Linear Shaft Motor

NPM **Nippon Pulse America, Inc.**
A subsidiary of Nippon Pulse Motor Co., Ltd.

Linear Shaft Motor

Linear Shaft Motor - The Next Generation Actuator

Nippon Pulse America's (NPA) family of Linear Shaft Motors are the next generation linear brushless motor. When reliability, zero maintenance, zero cogging, and precision are paramount, the Linear Shaft Motors from NPA are an ideal component choice, offering the user uncompromised performance, ease of use, compact package size, and high value.

What is a Linear Shaft Motor?

The Linear Shaft Motor is a high precision direct drive linear servomotor that consists of a shaft of Rare Earth-Iron-Boron Permanent Neodymium Magnets and a "forcer" of cylindrically wound coils which can be supplied with optional Hall Effect devices. The shaft supplies the magnetic field which the forcer acts upon. The forcer assembly, combined with the amplifier and control electronics, produces the force for the motor. The Hall Effect devices can be supplied, if they are required by your selected servo driver for proper commutation of a brushless linear motor and are integrated into the forcer assembly.

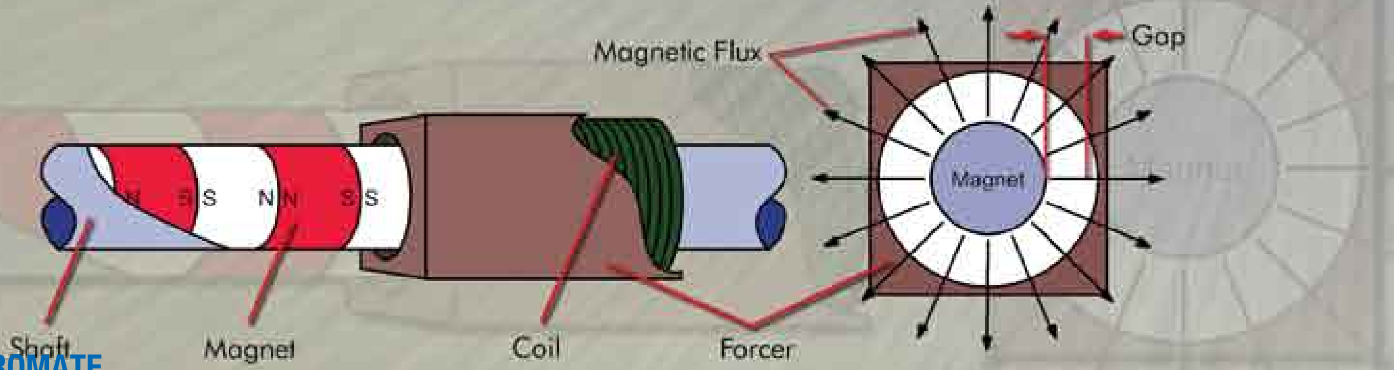
The Linear Shaft Motor was designed with three basic design concepts:

\- Simple - High Precision - Non Contact -

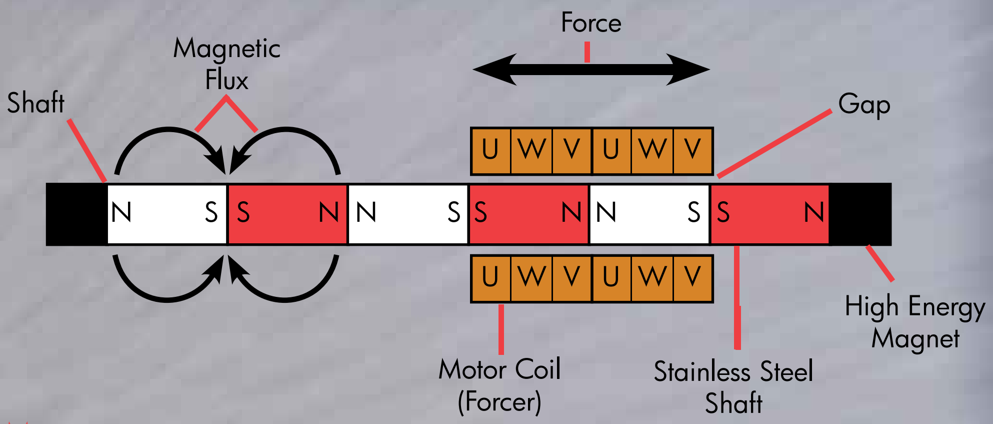
Linear Shaft Motors are simple. They consist of only two parts, a magnetic shaft, and a "forcer" of cylindrically wound coils.

Linear Shaft Motors provide ultra high precision. They have no iron in the forcer or shaft thus giving you the precision and zero cogging expected in a coreless design. The coils of the Linear Shaft Motor themselves form the core thus giving you the stiffness expected in an iron cored motor.

Linear Shaft Motor is non-contact. Since the coil completely wraps around the magnets, all the magnetic flux is efficiently used. This allows for a large (0.5 to 2.5mm) nominal annular air gap. This air gap is <u>non-critical</u>, meaning there is no variation in force as the gap varies over the stroke of the device.



The Next Generation Linear Motor.



Basic Structure of a Linear Shaft Motor

The magnetic structure of the Shaft is built in such a manner that there is no space between each magnet and is fully supported within itself. The magnetic structure is then inserted into a protective stainless steel tube. This is a patented process which is protected by numerous patents throughout the world. Thus the patented process used by the Linear Shaft Motor produces a very strong magnetic field which is twice that of other linear motors.

Forcer Construction

The coils of the Linear Shaft Motor are of a cylindrical design, thus providing a number of key advantages over other linear motors.

- The cylindrical design of the coil assembly is very stiff without external stiffening materials (i.e. iron used by platen style linear motors).
- The coils surrounding the magnets allow for the optimal use of all the magnetic flux. This makes the air gap non-critical. As long as the forcer does not come in contact with the shaft there is no variation in the linear force.
- The magnetic flux cuts motor windings at right angles for maximum efficiency.
- All sides of the coil are positioned to allow for maximum dissipation of heat.
- The more efficient Linear Shaft Motor requires less power in a more compact design to produce a comparable force in an similarly-sized traditional linear motor.

Outstanding Features of Linear Shaft Motors

- Capable of high thrust (up to 100,000 N)
- Quiet due to the absence of friction, the only mechanical contact section is the linear guide. (Fully non-contact operation is possible using an air slider.)
- Simplified unit construction allows a stroke of up to 4.6 meters
- High precision (0.07nm[1])
- High speed drive (greater than 10 m/s) with acceleration up to 20 G
- Low speed drive (8μm/s)
- Virtually no speed fluctuations (±0.006% at 100mm/s)
- Durable construction, capable of operation even underwater or in a vacuum

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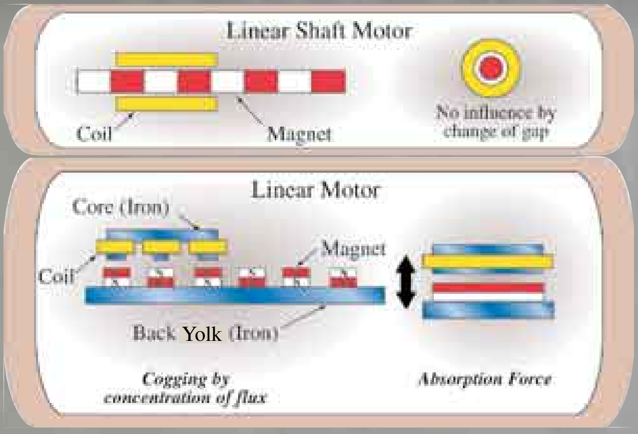
[1] *The precision of repetitive positioning is dependent on the resolution of the linear encoder. In addition, it is also necessary to have sufficient machine rigidity. In the same way, the absolute positioning precision is also fundamentally dependent on the linear encoder. It is not dependent on the expansion or contraction caused by the heat of the Linear Shaft Motor.*

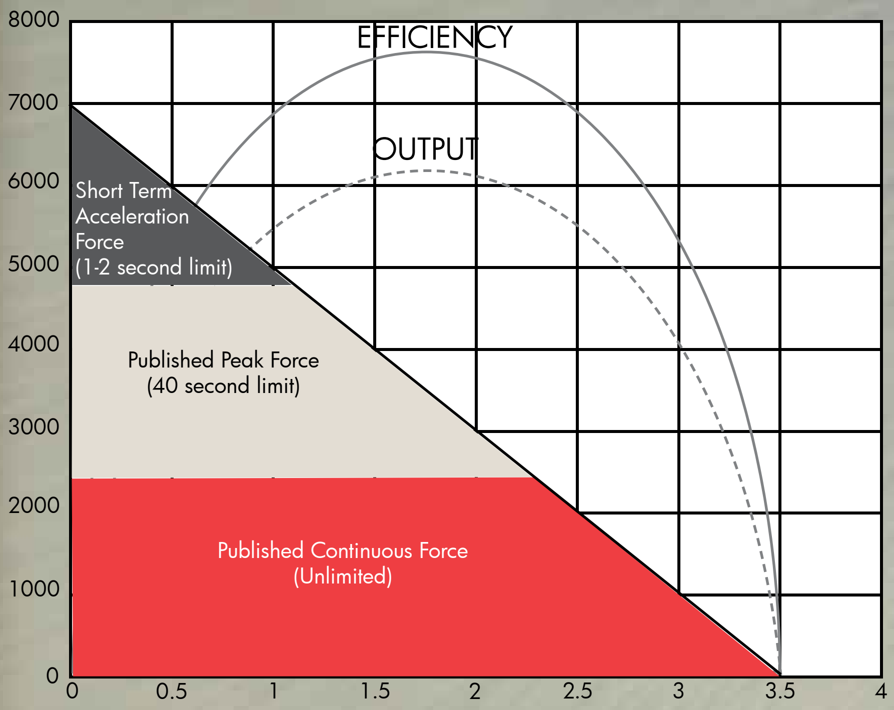
Linear Shaft Motor

Traditionally, linear electric motors have been designed by "opening out flat" their rotary counterparts. Thus, for every rotary motor there is a linear motion counterpart, although the opposite of this statement may not always be true. Thus, corresponding to the DC motor and AC induction, stepper and synchronous motor, we have the Linear DC Motor (DCLM), Linear Induction Motor (LIM), Linear Pulse Motor (LPM), and Linear Synchronous Motor (LSM) respectively. Although this does provide a solution, a number of inherent disadvantages arise.



Like the voice coil motor, the force velocity (FV) curve of the Linear Shaft Motor is a straight line from peak velocity to peak force. The Linear Shaft Motor's FV curves are split into three regions. Published in Nippon Pulse literature as the Continuous Force, it is the region were the motor can operate indefinitely without the need for any external cooling, including heat sinks. The second is the published Peak Force. It is the amount of force which can be delivered by the motor for 40 seconds without the need for any external cooling, including heat sinks. The third region is limited only by the power which can be supplied and the duty cycle. It is the Acceleration Force and is limited to 1 to 2 seconds. Your local NPA application engineer can help you map this for your particular application.

The Linear Shaft Motor is a very simple design which consists of a coil assembly (Forcer), which encircles a patented round magnetic shaft. This design offers a number of advantages when compared to other types of linear motion systems:



No Need for Precision Air Gap

Unlike other types of linear motor technologies the cylindrical design of the Linear Shaft Motor allows for a very large (0.5 mm to 2.5 mm) non-critical air gap. This allows for a constant linear force, which is not effected by the alignment or misalignment of the Forcer (coil) to the Shaft (Magnets). This allows for quick and simple assembly into the final product without the need for extensive machining and alignment time.

High Efficiency

The patented shaft design and resulting magnetic field allow for an unparalleled magnetic field strength. This allows a small amount of current to produce large amounts of force. Along with the cylindrical design which allows for 100% for the copper, current, and magnetic field to produce force only in the direction of travel.

Coreless Design with Ultra-High Stiffness

Platen style linear motors rightly boast high levels of stiffness due to their iron core. This iron also allows for the creation of eddy currents which generate large amounts of heat while allowing moderate amounts of heat dissipation. The iron core also introduces large amounts of absorption forces between the stator and armature and cogging into the linear motion. U-Shaped linear motors on the other hand use epoxy as their core which does not create eddy currents or any absorption forces. This type of motor has a stiffness that is at best 1/125 that of a similar iron-cored motor. The sandwiching of the coil between the magnetic track and the very low thermal conductivity of epoxy produce a very thermally limited motor. The Linear Shaft Motor is designed to have a motor stiffness which is 100 times better then that of the U-Shaped motor. While having a heat dissipation which is over four times greater than that of similar sized Platen style linear motors.

Shaft Motor Advantages

- Compact & Lightweight: Lower weight when compared to traditional type of linear motors.
- Zero Cogging: The coreless design results in no magnetic cogging whatsoever.
- Large Air Gap: The non-critical 0.5 mm to 2.5 mm nominal annular air gap allows for easy installation and alignment.
- Highly Efficient: Some of the highest efficiencies of any linear motor.
- Enclosed Magnets: Easy integration into a number of environments.
- Efficient Use of Magnetic Flux: Forcer encircles the magnets allowing full use of the magnetic flux.

Linear Stepping Motors

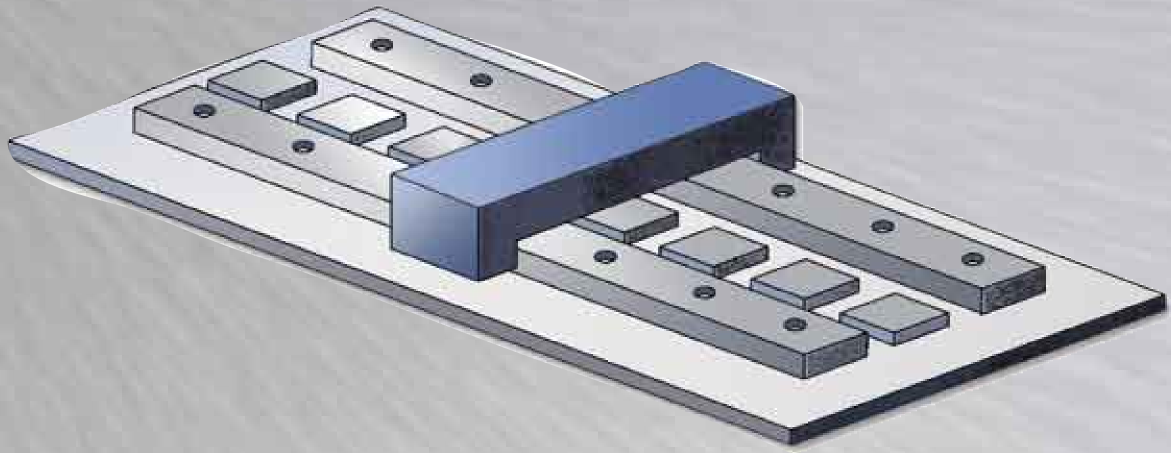
- Open loop or low servo stiffness
- Limited force/speed

Platen-Style Linear Motors

- Precision air gap required
- Large force between stator and armature
- Exposed magnet track

Piezo motors

- Side loading
- Constant contact results in wear
- Audible noise generated
- Custom electronics needed



Linear Induction Motors

- Large physical size
- High power consumption
- Complex cooling typically required
- Large force between stator/armature

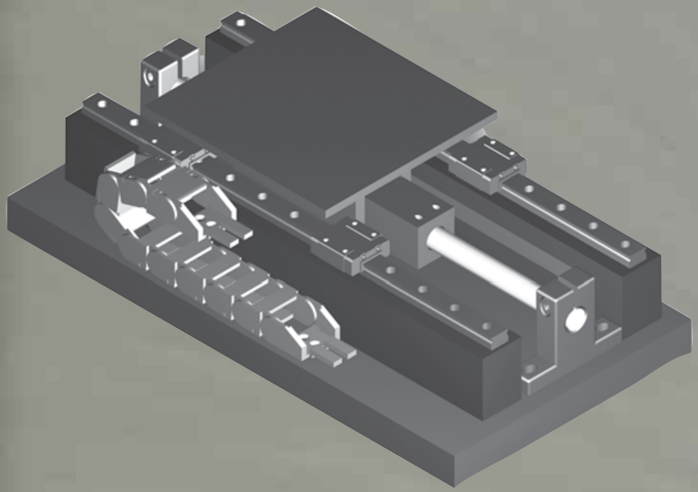
U-Shaped Linear Motors

- Restricted heat dissipation from sandwiched armature coils
- Partial use of magnetic flux in design
- Limited mechanical stiffness

Linear Shaft Motors

vs. Rotary-to-Linear Technologies

Linear Shaft Motors provide direct thrust for the positioning of the payload.
It eliminates the need for a rotary-to-linear conversion mechanism.
Example: ball screw, rack and pinion, toothed belt.



No Lubrication/Adjustment Maintenance Necessary

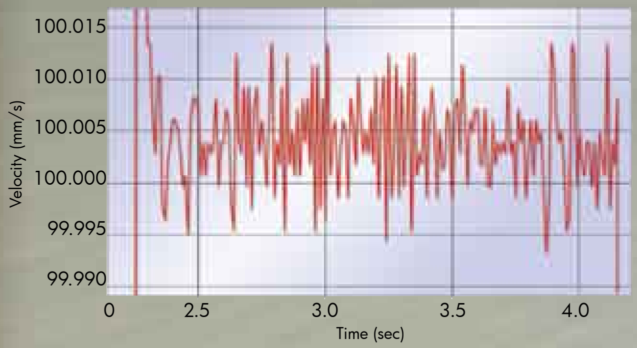
No greasing, as is necessary with a ball screw, and no performance degradation because of wear/aging as with ball screw and belt drive systems. Its maintenance-free long lifespan contributes to cost reduction throughout the life of the product. The clearance between the shaft and the forcer eliminates the need for adjustments such as positioning of the guide or concentric adjustment, which are all required for ball screws.

No Noise/No Dust Operation

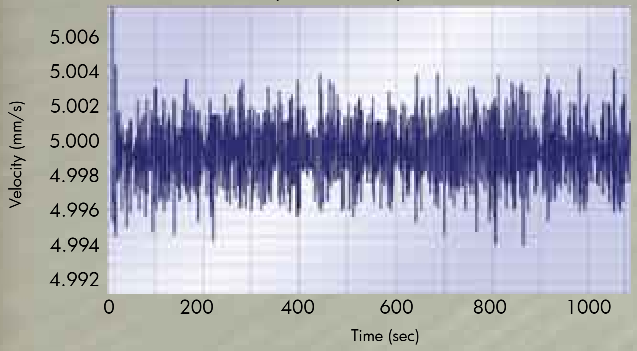
Dust and noise, inevitable in ball screw and pneumatic systems, does not exist in the non-contact Linear Shaft Motor. This is not only very applicable for clean room environments, but it also magnificently improves the work environment by reducing noise and dust.

Speed Fluctuation

High Speed (Velocity: 100mm/Sec)



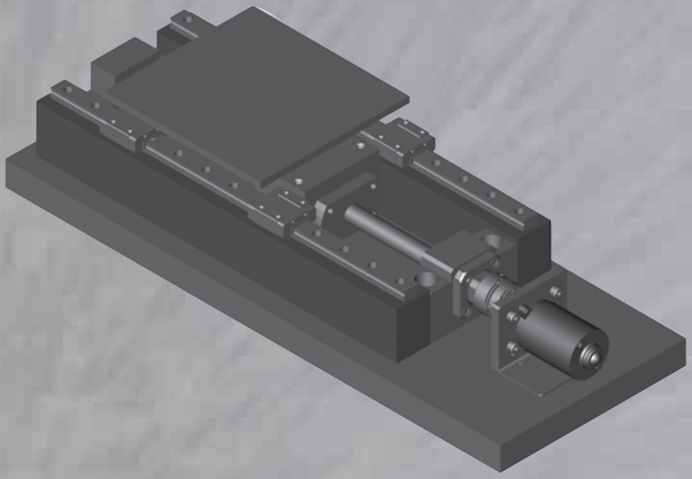
Low Speed (Velocity: 5mm/Sec)



The Linear Shaft Motor is coreless and thus able to provide uniformity of speed over a wide range of speeds.

Advantages of Linear Shaft Motors

• Simple mechanical arrangement	Minimum number of moving parts
• Direct thrust motor	No backlash, no wear
• Wide speed range	8μm/sec to >10m/sec
• Smooth	Virtually no speed fluctuation
• Quiet	Virtually silent motion
• Maintenance-free motor	No internal moving parts
• Lower inertia	Less mass to move
• Lower power requirements	Direct drive systems are more efficient than coupled systems



Extremely High Precision[1] / Low Speed Uniformity / High Repeatability

The Linear Shaft Motor enables a level of precision not achievable in ball screws, and allows you to drastically improve the yield of high precision process, which had been limited by other linear mechanisms.

Realizes High Speed Motions while Retaining High Precision

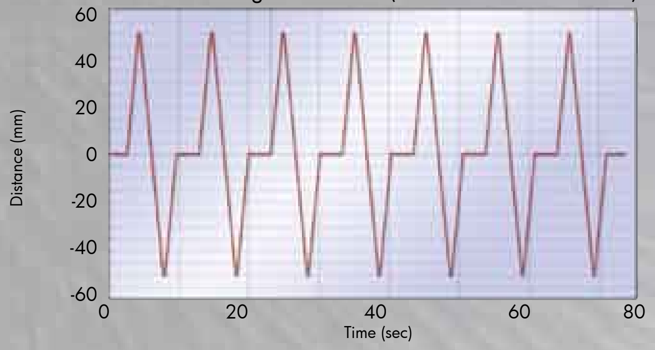
Linear Shaft Motor's high precision in high-speed operation shortens the travel time required by ball screws.

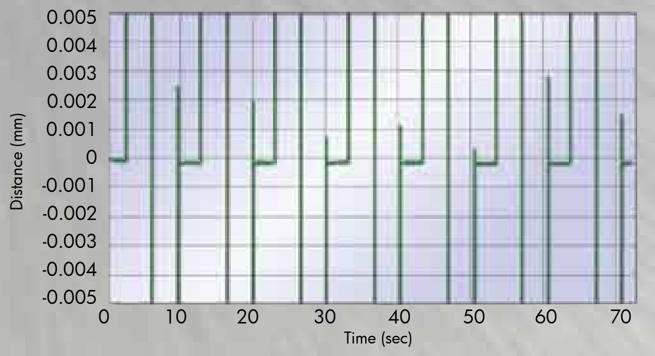
Good Resistance Against Environmental Changes such as Temperature

For precision operation other linear mechanisms require strict control of work environment including temperature. The Linear Shaft Motor, which operates without direct contact, allows constant precision that is unaffected by environmental changes and facilitates a large reduction in climate control cost.

Precision

Static Positioning Performance (encoder resolution 8.6nm)





This is the center section of the top graph displayed at 10,000X magnification.

Using Linear Shaft Motors can:

- Reduce the number of parts
- Save space
- Eliminate the need to adjust with locating guides and concentrics
- Reduce base machining costs and time
- Lower design costs and time

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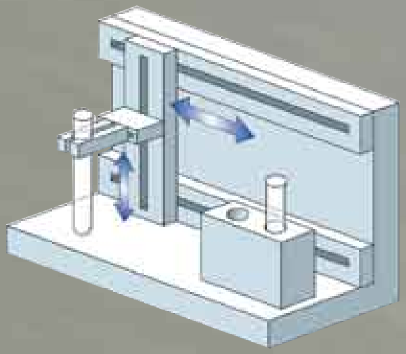
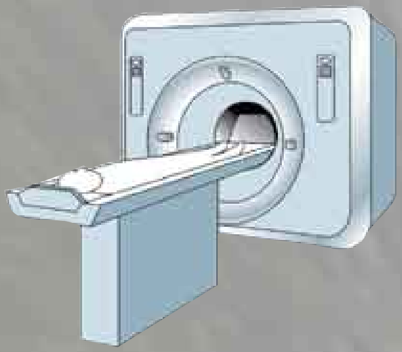
A wide range of applications is possible by utilizing one or more of the features of the Linear Shaft Motor listed on these two pages.



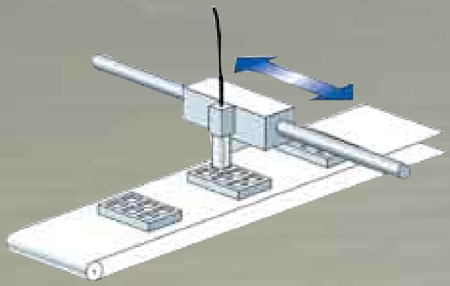
Friction free and quiet.

The Linear Shaft Motor's moving parts are all non-contact. Thus, all sources of noise and friction are eliminated, allowing use in quiet and clean room surroundings, such as test laboratories or medical facilities



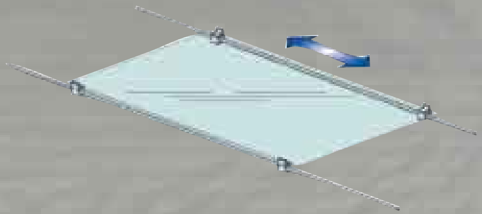
High thrust.

Peak thrust of up to 100,000 Newtons is achievable. Can be used for precisely conveying heavy loads such as in clinical equipment or transfer lines on the factory floor.



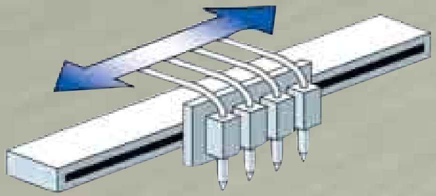
Environmental compatibility.

Operates well in production locations where oil or water are used, or in a vacuum.



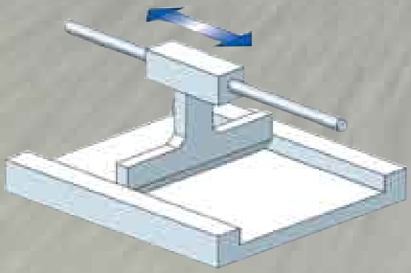
Large stroke lengths.

Up to 4.6 meters, are ideal for high-precision conveying, such as LCD's over relatively long distances.



High controllable speed.

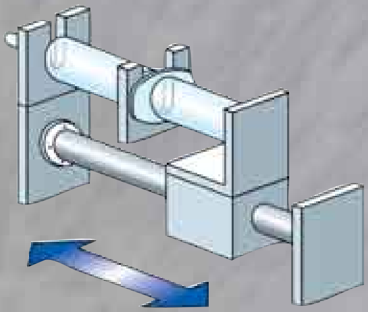
Speeds of greater than 10 meters/sec have been documented. Ideal for line head drives in high-speed printers.



Low speed drives.

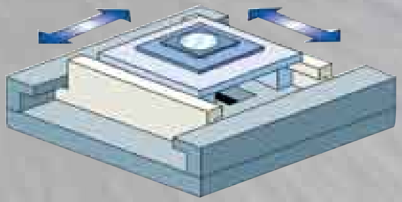
Speeds as low as 8μm/sec have been documented. Ideal for equipment, such as in life sciences, which may be difficult to handle with ball screws.

The Linear Shaft Motor can be mixed and matched to achieve the desired load thrust, based upon the complexity of the application.



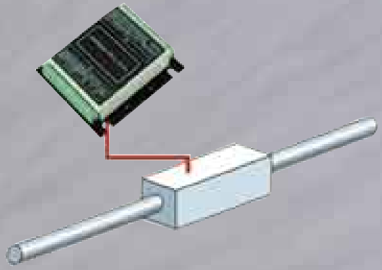
No speed fluctuation.

Ideal for constant speed drug dispensing which may be difficult to achieve with lead screws or ball screws.



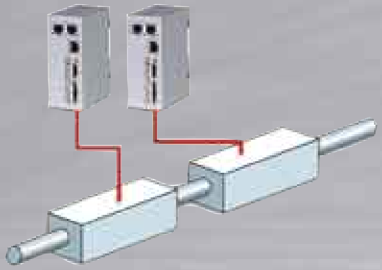
High resolution.

Useful for precise micro positioning required in semiconductor equipment.



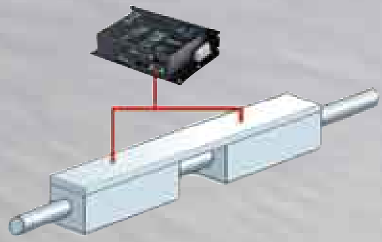
Single Drive System

This is a basic drive system. The X and Y shafts can be used to create an X-Y stage.



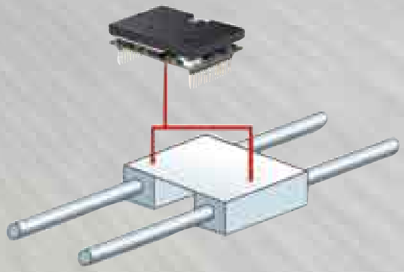
Multi-Drive System

Multiple forcers can be used with a single shaft to support complex movements required by of some applications.



Tandem Drive System

Two or more forcers can be used on the same shaft to multiply the thrust.



Parallel Drive System

Linear Shaft Motors can be used in parallel as shown (two or more forcers and two shafts connected to the same load), to achieve large thrusts for moving heavy objects.

Linear Slider

In this application, a single Linear Shaft Motor was used with a servo driver, motion controller, linear encoder, and linear guide (bearing).

- Linear Shaft Motor: S160T
- Stroke: 300 mm
- Thrust: 15 Newtons
- Resolution: 0.082 μ to 5 μ (settable in eight levels within this range).
- Maximum operating speed: 7.2 meters per second.

A Linear Shaft Motor was selected because of it's high speed and acceleration along with high precision.

Linear Station

In this application, two Linear Shaft Motors were used in blood testing equipment. A single Linear Shaft Motor with two sliders for two independent movements was used on the X-axis and a single Linear Shaft Motor was used on the Y-axis. A dedicated controller controlled the axes.

- Linear Shaft Motors:
  X axis S160T
  Y axis S200T
- Stroke: X axis 350 mm
  Y axis 200 mm
- Thrust: X axis 15 Newtons
  Y axis 28 Newtons
- Resolution: 4 micrometers
- Stepping motors were used on the other axes for specimen aspiration/dispensing, aspiration tip disposal, test tube chucking and test tube position control.
- Controller: Motionnet for multi-axis control and cable saving.
- Processing time: One specimen every 35 seconds
- Maximum operating speed: 0.5 meters per second.

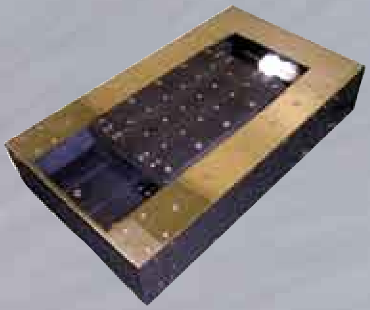
The Linear Shaft Motor was selected because of it's ability to have two heads running at the same time.

Real Life Applications

High Precision Stage

In this application, a single Linear Shaft Motor was used for a high precision granite stage.

- Linear Shaft Motor: S320D
- Stroke: 40 mm
- Thrust: 56 Newtons
- Resolution: 0.14 nm
- Controller: UMAC made by Delta-Tau Data Systems. Inc,
- Servo driver: SVDH5-A made by Servoland
- Linear Encoder: Laser scale P/N BS55A made by Sony Manufacturing System (±0.04 micrometers on 40 mm effective length)
- Interpolator: BD95-T12 by Sony Manufacturing System (Resolution is 0.14 nm)
- Linear guide: Air slider



The Linear Shaft Motor was selected because of its high motor stiffness and its ability for ultra high precision.

Vertical Slider

In this application, a single Linear Shaft Motor was used for smooth vertical movement and for quiet operation.

- Linear Shaft Motor: S250D
- Stroke: 50 mm
- Thrust: 46 Newtons
- Resolution: 100 μm
- Maximum operating speed: 1.3 m per second

A Linear Shaft Motor was selected because of its totally quiet operation.

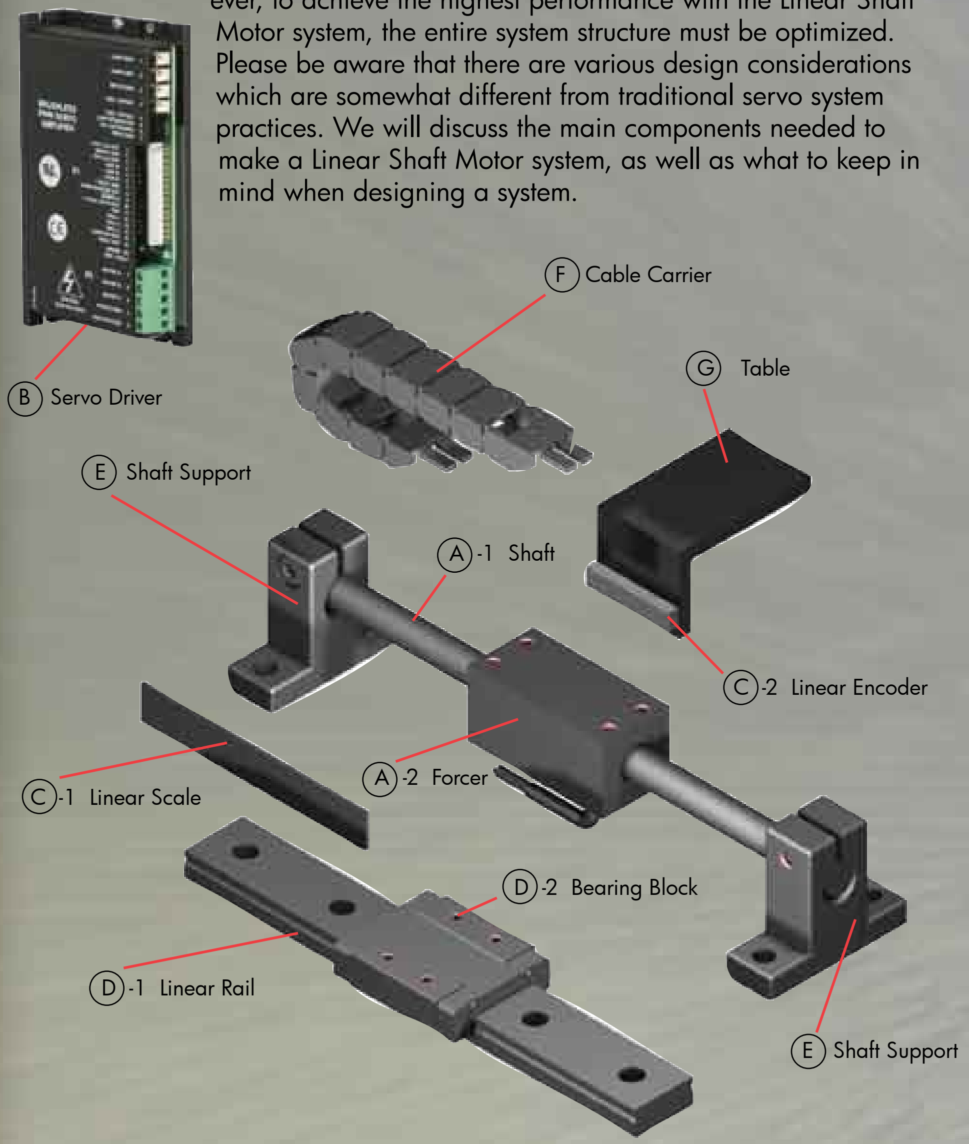
Clean Room Pick and Place

In this application, a single Linear Shaft Motor was used in a non-contact stage suitable for a class 10,000 clean room.

- Linear Shaft Motor: S200T
- Stroke: 500 mm
- Thrust: 28 Newtons
- Maximum operating speed: 1.0 m per second

A Linear Shaft Motor was selected because of its non contact construction, and the fact that it does not require maintenance.

The design of the Linear Shaft Motor allows you to replace the standard ball screw system with the Linear Shaft Motor and achieve higher speed and resolution. However, to achieve the highest performance with the Linear Shaft Motor system, the entire system structure must be optimized. Please be aware that there are various design considerations which are somewhat different from traditional servo system practices. We will discuss the main components needed to make a Linear Shaft Motor system, as well as what to keep in mind when designing a system.



Configure the Linear Shaft Motor

To configure a system using the Linear Shaft Motor, the following peripheral devices are required:

A. Linear Shaft Motor
B. Servo Driver
C. Linear encoder (optical or magnetic)

Item D (Linear Guide) is a necessary part of a system, but much consideration must be given to the application, demand specifications, environmental conditions, and which will be moving, the forcer or the shaft.

The other items, E through G, are optional and will need to be selected depending on the application.

Steps to putting together a Linear Shaft Motor System

Choose the Linear Shaft Motor based on force and stroke requirements.

↓

Choose the Shaft Supports based on design and motor specifications.

↓

Choose the Linear Guide (Bearings) based on cost and smoothness (performance) constraints.

↓

Choose the Linear Encoder to achieve the required position resolution.

↓

Choose the Servo Driver to match the power requirements of the Linear Shaft Motor.

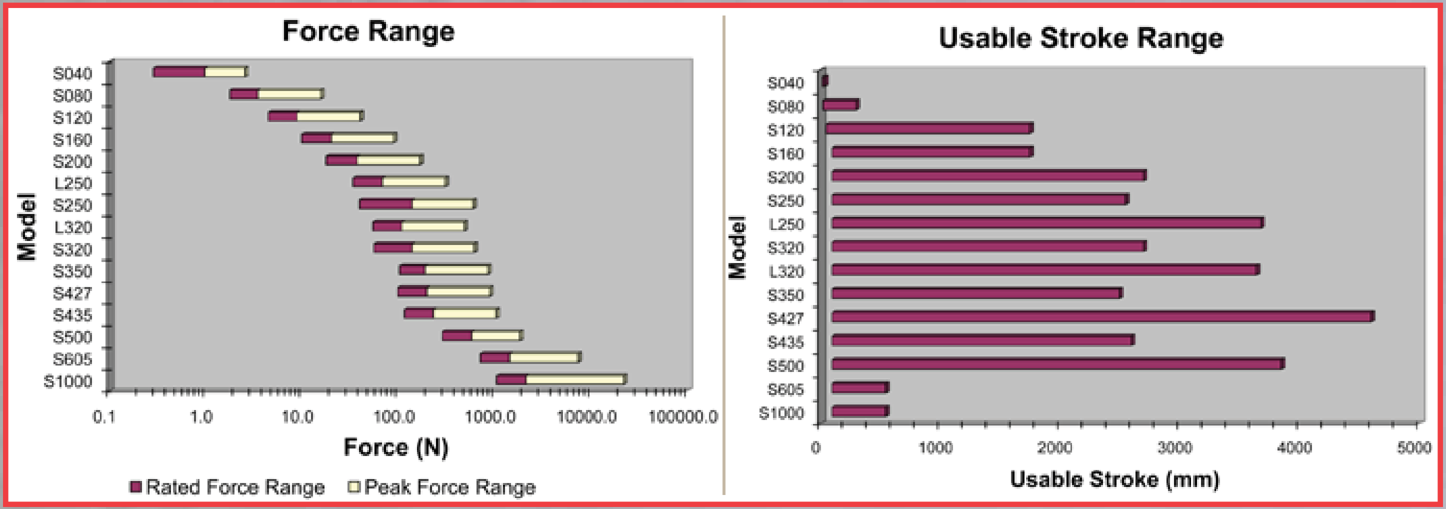
↓

Choose the OTL, Limit Switches & other components & assemble the Linear Shaft Motor System.

Choose the Linear Shaft Motor Based on Force and Stroke Requirements

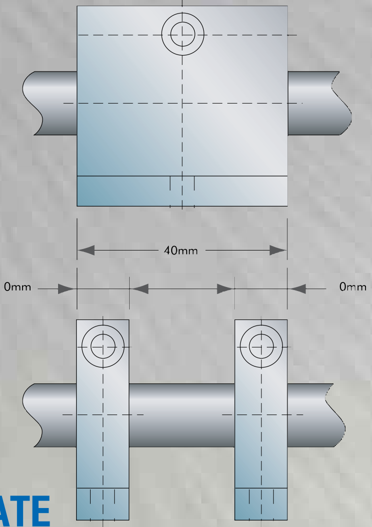
To assist in selecting the correct Linear Shaft Motor, feel free to make use of the Selection Guide in the Engineering Notes section and "NPA SMART" (Linear Shaft Motor Application Resource Tool). The Linear Shaft Motor should be mounted as closely as possible to the center of gravity of the moving load and to the working point of the machine.

If the motor and feedback are far apart, the machine structure and linear guide (bearings) must be of sufficient mechanical stiffness to minimize dynamic deflections of the structure. Be sure to allow clearance for ventilation and access for cleaning, repair, service, and inspections. Ventilation is extremely important. Be sure the area for ventilation is not obstructed. Obstructions limit the free passage of air. Motors get warm and the heat must be dissipated to prevent damage.



Choose the Shaft Supports Based on Force and Stroke Requirements

Select a shaft support as outlined in the data sheet of your selected Linear Shaft Motor. The shaft support is what allows longer strokes in a Linear Shaft Motor system without excessive bending of the shaft. The shaft support should not only be able to support the mass of the shaft, but also be in contact with the shaft for the specified support length. While a single shaft support will provide better security and easier alignment, a lower cost option is to space two smaller shaft supports for the specified support length. The drawing to the right illustrates these two different options.



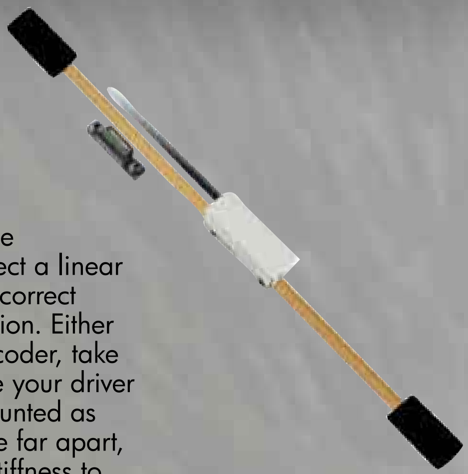
Choose the Linear Guide (bearings) Based on Cost and Smoothness (performance) Constraints

The linear guide (bearings) must be selected to support the moving load. Often, the linear guide (bearings) is the only moving contact type component in the system. Therefore, this component requires special attention. Desirable bearing characteristics include high mechanical stiffness (for increased natural frequency) and low friction. Because the Linear Shaft Motors can provide high velocities, the speed and acceleration limitations of the bearings need to be considered. Some common bearing choices are compared in the table below. Air bearings are most desirable from the standpoint of smoothness, but they are also the most costly. Mechanical slide rails on the other hand are the least expensive, but they are least desirable with respect to load carrying capability.

	Slide Rails	Cam Follower	Crossed Roller	Recirculating Element	Air
Travel	⊙	⊙	●	⊙	◉
Stiffness	●	●	⊙	⊙	◉
Speed	●	⊙	◉	○	◉
Smoothness	●	◉	◉	⊙	○
Precision	●	●	◉	◉	○
Load	◉	●	◉	⊙	●
Cost	○	○	◉	◉	●

Least Desirable ● ◉ ⊙ ○ *Most Desirable*

Choose the Linear Encoder to Achieve the Required Position Resolution



The linear encoder is one of the most important parts of your Linear Shaft Motor system. A processed signal from the linear encoder is used to precisely measure the actual position of the system. The positioning resolution, repeatability, and smoothness of operation depend on the resolution of the encoder. For this reason, it is recommended you use an encoder with a 1µm resolution or better. In addition, the maximum response speed of the encoder may limit the maximum system speed. Select a linear encoder that will supply ten times your required resolution. To assist in selecting the correct encoder, feel free to make use of the Encoder formula in the Engineering Notes section. Either an optical or a magnetic encoder can be used. In the case of a magnetic linear encoder, take care that it is installed so that the magnetic shaft does not affect the encoder. Ensure your driver supports the output mode of the selected encoder. The linear encoder should be mounted as close as possible to the working point of the machine. If the motor and feedback are far apart, the machine structure and linear guide (bearings) must be of sufficient mechanical stiffness to minimize dynamic deflections of the structure.

Choose the Servo Driver to Match the Power Requirements of the Linear Shaft Motor

Select a servo driver that can meet the power requirements of your selected Linear Shaft Motor. To assist in selecting the correct servo driver, feel free to make use of the Driver Sizing Guide in the Engineering Notes section. Any three phase brushless DC servomotor driver can be used to drive the Linear Shaft Motor. In selecting a servo driver, check the method in which the magnetic position is detected.

Since the Linear Shaft Motor does not come with hall effect sensors in its standard configuration, they will need to be added as an option if required by your selected servo driver. If the servo driver does not require the use of hall effect sensors, you may use the Linear Shaft Motor in its standard configuration.

Most servo drivers use peak (DC) units for voltage and current ratings while most servomotors (like the Linear Shaft Motor) use RMS (AC) units. Please pay attention to the units when selecting a servo driver. The Engineering Notes section has formulas for converting peak values to RMS values.

For Servo Driver/Amplifier suggestions see Appendix C of the Installation and User's Guide, available at www.nipponpulse.com as part of the Linear Shaft Motor Design Toolkit.

Choose the OTL, Limit Switches, and Other Components and Assemble the Linear Shaft Motor System

Temperature Sensor

A temperature sensor OTL (Over Temperature Limit), which will cut power to the motor should it get too hot due to over load, can be added in series with the main power to the driver. The maximum coil temperature limit of the Linear Shaft Motor is 135°C.

Limit Switches

Limit switches can be added on either side of the load on the shaft to prevent the load from overshooting and causing harm. Many quality linear encoders include limit switches.

The Linear Shaft Motor is typically operated with a stationary shaft and a moving forcer. With such an arrangement, you will have moving cables. A provision must be provided in the machine to carry the cables. A connector is provided with the Linear Shaft Motor to allow you to connect cables for proper flex life at the designed bend radius in the locations were the cable would move. Cables should be made in a twisted pair configuration, shielded, and grounded properly to the machine base, servo driver, and motor in order to reduce RFI.

Hall Effect Sensor

Hall effect sensors are devices, which can sense position magnetically and provide this information to the servo driver. Some servo drivers require hall sensor feedback for commutation. The hall effect sensors are used by some servo drivers to obtain forcer position information relative to the shaft for commutation. Other servo drivers are able to obtain information for commutation from the linear encoder.

For most horizontal applications using servo drivers, there is no need for digital hall effects. The commutation is based on a commutation table built during the tuning process, and thus derived from the linear encoder. For most vertical applications, it is best to use digital hall effects. The Linear Shaft Motor does not come with hall effect sensors in its standard configuration; they will need to be selected as an option if required by your selected servo driver.

Other Components

Each component must be of the lowest mass and highest mechanical stiffness possible in order to decrease settling times. Hollowed and ribbed components or honeycomb structures, along with special materials, are often utilized to achieve this. Obtaining the highest mechanical stiffness with the lowest mass requires that the linear motor be treated as an integral element to a motion system and not an add-on part.

For More Information

Feel free to download the Application Note:
“Basics of servomotor control”
or the Linear Stepper Motor Installation Guide from our website, www.NipponPulse.com

Motion controller

Cards

NPMC/PPCI series, board-level motion controllers are multi-axes digital servomotor controllers. The boards are available in 4-axes PC/104 bus (NPMC6045A-4104) and 4-axes PCI-bus (PPCI7443).

General features are high pulse rate capability (6.5 Mpps), S-curve ramp-up and down, encoder feedback inputs, and circular and linear interpolations. The NPMC/PPCI series is powerful and makes it easy to program your own motion profiles (the software uses Microsoft Windows™ to provide quick setup and testing, and is included along with a C programming library).

Network

The Motionnet System is a communication system that allows for cost and wire savings while supplying high-speed serial communications (20Mbps) and high precision motion control.

The Motionnet System is a modular serial communication product that allows you to create the configuration you need.

There are three devices in the Motionnet System:

Master Device

PCI	PPCI-L112
PC/104	NPMCMNET-I/O104

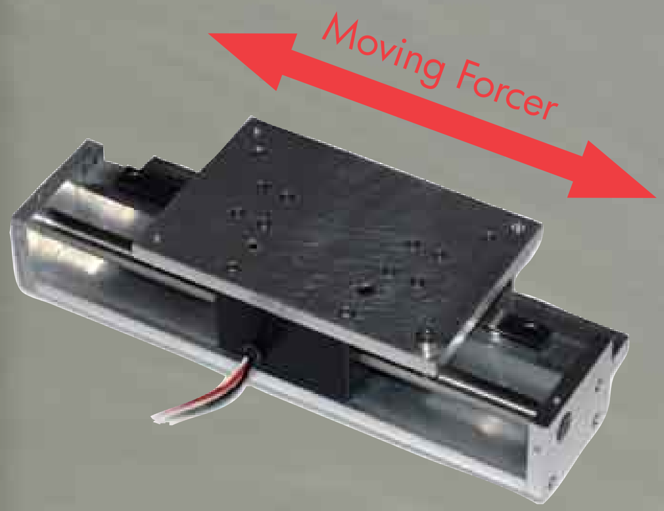
I/O Device

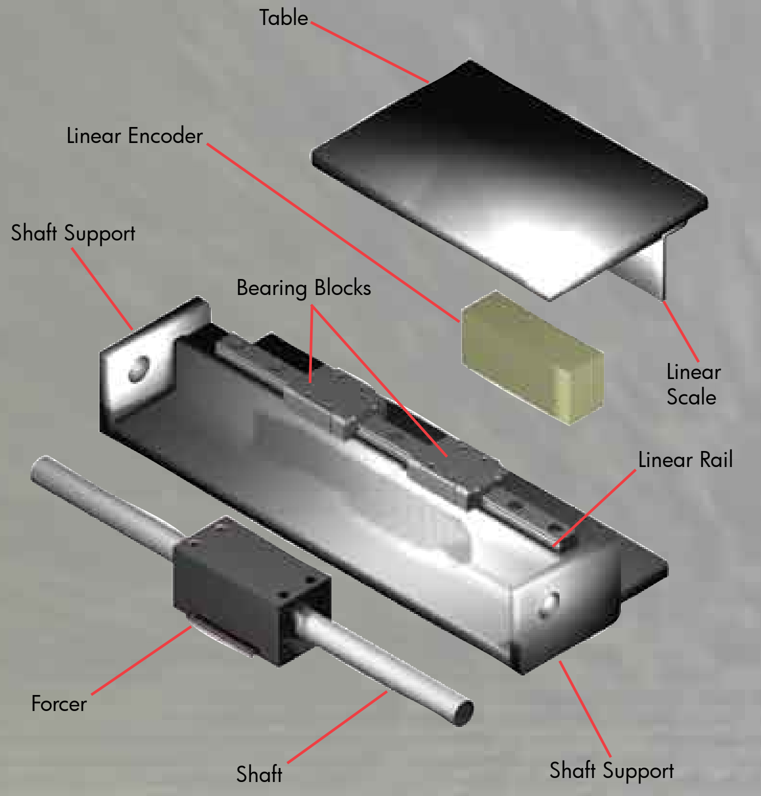
32 – digital input	MNET-D340
32 – digital output	MNET-D304
16 – digital input & 16 digital output	MNET-D322

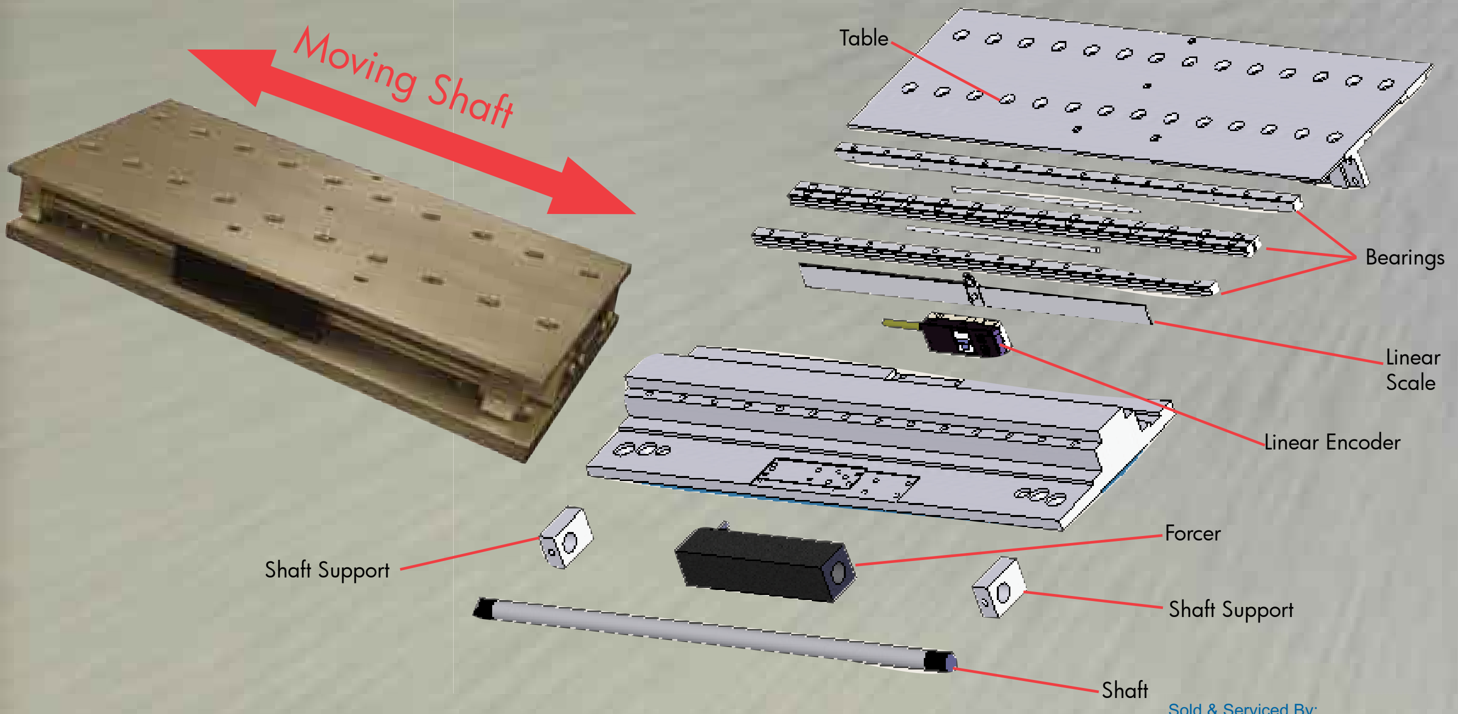
Motion Control Device
MNET-M101-DUM

Horizontal Arrangements

When used in a horizontal application, Linear Shaft Motors typically will have the load attached to the forcer so as to achieve very simple and precise linear movements. In a Linear Shaft Motor system, the shaft is supported at both shaft supports and the load moves along slide rails, linear bearings or air bearings. A linear encoder scale is attached to the guide rails to provide linear position feedback for servo control.

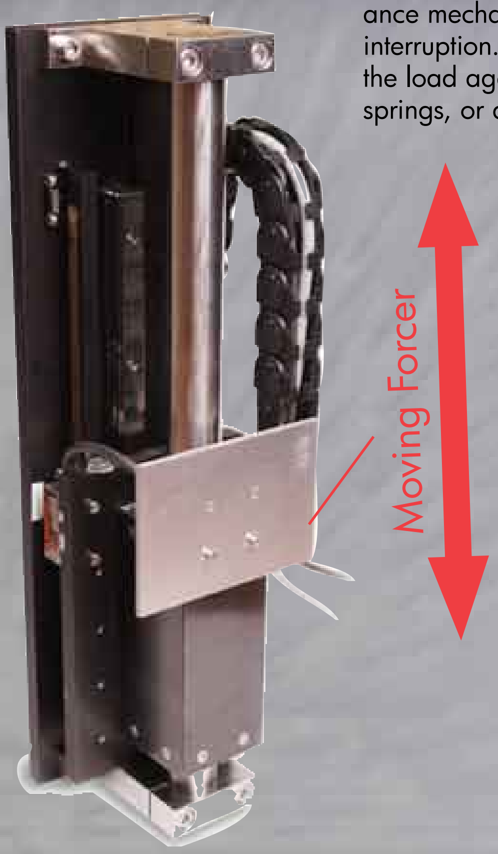


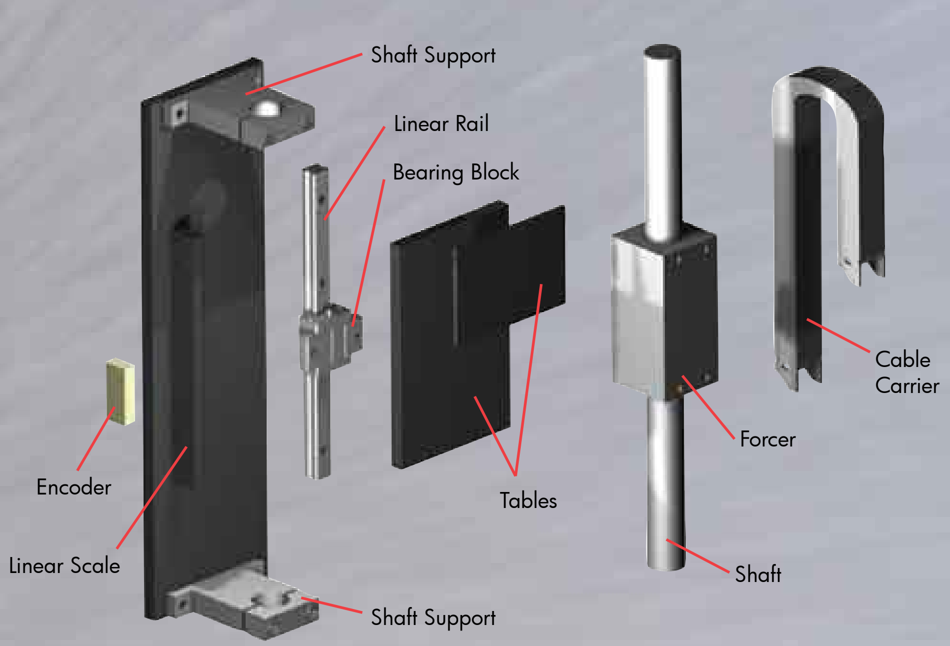


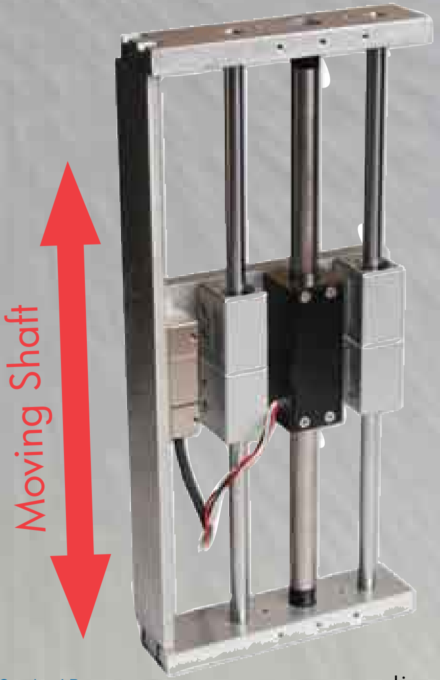


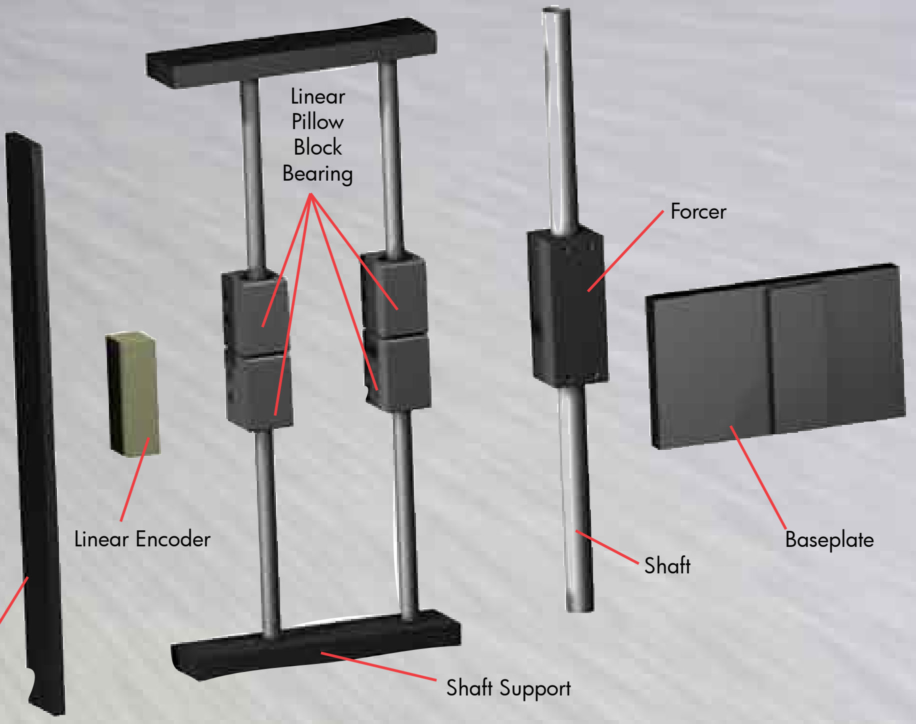
Vertical Arrangements

When used in a vertical application, Linear Shaft Motors typically require a counterbalance mechanism, or brake, to prevent the load from dropping in the event of a power interruption. The counter balance can also reduce the net load on the motor by supporting the load against gravity. Typical counterbalance techniques include a pneumatic cylinder, springs, or a counterweight.









Linear Shaft Motor Part Number Guide

S — Shaft Size (D) — Forcer Size (A) — Usable Stroke — Options — Options
S — [040 / 080 / 160 / 200 / 250 / 320 / 350 / 427 / 435 / 500 / 605 / 1000] — X — XXXX — XX — XX

FO	Forcer Only
SO	Shaft Only
XX	Two digit for custom motor

ST	Standard
WP	Waterproof
HA	Digital Hall Effect
CE	CE type motor (only needed if ordering forcer)

XX Usable stroke in millimeters (only needed if ordering shaft)

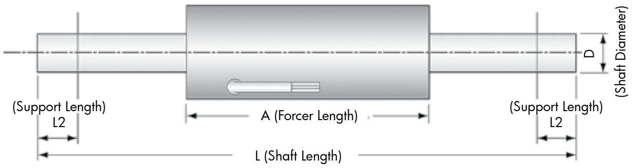
S	Single winding
D	Double (2) windings
T	Triple (3) windings
Q	Quadruple (4) windings
H	Hextuple (6) windings
X	Octuple (8) windings

XX Shaft diameter in mm *10

S	Linear Shaft Motor
L	Long Stroke Linear Shaft MotorV

Vacuum Linear Shaft Motor

Usable Stroke is = L - (L2 * 2) - A



Example: For a S080D-250

L = 310
L2 = 10
A = 40

Stroke = 310 - (10*2) - 40
Stroke = 310 - 20 - 40
Stroke = 250

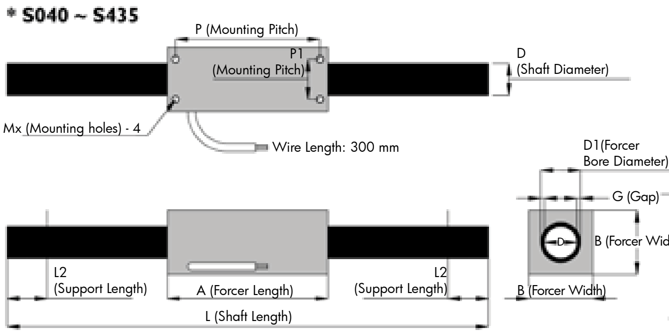
Examples:

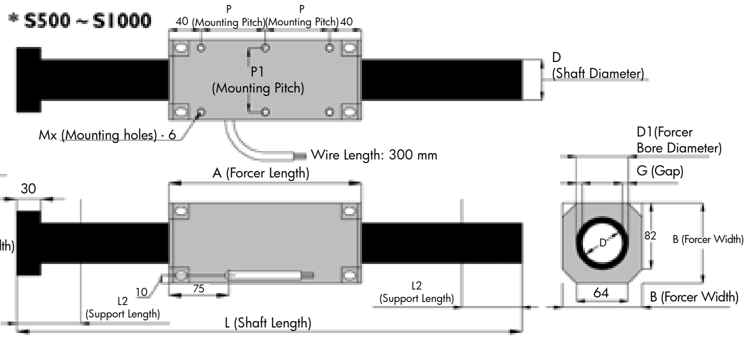
S160T-350-ST
A standard 16 mm Shaft Motor with a triple coil and a 350 mm usable stroke length.

S250Q-WP-FO
A Waterproof 25 mm Shaft Motor with a quadruple coil only.

S080D-250-SO
A standard 8 mm Shaft only for a double coil with a 250 mm usable stroke length. Total shaft length of 310 mm.

Linear Shaft Motor Dimension Guide





Notes:

- The dimension S (Stroke) should be used for limit switch spacing.
- The total length of the shaft (L) can be calculated using the following formula: L (Total Length) = S (Stroke) + A (Forcer Length) + 2 * L2 (Support Length)

Specifications

Model Number	Continuous Force N	Continuous Current A rms	Peak Force N	Peak Current A rms	Force Constant (Kf) N/A rms	Back EMF V rms/m/s	Resistance Ω	Inductance mH	Forcer Length mm	Forcer Weight kg	Gap mm	
S040D	0.29	0.3	1.2	1.1	1.0	0.4	11.2	0.5	25	0.01	0.50	4 mm shaft diameter
S040T	0.45	0.3	1.8	1.1	1.6	0.5	16.8	0.7	34	0.01	0.50	
S040Q	0.58	0.3	2.3	1.1	2.1	0.7	22.4	1.0	43	0.01	0.50	
S040X	0.94	0.6	3.8	2.2	1.7	0.6	11.2	0.5	79	0.01	0.50	
S080D	1.8	0.8	7.2	3.4	2.1	0.7	4.7	0.7	40	0.05	0.50	8 mm shaft diameter
S080T	2.7	0.8	10.7	3.4	3.2	1.1	6.8	1.0	55	0.06	0.50	
S080Q	3.5	0.8	14	3.4	4.2	1.4	9.0	1.3	70	0.08	0.50	
S120D	4.5	0.4	18	1.6	11	3.7	37.0	12.0	64	0.09	0.50	12 mm shaft diameter
S120T	6.6	0.4	27	1.6	17	5.5	54.0	18.0	88	0.12	0.50	
S120Q	8.9	0.4	36	1.6	22	7.4	73.0	24.0	112	0.16	0.50	
S160D	10	0.6	40	2.5	16	5.4	21.0	8.2	80	0.15	0.50	16 mm shaft diameter
S160T	15	0.6	60	2.5	24	8.1	33.0	12.0	110	0.20	0.50	
S160Q	20	0.6	81	2.5	33	11	43.0	16.0	140	0.30	0.50	
S200D	18	0.6	72	2.4	31	10	28.7	19.3	94	0.30	0.75	20 mm shaft diameter
S200T	28	0.6	112	2.4	47	16	43.0	29.0	130	0.50	0.75	
S200Q	38	0.6	152	2.4	64	21	56.0	39.0	166	0.70	0.75	
S250D	40	1.3	160	5.1	31	10.4	7.8	9.8	120	0.80	0.75	25 mm shaft diameter
S250T	60	1.3	240	5.1	47	16	12.0	15.0	165	1.1	0.75	
S250Q	75	1.3	300	5.1	59	20	15.0	19.0	210	1.5	0.75	
S250X	140	2.4	560	9.6	58	19	7.5	9.5	390	2.9	0.75	
L250D	34	1.3	138	5.2	27	8.8	8.4	9.2	120	0.77	2.0	Large Air Gap Series
L250T	52	1.3	207	5.2	40	13	13	14	165	1.1	2.0	
L250Q	69	1.3	276	5.2	53	18	17	18	210	1.5	2.0	
S320D	56	1.2	226	5.0	45	15	11.0	17.0	160	1.2	1.00	32 mm shaft diameter
S320T	85	1.2	338	5.0	68	23	17.0	26.0	220	1.7	1.00	
S320Q	113	1.2	451	5.0	91	30	23.0	34.0	280	2.2	1.00	
L320D	55	1.3	218	5.0	44	15	12	14.0	160	1.3	2.50	
L320T	82	1.3	327	5.0	65	22	17	21.0	220	1.9	2.50	Large Air Gap Series
L320Q	109	1.3	436	5.0	87	29	23	28.0	280	2.6	2.50	
S320X	226	2.5	902	9.96	91	30	23.0	34.0	520	4.2	1.00	
S350D	104	1.5	416	6.0	69	23	13.8	21.8	160	1.3	1.00	35 mm shaft diameter
S350T	148	1.5	592	6.0	99	33	20.2	33.0	220	1.9	1.00	
S350Q	190	2.7	760	10.8	70	23	6.9	10.9	280	2.4	1.00	
S427D	100	3.0	400	12.0	33	11	2.7	7	220	3.0	1.65	42.7 mm shaft diameter
S427T	150	3.0	600	12.0	50	17	3.9	11	310	4.2	1.65	
S427Q	200	3.0	800	12.0	67	22	5.2	15	400	5.4	1.65	
S435D	116	3.0	464	12.0	39	13	2.7	7	220	3.0	1.25	43.5 mm shaft diameter
S435T	175	3.0	700	12.0	58	19	3.9	11	310	4.2	1.25	
S435Q	233	3.0	932	12.0	78	26	5.2	15	400	5.4	1.25	
S500D	289	3.8	1156	15.2	76	25	4.4	27	240	10	1.75	50 mm shaft diameter
S500T	440	5.8	1760	23.2	76	25	3.3	20	330	13	1.75	
S500Q	585	7.7	2340	30.8	76	25	2.2	13	420	15	1.75	
S605T	610	8.6	2400	34.0	71	24	1.7	10	430	21	1.75	60.5 mm shaft diameter
S605Q	780	8.4	3100	34.0	93	31	2.2	13	550	27	1.75	

For more detailed specifications, please visit www.nipponpulse.com and download the specific model data sheet.

Common Motion Profile Formulas

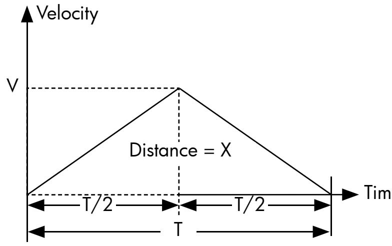
Triangular Profile 1/2, 1/2

Accelerate to speed and decelerate back to original speed or zero, rest and repeat the process as needed. This is very simple and is common in applications such as pick & place.

Trapezoidal Profile

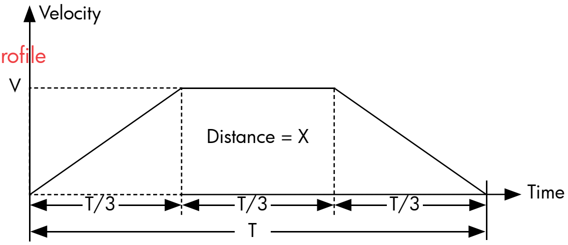
Accelerate to constant speed, travel at that constant speed, and then decelerate back to original speed or zero. This is common in applications such as scanning inspection. There are two types, the 1/3 Trapezoidal Profile and the Variable Trapezoidal Profile

Triangular Profile
1/2
1/2



Have / Solve For	X (m) T (sec)	V (m/sec) T (sec)	A (m/sec²) T (sec)	A (m/sec²) V (m/sec)
Distance X(m)		X= (1/2) * V * T	$X= (1/4) * A * T^2$	$X= (V^2/A)$
Velocity V (m/sec)	V= 2 * (X/T)		V = (A*T)/2	$V= \sqrt{(A*X)}$
Acceleration A (m/sec²)	$A= 4 * (X/T^2)$	A= 2 * (V/T)		$A= V^2/X$

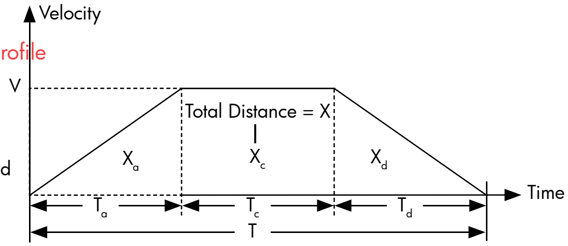
Trapezoidal Profile
1/3
1/3
1/3



Have / Solve For	X (m) T (sec)	V (m/sec) T (sec)	A (m/sec²) T (sec)	A (m/sec²) V (m/sec)
Distance X(m)		X= (2/3) * V * T	$X= (1/4.5 * A * T^2$	$X= 2 * (V^2/A)$
Velocity V (m/sec)	V= 1.5 * (X/T)		V = (A*T)/3	$V=\sqrt{(A*X)/2}$
Acceleration A (m/sec²)	$A= 4.5 * (X/T^2)$	A= 3 * (V/T)		$A= 2 * (V^2/X)$

Variable Trapezoidal Profile

(Formulas listed below are for calculating acceleration and deceleration)



Have / Solve For	X (m) T (sec)	V (m/sec) T (sec)	A (m/sec²) T (sec)	A (m/sec²) V (m/sec)
Distance X (m)		X= (V * T)/2	$X= (A * T^2)/2$	$X= V^2/(2 * A)$
Velocity V (m/sec)	V= (2 * X)/T		V = A * T	$V=\sqrt{(2*A)/X}$
Acceleration A (m/sec²)	$A= (2 * X)/T^2$	A= V/T		$A= V^2/(2 * X)$

Useful Formulas

General Formulas

Acceleration G	$ACCG = A\ (m/sec^2) / 9.81$
Gravity	G = 9.81
Friction Coefficient	Friction Coefficient can be calculated in the following way. The mass of the load to be moved being M1, and the amount of force required to move the mass being M2. Friction Coefficient (FC) = M2/M1
Voltage	V=I*R
Current	I=V/R
Resistance	R=V/I

Voltage and Current RMS vs. Peak

RMS (AC)	Peak * 0.707
Peak (DC)	RMS * 1.414

Examples:

	Voltage	Resistance	Current
RMS Values	5	25	0.2
Peak Values	3.535	25	0.1414

Please ensure your units remain constant when calculating RMS or Peak Values.

Encoder Formulas

Encoder Resolution $Er = \frac{\text{Scale Pitch}}{(4 * \text{Interpolation})}$

Enc. Output Freq. (A-B Phase) $E_{OF} = \frac{\text{Velocity} * 10^6}{(4 * \text{Encoder Resolution})}$

Enc. Output Freq. (Sine-Cosine) $E_{OF} = \frac{\text{Velocity} * 10^6}{(\text{Scale Pitch})}$

Amplifier Sizing Formulas

Voltage due to Back EMF $V_{BEMF} =$ Back EMF * Velocity

Voltage due to R * I $V_{ri} = 1.225 *$ Resistance * Peak Current

Voltage due to Inductance $V_L = \frac{7.695 * \text{Velocity} * \text{Inductance} * \text{Peak Current}}{\text{Magnetic Pitch}}$

Min. Bus Voltage needed $V_{bus} = 1.15 \sqrt{[(V_{bemf} + V_{ri})^2 + V_L^2]}$

Peak Current (rms value) $I_{prms} =$ Peak Current * 1.2

Continuous Current (rms value) $I_{Crms} =$ Continuous Current * 1.2

These formulas add a 20% safety margin for current and a 1[illegible]% safety margin for voltage

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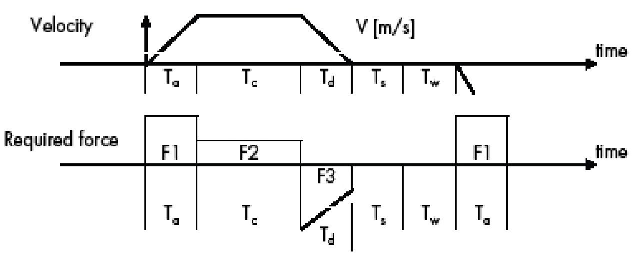
Linear Shaft Motor Selection Guide

One of the most straight forward tasks in the design of a linear motion system is to specify a motor and drive combination that can provide the force, speed and acceleration required. This is often the most overlooked aspect of the linear motion system design, making the motor the most costly part of the system, not only from the perspective of the initial cost, but also in relation to service maintenance and energy cost.

The unique properties of the Linear Shaft Motor make its sizing for applications slightly different then that of other liner motors. Nevertheless, the proper sizing of a Linear Shaft Motor is rather straight forward. Nippon Pulse America provides the NPA Smart sizing software to assist in the selection of a proper motor and drive combination for your mechanical design. Please use the following chart to assist in organizing the operation conditions for your system.

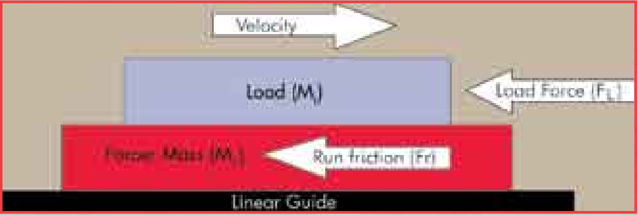
Item	Symbol	Value	Unit	Notes	Examples
Load mass	M_L		Kg	Mass of the moving part of your system less the mass of the motor.	Example: Table, Encoder
Load (thrust) Force	F_L		N	Thrust Force is added to all segments of the motion profile. This is in addition to force needed to overcome mass, acceleration, and friction.	Example: As the motor moves, it needs to maintain 10 lbs of force on an object.
Run (pre-load) Friction	F_r		N	Pre-load Force is considered in all moving segments of the motion profile. Keep in mind all external forces that disturb the movement.	Example: Cable Chain, Bearing wipers, Preloaded Guide, springs
Moving Motor Mass	M_c		Kg	If you are not sure which motor you are going to need, start with a value of 1/10 of Load mass	
Friction coefficient	μ				
Incline Angle	α		°	*0°* is Horizontal while *90°* is Vertical	
Available Voltage	V		Vac		
Available Current	A		Arms		
Max Allowable temperature			°C		

Next, define what movements, if any, your system will be making using the following chart for assistance:

Item	Symbol	Value	Unit	Notes
Stroke	X		mm	 Note: This application note walks you through sizing with only one segment. It is recommended that for the best sizing of a Linear Shaft Motor, a complete cycle should be used for sizing. Stroke out and back. The NPA SMART sizing software allows for sizing with up to 6 segments.
Velocity	V		m/s	
Acceleration time	T_a		s	
Continuous time	T_c		s	
Deceleration time	T_d		s	
Settling time	T_s		s	
Waiting time	T_w		s	

1. Calculations for Load Condition

The chart shown here helps to calculate a load force. The frictional load of the linear guide and the resistance force of the cable carrier (FC) are run friction and treated as pre-load force. For your initial calculations, it is suggested that you use 1/10 the load mass, as the value for Forcer mass (MC).



2. Calculations for Required Thrust - You will need to calculate a thrust value for each section of the motion profile. In these equations, "μ" is the coefficient of friction on the guide. "G" is as the acceleration of gravity. G = 9.81 m/sec2. "∝" is the angle of incline. For vertical or incline moves use F_r for moves against gravity and F_{rd} for moves with gravity.

F_i	Force (Inertia)	$F_i = (M_L + M_C) * (V / T_a)$	
F_f	Force (Friction)	$F_f = (M_L + M_C) * G * [\sin(\propto) + \mu * \cos(\propto)] + F_r$	
F_{fd}	Force (Friction) down	$F_{fd} = (M_L + M_C) * G * [\sin(\propto) + \mu * \cos(\propto) * -1] + F_r$	
F1	Acceleration force	$F1 = Fi + F_L + F_r$	Inertia force + external force
F2	Constant velocity force	$F2 = F_L + F_f$	load of external force
F3	Deceleration force	$F3 = Fi -(F_L + Fr)$	inertia force - external force
F4	Dwell force	$F4 = (M_L + M_C) * G * [\sin(\propto)] +FL$	

3. Temporary Selection - The largest thrust value calculated in section 2, must be less than peak thrust of the selected Linear Shaft Motor. It is good practice to add 20 to 50% to the peak thrust as a safety margin. Please note that the peak thrust of the Linear Shaft Motor may vary with operation speed.

4. Confirm that MC (forcer mass) is smaller than the value used in section 1. If it is larger, please return to section 1 to recalculate using the new MC value.

5. Confirm Effective thrust (Feff) - Please confirm that effective force (Feff) is less than the continuous rated force (Frated) of the motor plus a safety factor (SF) of 30% to 50%.

6. If the effective force (Feff) is larger, please select a new motor where the rated force (Frated) is met in the equation.

$$F_{eff} = \sqrt{\frac{(f1^2 * t1) + (F2^2 * t2) + (F3^2 * t3)}{(t1 + t2 + t3 + t4 + t5)}} < SFrated + SF$$

NPA SMART (Shaft Motor Application Resource Tool)

Nippon Pulse America has available the Linear Shaft Motor Application Resource Tool (SMART). It requires Microsoft Excel 98 or newer. SMART is available at www.nipponpulse.com as part of the linear shaft motor design toolkit.

Motor Sizing Example

Let's assume we want to move horizontally a mass of 6 kg point to point for a distance of 100 mm (X) in 160 msec including settling time (Tm) to +/- 1 micron. Total travel is 400 mm, and a dwell time of 200 msec is needed after each move.

Item	Symbol	Value	Unit
Load Mass	M_L	7	kg
Load (Thrust) Force	F_L	0	N
Run (Pre-Load) Friction	F_r	20	N
Moving Motor Mass	M_c	1.9	kg
Friction Coefficient	µ	0.005	
Incline Angle	∝	0	°
Available Voltage	V	120	Vac
Available Current	A	7	Arms
Max Allowable Temperature		110	°C

Move Profile

We will assume an estimated settling time of 10 msec (Ts).
So the move cycle time (Tc) is 160+200 = 360 msec
Using previous move formula:
T (msec) = Tm – (Ts)
T (msec) = 160 – 10 = 150 msec
We will assume an efficient trapezoidal profile (1/3, 1/3, 1/3)

Acceleration needed here (see previous move formula):
A = (4.5)*(0.1*0.15^2)
A = 20 m/sec2 (about 2 "G")

V = (1.5)*(0.1/0.15)
V = 1 m/sec
The acceleration and deceleration time becomes (150/3)= 50 msec
The time at constant speed is (150/3) = 50 msec
We can estimate the acceleration force of the load only (see previously mentioned formula) at 2g*9.81*6 kg = 117 N.
Based on this we can select S350T (peak force = 592 N, continuous force = 148 N) assuming a coil mounting plate of 1 kg.
Total moving mass: 6 kg (load) + 1 kg (plate) + 1.9 kg (coil mass) = 8.9 kg
Coil resistance = 20.2 ohm, Coil Force constant 99 N/Ap, Thermal Resistance 2.4°C/W, Back Emf 33 Vp/m/sec,
Inductance p-p 33 mH, Electrical cycle length 120 mm
We assume a good set of linear bearings with µ=0.005 and 20 N of friction.

Item	Symbol	Value	Unit
Stroke	X	100	mm
Velocity	V	1	m/s
Acceleration Time	Ta	0.05	s
Constant velocity force	Tc	0.05	s
Deceleration Time	Tδ	0.05	s
Settling Time	Tσ	0.01	s
Waiting Time	Tw	0.2	s

Friction Force: F_f(N) = 8.9*9.81*[sin(0) + 0.005*cos(0)] + 20 = 20.4 N
Inertial Force: F_i (N) = 8.9*20 = 178 N
Total Acceleration Force: F1 (N) = 178 + 20.4 = 198.4 N
Total Constant Velocity Force: F2 (N) = 20.4 N
Total Deceleration Force: F3 (N) = 178 – 20.4 = 157.6 N
Total Dwell Force: F4 (N) = 0 N
RMS Force: Frms (N) = √[{198.42*0.05)+(20.42*0.025)+(157.62*0.05)/0.36]
Frms (N) = 94.7 N

RMS Current: Ica = 94.7/99 = 0.96 Amp rms
Peak Current: Ipa = 198.4/99 = 2 Amp rms
Motor Resistance Hot: Rhot = 20.2 * 1.423 = 28.7Ω
Voltage due B EMF: Vbemf = 33 * 1 = 33 Vac
Voltage due I*R: Vir = 1.225 * 28.7 *2 = 70.32 Vac
Voltage due Inductance: VL = 7.695 * 1 * 33 * 2 / 120 = 4.23 Vac
Bus Voltage needed: Vbus = 1.15 * √ [(33 + 70.3)2 + 4.232 = 118.8 Vac

For More Information

A more detailed step-by-step guide is available as part of the Linear Shaft Motor Design Toolkit at our website, www.NipponPulse.com for assistance in motor sizing and selection.

Sold & Serviced By:
ELECTROMATE
Toll Free Phone (877) SERV098
Toll Free Fax (877) SERV099
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Custom Motors

Nippon Pulse America has the ability to provide customers with custom motors for unique applications. This includes motors with special sizes, stroke and shaft lengths. The versatility of the shaft motor allows it to be utilized in a number of specialized linear applications. Contact Nippon Pulse America or you local representative for customization possibilities.

SCR Series Stages

The SCR series stage is a complete single axis stage which integrates a slide guide, encoder, and Linear Shaft Motor. It offers a wide range of advantages for applications requiring high performance and accuracy. The Linear Shaft Motor allows for higher resolution, speed, and continuous force than the standard stepper or piezo servomotor.

The Linear Shaft Motor and non-contact optical linear encoders are self-contained inside the stage, making it a low-profile compact solution.

Each SCR stage requires a servo driver to operate the stage. Any two SCR stages will bolt directly together to form a very stiff, compact X-Y assembly standard, without the need for adapter plates. Two SCR stages can be supplied as an X-Y stage to ensure true orthogonal orientation between the two axes.

SLP Series Stages

The SLP (Acculine) series, based on the coreless Linear Shaft Motor, puts out equal or greater force than typical flat type linear stages with a core. The SLP line has been designed with a compact body, ensuring greater space efficiency than any other conventional product.

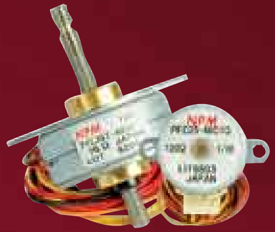
Possessing characteristics such as high responsiveness, low-speed ripple from the coreless structure and superior positioning on account of the constant feedback pulled directly from the table position, The SLP accomplishes simple out-and-back drives as well as complex motions with stable precision.

There is no adhesion between the coil and the shaft. A non-critical air gap provides no variation of force due to gap variations. In addition, it is easy to switch from a conventional ball-screw system. The configuration of the shaft is simple to layout and assembly is a snap.

With a simple, lightweight, compact shaft-type linear motor comprised of only a magnet and a coil, large drive force is gained with an efficient and short coil length. In addition, because there is no friction, there is no sound or dust, making the motor maintenance-free.

Custom Stages

In addition to the two standard stage series, Nippon Pulse America also has the ability to build custom stages to fit a client's applications. Please contact Nippon Pulse America or a local representative for more information and pricing of a custom stage unit



The Nippon Pulse Advantage

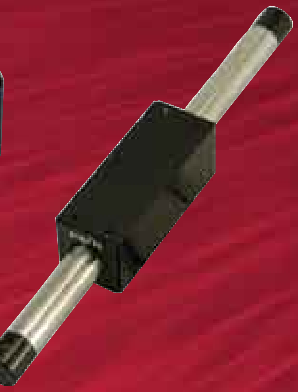
For nearly sixty years, Nippon Pulse has built state-of-of-the-art products based on a solid foundation of advancing technology and thorough product research.

Nippon Pulse America, Inc. (NPA) faithfully provides these high-quality products to a wide range of industries in North and South America and Europe. NPA has established itself as a leader in stepper motor, driver and controller technology while introducing innovative products such as the Linear Shaft Motor and MotionNet. At NPA, we believe that by bringing products to market which not only meet the customers' requirements, but actually impress them, we contribute to the progression of technology and its positive impact on our society. We pride ourselves on the reputation of our high-quality products that provide that impact. A wholly owned subsidiary of Nippon Pulse Motor Co., Ltd., Nippon Pulse America is headquartered in Radford, Va.

NPA has representatives throughout North and South America and Europe to assist customers directly. Limited quantities of stock on standard motors and electronics are available to allow faster response to customer needs. In addition, Nippon Pulse America has a model shop in its headquarters for quick turnaround on custom prototypes and special orders. NPA's mission is to faithfully create the new products sought by its customers and to contribute to the development of society from a global viewpoint.

When you choose a Nippon Pulse motor, driver, controller, network or stage, you're doing more than just buying a quality product. You're benefitting from what we call the Nippon Pulse Advantage. This includes superior prototyping, complete system engineering, proper compliance and certification according to international guidelines and exceptional tailoring to your needs. It also includes unmatched support.

Our biggest asset at NPA is our people, both our employees and our customers, so we ensure that we have the best people working for us so that we build loyalty among those buying from us. It's an advantage you won't find at any of our competitors and why we pride ourselves on our products and our company.



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