HOW TO: Designing the perfect linear system

Consider all components separately and as a whole.

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Key points:
- Consider supports, guides, drives, and seals when designing a linear system.
- Know your precision, repeatability, loading, and environmental requirements before starting linear-system design.
- Save design time and money by using Web-based tools that use standard calculations and components.

Resources:

Thomson Industries Inc., *www.thomsonlinear.com*

Thomson's Linear Motioneering Web-based sizing tool: *www.linearmotioneering.com*

"Component-life theory comes down to earth," Machine Design, Dec. 13, 2007, *tinyurl.com/MDLMSlife*

The shortest path between two points is a straight line. But if you're designing a linear-motion system, you'll have to consider structural support, guides, drives, seals, lubrication, and accessories between points A and B.

Whether you decide to design and build your system from scratch using standard parts or buy one that's engineered for you, making the right choices from the outset should help keep things moving for the long term.

Support and guidance

Building a linear system literally means starting from the ground up — with a structural-support system. The support system's main component is typically an aluminum extrusion.

You can have the mounting surface of the base extrusion and the surface the linear guide mounts to machined for applications that require accurate positioning. For lower accuracy, transport-type applications, optimize bases to resist bending under load and to prevent distortion during extrusion instead.

A robust base lets the system rest on end supports only. Lighter extrusions may need intermittent supports along their lengths.

Guides attach to the base to facilitate motion. The main types are ball guides, wheel guides, and slide or prism guides.

Ball guides carry the heaviest payloads and have the highest stiffness. Their single or dual-rail configurations move with little friction. The downsides are higher cost and the amount of noise they generate.

Wheel guides operate at up to 10 m/sec with low friction and high stiffness. However, shock loads can damage them.

In slide guides, prism-shaped polymer bushings run on the profile surface. The polymer helps them move quietly and withstand high shock loads. They tolerate environments contaminated by dirt, grit, dust, oil, and chemicals, but operate with more slowly and under lighter loads than ball or wheel guides, as denoted by their PV rating, the product of pressure and velocity they can tolerate.

Driving force

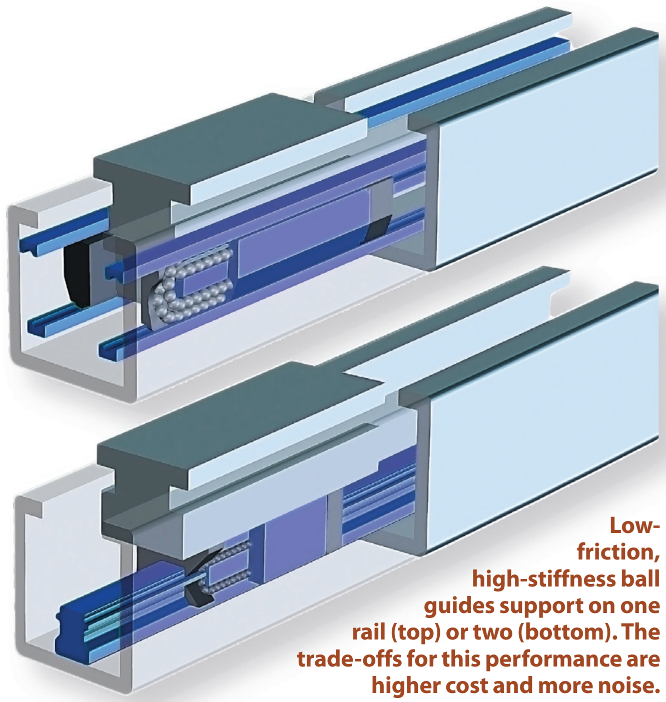
Drives move the carriage to the desired positions. The most common drive technologies are ball-screw drives, leadscrew drives, and belt drives.

In a ball-screw drive, ball bearings travel along the grooves in a threaded shaft — the ball screw — and recirculate through a ball nut. Because bearings share the load, ball-screw drives have relatively high thrust capacity.

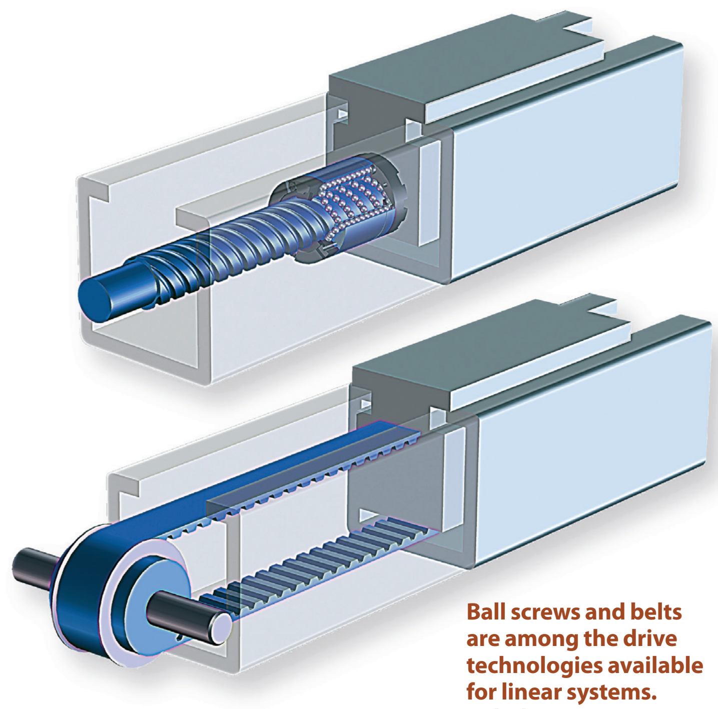
The result is absolute accuracy, defined as the maximum error between the expected and actual position, down to 0.005 mm. Systems with ground and preloaded ball screws are the most accurate.

The systems have thrust capacity up to 40 kN and high stiffness. Their critical speed is determined by screw root diameter, unsupported length, and end-support configuration. With a novel screw support, screw-driven units can travel up to 12 m and accept 3,000-rpm input speeds. Ball-screw drives provide mechanical efficiency of 90%, so their higher cost is often offset by lower power requirements.

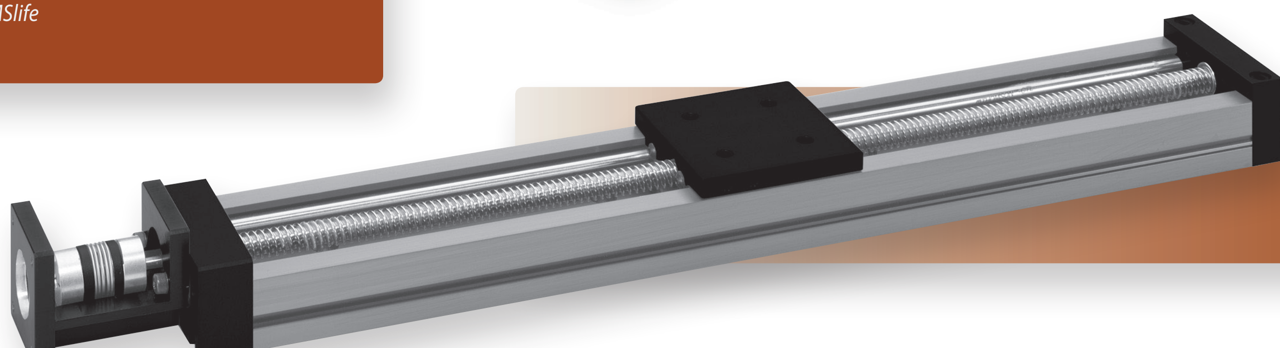
Leadscrew drives cannot match the absolute positioning accuracy of ball-screw drives, but their repeatability — the ability to return to a location during operation when approaching from the same direction at the same speed and deceleration rate — is 0.005 mm. They are used in low to medium-duty-cycle positioning and operate quietly.



Low-friction, high-stiffness ball guides support on one rail (top) or two (bottom). The trade-offs for this performance are higher cost and more noise.



Ball screws and belts are among the drive technologies available for linear systems. Belt drives are quiet and good for high-throughput, lower-precision applications. More-expensive ball-screw drives provide high efficiency, accuracy, and stiffness.



Linear system supports are usually aluminum extrusions that can be machined for extra precision.

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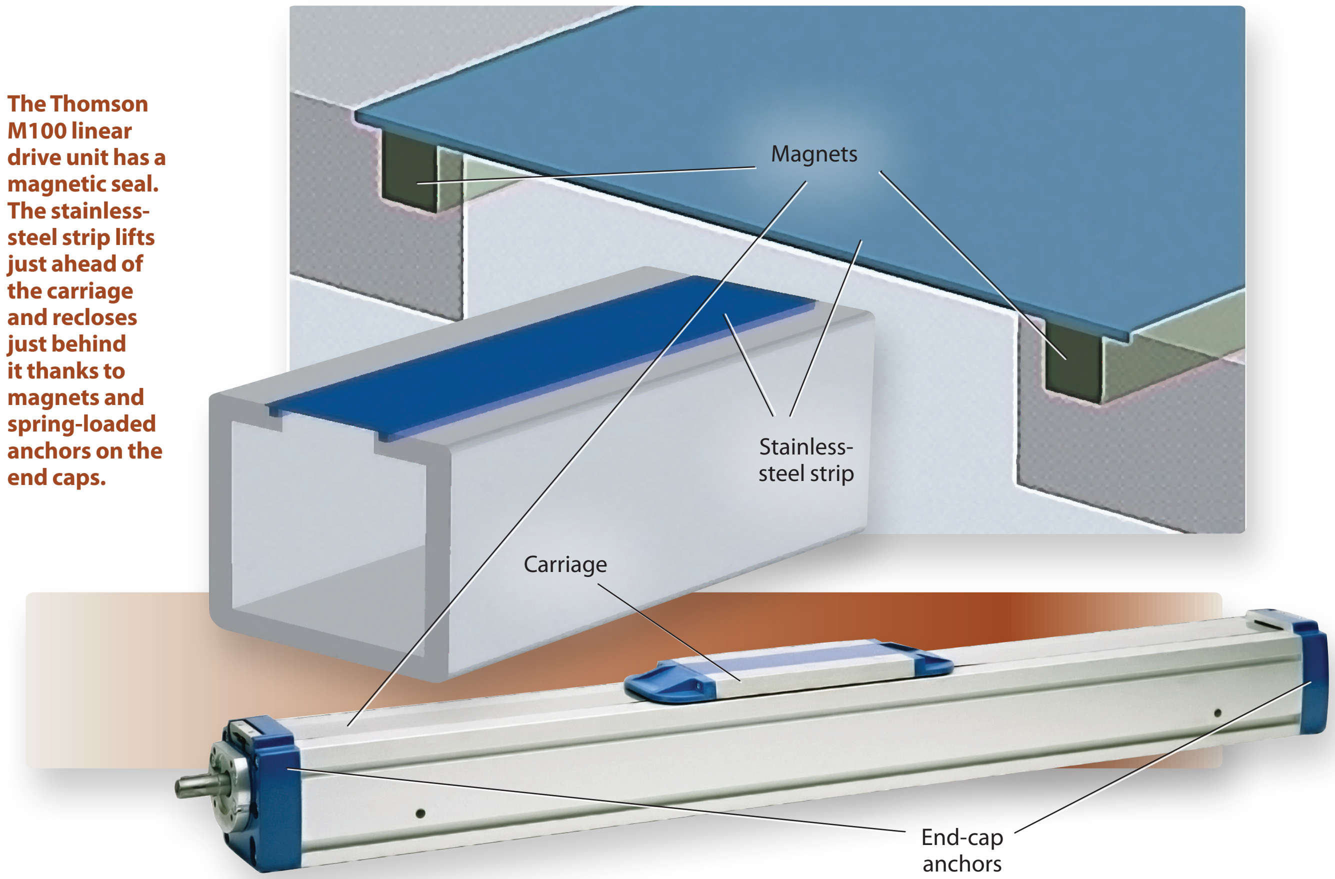
http://tinyurl.com/2donaao

The Thomson M100 linear drive unit has a magnetic seal. The stainless-steel strip lifts just ahead of the carriage and recloses just behind it thanks to magnets and spring-loaded anchors on the end caps.



Belt drives work in high-throughput transport applications with velocities up to 10 m/sec and acceleration up to 40 m/sec^2.

Lube and seal

Most guide systems and the drive systems require lubrication. You can simplify future preventive maintenance by ensuring easy access to lubrication fittings. For instance, Zerk fittings installed on the carriage can feed a lubrication network that serves both the ball screw and linear-bearing system during installation and at periodic maintenance intervals.

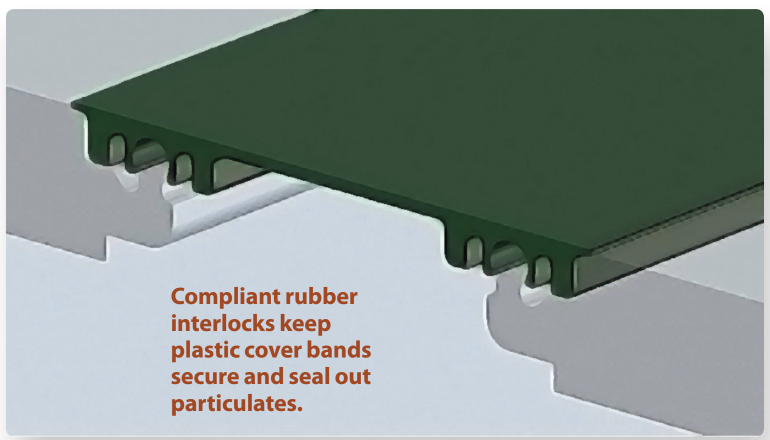
Prism guides are maintenance-free. The polymer material of the slide has inherent lubricity, and lubricated felt wipers replenish lubricant each stroke.

Seals keep lubricant in and contaminants out. One type is magnetic-strip seals — stainless-steel magnetic bands extending from one end of the channel to the other. The bands are fixed to the end caps and spring-loaded to maintain tension. They run through a cavity in the carriage so the strip is raised off the magnets just ahead of and behind the carriage as it traverses the system.

An alternate sealing technology, plastic cover bands, uses compliant rubber strips that interlock with the base extrusion, like a zip-top freezer bag. Mating tongue-and-groove profiles create a labyrinth seal that keeps out particulates.

One more consideration is how you will mount your motor. A motor housing and coupling must mate with the bolt size and bolt-circle diameter on the motor flange, motor pilot diameter, and motor shaft diameter and length.

Many motors have dimensions that meet NEMA standards, but others are manufacturer and model specific. In either case, flexible motor mounts machined from common blanks make it easy to mount to nearly any motor with guaranteed alignment.



Compliant rubber interlocks keep plastic cover bands secure and seal out particulates.

Mix and match

Not every combination of drives and guides makes sense. In practical applications, you're most likely to see leadscrews driving ball or slide guides; ball screws paired with ball or slide guides; and belts driving ball, slide, or wheel guides.

A ball-screw drive combines with a ball guide for repeatable motion and a stiff system that handles high forces and moments. Such systems work well in precision-positioning applications with high loads and high duty cycles, such as loading and unloading gear blanks on machine tools.

Belt-driven, ball-guided units are for high-speed, high-acceleration applications with heavy payloads and high moment loads. These units work on bases that span a gap and are supported either at the ends or intermittently. Palletizing cans is one application.

Belt-driven, slide-guided linear systems are lower-cost units that are quiet and need little maintenance. They work at moderate speeds and accelerations but excel at managing impact loads. Adding a magnetic cover band makes this type of system suitable for environments with a high particulate content and wash-down requirements such as sheet-metal spray treatment.

Because wheel guides need less maintenance than ball guides, but more than slides, wheels driven by belts are another moderate-cost, low-noise, low-maintenance option. These systems achieve high linear velocities and accelerations and are often found in packaging and filling machines.

Make or buy?

When considering whether to make or buy a linear system, think about the engineering time and expertise you'll need to design the system from scratch. You'll need to calculate linear and radial-bearing life, ball-screw life, ball-screw critical speed, and deflection of the support profile, among other parameters. You'll also need to select a lubricant and lubrication

Application engineering

Engineers walked three distinct applications, each from a different market, and each with a 500-lb load through LinearMotioneering. They arrived at three very different end results due to the variations in environment and application details.

Application 1 – Packaging

A linear unit is needed to vertically position an automatic shrink-wrapping machine. For safety reasons, the vertical orientation drives us toward a ball screw. While the sealing, speed, and accuracy requirements are low, the moment loading is quite severe due to the rotational wrapping motion. The high moment load drives us to a ball-guided carriage.

Application 2 – Machine automation

A linear unit needs high acceleration and smooth operation for a paint-spray booth. The 1.5-m/sec speed requirement points to a belt drive. Additionally, the application needed to be maintenance-free, which drives the selection of a slide guide. Although the overhanging spray arm could present a severe moment, using two synchronized slides eliminates the potential moment.

Application 3 – Dispensing and filling

A linear unit is needed to quickly position the dispensing head. Throughput is the most important matter; a belt-driven, wheel-guided unit can deliver the highest speeds. Zip-lock sealing protects the unit from spills or splashes. A slightly larger frame size supports the underhanging dispensing head.

APPLICATION	PACKAGING	MACHINE AUTOMATION	DISPENSING & FILLING
TASK	Vertically position automatic shrink wrapping machine	Smooth, programmable motion for paint-spray booth	Quickly position dispensing head
SPECS			
System orientation	Vertical	Horizontal	Horizontal, Inverted
Accuracy requirements	Transport grade	Transport grade	< 0.005 in./12 in.
Environmental conditions	Clean area, minimal sealing	Heavily caustic, sealing required, zero maintenance	Possible chemical splash/spill, sealing required
Load (lb)	500	500	500
Moment	500 ft-lb	Overhanging spray arm	Minimal, load centered
Speed (m/sec)	0.2	1.5	8
SIZING			
Linear Motioneering result	2EB16H0 unit	Dual TG07B units	WH120Z unit
Description	Ball-screw-driven, ball guided	Belt-driven, slide guided	Belt-driven, wheel guided

system, and design a cover to keep out contaminants.

You could supersize the system to shorten design time, but the final system will cost more and take up more space. And you'll still have to do a basic engineering review to make sure you didn't miss anything.

On the other hand, if you decide to buy your linear system, there will be times when standard catalog products do not meet the requirements of the application. You may need to have the vendor modify a standard product or design a component from scratch for you.

A vendor with a broad range of products and engineering capabilities can partner with you to solve the problems your application presents. The end result is that you'll save time and money and speed up your development cycle. **MD**

Web-based sizing and selection

Need to design a custom linear system while enjoying the cost and time savings of using standard components? Try Web-based sizing and selection tools linear-system vendors offer.

One example is Linear Motioneering (*www.linearmotioneering.com*) from Thomson. The user enters key application parameters that the tool inputs into calculations such as linear bearing load/life, ball-screw load/life, and ball-screw critical speed.

It converts calculation results into a listing of products that meet the requirements. Output listings, ranked by cost, include 3D models, pricing, delivery times, and ordering information.

Here's a step-by-step look at how to get the most out of Linear Motioneering and tools like it:

Step 1: Establishing the system orientation

Pick the orientation of your application: inverted, vertical, horizontal side or horizontal. Then choose the mounting configuration: fully supported, end supported, or intermittently supported.

Step 2: Set positioning requirements

Enter the stroke length from hard stop to hard stop. Select a framework for defining positioning requirements — accuracy, repeatability, or maximum allowable backlash — and set the positioning requirement value.

Step 3: Disclose environmental conditions

Knowing these conditions is critical to choosing the right material, cover strategy, and lubrication scheme. Select clean, water/chemical spray/fog, impact/press application/vibration, moderate to heavy dust-particulate count, high pressure/temperature wash down, water/chemical splash, or clean room. The application will recommend linear slide options — such as chrome-plated, stainless-steel, or Raydent-surface ball guides, CR linear bearings, or polymer plain bearings — that you can change later.

Step 4: Enter load and applied force

Load is the weight supported by the carrier or saddle supports, including the payload, fixturing, and tooling. Enter the *X*, *Y*, and *Z* coordinates of the center of gravity of the load with respect to the center of the carriage or saddle by entering *X*, *Y*, and *Z* values. You can also record an applied or external force, which the tool will assume acts at the center of gravity of the load.

Step 5: Set up move profile

Enter the move distance, move time, and dwell time which the tool will convert into acceleration rates. Choose a system from the list the tool will present.

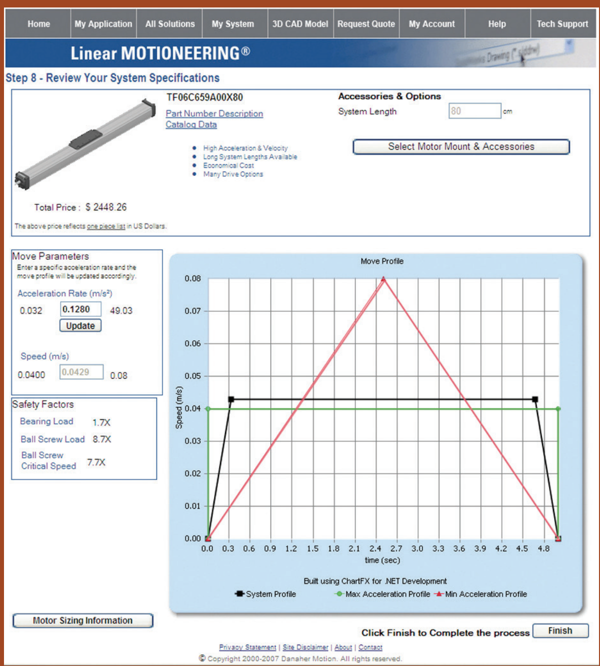
Next, the tool creates recommended move profiles for the selected system — a green maximum-acceleration profile, a red minimum-acceleration profile, and several in between. Choose your preferred profile and desired acceleration rate. You can also enter your own acceleration rate.

Based on the chosen profile, the tool calculates safety factors, bearing and drive loads, and ball screw critical speed.

Step 6: Select options

Choose accessories like motor mounts, covers, brakes, limit switches, and gearheads.

Finally, the tool displays the system's total price and dimensions. You can then download a 3D CAD model of the system in your preferred file format, views and print specifications, save the application, or requests a quote.



Web-based tools can help engineers build economical linear systems in less time. This tool calculates several move profiles: minimum acceleration (green), recommended (black), and maximum acceleration (red).