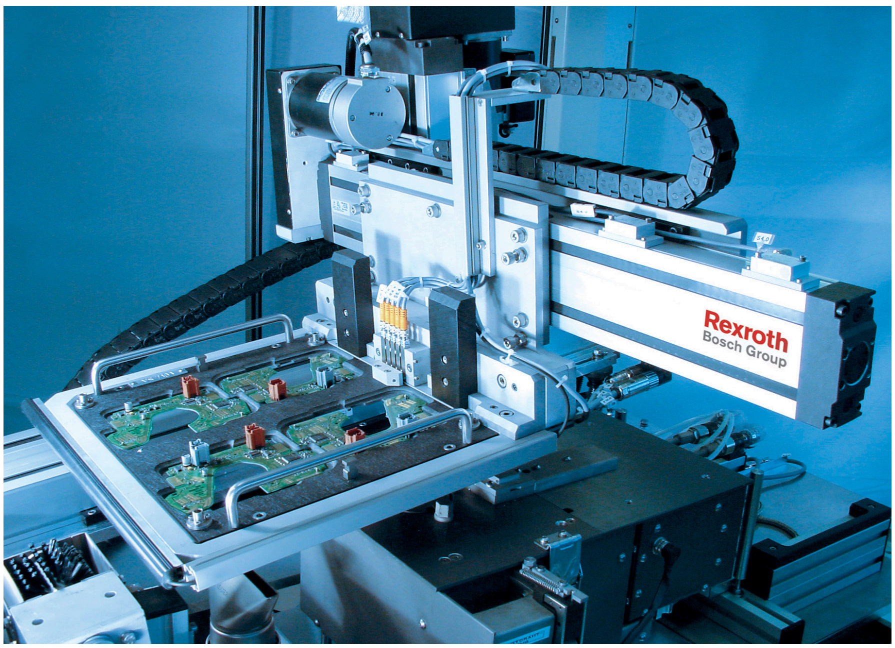
Drive & Control
profile

How mechanical linear motion hardware affects precision motion control



While there's a lot of focus on electronic controllers that can handle nano-level positioning or multi-axis synchronization, machine designers need to consider mechanical linear motion components to obtain the best accuracy possible.

Precise electronic motion controllers are certainly important in today's advanced manufacturing equipment. Indeed, it's hard to imagine processes that require motion control of any kind without them. But just as the performance of a super athlete depends on a combination of brains and physical ability, so do high-precision linear motion systems.

Without mechanical systems capable of taking full advantage of the instructions supplied by the motion controller, many of the processes we depend on today, from high-precision metal-cutting to advanced radiation therapy, wouldn't be possible. This article looks at how mechanical linear motion systems can affect precision motion and what machine designers

Getting the most from your linear motion hardware

- Component sizing, linear guide and bearing design, ball screw and nut options, and linear module housing material are critical in providing the best accuracy.
- Consider other basic design criteria such as the environment in which the system is operating, the angle at which the load is mounted, the speed required, travel distance, and the required duty cycle.
- An important area of refinement is the smoothness of ball recirculation inside the runner block as it travels along the rail.
- For linear modules, the housing design itself is crucial when it comes to accuracy and precision.
- The design of the extrusion and guide system will also affect system rigidity.
- The most widely used housing material is extruded aluminum because it allows longer continuous lengths.
- Modules mounted on a steel base provide an additional level of travel accuracy.

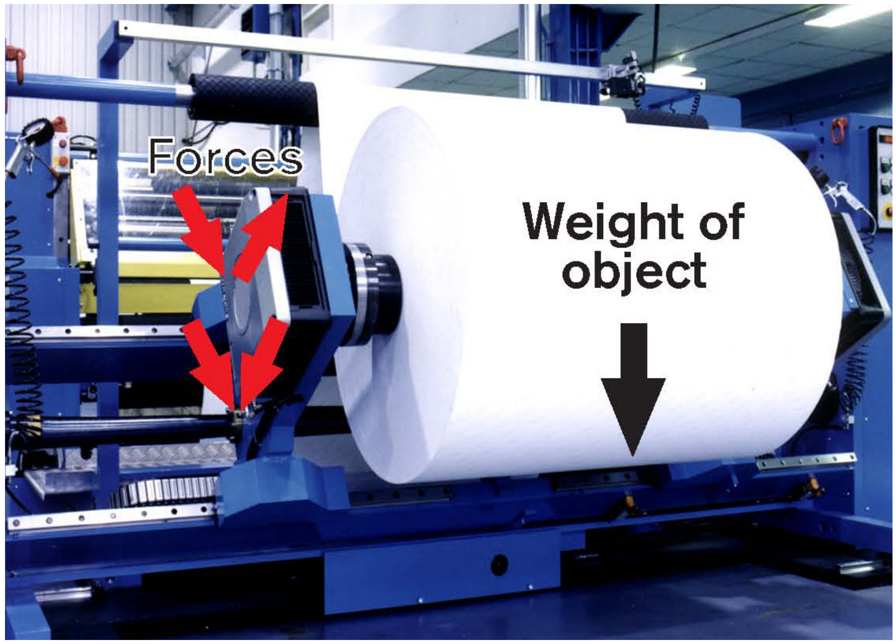
and manufacturing engineers should know to get the most performance out of their machines.

Why the need for increased precision?

The drive for increased precision is like the classic chicken or egg question. Does the development of more precise technology drive machine innovation, or does the need for better and more precise machines lead to the development of more precise motion systems? Designers continue to dream up systems that hadn't been thinkable with previous generations of technology, with sometimes seemingly unrelated technologies driving progress in each other. For example, it may seem difficult for the layman to see an immediate connection between advanced 3-D medical imaging techniques, computer modeling and the need for improved precision in linear guidance systems.

But that's exactly how technology moves forward: Because doctors can now look at a human heart with what amounts to a high-end video system instead of using invasive surgery, they quickly develop a desire for sharper images, with greater detail. This in turn leads medical equipment designers to seek more precision in moving and positioning their imaging systems, which then leads manufacturers to develop linear guidance systems capable of ever-increasing precision.

The same drive for precision leads to ongoing improvement in virtually every industry, from semiconductor and medical to automotive and woodworking. While there's a lot of focus on electronic controllers that can handle nano-level positioning or multi-axis synchronization, what do machine designers need to consider in mechanical linear motion components to keep the progress coming?



Axial or torsional loading, for example, may require wider or heavier-duty components than simple radial loading.

Basic considerations for more precise motion

In many machines, motion is guided by runner blocks or carriages moving along one or more precision ground steel rails. The motion is commonly driven by a ball screw (or in cases where precision is not so critical, a toothed belt). A machine may have one, two, three or more of these axes, depending on the job it's being designed to do. A very common configuration is an X-Y-Z system, with the machine's tool mounted to the end of the Z axis.

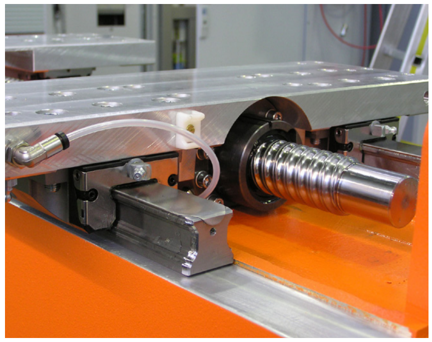
If very precise operation is required, one of the most critical places to start is simply selecting the right size components to handle the load. Axial or torsional loading, for example, may require wider or heavier-duty components than simple radial loading. But even here it's critical to remember that you're building a system to do a job, not just buying the best linear motion components available. A poor machine frame design that's too light for the application will affect precision much more than the specified accuracy of the mechanical guide components. You also don't want to overpay for heavier duty linear motion components simply because you're compensating for other weaknesses in the system.

In addition, it's important to consider other basic design criteria such as the environment in which the system is operating, the angle at which the load is mounted, the speed required, travel distance, and the required duty cycle. (For more on each of the factors to consider when selecting linear motion components, download Rexroth's white paper *LOSTPED* from www.boschrexroth-us.com/brlcatalogs).

Linear guides and ball screws: Precision-critical factors

Let's assume that all these fundamental machine design factors have been taken into account and look first at linear guides. Accuracy in linear guides depends on many factors: the trueness of the rail on which the runner block or bearing travels, the raceways inside the bearing through which the balls or rollers travel, as well as the flatness of the rail mounting surface, and a host of other factors. But among high-performance linear bearings, the most important area of refinement is the smoothness of ball recirculation inside the runner block as it travels along the rail.

Applications at the very high end of the accuracy spectrum, such as gaging, coordinate measuring machines, microelectronics—even super high-end metal cutting—can be adversely affected by even minute movement of the balls in the recirculation chamber, or by just a slight pivoting of the rail system about its axis. Any deflection or clearance at all reduces accuracy, and any roughness in the recirculation of the balls can cause inaccuracy in the machine output, even when coupled with highly sophisticated motion controllers. Non-recirculating linear systems such as cross roller slides or air bearings often allow only a limited stroke or require complex air supply systems and extremely heavy polished granite support systems. Considerable cost could be eliminated



Ball screw and rail combinations like this provide a good balance of travel accuracy and load carrying capability, even with axial or torsional loading.

if highly accurate linear guides could be used instead.

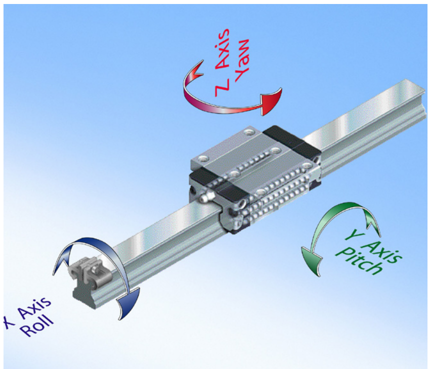
To make linear guides that work in these applications, the solution is to alter the geometry of the recirculation pathways and eliminate roughness at key transition points. One example is Rexroth's High-Precision Ball Rail System, which overcomes these limitations by optimizing the re-circulation, providing extremely smooth motion consistently as the balls circulate in the bearing raceways with accuracies ranging between 4 and 6 microns. Because the mechanical Ball Rail System makes this performance so repeatable, it's now possible to compensate for such minor deviations in the control of a precision machine, enabling achievement of near-perfect accuracy.

Ball screws are typically the technology of choice for driving motion in high-performance machines. Their combination of high rigidity, high precision and respectable speed make them useful in a wide variety of situations. Specifically their ability to handle substantial axial loading often makes them a better choice than linear motors, particularly in metal, wood and stone-cutting applications.

Ball screws are manufactured in a wide variety of accuracy classes that allows machine designers to select the product accuracy they need. In addition, rolling technology has now advanced to the point that rolled ball screws rival the performance of their ground screw counterparts in a given accuracy class. And since rolled screws are more cost effective than equivalent ground screws, many designers are taking a new look at them, especially if the application calls for a class 5 screw—about the highest precision current rolling technology allows.

As with runner block technology, ball recirculation inside the ball nut can also affect precision. As a result, ball nuts are available with a range of pre-load options to reduce the play as it rotates around the screw. Pre-load can be achieved by oversizing the balls inside the nut housing, using the so-called "double-nut" or "jam nut" method, or by using a manufactured offset in the raceway spiral to change the angle of ball engagement (the "lead shift" method). Each method has its advantages and disadvantages, but all serve to minimize backlash between the nut and screw.

In metal-cutting machines, tool travel is typically short, and higher speeds can be achieved by adding the proper end supports. However, in high-speed, long stroke applications such as CNC wood routers, screw "whip" can become a problem, causing unwanted chatter and imprecise



True high-precision performance with linear guides is only possible by limiting unwanted motion in the X, Y and Z axes as the runner block travels along the rail. Rexroth achieves this by optimizing ball recirculation inside the Ball Rail runner block.

cutting—unacceptable with fine wood products and furniture. To overcome this, many ball screw manufacturers offer a driven nut option, in which the nut rotates along a stationary screw. Coupled with an integrated measuring system on the associated Ball Rail guides, self-driven nut products like Rexroth's FAR Rotating Nut can achieve precision ratings rivaling those of linear motors, even with long strokes. And the cost of ball screws, even for high-tech systems like Rexroth's FAR, is still considerably less than that of a linear motor.

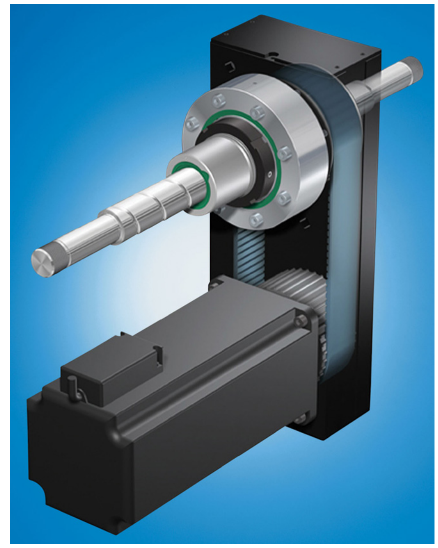
Putting it in a box:
Linear actuators and modules

Until now, these guidelines have focused on how mechanical linear motion components within the machine can affect precision. In some applications, such as Cartesian robotic systems, the "machine" consists primarily of linear motion components commanded by an electric controller. Cartesian robots are often used in so-called "pick-and-place" applications, assembly operations, material handling or in light automation that doesn't require a substantial machine base. Laboratory and semiconductor applications are good examples of light automation, because the parts handled are extremely delicate and lightweight, but often require very high precision.

Cartesian robotic systems are frequently constructed from linear motion modules or actuators, which may be used in one axis, or combined in two or three axes with simple mounting plates. Each module consists essentially of a mechanism to guide motion and a mechanism to drive motion. In many cases, a module is composed of one or more linear guides plus a ball screw mounted in an aluminum extrusion or on a steel base. In cases where precision is not a critical factor, the drive mechanism is a toothed belt.

The same factors mentioned earlier relative to linear guides and ball screws apply with modules, too. If the module has high-performance components inside, it's likely to give you better precision overall. And since it's possible to combine such a wide range of components inside different housing designs, a module design can be found that suits virtually any application.

Besides the internal ball screws and guides, however, the housing design itself is crucial when it comes to accuracy and precision. The most widely used housing material is extruded aluminum because it allows longer continuous lengths. With aluminum extrusion modules, the mounting surface or number of supports will have the most significant



Self-driven nut products like Rexroth's FAR Rotating Nut can achieve precision ratings rivaling those of linear motors, even with long strokes.

influence on the deflection of the system. The design of the extrusion and guide system will also affect system rigidity. Rexroth's CKK and CKR Compact Modules, for example, integrate two Ball Rails into the aluminum extrusion to add stiffness while providing smooth motion. This combination allows lengths up to 10 meters, load capacities up to 15,000 lbs and positioning accuracy of 52 microns for every 300 mm of travel.

Modules that are mounted on a steel base—or in the case of the Rexroth PSK Precision Module, in a steel housing—provide an additional level of travel accuracy that aluminum extrusion-based modules cannot achieve. Because steel can be machined much more precisely than aluminum, applications such as semiconductor inspection that require very high flatness or straightness of travel often lead designers to use modules that are built with a steel base or housing. These products are typically driven by a ball screw to achieve high positioning accuracy. Steel modules are also much more rigid than aluminum modules, so full mounting support is not required in most applications.

Besides the internal ball screws and guides, the linear module housing design itself is crucial when it comes to accuracy and precision.

In summary, machine designers working on highly accurate systems must incorporate precise electronic systems. But equal billing should be given to the mechanical components as well. Factors such as component sizing, linear guide and bearing design, ball screw and nut options, and linear module housing material are just as critical in providing the best accuracy possible in your machine. Considering these items early in the design will help ensure your mechanical elements work as smoothly as possible with your motion controller to provide the precision your application demands.

Accuracy in linear guides depends on many factors, including the trueness of the rail on which the runner block travels.

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