



Round or Square?

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Since the introduction of the original round rail Ball Bushing linear bearing invented by Thomson in the 1940's, there has been steady development in the field of recirculating ball linear guides. Advancements in load capacity, life and ease of manufacture allowed an ever-widening range of applications to benefit from nearly friction free linear guidance. Since the introduction of the square, or profile rail, linear guide in the 1970's, the design engineer has been faced with the pivotal question: round or square?

While square rails initially cost many times more than round technology due to the extensive grinding requirements inherent in the design, new manufacturing techniques and economies of scale have allowed square rails to compete effectively in a broader application space. Once subjugated to the realm of machine tools, profile rails can now be found in many of the same applications that were once only supported by round rail product. However, sales of round linear bearings have also increased over the years. Ball bushing guides remain popular due to some intrinsically unique and often advantageous characteristics that lend themselves to specific applications, not the least of which is that they are round, and sometimes a square peg simply can't fit in a round hole.

In order to apply the correct type of linear guide in a particular application, the design engineer must consider the advantages and capabilities of each. Scoping out the design requirements is always the first step. This may result in a realization that load, accuracy, stiffness, smoothness, or geometry is the critical factor. Many times there is interplay between more than one of these and other requirements.

Profile rail products are well suited for high load applications (in the range of ~20 kN for a 25mm size is typical) that require good stiffness (on the order of 1 to 4 $\mu\text{m}/\text{kN}$ for a 13% preload, for example), and high accuracy of 3 to 10 $\mu\text{m}/\text{m}$ when running parallelism between the bearing guide and rail. They achieve their performance through the precise grinding of the ball tracks in the rail, which have

close conformity to the balls. That is, the race, which the ball rides in on the rail, is only slightly larger in radius than the ball itself. This causes the contact area between the balls and race under load to be larger than on a round rail assembly where the balls and the inner race (shaft) are both convex surfaces. As a result, profile rail bearings are approximately five times stiffer when loaded because the ball is cradled as it flattens out under load.

Square rails are also available with preloads that can be specified from light (3% of the rated dynamic load) to heavy (13% of the rated dynamic load). The classic application for profile rail bearings is in the machine tool industry where load capacity, stiffness and accuracy are paramount. Heavy preloads further reduce the amount of deflection under load since the bearings have already been subjected to an initial deflection. Up to this point we have been discussing bearings that use spherical ball elements. It should be noted that in applications requiring even more load capacity (~2x greater) than a ball type profile rail without increasing the envelope size, another option is profile rail bearings with cylindrical roller type elements.

With load capacity, stiffness and accuracy all going for profile rail, some engineers are tempted to look no further. However, this can result in poor system performance and increased up front and service costs. Round rail products can offer several advantages, one of which is the ability to run smoothly when mounted to less than perfect surfaces defined as having a flatness error of over 150 μm /m. Consider the challenge involved in mounting a linear bearing which is rigid in roll, pitch and yaw. Flatness errors in mounting surfaces often cause binding resulting in increased drag, and can even reduce life by up to 50%. To counteract this problem, the mating surfaces must be carefully prepared or the parts must be shimmed and adjusted to run properly during assembly which increases cost. For more precise machining applications this can increase up front costs and operational costs due to increased service requirements. This cost varies widely with application and could range from less than \$100 to several thousand dollars. Applications involving mounting bearings to welded tubular frames or even direct to concrete factory floors can be accomplished using round rail products.

Ball bushing linear bearings can adapt to a variety of conditions due to their self-aligning capability. Because the shaft is round, ball bushings are free to rotate in roll around their axis. This allows one rail to be installed at a slightly different elevation than the other, with height differences of 1 or 2 mm often being acceptable when rails are installed 300mm or more apart. Also, the bearing races on most ball bushings are designed in such a way that each linear bearing can rotate up to $\frac{1}{2}$ a degree in pitch and yaw to accommodate flatness or alignment errors. The pillow blocks that are normally used to constrain a ball bushing as well as the rail supports are typically constructed of aluminum, which provides a small amount of flexibility to accommodate an up to 25 μm parallelism error between the shafts. The result is the ability to achieve friction coefficients

between .001 and .004 for very efficient guidance in less than ideal circumstances. It is very common in factory automation to mount linear guides to a welded tubular frame. In many OEM applications, the mounting surfaces are drawn tubing and sheet metal. Round rail product typically install quickly and run more smoothly in these conditions than their square brethren.

A significant benefit of round rail products is their circular profile, which allows the shaft to be end supported. This enables round linear bearing designs to span gaps of 12 to 24 times the shaft diameter, which is very useful in a range of applications from gantry systems in factory automation to pick and place modules in DNA sampling machines. The axis of motion is established entirely by fixing the two ends of the shaft. It doesn't matter what the surface of the machine does between these two points or whether there is one at all. The precision of the device only depends on the accuracy of the end support mounting. In addition, there is no easier way to align a screw drive system with linear rails than to simply mill three holes in a plate which reference the two round rails and the support bearing for a screw. Alignment is designed in and no adjustments are required during assembly.

The square rail solution to the problem of alignment is to simply use one rail. Because they can support moments in all directions, profile rail bearings do not need to be used in rail pairs or even bearing pairs. For light loads, namely those that stay within the load and moment capacity of the bearing, a single profile rail bearing can provide the desired guidance (note that not all profile rail products are designed for this type of operation). This eliminates the problem of aligning two rails on divergent surfaces. However, alignment with the drive mechanism such as a screw must still be accounted for and profile rails are not designed to span gaps or be end supported. Applications with a wide (~300mm) motion foot print may not be well suited for a single guide due to the moments induced on the rail by the off center loading. Check the moment rating of the guide you are considering along with it's stiffness under a moment load before specifying.

Design flexibility can be an important consideration in the choice of components. Often, to achieve optimum performance, components must be modified to enhance function or fit in the desired space. Profile rail bearings are more compact than round ball bushing bearings when load ratings are compared. So if the geometry supports your system needs you will have a fairly optimized package. However, if modifications are necessary, it is generally easier to make those on a round rail system. The round shafting can be configured in many ways to facilitate holding the ends of the shaft and can even be used as a structural member in the larger assembly. Diameters, flats, drilled holes both on center and radially through the case of the shaft can all be accommodated. Ball bushings can be purchased alone and fit to a bore integrated directly in the adjacent component or they can be provided in an aluminum or steel pillow block. The pillow blocks make the bearing easy to mount but also allow for a fair amount of modification.

In some applications smoothness can be a major consideration. Although specifics can vary between components and applications and there is a general lack of data in the industry relative to smoothness, ball bushing bearings tend to operate very smoothly, and the difference between profile rail and round rail can typically be felt by hand. The point contact of the convex surfaces between ball and rail minimize scuffing. Normally ball bushings are run with slight clearance or light preload of 1-2% of the rated dynamic load, which also promotes smooth operation. Due to their high conformity and typically higher preloads, profile rail bearings can run with some "notchiness". In most cases this is not objectionable but if instrument grade bearings are required, round may have the edge. Also, the seals on round bushings tend to be more reliable and cause less drag due to their simple circular geometry. Profile rail wipers must conform to the ball tracks ground in the rail and may be designed with more drag commonly 2x that of round linear bearings, to get a robust seal.

One last consideration for round rail installations is that one can also run non-ball type polymer bushings on the shafts. These are available with high performance bearing grade materials applied to aluminum or other substrates to provide good load capacity (20% of that of a ball bushing) and a reasonably low friction coefficient in the range of .05 to .25. Bushing bearings work particularly well in harsh environments where particulate would damage even a well-sealed ball bushing. They also perform admirably under impact loads that would damage ball bearing systems. On the other side of the coin, they can be essentially silent for applications where the small amount of ball recirculation noise in a ball bushing or profile rail bearing would be a problem. Since the contact area is distributed over a large area, there is no need for hardened steel shafting as with a ball bushing. Stainless steel shafting can be used which is ideal for use in both clean environments such as Semiconductor and Medical as well as harsh environments like food processing.

In many cases the designer has a fair amount of flexibility between which technologies they employ. Tuning the performance of one's system by choosing the most appropriate component for each function will result in the optimum solution, translating into competitive advantage relative to cost and performance. But overall installed cost should be considered, taking into account machining, surface preparation and installation costs in order to reach that optimum design solution.

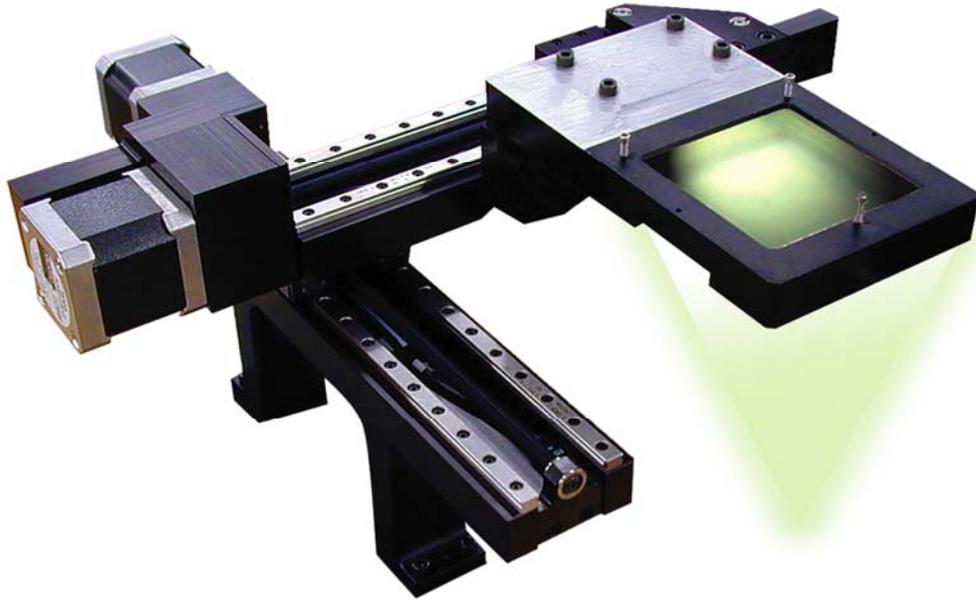
FIGURES

Figure 1:



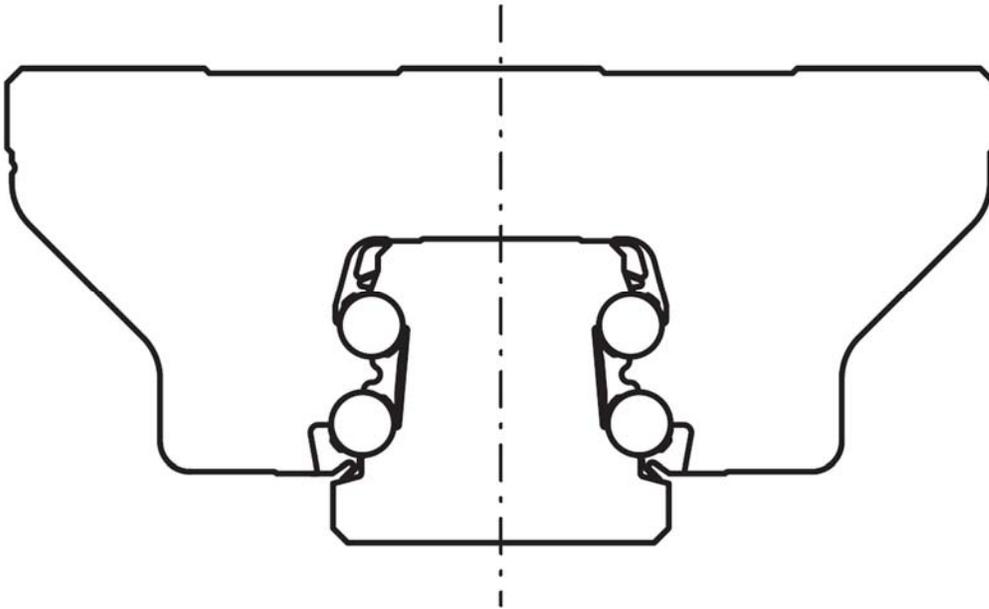
Round and square recirculating ball linear bearings are the most popular solution for linear guidance today.

Figure 2:



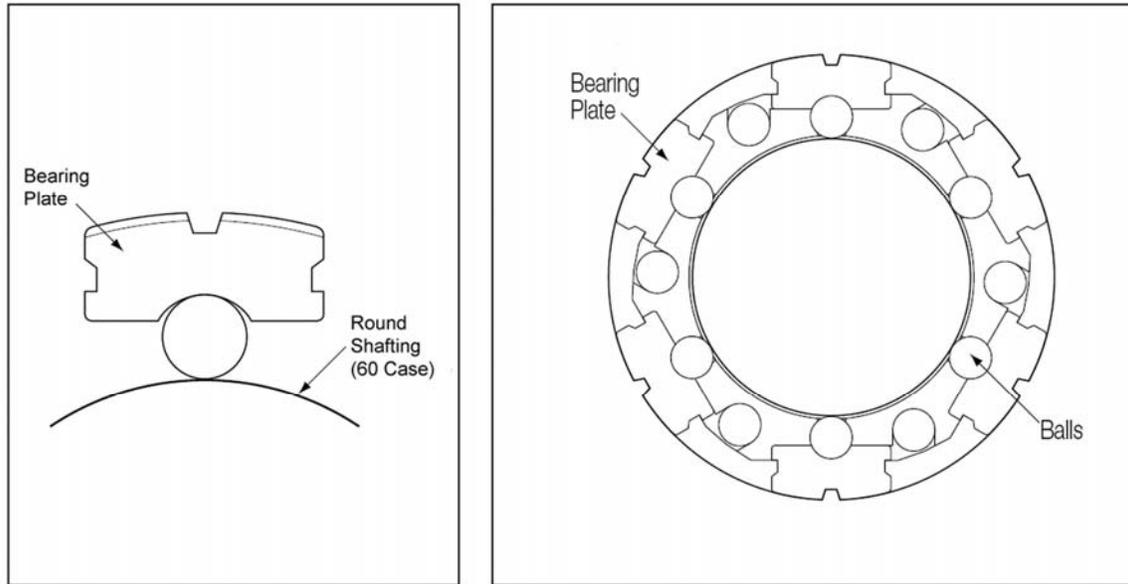
An example of an X-Y stage type assembly utilizing profile rails that provide stiffness and precision for this overhung moment loaded inspection application.

Figure 3:



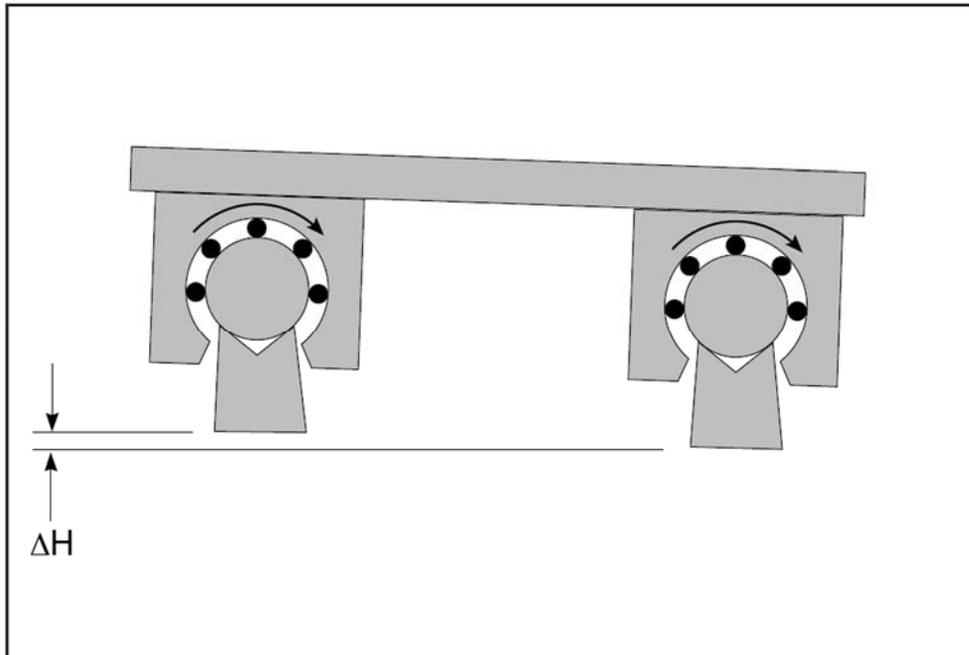
This cross section of a profile rail bearing illustrates how the balls are captured between the carriage and rail, both having races with close conformity to the balls.

Figure 4:



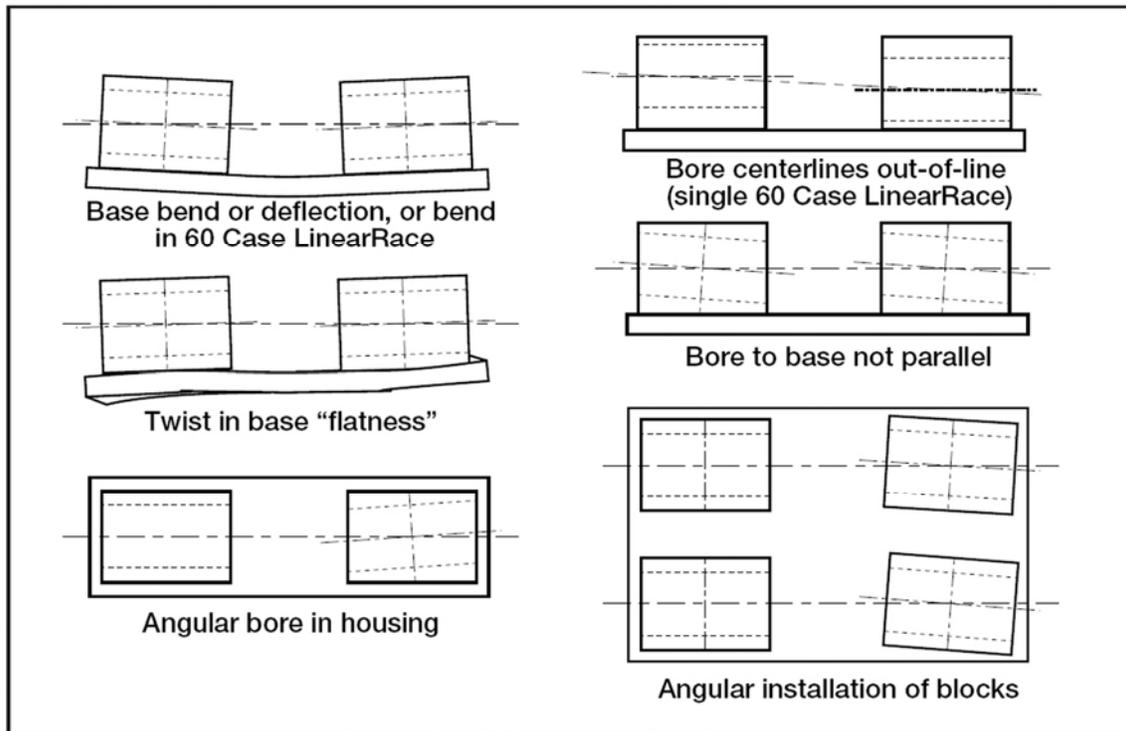
Cross section of a round ball bushing bearing showing how the balls ride between the bearing plate and round shaft and the manner in which the plates are arranged in a housing to contain the ball circuits.

Figure 5:



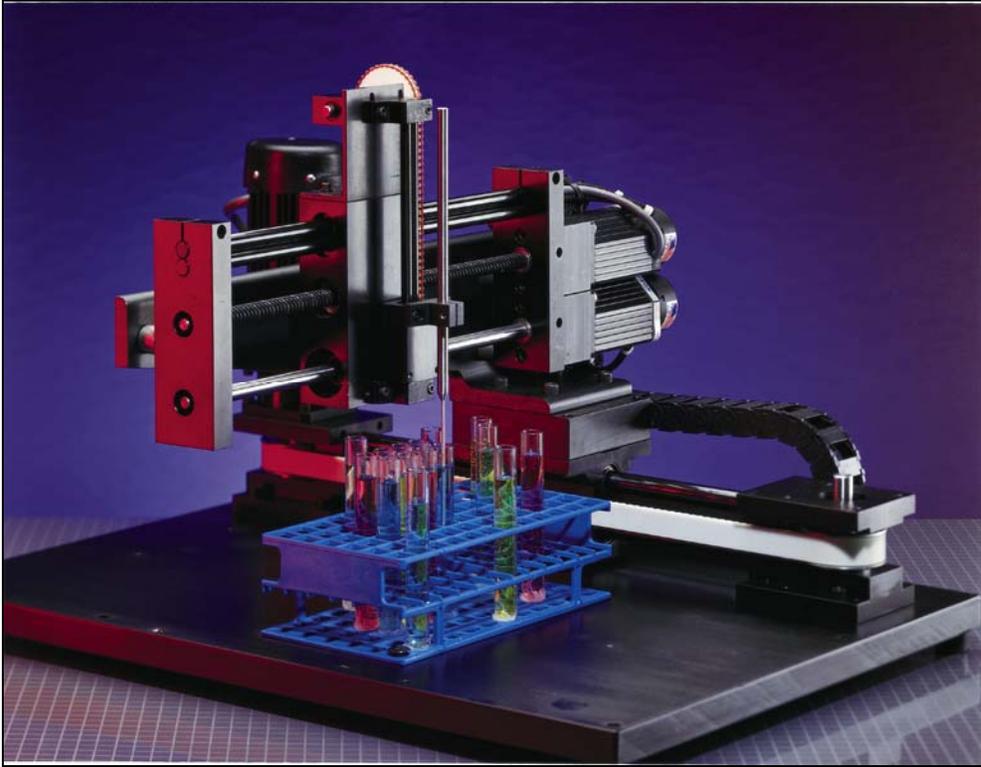
Since round rail linear bearings are free to rotate around their shafts, height mismatch does not result in binding.

Figure 6:



The self-aligning design of round rail ball bushing bearings allows them to be installed into imperfect systems. Normally four bearings installed in square pillow blocks are used to support a load and connected by a carriage plate.

Figure 7:



A fluid dispensing device that benefits from end supported round rail bearings which are captured in simple end plates, span a gap and offer smooth motion for this laboratory type application.