically the first components to experience fatigue. Required torque or thrust and operating environment are the factors which affect these motor components.

Extensive testing has shown that motor life increases exponentially with reduced operating loads. Environmental factors such as high humidity, exposure to harsh chemicals or gases, excessive dirt/debris, and heat will affect motor life. Mechanical factors in the assembly such as side loading of the shaft (linear actuators) or an unbalanced load (rotary motors) will also affect life.

Properly designing a system which minimizes these factors and also insuring the motor is operating within electrical specifications will ensure maximum motor life. The first step in maximizing life is choosing a motor which has a safety factor of 2 or more. The second step is insuring the system is mechanically sound by minimizing side loading, unbalanced loads, and impact loads. Also, design the system to allow effective heat dissipation. Air flow around the motor or mounting which provides some heat sinking are effective means to maintain a safe operating temperature.

If these simple, yet effective guidelines are followed, the linear actuators will provide reliable operation over millions of cycles.



Putting It All Together

Figure 8 below is a cross section drawing of a "captive" type linear actuator. Captive indicates that there is already an anti-rotation mechanism built into the actuator through the use of a splined "anti-rotation" shaft and a "captive sleeve". The "captive" configuration is ideal for use in precision liquid drawing/dispensing and proportional valve control. Other forms of linear actuators are "non-captive" and "external linear" as pictured in Figures 9 and 10.

Figure 8. **TYPICAL HYBRID LINEAR ACTUATOR**
Captive stepper motor linear actuator

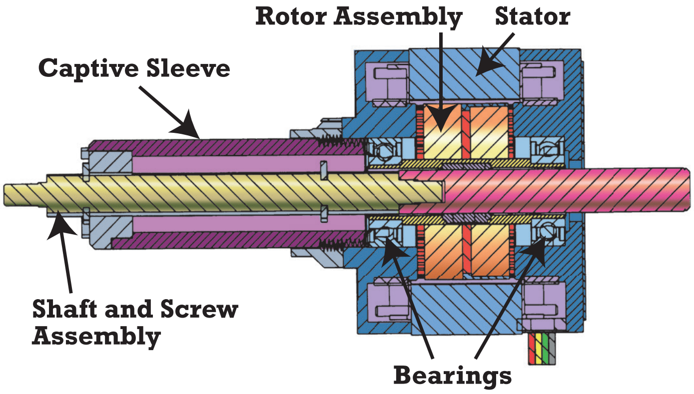


Figure 9. **HYBRID LINEAR ACTUATORS**
Size 17 Series: (1.7-in / 43 mm square) captive, non-captive and external linear, available in 1.8 and 0.9 rotational degrees per step.

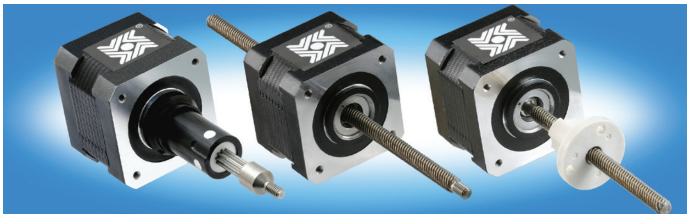
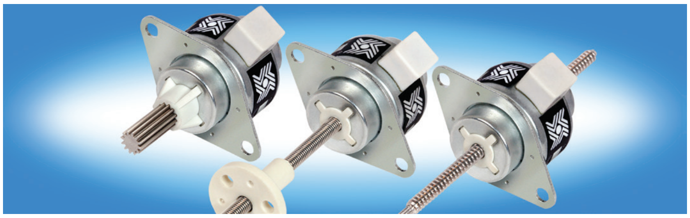


Figure 10. **CAN-STACK LINEAR ACTUATORS**
G4 25000 Series: (Ø 1-in / 25.4 mm) captive, external linear, non-captive available in 15 and 7.5 rotational degrees per step.



All This Theory Is Good, But How Are They Sized?

Sizing a linear actuator is quite easy once you understand the basic needs of the application. The following is the minimum information needed to begin sizing the proper device.

1) Linear force needed to move the load, expressed in Newtons (N)
2) Linear distance the load needs to be moved, expressed in meters (M)
3) Time required to move the load, expressed in seconds (s)
4) Table 1 (next page)
5) Performance curves illustrated in *Haydon Kerk* linear actuator catalog

Power Requirements

The power required to meet the application is now calculated using the parameters above. This will allow the user to easily choose the correct motor framesize needed.

$$P_{\text{linear}} = \frac{(\text{distance traveled in meters})\ (\text{force in Newtons})}{(\text{Time to travel the distance in Seconds})} = \text{watts}$$

Once the power is known in watts, choose the proper framesize of the actuator as listed in Table 1 (next page).

All stepper motor linear actuators require a drive to send the pulses to the motor. As seen in the table, the power for both an L/R drive and a chopper drive is listed. Most applications today use an electronic chopper drive. Unless the application is battery powered (as in a hand-held portable device), a chopper drive is highly recommended to get the maximum performance from the linear actuator.

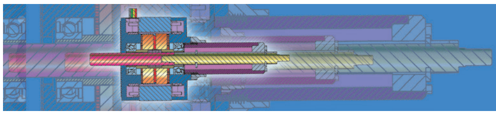


Table 1. Frame Sizes and Performance Based On Required Output Power

Hybrid Single Stack

				Max. Linear Power (watts)	
Series	**Size**	**Max Force (N)**	**Linear Travel Per Step (micron)**	**L/R Drive**	**Chopper Drive**
21000	8	44	1.5 – 40	0.3	0.37
28000	11	90	3 – 50	0.27	0.51
35000	14	220	1.5 – 50	0 .59	1.5
43000	17	220	1.5 – 50	1.02	2.31
57000	23	890	4 – 50	1.47	6
87000	34	2224	12.7 – 127	N/A	21.19

Hybrid Double Stack

				Max. Linear Power (watts)	
Series	**Size**	**Max Force (N)**	**Linear Travel Per Step (micron)**	**L/R Drive**	**Chopper Drive**
28000	11	133	3 – 50	N/A	1.14
35000	14	220	15.8 – 127	N/A	2.7
43000	17	337	15.8 – 127	N/A	4.62
57000	23	890	12.7 – 127	N/A	10.08

Can-Stack

				Max. Linear Power (watts)	
Series	**Size Ø (mm)**	**Max Force (N)**	**Linear Travel Per Step (micron)**	**L/R Drive**	**Chopper Drive**
G4 19000	20	50	25 – 100	0.17	0.35
G4 25000	26	90	12.7 – 100	0.26	0.53
G4 37000	36	260	12.7 – 100	0.44	0.66
15000	15	7	20	0.025	0.03
20000	20	16	25 – 100	0.05	0.06
Z20000	20	35	25 – 100	0 .09	0.23
26000	26	50	6 – 100	0.17	0.18
Z26000	26	80	6 – 100	0.18	0.48
36000	36	160	3 – 100	0.23	0.51
46000	46	260	12.7 – 400	0.55	1.13

Velocity

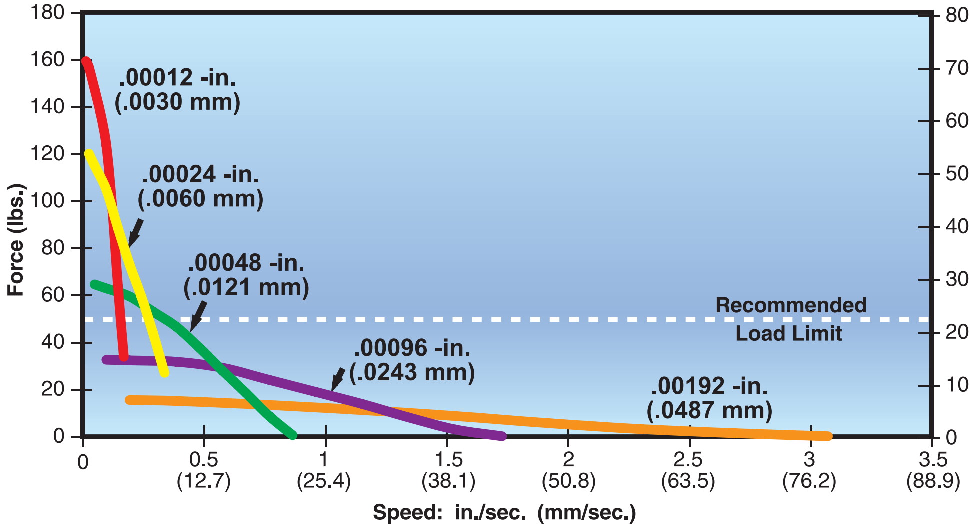
After calculating the mechanical power needed to meet the application requirements, the linear velocity in inches per second is calculated using the following equation.

$$\text{Velocity}_{\text{linear}} = \frac{\text{Required travel distance (inches)}}{\text{Time to achieve travel (seconds)}} = \text{in / sec}$$

Force vs Linear Velocity Curves

Once the required actuator framesize is determined and the linear velocity is calculated, the "force vs linear velocity curve" is used to determine the proper resolution of the actuator lead screw.

Figure 11.
FORCE vs LINEAR VELOCITY SIZE 17 SERIES 43000
.218-in. (5.54 mm) Ø lead-screw, Bipolar, Chopper Drive, 100% Duty Cycle

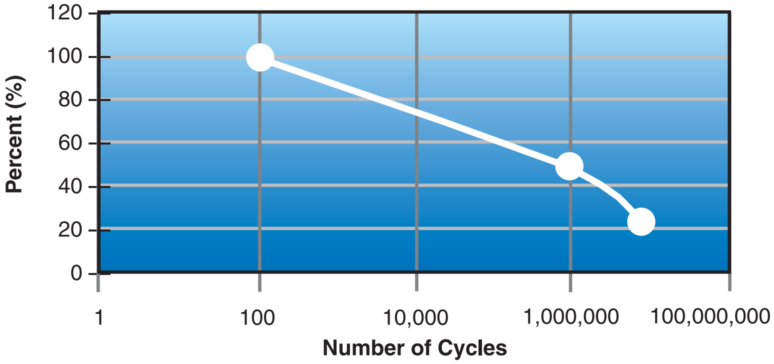


Actuator Life

There are many variables that ultimately determine life of the actuator. The best way to predict life is through application testing, which is highly recommended.

There is, however, a first approximation technique that can help estimate this value. The stepper motor prime mover contains no brushes to wear out and also utilize precision long-life ball bearings. The main wear component is the power nut. The number of cycles can be summarized as a function of load, as illustrated in Figure 12 below.

Figure 12.
% RATED LOAD vs NUMBER OF CYCLES
Cycles on a standard stroke actuator



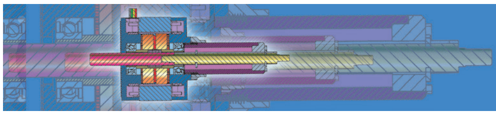
With proper application, Haydon Kerk linear actuators deliver up to 20 million cycles. Ultimately motor fatigue and resultant life are determined by each customer's unique application. The following definitions are important for understanding motor life and fatigue.

Continuous Duty: Running a motor continuously at rated voltage.

25% Duty Cycle: Running a motor at double its rated voltage (L/R drive) or double its rated current (chopper drive). The motor is "on" approximately 25% of the time. As a general guideline, the "on" time should not exceed 1 minute when overdriving a motor. The motor generates about 60% more output than at rated voltage or current. Note, duty cycle is not related to the load placed on the motor.

Life: A linear actuator's life is the number of cycles that the motor is able to move at a prescribed load and maintain step accuracy.

One Cycle: A linear actuator's cycle consists of extending and retracting back to the original position.



EXAMPLE #1

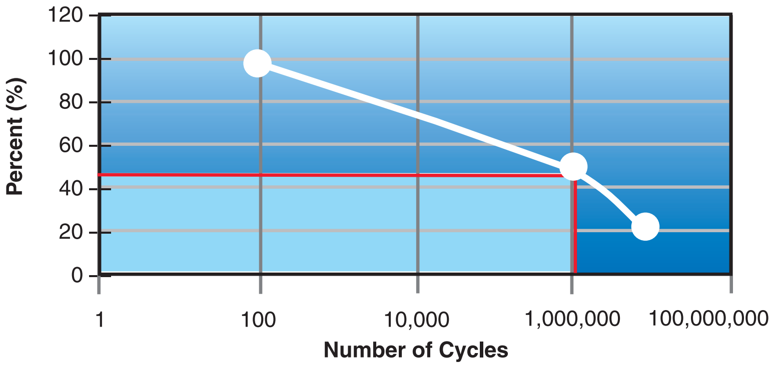
Application Requirements:

Required Force (lbs) =	15 lbs
Required Travel (inches) =	3-in
Time To Achieve Travel (sec) =	6 sec
Desired Cycles =	1,000,000
Linear Velocity (in / sec) =	3-in / 6 sec = 0.5-in / sec

Calculate the initial rated force based on required # of cycles:

Step 1:
Refer to Figure 12 and determine the % rated load required to meet 1,000,000 cycles.
This is indicated with the red line in Figure 13.

Figure 13. **LIFE EXPECTANCY**
Cycles on a standard stroke actuator



Step 2:
As indicated in the chart, in order to get 1,000,000 cycles, a factor of 0.5 must be used when sizing the actuator. The initial rated force required in order to meet the load after 1,000,000 cycles is **15 lbs / 0.5 = 30 lbs.**

Step 3:
Convert lbs to Newtons: **30 lbs / (0.225 lbs / N) = 133 N**

Determine required travel in meters: **3-in x (0.0254 m / in) = 0.0762 m**

Choose the proper framesize actuator using the selector chart

Step 1:
Determine the required linear mechanical power in watts:

$$P_{linear} = (133\ N \times 0.0762\ m) / 6\ sec = 1.7\ N\text{-}m / sec = 1.7\ watts$$

Step 2:
Use **Table 1** to determine the correct framesize actuator. As discussed earlier in the paper, most applications will use a chopper drive to supply the required input pulses to the stepper motor. The 43000 (Size 17 Hybrid) was chosen for this application, as highlighted in the **"Hybrid Single Stack"** section of Table 1.

Hybrid Single Stack					
				Max. Linear Power (watts)	
Series	Size	Max Force (N)	Linear Travel Per Step (micron)	L/R Drive	Chopper Drive
21000	8	45	1.5 – 40	0.3	0.37
28000	11	90	3 – 50	0.27	0.51
35000	14	220	1.5 – 50	0 .59	1.5
43000	**17**	220	1.5 – 50	1.02	**2.31**
57000	23	880	4 – 50	1.47	6
87000	34	2200	12.7 – 127	N/A	21.19

Determine the proper resolution using the "Force vs Linear Velocity" chart

As determined by the life calculation performed above, an initial load of 30 lbs is to be moved at a velocity of 0.5 in / sec. The resulting lead screw resolution required in the Size 17 hybrid motor is 0.00048" (0.0121 mm), as indicated in figure 14 below.

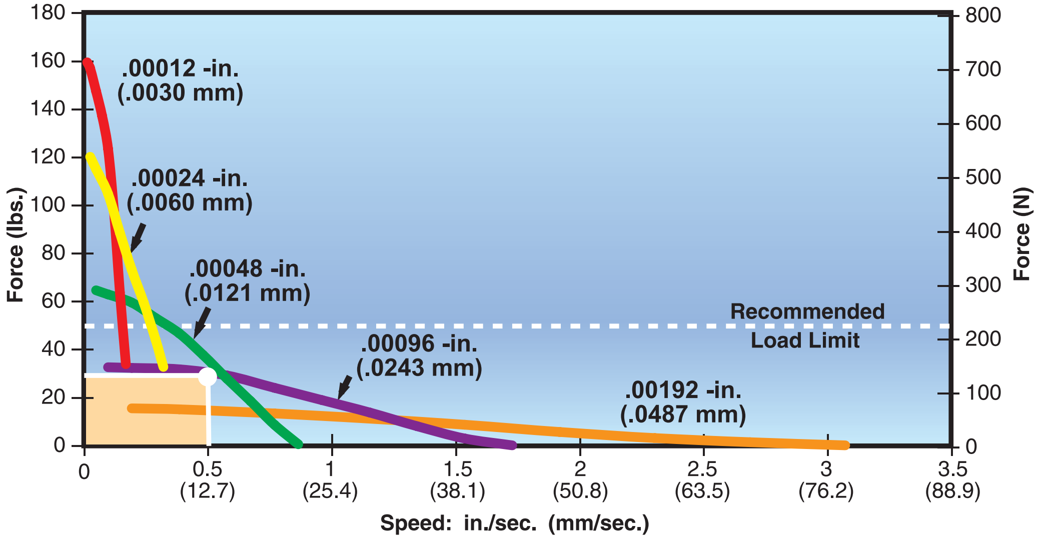


Figure 14.
FORCE vs
LINEAR VELOCITY
SIZE 17 SERIES 43000

.218 (5.54 mm)
Ø lead screw,
Bipolar, Chopper Drive,
100% Duty Cycle

Verify selection by checking force at the required step rate

Earlier in the paper, it was discussed that the lead screw advances based on the number of input steps to the motor. Haydon performance curves are expressed in both "in/sec" (as illustrated in Figure 14) and also in "steps / sec" (Figure 15 below). As an effective check, verify the selection by checking the force at the required step rate.

Resolution chosen:	0.00048-in / step (0.0121 mm / step)
Required linear velocity:	0.5-in / sec (12.7 mm / sec)
Required step rate:	(0.5 in / sec) / (0.00048-in / step) = 1041 steps / sec

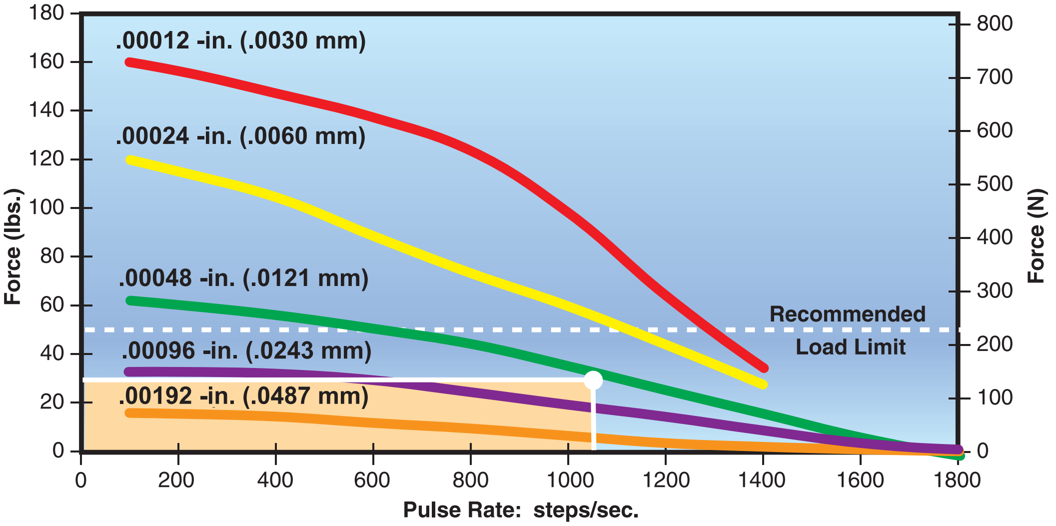
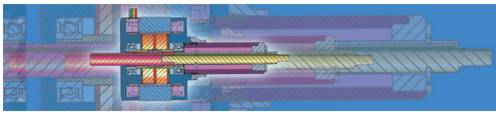


Figure 15.
FORCE vs
PULSE RATE
SIZE 17 SERIES 43000

.218 (5.54 mm)
Ø lead-screw,
Bipolar, Chopper Drive,
100% Duty Cycle

Figures 14 and 15 are good illustrations of how the pulses to the stepper motor translate into linear motion through the lead screw.



EXAMPLE #2

Haydon Kerk Motion Solutions, Inc. offers a line of Double Stack Hybrid Actuators that are designed to meet the needs of higher speed applications. This next example illustrates a typical situation where higher speed is required to perform the motion.

All other application requirements with the exception of the move velocity is unchanged from Example #1.

Application Requirements:

Required Force (lbs) =	15 lbs
Required Travel (inches) =	3-in
Time To Achieve Travel (sec) =	3 sec (modified application requirement)
Desired Cycles =	1,000,000
Linear Velocity (in / sec) =	3-in / 3 sec = 1.0-in / sec (modified linear velocity)

Calculate the initial rated force based on required # of cycles:

Step 1:
Refer to Fig. 12 and determine the % rated load required to meet 1,000,000 cycles. This is indicated with the red line in Fig. 1x3. This will be identical to that shown in Sizing Example #1 because the number of desired cycles did not change.

Step 2:
As indicated in Fig. 13, in order to get 1,000,000 cycles, a factor of 0.5 must be used when sizing the actuator. The initial force required in order to meet the load after 1,000,000 cycles is

15 lbs / 0.5 = 30 lbs *(Unchanged from Example #1)*

Step 3:
Convert lbs to Newtons (N): **30 lbs / (0.225 lbs / N) = 133 N** *(Unchanged from Example #1)*

Determine required travel in meters

3-in x (0.0254 m / in) = 0.0762 m *(Unchanged from Example #1)*

Choose the proper framesize actuator using the selector chart

Step 1:
Determine the required linear mechanical power in watts

P_{linear} = (133N x 0.0762 m) / 3 sec = 3.4 N-m / s = 3.4 watts *(This changed from 1.7 watts needed in Example #1)*

As shown from the result above, the required output power increased by 100% due to the application requirement change from a 6 sec Time to Achieve Travel (Example #1) to a 3 sec Time to Achieve Travel.

Step 2:
Assuming the mounting footprint is to remain unchanged (in this case, the Size 17 motor frame), using the Double Stack version of the actuator would easily meet the application requirements. This is highlighted in the **"Hybrid Double Stack"** section of **Table 1**.

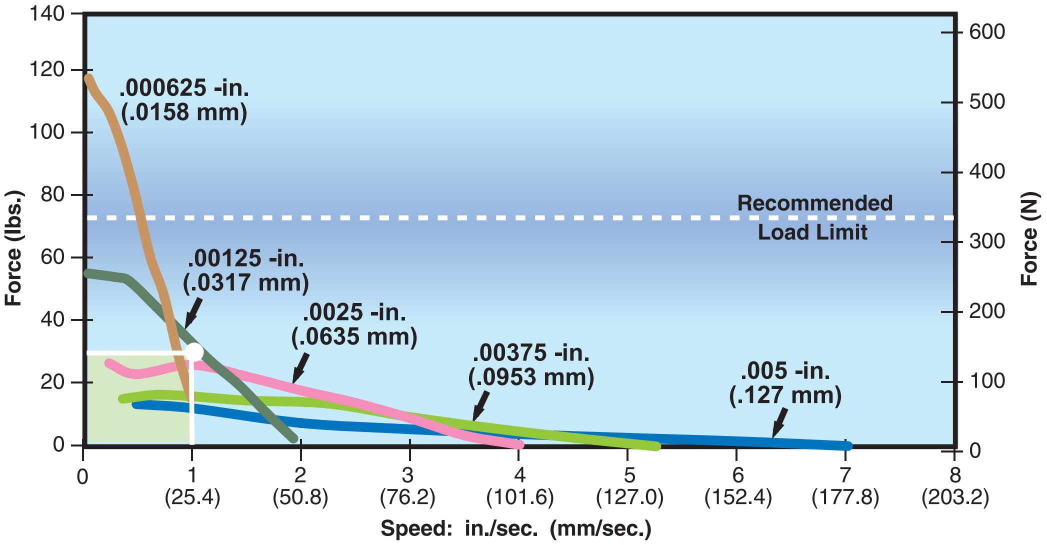
Hybrid Double Stack					
				Max. Linear Power (watts)	
Series	Size	Max Force (N)	Linear Travel Per Step (micron)	L/R Drive	Chopper Drive
28000	11	133	3 – 50	N/A	1.14
35000	14	220	15.8 – 127	N/A	2.7
43000	**17**	350	15.8 – 127	N/A	**4.62**
57000	23	880	12.7 – 127	N/A	10.08

Determine the proper resolution using the "Force vs Linear Velocity" chart

As determined by the life calculation performed above, an initial load of 30 lbs is to be moved at a new velocity of 1.0-in/sec. The intercept falls under curve 0.00125-in (0.0317 mm). The resulting lead screw resolution required in the Size 17 double stack hybrid motor is 0.00125-in (0.0317 mm), as indicated in Figure 16 below.

Figure 16.
FORCE vs
LINEAR VELOCITY
SIZE 17 DOUBLE
STACK
SERIES 43000

.250 (6.35 mm)
Ø lead-screw,
Bipolar, Chopper Drive,
100% Duty Cycle



Verify selection by checking force at the required step rate

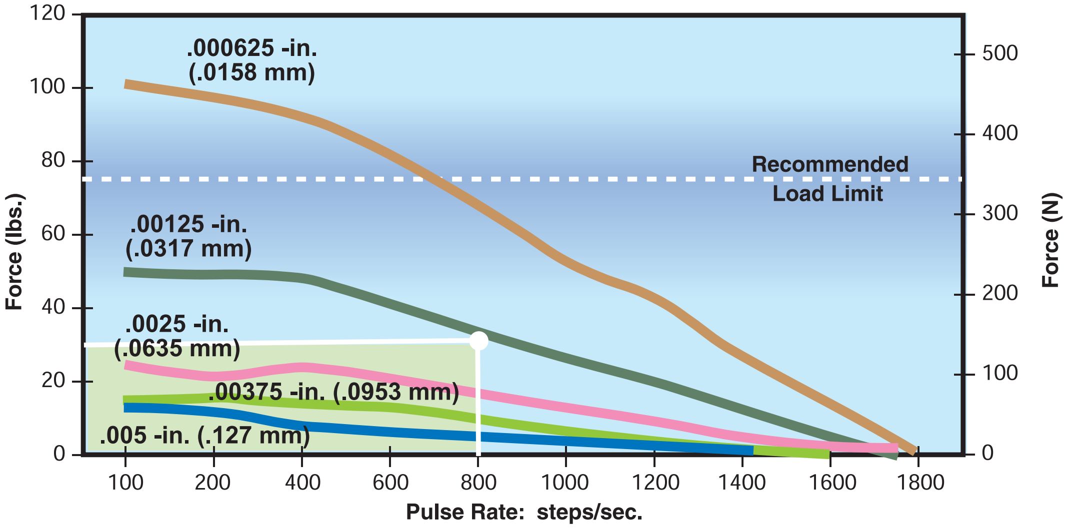
As discussed earlier, Haydon Kerk motor performance curves are expressed in both "in/sec" and also in "steps/sec". As an effective check, verify the selection by checking the force at the required step rate.

Resolution chosen: 0.00125-in / step (.0317 mm / step) screw
Required linear velocity: 1.0-in / sec
Required step rate: (1.0-in / sec) / (0.00125-in / step) = 800 steps / sec

The intercept of the required force and pulse rate (load point) is confirmed to fall under curve "0.00125-in / step (.0317 mm / step screw)" as calculated.

Figure 17.
FORCE vs
PULSE RATE
SIZE 17 DOUBLE
STACK
SERIES 43000

.250 (6.35 mm)
Ø lead-screw,
Bipolar, Chopper Drive,
100% Duty Cycle



Resolution, Accuracy, and Repeatability – What's The Difference?

In any linear motion application, the subject of resolution, accuracy, and repeatability inevitability comes up. These terms have very different meanings, but are frequently used interchangeably.

Resolution

This is defined as the incremental distance the actuator's output shaft will extend per input pulse.

Resolution is expressed as inches/step or mm/step. As seen in the curves above, resolutions are available in fractions or subfractions of an inch per step or mm per step allowing very controlled linear motion.

Resolution = (screw lead) / (360 deg / step angle)

Example:

Screw lead = 0.096-in / rev (inch / revolution)
Step angle = 1.8 deg / step

Actuator Resolution = (0.096-in / rev) / (360 deg / (1.8 deg / step) = 0.00048-in / step
(see "Force vs Linear Velocity .00048 (.0121 mm) curves, Figures 11, 14, 15)

Accuracy

The difference between the theoretical distance and the actual distance traveled. Due to manufacturing tolerances in the individual components of the actuator, the actual travel will be slightly different. The tight design tolerances of the Haydon Kerk actuators allow this error to be very small, but nevertheless, it exists. See Figure 18.

For a Haydon Kerk hybrid linear actuator utilizing a screw with a 1-in lead, 360° of rotary motion will result in a theoretical 1-in stoke. In general, the tolerance of a Haydon Kerk Hybrid linear actuator with a 1-in move will be +/– 0.0005-in (.0127 mm).

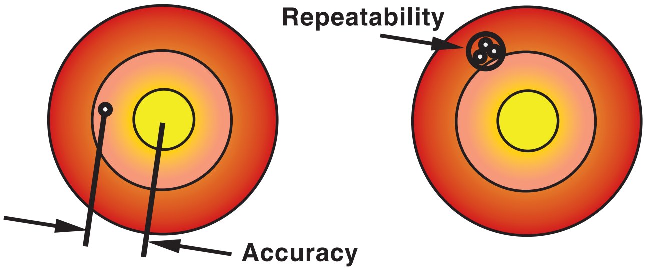
Repeatability

The range of positions attained when the actuator is commanded to approach the same target multiple times under identical conditions.

Example:

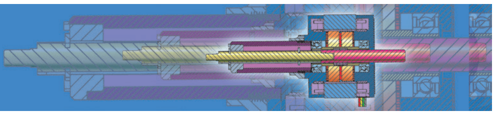
Allow the actuator to extend a commanded distance from its home position (starting point).
Measure and record this distance and call it "x". Retract the actuator back to its home position.
Command the actuator to repeatedly return to the commanded distance "x".
The differences between the actual distances traveled and "x" is the repeatability.

Figure 18.
ACCURACY and REPEATABILITY



Resonance

Stepper motors have a natural resonant frequency as a result of the motor being a spring-mass system. When the step rate equals the motor's natural frequency, there may be an audible change in noise made by the motor, as well as an increase in vibration. The resonant point will vary with the application and load, but typically occurs somewhere between 100 and 250 steps per second. In severe cases the motor may lose steps at the resonant frequency. Changing the step rate is the simplest means of avoiding many problems related to resonance in a system. Also, half stepping or micro stepping usually reduces resonance problems. When accelerating/decelerating to the desired speed, the resonance zone should be passed through as quickly as possible.



Selecting the Proper Motor – Checklist

In order to select the proper motor several factors must be considered. ***Is linear or rotary motion required?*** This checklist provides you some basic requirements to consider when selecting a motor.

Rotary Stepper Motor

How much torque is required?
What is the duty cycle?
What is desired step angle?
What is the step rate or RPM?
Bipolar or unipolar coils?
Coil Voltage?
Detent or holding torque requirements?
Are there size restrictions?
What is anticipated life requirement?
Temperature of operating environment?
Sleeve or ball bearings?
Radial and axial load?
Type of driver?

Linear Actuator Stepper Motor

How much force is required?
What is the duty cycle?
What is desired step increment?
What is the step rate or speed of travel?
Bipolar or unipolar coils?
Coil Voltage?
Must the screw hold position with power off or must it be "backdrivable"with power off?
Are there size restrictions?
What is anticipated life requirement?
Temperature of operating environment?
Captive or non-captive shaft?
Type of driver?

Drives

Stepper motors require some external electrical components in order to run. These components typically include a power supply, logic sequencer, switching components and a clock pulse source to determine the step rate. Many commercially available drives have integrated these components into a complete package. Some basic drive units have only the final power stage without the controller electronics to generate the proper step sequencing.

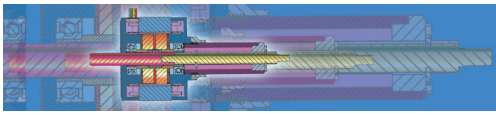
Bipolar Drive – This is a very popular drive for a two phase bipolar motor having four leads. In a complete driver/controller the electronics alternately reverse the current in each phase.

Unipolar Drive – This drive requires a motor with a center-tap at each phase (6 leads). Instead of reversing the current in each phase, the drive only has to switch current from one coil to the other in each phase. The windings are such that this switching reverses the magnetic fields within the motor. This option makes for a simpler drive but only half of the copper winding is used at any one time. This results in approximately 30% less available torque in a rotary motor or force in a linear actuator as compared to an equivalent bipolar motor.

L/R Drives – This type of drive is also referred to as a constant voltage drive. Many of these drives can be configured to run bipolar or unipolar stepper motors. L/R stands for the electrical relationship of inductance (L) to resistance (R). Motor coil impedance vs. step rate is determined by these parameters. The L/R drive should "match" the power supply output voltage to the motor coil voltage rating for continuous duty operation. Most published motor performance curves are based on full rated voltage applied at the motor leads. Power supply output voltage level must be set high enough to account for electrical drops within the drive circuitry for optimum continuous operation.Performance levels of most steppers can be improved by increasing the applied voltage for shortened duty cycles. This is typically referred to as "over-driving" the motor. When over-driving a motor, the operating cycle must have sufficient off time (no power applied) to prevent the motor temperature rise from exceeding the published specification.

Chopper Drives – A chopper drive allows a stepper motor to maintain greater torque or force at higher speeds than with an L/R drive. The chopper drive is a constant current drive and is almost always the bipolar type. The chopper gets its name from the technique of rapidly turning the output voltage on and off (chopping) to control motor current. For this setup, low impedance motor coils and the maximum voltage power supply that can be used with the drive will deliver the best performance. As a general rule, to achieve optimum performance, the recommended ratio between power supply and rated motor voltage is eight to one. An eight to one ratio was used for the performance curves in this paper.

Haydon Kerk IDEA™ drives feature Graphic User Interface programming and USB or RS-485 connectivity.



Microstepping Drives – Most modern bipolar drives offer a microstepping feature allowing the drive to divide a full step into smaller increments. The IDEA Drives offered by Haydon Kerk allow microstepping capability of ½ , ¼ , 1/8, 1/16, 1/32, and 1/64 step increments. For example, there are 200 full steps per revolution using a 1.8° hybrid stepper motor. When microstepping using a 1/4 setting, a 200 step/rev stepper motor will now have 800 microsteps/rev. On a linear actuator with a move distance of 0.001 inch/full step, one microstep would equal 0.00025 inches. Incremental errors are non-cumulative, however, keep in mind that the maximum accuracy when microstepping is still based on a full step. When microstepping, extremely high positioning resolutions can be achieved. The other benefits of microstepping include smoother operation, reduced audible noise, and reduced resonance issues.

Summary

Stepper motors have been used in a wide array of applications for many years. With trends towards miniaturization, computer control and cost reduction, "hybrid" style stepper motor actuators are being used in an ever increasing range of applications. In particular the use of linear actuators has rapidly expanded in recent years. These precise, reliable motors can be found in many applications including blood analyzers and other medical instrumentation, automated stage lighting, imaging equipment, HVAC equipment, valve control, printing equipment, X-Y tables, integrated chip manufacturing, inspection and test equipment. This attractive technical solution eliminates the use of numerous components and the associated costs related to assembly, purchasing, inventory, etc. The applications for these motors are only limited by the designer's imagination.

Terminology

Detent or residual torque: The torque required to rotate the motor's output shaft with no current applied to the windings.

Drives: A term depicting the external electrical components to run a Stepper Motor System. This will include power supplies, logic sequencers, switching components and usually a variable frequency pulse source to determine the step rate.

Dynamic torque: The torque generated by the motor at a given step rate. Dynamic torque can be represented by PULL IN torque or PULL OUT torque.

Holding torque: The torque required to rotate the motor's output shaft while the windings are energized with a steady state D.C. current.

Inertia: The measure of a body's resistance to acceleration or deceleration. Typically used in reference to the inertia of the load to be moved by a motor or the inertia of a motor's rotor.

Linear step increment: The linear travel movement generated by the lead-screw with each single step of the rotor.

Maximum temperature rise: Allowable increase in motor temperature by design. Motor temperature rise is caused by the internal power dissipation of the motor as a function of load. This power dissipation is the sum total from I^2R (copper loss), iron (core) loss, and friction. The final motor temperature is the sum of the temperature rise and ambient temperature.

Pulse rate: The number of pulses per second (pps) applied to the windings of the motor. The pulse rate is equivalent to the motor step rate.

Pulses per second (PPS): The number of steps that the motor takes in one second (sometimes called "steps per second"). This is determined by the frequency of pulses produced by the motor drive.

Ramping: A drive technique to accelerate a given load from a low step rate, to a given maximum step rate and then to decelerate to the initial step rate without the loss of steps.

Single step response: The time required for the motor to make one complete step.

Step: The angular rotation produced by the rotor each time the motor receives a pulse. For linear actuators a step translates to a specific linear distance.

Step angle: The angular rotation of the rotor caused by each step, measured in degrees.

Steps per revolution: The total number of steps required for the rotor to rotate 360°.

Torque: The force resulting from electromagnetic induction applied to the radius of a motor rotor.

Pull out torque: The maximum torque the motor can deliver once the motor is running at constant speed. Since there is no change in speed there is no inertial torque. Also, the kinetic energy stored in the rotor and load inertia help to increase the pull out torque.

Pull in torque: The torque required to accelerate the rotor inertia and any rigidly attached external load up to speed plus whatever friction torque must be overcome. Pull in torque, therefore, is always less than pull out torque.

Torque to inertia ratio: Holding torque divided by rotor inertia.

With over 50 years of experience, Haydon Kerk Motion Solutions continues to be a leader in innovative linear motion control solutions. Haydon Kerk is a global manufacturer of miniature stepper motor linear actuators that integrate patented engineering methods capable of producing unmatched performance-to-size ratios and millions of custom configuration options.

Haydon Kerk diversified motion control product lines include:

- **Linear Actuators** - a broad selection of standard and custom Can-Stack and Hybrid stepper motors designed for direct conversion to linear motion. Haydon Kerk also offers a series of drives that electronically enhance the motor's performance.

- **Precision Lead Screw / Nut Assemblies** - Extensive offering of 303 stainless steel lead screws along with standard, anti-backlash, and custom design nut options. Custom designs include multi-functionality to help simplify product manufacturing.

- **Motorized and Non-Motorized Linear Rails** - More extensive linear motion assemblies designed to minimize engineering time and end-user final assembly cost.

Haydon Kerk Motion Solutions is part of Ametek® Precision Motion Control – a global network of people, facilities and services dedicated to engineering and manufacturing the world's most advanced electromechanical products.

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