Linear Systems 101 – Basics for Design Engineers

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This article will explain the basics of designing a linear system including the structural support system, guidance technology, drive technology and sealing, lubrication and accessories. First it will discuss the pros and cons of the different technologies such as lead screw drives, ball screw drives, belt drives, ball guides, slide guides and wheel guides. The article will then look at the advantages and disadvantages of designing and building your own linear system vs. configuring a system from standard building blocks. Finally, the article will describe a step-by-step web-based process for sizing and selecting a linear system based on economical standard components.

Linear systems technology choices

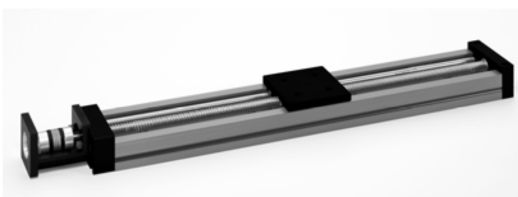

Figure 1: Structural support system

The building blocks of a linear system are the structural support system, drive system, guide system, sealing, lubrication and accessories. The main component of the structural support system is typically an aluminum extrusion that is available in lengths up to 12 meters. The mounting surface of the base can be machined for applications that require accurate positioning. Base extrusions for lower accuracy transport-type applications are usually not machined. Bases used in transport applications are optimized for resistance to bending under load and distortion during the extrusion process, allowing the system to be supported at the ends only.

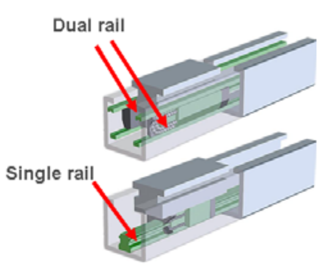

Figure 2: Ball guides

The main types of guides are ball guides, wheel guides and slide or prism guides. Ball guides support high payloads up to 38,000 Newtons (N) and high moment loads up to 27.60 Newton meters (Nm). Other advantages of ball guides include low friction and high stiffness. Ball guides are available in either single or dual rail configurations. The weaknesses of ball guides include relatively high cost and high noise levels.

A key advantage of wheel guides is their ability to operate at exceptionally high speeds, up to 10 meters per second (m/s). Wheel guides also offer low friction and very high stiffness. On the other hand, wheel guides have relatively low resistance to shock loading.

Slide guides use prism shaped polymer bushings running directly on the profile surface to deliver very quiet operation and withstand high shock loads. A key advantage of slide guides is their ability to operate in contaminated environments. Slide guides have lower speed and load capacity than ball or wheel guides.

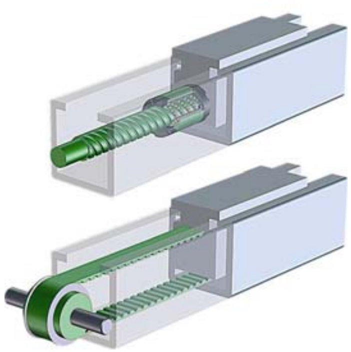

Figure 3: Ball screw drive (top) and belt drive (bottom)

The most popular drive technologies are ball screw drives, lead screw drives and belt drives. The ball screw drive consists of a ball screw and ball nut with recirculating ball bearings. Ground and preloaded ball screws provide exceptionally high positioning accuracy. The load on the ball screw is distributed over a large number of ball bearings so that each ball is subjected to a relatively low load. The result is high absolute accuracy to 0.005 mm, high thrust capacity up to 40 KN and high stiffness. Absolute accuracy is defined as the maximum error between the expected and actual position.

Ball screw drives typically provide mechanical efficiency of 90% so their higher cost is often offset by reduced power requirements. The critical speed of a ball screw is determined by the screw's root diameter, unsupported length and the end support configuration. Ball screw supports enable the use of screw driven units up to 12 meters of stroke and 3,000 rpm input speed.

Lead screw drives cannot match the absolute positioning accuracy of ball screw drives but they provide excellent repeatability of 0.005 mm. Repeatability is defined as the ability of a positioning system to return to a location during operation when approaching from the same direction at the same speed and deceleration rate. Lead screw drives are used in low to medium duty cycle positioning applications and operate at low noise levels. Belt drives are used in high speed, high throughput transport applications with velocities up to 10 m/s and acceleration up to 40 m/s^2.

Both the guide system and the drive system typically require lubrication. Easy access to lubrication fittings simplifies preventative maintenance. One effective approach is the use of Zerk fittings on the carriage that feed a network through which both the ball screw and linear bearing system are lubricated during installation and at periodic maintenance intervals. The prism guide system is maintenance free. In addition to the polymer's inherent lubricity there are lubricated felt wipers that replenish lubricant on every stroke.

Sealing technology is important in many applications. A magnetic strip seal consists of a stainless steel magnetic band that is spring loaded to maintain tension. The two ends are fixed to the end plates of the system and the cover band or sealing strip is routed through a cavity in the carriage. As the carriages traverse the length of the system, the strip is raised off the magnets to allow the carriage to pass (fig4).

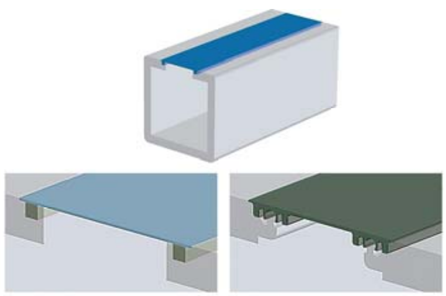

Figure 4a: Examples of magnetic seals (top and left), and a plastic cover band (right).

Figure 4b: Thomson M100 linear drive unit with magnetic seal (bottom).

An alternate sealing technology, plastic cover bands (see Fig 4a, right) use a compliant rubber strip that interlocks with the base extrusion, acting much like a Ziploc bag. The mating "tongue and groove" profiles create a labyrinth seal that is extremely effective in preventing the ingress of particulates.

Flexible motor mounts simplify the integration of linear systems into automated assemblies. Users can simply request a standard NEMA motor mount or provide mounting information specific to their motor or provide the motor manufacturer's name and part number. The housing and coupling are machined from common blanks to mate with the key characteristics of the customer's motor:

bolt size and bolt circle diameter on the motor flange; motor pilot diameter; and motor shaft diameter and length. This allows slides to easily mount, horizontally, vertically, inclined or inverted, to nearly any motor, with guaranteed alignment.

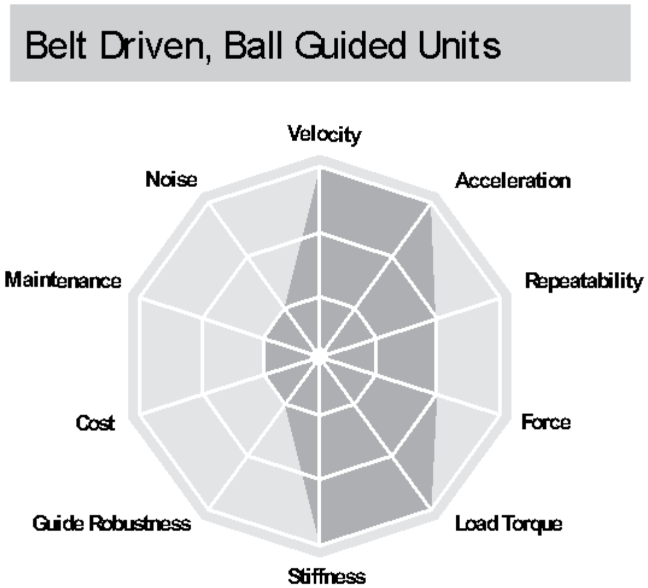

Figure 5: Spider diagrams show pluses and minuses of technology combinations

Not every drive type and guide type combination makes sense. The seven technology groups that are used in practical applications include lead screw drive and ball guide, lead screw drive and slide guide, ball screw drive and ball guide, ball screw drive and slide guide, belt drive and ball guide, belt drive and slide guide, and belt drive and wheel guide. Spider diagrams such as the one shown in Figure 5 depict the relative strengths and weakness of each of these technologies.

The ball screw drive and ball guide technology offers high repeatability, high stiffness and ability to handle high forces and moments. It is used in precision positioning applications with high loads and high duty cycles such as the linear system used to load and unload gear blanks on a machine tool.

Belt-driven, ball-guided units are designed for high speed and acceleration applications with heavy payloads and high moment loads. This technology group is suitable for applications that span a gap and are supported either at the ends or intermittently. A typical application involves can palletization.

Belt-driven, slide-guided linear systems provide moderate speed and acceleration capability. Slide guides can manage impact loads but are somewhat limited in their linear velocities. This combination provides a cost-effective, low-noise solution that requires low maintenance. Adding a magnetic cover band makes this solution ideal for environments with a high particulate content and wash down requirements such as a sheet metal spray treatment application.

Belt-driven, wheel-guided units provide high linear velocity and acceleration capabilities along with moderate cost, low noise and relatively low maintenance requirements. A typical application is the packaging and filling machine.

Make or buy?

When considering whether to make or buy a linear system, it's important to look at the engineering time and expertise that is required to design a linear system. Designing a system includes engineering calculations such as linear and radial bearing life, ball screw life, critical speed of the ball screw, deflection of the support profile, lubrication selection, cover design, etc. The approach of super-sizing the linear system to reduce design time has the disadvantage that the cost and envelope increases and basic engineering is still required to make sure that nothing basic was missed.

When buying linear systems, there will be times when standard catalog products do not meet the requirements of the application. In this case, significant modifications to standard products or white sheet designs are viable alternatives. A partner with a broad range of products and engineering capabilities can work with you to solve your problem while saving time and money and speeding up the development cycle.

Web-based sizing and selection application

A new approach to linear systems design greatly reduces the time required to utilize economical and proven standard components to meet the vast majority of linear motion requirements.

One example is Linear MOTIONEERING® (www.linearmotioneering.com) from Thomson. The user enters the key parameters of the application including mounting configuration, positioning requirements, environmental conditions, loading conditions and move requirements. These requirements are filtered through a comprehensive set of calculations such as linear bearing load/life, ballscrew load/life and ballscrew critical speed. The application then presents a listing of products that meet the application requirements ranked by cost. Outputs include 3D models, pricing, delivery times and ordering information.

Step 1 is establishing the system orientation. The user picks the application's orientation: inverted, vertical, horizontal side or horizontal. Then the user selects the mounting configuration – fully supported, end supported or intermittently supported.

In step 2, the user enters the positioning requirements and the stroke length which is defined from hard stop to hard stop. The user selects whether the positioning requirement will be defined in terms of accuracy, repeatability or maximum allowable backlash. The user then selects a value for the choice that was selected.

Step 3 involves defining the environmental conditions which are critical in determining the correct material selection, cover strategy and lubrication scheme. The user selects a condition from the following choices: clean, water/chemical spray/fog, impact/press application/vibration, moderate to heavy dust particulate count, high pressure/temperature washdown, water/chemical splash and clean room. Based on the environment selection, the application will recommend linear slide options such as chrome plated ball guide, stainless steel ball guide, Raydent surface ball guide, CR linear bearings, polymer plain bearings, etc. The user can change these options.

In step 4, the user enters the load and applied force. The load is the weight that the carrier or saddle supports, including the payload, fixturing and tooling. The user locates the center of gravity of the load with respect to the center of the carriage/saddle by entering x, y and z values. The user enters the applied or external force. This process related force is assumed to be exerted at the center of gravity of the load.

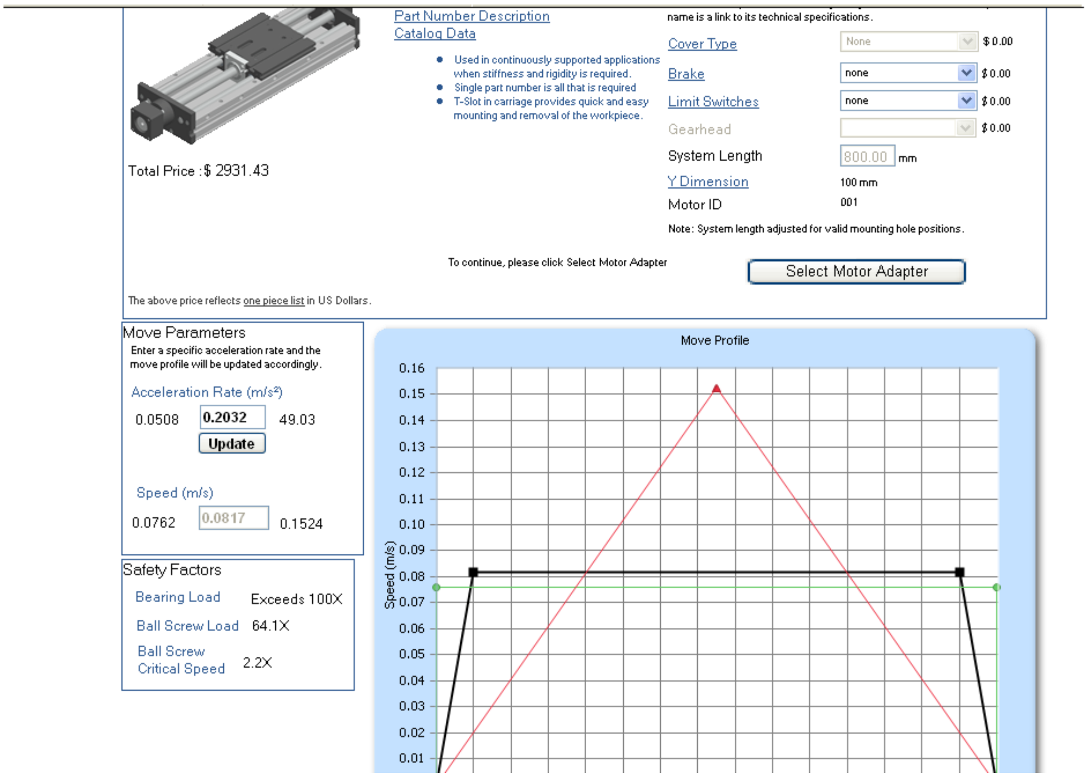

Figure 6: Application calculates minimum acceleration move profile (green), recommended move profile (black) and maximum acceleration move profile (red). Screen shot from Linear MOTIONEERING (www.linearmotioneering.com) web-based sizing and selection tool.

Step 5 involves entering the move profile requirements. The user enters the move distance, move time and dwell time. The program determines the appropriate acceleration rates for each individual system that meets the requirements of the applications. The user then selects one of the systems in the solution set. The application presents several move profiles. The green move profile is based on maximum acceleration and the red move profile is based on minimum acceleration. The user determines a recommended move profile between the maximum and minimum and provides the desired acceleration rate.

Based on the recommended move profile, the application calculates the bearing and drive loads, and ball screw critical speed. The user can also enter his own acceleration rate. When the user does so and presses the update button, the application presents the user's selected move profile and updates the safety factors based on the new move profile.

Finally, the user has the opportunity to select options such as motor mounts, cover type, brake, limit switches, and gearhead. The application presents the total price of the system, and dimensions. The user can download a 3D CAD model of the solution in the native format of 20+ major CAD software packages or a neutral file format. The user views and prints the specifications, saves the application or requests a quote. This approach dramatically reduces the time and cost involved in designing and sourcing a linear system. It provides the opportunity for a company to focus its scarce engineering resources on its core competencies while taking advantage of the linear systems supplier's extensive experience.

About Thomson

With more than 60 years of motion control innovation and quality, Thomson is the industry's premier producer of Linear Ball Bushing® Bearings and Profile Rail Bearings, 60 Case™ Shafting, ground and rolled Ball Screws, Linear Actuators, Gearheads, Clutches, Brakes, Linear Systems, and related accessories. Thomson invented the Linear Ball Bushing Bearing in 1945, and has set the standard ever since with an unsurpassed set of mechanical motion control solutions serving global commercial and aerospace & defense markets. Thomson Industries, Inc. has facilities in North America, Europe and Asia with over 2000 distributor locations around the world.

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