Linear Shaft Motor
Linear Shaft Motor - The Next Generation Actuator

Nippon Pulse’s 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 Nippon Pulse 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 consisting 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 for precision and zero cogging. The coils of the Linear Shaft Motor form the core, providing the stiffness expected in an iron-core motor.

Linear Shaft Motors are 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 5.0mm) nominal annular air gap. This air gap is non-critical, meaning there is no variation in force as the gap varies over the stroke of the device.
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; it is fully supported within itself. The magnetic structure is then inserted into a protective stainless-steel tube. This process is protected by numerous patents. This patented process produces a very strong magnetic field twice that of other linear motors.

Forcer Construction

The coils of the Linear Shaft Motor are of a cylindrical design, 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 compact design while producing a comparable force to that of a similarly sized traditional linear motor.

Features of Linear Shaft Motors

- Capable of high thrust (up to 100,000N)
- 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 10m/s) with acceleration up to 20G
- Low speed drive (8μm/s)
- Allows for parallel drive using only one encoder and one driver\(^2\)
- Virtually no speed fluctuation (±0.006% at 100mm/s)
- Durable construction, capable of operation even underwater or in a vacuum

\(1\) The precision of repetitive positioning is dependent on the resolution of the linear encoder. In addition, it is necessary to have sufficient machine rigidity. Also, absolute positioning precision is fundamentally dependent on the linear encoder. It is not dependent on the expansion or contraction caused by the heat of the Linear Shaft Motor.

\(2\) The mechanism must allow for 1-degree freedom of motion between the two motors.
Linear Shaft Motor

Traditionally, linear electric motors have been designed by “opening out flat” their rotary counterparts. 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. The first is what we call Continuous Force. It is the region in which the motor can operate indefinitely without the need for any external cooling, including heat sinks. The second is Acceleration Force, which is the amount of force that can be delivered by the motor for 40 seconds without the need for any external cooling. The third region, the Peak Force, is limited only by the power which can be supplied and the duty cycle. It is limited to 1 to 2 seconds. Your local Nippon Pulse application engineer can help you map this for your particular application.

The Linear Shaft Motor is a very simple design that 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:

![Diagram of Linear Shaft Motor vs. Standard Linear Motor]

- **No Need for Precision Air Gap**
  Unlike other types of linear motor technologies, the cylindrical design of the Linear Shaft Motor contains a very large (0.5 to 5.0mm) non-critical air gap. This allows for a constant linear force, which is not affected 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. The cylindrical design allows for 100 percent of the copper, current, and magnetic field to produce force in the direction of travel.
Coreless Design with Ultra-High Stiffness

Platen-style linear motors boast high levels of stiffness due to iron cores. This iron also results in 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, have cores of epoxy, which does not create Eddy currents or any absorption force. 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 produces a very thermally limited motor. The Linear Shaft Motor is designed to have a motor stiffness 100 times better than that of the U-shaped motor, while dissipating heat at a rate of four times that of similar sized Platen-style linear motors.

Linear Shaft Motor Advantages

- Compact & Lightweight: Lower weight when compared to traditional type of linear motors
- Zero Cogging: The coreless, ironless design results in no magnetic cogging
- Large Air Gap: The non-critical 0.5 to 5.0mm 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

1 An independent study by the University of Virginia (Oct. 2010) shows, when all factors are equal, the Linear Shaft Motor is at least 50 percent more efficient than U-shaped linear motors.

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 provide direct thrust for the positioning of the payload. They eliminate the need for a rotary-to-linear conversion mechanism. Examples: ball-screw, rack and pinion, toothed belt.

**No Lubrication or Adjustment Maintenance Necessary**

The Linear Shaft Motor requires no greasing, and has no performance degradation because of wear or aging, as with ball-screw and belt drive systems. Because the Linear Shaft Motor is maintenance-free, there is significant cost reduction throughout its lifespan. The air gap 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-screw systems.

**No Noise and No Dust Operation**

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

**Advantages of Linear Shaft Motors**

- Simple mechanical arrangement
- Direct thrust motor
- Wide speed range
- Smooth
- Quiet
- Maintenance-free motor
- Lower inertia
- Lower power requirements

The Linear Shaft Motor is coreless and, as a result, is able to provide uniformity of speed.
Extremely High Precision\textsuperscript{1}, Low Speed
Uniformity and 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 processes, which are limited by other
linear mechanisms.

Realizes High Speed Motions while Retaining High Precision
The Linear Shaft Motor’s accuracy in high-speed
operation shortens the travel time required by
ball-screws.

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

Using Linear Shaft Motors Can:
\begin{itemize}
  \item Reduce the number of parts
  \item Save space
  \item Eliminate the need to adjust with locating
guides and concentrics
  \item Reduce base machining costs and time
  \item Lower design costs and time
\end{itemize}

\textsuperscript{1} The accuracy of repetitive positioning is dependent on the
resolution of the linear encoder. It is necessary to have sufficient
machine rigidity. Absolute positioning precision is fundamentally
dependent on the linear encoder. It is not dependent on the
expansion or contraction caused by the heat of the Linear Shaft Motor.

This is the center section of the top graph displayed at 10,000X magnification.
A wide range of applications are possible by utilizing one or more of the features of the Linear Shaft Motor.

**Friction-free and quiet**
The Linear Shaft Motor’s moving parts are all non-contact. All sources of noise and friction are eliminated, allowing use in quiet surroundings, such as test laboratories and medical facilities.

**High resolution**
Useful for precise micro positioning, such as those required in semiconductor equipment.

**Environmental compatibility**
Operates well in a vacuum and in production locations where oil or water are factors.

**Large stroke lengths**
Stroke lengths up to 4.6 meters. Ideal for high-precision conveying, such as LCDs over relatively long distances.

**High controllable speed**
Speeds greater than 10 meters/second have been documented. Ideal for line head drives in high-speed printers.

**Low speed drives**
Speeds as low as 8μm/second have been documented. Ideal for equipment that may be difficult to handle with ball-screws, such as life sciences equipment.
High thrust
Peak thrust of up to 100,000 Newtons is achievable. This can be used to precisely convey heavy loads such as clinical equipment, machine tool, or transfer lines on a factory floor.

No speed fluctuation
Ideal for constant speed drug dispensing, which may be difficult to achieve with lead-screw or ball-screw systems.

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

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 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 (two or more forcers and two or more shafts connected to the same load), to achieve large thrusts for moving heavy objects.
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. There are various design considerations that are different from traditional servo system practices. The following are the main components needed to make a Linear Shaft Motor system, as well as factors to consider when designing a system.

**Configuring 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 consideration must be given to the application, demand specifications, environmental conditions, and whether the forcer or the shaft will be moving.

The other items, E through G, are optional and will depend on the application.

Putting Together a Linear Shaft Motor System

1. Choose your Linear Shaft Motor based on force and stroke requirements.
2. Choose the shaft supports based on design and motor specifications.
3. Choose the linear guide (bearings) based on cost and smoothness (performance) constraints.
4. Choose the linear encoder to achieve the required position resolution.
5. Choose the servo driver to match the power requirements of the Linear Shaft Motor.
6. Choose the Over Temperature Limit, switches and other components, and assemble the Linear Shaft Motor system.
Choose the Linear Shaft Motor Based on Force and Stroke Requirements

For assistance in selecting the correct Linear Shaft Motor, check out Nippon Pulse’s "SMART" tool (Linear Shaft Motor Application Resource Tool) which can be found at nipponpulse.com. 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, as motors may get warm, and heat must be dissipated to prevent damage.

Choose the Linear Guide (Bearings) Based on Smoothness (Performance) Constraints

The linear guide (bearings) must be selected to support the moving load. Often, the linear guide 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 Motor 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, while mechanical slide rails are desirable due to portability.

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, another 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 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 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 10 times your required resolution. Either an optical or a magnetic encoder can be used. (For more information about selecting your encoder, see Engineering Notes at the back of this booklet.)

In the case of a magnetic linear encoder, take care it is installed so 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 Amplifier/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. (For help selecting the correct servo driver, check out our SMART tool at nipponpulse.com, or see the Engineering Notes at the back of this booklet.) 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.

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

Temperature Sensor
A temperature sensor OTL (Over Temperature Limit) will cut power to the motor should it get too hot due to overload. This 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.

Cabling & Cable Carrier
The Linear Shaft Motor is typically operated with a stationary shaft and a moving forcer (it can be operated with a stationary forcer and moving shaft). 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 where the cable will 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 radio frequency interference.
Hall Effect Sensors
Hall effect sensors are devices able to 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 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 is 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.

Because of the size of Hall effect sensors, they are not available on our 4mm Linear Shaft Motor. On the 8-20mm motors, the dimensions of your project must be expanded to include the sensors, which must be connected externally to the motor. On the 25mm series and above, the sensors fit inside the motor and no additional space is needed in your design.

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.

Cooling Methods
Although the Linear Shaft Motor inherently runs cooler than other linear motors, using heat dissipation can improve the ratings of the LSM by 30 to 40 percent. Cooling methods include, but are not limited to: heat routing, heat fins (see left side of image, left), heat fans (see right side of image, left), forced air, and water cooling.

Attached to a S080D, a 200mm x 100mm x 12mm heat sink improved the rated current by 75 percent. The same heat sink improved the rated current of a S160D by 30 percent.

Nippon Pulse sales engineers can suggest a variety of cooling methods, if cooling is necessary for your application.

Linear Shaft Motor in Parallel Systems
Parallel drive systems are any application that has two or more linear motors in parallel. In parallel applications, the wires extend from the shaft on opposite sides, whereas in non-parallel applications, other motor locations are not accounted for in the wiring.

Parallel Linear Shaft Motor Design

Parallel Option Non-Parallel Option

Advantages of Using Linear Shaft Motor in a Parallel Alignment
In high-precision, single-axis robot applications, truly accurate positioning is only possible when the feedback is directly in the center of mass of the work point. You also want your force generation from the motor directly in the center of mass of the work point as well; however, it is impossible to have the motor and feedback in the exact same location.

By putting an encoder in the center of mass, and using parallel Linear Shaft Motors equally spaced off the center of mass, you, in effect, are getting the desired feedback and force generation in the center of mass. You also are able to remove the heat source from the center of mass in high precision applications. This is impossible for other types of parallel drive systems, which require two sets of encoders and servo drives to provide this parallel drive functionality.

Multiple Motors, One Encoder, One Amplifier
In the past, systems may have had two different motors driving separate ball-screws, using two different controllers electronically connected together. Now that same system can be accomplished with two shaft motors, one encoder and one amplifier, as long as the stiffness in the system itself is sufficiently high.

Examples of Parallel Systems

Unlimited Linear Shaft Motors Connected Together
This is also is an advantage for applications where extremely high amounts of force are needed. It is possible to connect any number of Linear Shaft Motors together, thus allowing their forces to be combined.
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.
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 counterbalance 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.
Specifications

Linear Shaft Motor Part Numbering Guide (S and L Series)

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<th>Forcer Size (A)</th>
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XX Usable stroke in millimeters only needed if ordering shaft

Blank Standard
PL Parallel Motors

XX Shaft diameter in mm *10

D Double (2) windings
T Triple (3) windings
Q Quadruple (4) windings
X Octuple (8) windings

Part Numbering Examples
1. S160T-200st: 16mm shaft diameter, triple winding, stroke of 200mm
2. S200D-250st-HA: 20mm shaft diameter, double winding, stroke of 250mm, Hall effects
3. L250Q-1000st: Large air gap, 25mm shaft diameter, quadruple winding, stroke of 1000mm
4. L320T-2500st-02: Large air gap, 32mm shaft diameter, triple winding, stroke of 2500mm, two forcers
5. S200D-FO: 20mm shaft diameter, double winding, forcer only
6. S120Q-200st-50: 12mm diameter, quadruple winding, stroke of 200mm, shaft only
7. S350Q-500st: 35mm shaft diameter, quadruple winding, parallel motors, stroke of 500mm

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

Alternate standard windings are available to meet your available voltage and performance needs. For more information, contact an applications engineer or review the datasheets available on nipponpulse.com under Manuals & Literature.

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)
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<th>Accel. Current</th>
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</tr>
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<td>276</td>
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<td>23.0</td>
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<td>L320D</td>
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<td>218</td>
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<td>87</td>
<td>29</td>
<td>23</td>
<td>28.0</td>
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</tbody>
</table>

Specifications

**Your Partner In Motion Control**

nipponpulse.com

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Scaleless SL Motor: Linear Motor with Built-In Encoder

- Line Driver output
- Built in Interpolator
- Real-time Single processing
- High dynamics
- Excellent force to volume ratio
- No residual force present
- Non-magnetic aluminum housing
- Compact and robust construction
- No lubrication required
- Simple installation and configuration
- Repeat accuracy: ± 1 count (5 μm)

The Scaleless SL Motor is a tubular linear motor with a built-in Linear Encoder. The simple design features just two parts, the shaft (magnets) and forcer (coils). In addition to the coils, the forcer also contains the integrated linear encoder and hall sensors. The stainless steel shaft has the scale for the linear encoder integrated into a single unit.

The Scaleless SL 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 mm nominal annular air gap that is non-critical, meaning there is no variation in force as the gap varies over the stroke of the device, or if the shaft is turned in the forcer.

The absence of residual static force and the excellent relationship between the linear force and current make these motors ideal for use in micro-positioning applications. Position control of the Scaleless SL Motor is made possible by the built-in Linear Encoder.

An integrated solution, the Scaleless SL Motor makes integration of a linear motion a very simple matter into a wide variety of applications in markets such as medical devices, laboratory equipment, instrumentation, factory automation and robotics, to name only a few.

<table>
<thead>
<tr>
<th>Pin</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A+</td>
</tr>
<tr>
<td>2</td>
<td>A-</td>
</tr>
<tr>
<td>3</td>
<td>NC</td>
</tr>
<tr>
<td>4</td>
<td>B+</td>
</tr>
<tr>
<td>5</td>
<td>B-</td>
</tr>
<tr>
<td>6</td>
<td>U (Hall Sensor)</td>
</tr>
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<td>7</td>
<td>V (Hall Sensor)</td>
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<td>8</td>
<td>W (Hall Sensor)</td>
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<td>9</td>
<td>GND1</td>
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<td>10</td>
<td>+5V VCC</td>
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<tr>
<td>11</td>
<td>Z+</td>
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<tr>
<td>12</td>
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<td>13</td>
<td>NC</td>
</tr>
<tr>
<td>14</td>
<td>GND2 (Hall Sensor)</td>
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<tr>
<td>15</td>
<td>+5V (Hall Sensor)</td>
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</table>

*Encoder and Hall Sensor power supply voltage are internally isolated
SS Series Linear Shaft Motor

The SS series Linear Shaft Motors have smaller sized forcers than other standard Linear Shaft Motors. In this series, the size of the motor coil in the forcer has been dramatically reduced, which makes this series perfect for compact applications. The SS series forcer measures 50mm in length, and multiple forcers can be added to a single shaft.

### Linear Shaft Motor Part Numbering Guide (SS Series)

<table>
<thead>
<tr>
<th>Model Number</th>
<th>Continuous Force</th>
<th>Continuous Current</th>
<th>Acceleration Force</th>
<th>Force Constant (Kf)</th>
<th>Back EMF (V/mm)</th>
<th>Resistance</th>
<th>Inductance</th>
<th>Forcer Length</th>
<th>Forcer Weight</th>
<th>Air Gap Width</th>
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<td>L250SS</td>
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<td>5.3</td>
<td>4.4</td>
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<td>0.78</td>
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<td>16</td>
<td>11</td>
<td>8.7</td>
<td>1.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Usable Stroke** = (L - (L2 * 2) - (A * # of Forcers)) mm

For example, for a L320SS-2500st-05:

- L = 2950
- L2 = 100
- A = 50
- # of Forcers = 5

**Usable stroke** =

= 2950 - (100 * 2) - (50 * 5)

= 2950 - 200 - 250

= 2500
Common Motion Profile Formulas

**Trapezoidal Profile 1/3, 1/3**
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.

**Variable Trapezoidal Profile**
(Formulas listed below are for calculating acceleration and deceleration)

### Useful Formulas

**General Formulas**
- Acceleration $G_{ACC}$
- Gravity $g = 9.81$
- Friction Coefficient $(FC) = M2/M1$, $M1$ being the mass of the load to be moved, and $M2$ being the amount of force required to move the mass.

**Voltage and Current RMS vs. Peak**
- RMS (AC) $Peak \times 0.707$
- Peak (DC) $RMS \times 1.15$

Examples:

**Encoder Formulas**
- Encoder Resolution $Er = \frac{Enc. \ Output \ Freq. \ (A-B \ Phase)}{Enc. \ Output \ Freq. \ (Sine-Cosine)}$

**Amplifier/Driver Sizing Formulas**
- Voltage due to Back EMF $V_{BEMF} = \frac{Back \ EMF}{(4 \times \text{Interpolation})}$
- Voltage due to $R \times I$ $V_{R} = 1.225 \times \text{Resistance} \ \times \text{Peak Current}$
- Voltage due to Inductance $V_{L} = 7.695 \times \text{Velocity} \times \text{Inductance} \times \text{Peak Current}$
- Min. Bus Voltage needed $V_{bus} = 1.15 \times \sqrt{(V_{bemf} + V_{R})^2 + V_{L}^2}$
- Peak Current (rms value) $I_{prms} = \text{Peak Current} \times 1.2$
- Continuous Current (rms value) $I_{crms} = \text{Continuous Current} \times 1.2$

These formulas add a 20 percent safety margin for current and a 15 percent safety margin for voltage.
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.

The unique properties of the Linear Shaft Motor make its sizing for applications slightly different than that of other linear motors. Nevertheless, the proper sizing of a Linear Shaft Motor is rather straight-forward. Nippon Pulse provides the 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.

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Unit</th>
<th>Notes</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load mass</td>
<td>M_{\text{c}}</td>
<td>kg</td>
<td>Mass of the moving part of your system less the mass of the motor.</td>
<td>Example: Table, Encoder</td>
</tr>
<tr>
<td>Load (thrust) Force</td>
<td>F_{\text{t}}</td>
<td>N</td>
<td>Thrust Force is added to all segments of the motion profile. This is in addition to force needed to overcome mass, acceleration and friction.</td>
<td>Example: As the motor moves, it needs to maintain 50 lbs of force on an object.</td>
</tr>
<tr>
<td>Run (pre-load) Friction</td>
<td>F_{\text{i}}</td>
<td>N</td>
<td>Pre-load Force is considered in all moving segments of the motion profile. Keep in mind all external forces that disturb the movement.</td>
<td></td>
</tr>
<tr>
<td>Moving Motor Mass</td>
<td>M_{\text{c}}</td>
<td>kg</td>
<td>If you are not sure which motor you are going to need, start with a value of 1/10 of load mass.</td>
<td></td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>\mu</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incline Angle</td>
<td>\alpha</td>
<td>°</td>
<td>0° is Horizontal while 90° is Vertical</td>
<td></td>
</tr>
<tr>
<td>Available Voltage</td>
<td>V</td>
<td>Vac</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available Current</td>
<td>A</td>
<td>Arms</td>
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<td></td>
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<tr>
<td>Max Allowable temperature</td>
<td>\degree</td>
<td>C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Unit</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke</td>
<td>X</td>
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</tr>
<tr>
<td>Velocity</td>
<td>V</td>
<td>m/s</td>
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<tr>
<td>Acceleration time</td>
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<td></td>
</tr>
<tr>
<td>Continuous time</td>
<td>T_{\text{c}}</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>Deceleration time</td>
<td>T_{\text{d}}</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>Settling time</td>
<td>T_{\text{s}}</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>Waiting time</td>
<td>T_{\text{w}}</td>
<td>s</td>
<td></td>
</tr>
</tbody>
</table>

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 you use 1/10 the load mass, as the value for Forzer 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, “\mu” is the coefficient of friction on the guide. “g” is as the acceleration of gravity. g = 9.81 m/sec². “\alpha” is the angle of incline. For vertical or incline moves use \alpha for gravity and \alpha for moves against gravity and \alpha for moves with gravity.

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 MC (Forzer 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 (F_{\text{eff}}) - Please confirm that effective force (F_{\text{eff}}) is less than the continuous rated force (F_{\text{rated}}) of the motor plus a safety factor (SF) of 30% to 50%.

6. If the effective force (F_{\text{eff}}) is larger, please select a new motor where the rated force (F_{\text{rated}}) is met in the equation.

\[
F_{\text{eff}} = \sqrt{ \frac{(F_{1}^2 \times t1) + (F_{2}^2 \times t2) + (F_{3}^2 \times t3)}{(t1 + t2 + t3 + t4 + t5)}} < SF_{\text{Rated}} + SF
\]
**Motor Sizing Example**

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

**Move Profile**

We will assume an estimated settling time of 10msec (T_s).

The move cycle time (T_c) is 160 + 200 = 360msec

Using previous move formula:

\[ T (\text{msec}) = T_m - (T_s) \]

\[ T (\text{msec}) = 160 - 10 = 150\text{msec} \]

We will assume an efficient trapezoidal profile (1/3, 1/3, 1/3)

Acceleration needed here (see previous move formula):

\[ A = (4.5)*(0.1*0.15^2) \]

\[ A = 20\text{m/sec}^2 \text{ (about 2 "g")} \]

\[ V = (1.5)*(0.1/0.15) \]

\[ V = 1\text{m/sec} \]

The acceleration and deceleration time becomes (150/3)= 50msec

The time at constant speed is (150/3) = 50msec

We can estimate the acceleration force of the load only (see previously mentioned formula) at 2g*9.81*6kg = 117N.

Based on this we can select S350T (peak force = 592N, continuous force = 148N) assuming a coil mounting plate of 1kg.

Total moving mass: 6kg (load) + 1kg (plate) + 1.9kg (coil mass) = 8.9kg

Coil resistance = 20.2ohm, Coil Force constant 99N/Ap, Thermal Resistance 2.4°C/W, Back Emf 33Vp/m/sec, Inductance p-p 33mH, Electrical cycle length 120mm

We assume a good set of linear bearings with \(\mu=0.005\) and 20N of friction.

Friction Force: \(F_f(N) = 8.9*9.81*\sin(0) + 0.005*\cos(0)) + 20 = 20.4N\)

Inertial Force: \(F_i(N) = 8.9*20 = 178N\)

Total Acceleration Force: \(F_a(N) = 178 + 20 = 198.4N\)

Total Constant Velocity Force: \(F_c(N) = 20.4N\)

Total Deceleration Force: \(F_d(N) = 178 - 20 = 157.6N\)

Total Dwell Force: \(F_w(N) = 0N\)

RMS Force: \(F_{rms}(N) = \sqrt{(198.42*0.05)+(20.42*0.025)+(157.62*0.05)/0.36} \)

\[ F_{rms}(N) = 94.7N \]

RMS Current: \(I_{rms} = 49.7/99 = 0.96\text{ Amp rms} \)

Peak Current: \(I_{peak} = 198.4/99 = 2\text{ Amp rms} \)

Motor Resistance Hot: \(R_{hot} = 20.2 * 1.423 = 28.7\Omega \)

Voltage due B EMF: \(V_{bus} = 33 * 1 = 33\text{Vac} \)

Voltage due I*R: \(V_I = 1.225 * 28.7 * 2 = 70.32\text{Vac} \)

Voltage due Inductance: \(V_L = 7.695 * 1 * 33 * 2 / 120 = 4.23\text{Vac} \)

Bus Voltage needed: \(V_{bus} = 1.15 * \sqrt{(33 + 70.3)^2 + 4.232} = 118.8\text{Vac} \)

For More Information

For assistance in sizing and selecting a motor, detailed step-by-step instructions are available on our website, nipponpulse.com, by searching for the Linear Shaft Motor Installation Guide, SMART Sizing software or Linear Shaft Motor Sizing application note. You can also call to speak with one of our application engineers for personalized recommendations for your specific application.
About Nippon Pulse

Since 1952, Nippon Pulse has provided a wide array of motion control solutions, including industry-leading stepper motors, the innovative Linear Shaft Motor, controllers, drivers and networks. With several customization options, we provide products that can be utilized in an extensive number of applications.

Your Partner in Motion Control

At Nippon Pulse, we approach customer applications from an overall project standpoint, enabling us to provide the best electro-mechatronic solutions that will help you design and build your motion control systems. Our system engineering services include complete design, engineering and manufacturing. We have experience working with applications that include various pick-and-place machines, large scale sorting and distributing systems, biomedical handling equipment, healthcare products, and more. Our sales engineers have extensive product knowledge and can help you determine the best solution for your particular motion control application.

From standard industrial sectors to high-level electronics, Nippon Pulse optimizes development and manufacturing, and provides many high-performance product groups. In order to provide the most efficient products and facilities, we are always conscious of a smooth flow from planning to design and manufacturing. This efficient flow makes it possible to create a wide variety of products that meet customers’ needs.

It is essential that we provide products that exceed customer expectations, so they are able to use them with complete confidence. Maintaining excellent quality while ensuring a stable supply chain for each of our products is achieved by thorough quality-control methods. These methods guarantee reliability above industry standards.

Whether we provide entire systems or just one motor, ensuring those products have exceeded expectations is part of our methodology. In-depth communications with the customer from the design phase through delivery and beyond installation guarantees this.

We strive to provide you with the best possible products and process through communication, world-class support, and reliable products.

In-House Model Shop

The Nippon Pulse model shop provides quick turnaround on prototype requests for our tin-can stepper motors. Most requests can be shipped within 24 hours, so you can test the product in your application before committing to a purchase order. Nippon Pulse sales engineers work closely with you to understand your project so we are able to suggest the best solution possible and get a high-quality prototype to you as quickly as possible. Nippon Pulse offers the flexibility to ship just one piece to make sure our product is the correct fit for your project. In addition to the tin-can type stepper motors, we have various linear step motors, hybrid motors, controllers and drivers in stock for quick prototyping.

INDUSTRIES WE SERVE

Automation
Bio-Medical & Medical Equipment Manufacturing
Instrumentation
Machine Tooling
OEM
Packaging
Pharmaceutical
Photonics
Semiconductor

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The Nippon Pulse Advantage

For more than 60 years, Nippon Pulse has built state-of-the-art products based on a solid foundation of advancing technology and thorough product research.

Nippon Pulse faithfully provides these high-quality products to a wide range of industries in North and South America and Europe. We have established ourselves as a leader in stepper motor, driver and controller technology while introducing innovative products, such as the Linear Shaft Motor. At Nippon Pulse, we believe that by bringing products to market that meet the customers’ requirements and exceed expectations, we contribute to the progression of technology and its positive impact on our society.

We have 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 has a model shop in its North American headquarters for quick turnaround on custom prototypes and special orders. Our mission is to faithfully create the new products sought by our 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, exceptional tailoring to your needs, and unmatched support.

A wholly owned subsidiary of Nippon Pulse Motor Co., Ltd., Nippon Pulse America is headquartered in Radford, Va.