LINEAR BEARING PRELOAD

INTRODUCTION

Preloading anti-friction linear bearings has been looked upon as more of an art than a science. This is primarily due to the fact that many variables in the mounting and assembly process make ‘torque’ adjustments less practical and adjustments by ‘feel’ or by hand more effective. As bearings are mounted on imperfect surfaces, with inconsistent threads for mounting and preloading the bearing, it is difficult to establish a foundation that will yield uniform results. This has not stopped people from striving to adopt scientific methods of preloading, with torque wrenches, or force gauges, however, it typically comes down to fine hand adjustments.

The purpose of preloading a bearing is to bring stiffness to a system (or axis) by taking out the clearance (or backlash) and generating the required life. Increased preload brings increased stiffness, which in turn yields much higher responsiveness. In devices such as high performance positioning systems and state-of-the-art machine tools, bearing preload is critical to establishing a system that can meet the dynamic requirements of a servo system. As high stiffness linear bearings are applied to high performance motion systems, it is important to understand the difference between a proper preload and an excessive preload. Simply adding preload to increase stiffness can result in the creation of inaccuracies, which will affect repeatability and resolution.

As the methods and effects of preload vary based on bearing type (non-recirculating linear and recirculating linear) it is important to separate the implications of preload on the two types of bearings. The discussions regarding non-recirculating linear bearings refer primarily to crossed roller bearings, as these bearings are the most stiff of mechanical bearings and are often utilized in high performance motion systems. Recirculating bearings refer primarily to linear ball guides, as these bearings are quite common in motion control and machine tool applications.
Non-Recirculating Linear Bearings

By “non-recirculating”, it is meant that all bearings remain in preload all of the time. The design of this bearing structure is ideal for very high smoothness (low friction) applications as bearings do not recirculate in and out of a preloaded condition. Specifically with crossed roller bearings, which offer a line contact that yields exceptional load capacity (stiffness) and very high accuracy, preload is an important consideration as it greatly impacts the bearings performance.

Crossed rollers, a series of cylindrically shaped rollers mounted on opposing 90° degree axes, posses the ability to utilize a preload in one axis bringing stiffness in two axes. The preload applied is typically a function of the load being applied to the bearing, and the amount of compression that a bearing will deflect. This is normally in the range of 2% to 20% of the applied load. As mentioned earlier, the higher the preload, the higher the stiffness. However, the risk of inducing errors in resolution and repeatability occurs. Since crossed roller bearings have very high load capacities due to the full line contact, preload is normally used more often than not to take out all of the bearing play without inducing any friction. This is permissible and quite common, as most applications use a very small percentage of the bearing capacity.

Even though applications typically use a small percentage of the capacity of the bearing, the mechanical preload which is set on the bearing can significantly contribute to the errors within the bearing structure. Mechanical preloads are typically achieved by utilizing a set screw, or forcing mechanism, to move one adjustable rail perpendicular to the direction of travel, thus taking out clearance. The preload forces are usually generated in intervals that are equivalent to and in-line with the mounting screws that fasten the rail in place.

While crossed roller bearings benefit greatly from a compliant preload, it is the uniformity of preload over the entire length of the bearing that creates the primary advantage. While a compliant preload reduces the bearing stiffness, the total capacity is still very high and more than adequate for the vast majority of applications.

The process of generating a compliant preload with a non-recirculating linear bearing is achieved by creating a spring constant in the adjustable rail. The spring constant must apply to both the rail mounting surface and the rail banking surface to have value to the bearing structure. All too often spring forces are used to create a preload (or alignment) and then the mechanism being preloaded is locked down, negating the spring force. While set screws are used to take out the bearing clearance, once the rollers and ways are in contact, the screws are used to apply the spring force built into the adjusting wall.

Depicted in the drawing, a compliant preload isolates the one adjustable rail and allows it to flex with any anomalies / inaccuracies in the bearing structure or mounting surface.
The compliant preload brings a host of performance benefits to the bearing and stage structure:

- Improved linear & angular accuracies by a factor of 2 to 4 times
- 10 time improvement in repeatability of errors for enhanced performance when mapping
- Significant increase in friction uniformity
- Z-axis jitter to 1m or better.

These specific benefits allow high accuracy mechanical bearings to compete in the arena previously limited to air bearings.

**Recirculating Linear Guide Bearings**

Recirculating linear guides, operate on a substantially different principle than non-recirculating bearings. A “puck” containing a ball track travels the length of a steel rail, allowing balls to recirculate in and out of preload. It is much easier to recirculate a ball bearing, and it is far more common that these bearing structures use a ball with a curved race to eliminate the point contact and generate higher capacities. The primary benefit of this bearing configuration is the ability to achieve longer travel lengths vs. non-recirculating designs.

Linear guides are typically preloaded by the selection of ball size, and in essence using the spring rate of the hardened steel ball to create the preload. While bearings are offered with a variety of preload percentages, there is little compliance within the bearing puck. More importantly, this style of bearing is typically applied with two rails and four pucks used to create an axis of motion. In this configuration it is common that the bearing preloads tend to fight each other, creating excessive stiffness, roughness and inaccuracies.

While each bearing puck has a defined preload unto itself, compliance can be applied in the mounting of multiple pucks. This can greatly improve the bearing performance in terms of bearing jitter and friction uniformity, but most importantly it can aid in managing the effects of thermal expansion. Compliance can be added to linear guide bearings through the mounting connection between the puck and the moving surface. When this connection is made with an engineered flexure, the spring rate of the flexure can be used to take out bearing play. The flexure also reduces jitter, and allows the bearing to operate normally although the structure may exhibit thermal expansion. The flexure design is specifically intended to absorb this vibration and minimize its effect, and to also improve frictional uniformity.

Recirculating bearings are normally mounted in the same plane, with two rails mounted parallel and four pucks fastened to the moving slide. Flexures can be used in this traditional mounting or more appropriately with one rail mounted sideways (on a perpendicular plane). While both mounting methods are effective, mounting one rail sideways can bring some performance advantages depending on the manufacturing processes used. For example, if the ball tracks are ground with dual spindles, most of the bearing error will relate to the parallelism of the tracks to the base (rather than one track to the other.) In this instance, the benefit of mounting sideways allows the flexure design to absorb a portion of the inaccuracies, providing a straighter line of travel. This is best accomplished when the bearing pucks have a low stiffness, ‘zero clearance’ preload, rather than a higher preload.

When linear guides are mounted in a traditional manner, it is still possible to create a flexure to connect one set of pucks to the other. This may require additional parts, but the benefits are the same.
The primary benefits of using a flexure to mount to a recirculating linear guide is the ability for the moving mass (or base) to grow thermally, at a different rate than the bearing. This is important, as many of the structures that use this bearing configuration are produced in aluminum and the bearing in steel. Particularly in stages that use linear motors, the motor heat is generated in the center of the slide plate and transferred directly to the aluminum slide. This causes substantially more thermal growth than a stage using a ball screw and an external motor. As either the drive technology, the environment, or the process can generate heat, the flexure design allows for growth, eliminating any fighting between bearing preloads. The flexure design also maintains a spring constant with the growth to allow the parts to return to the original position.

Summary

While adding compliance to any bearing structure reduces the ultimate stiffness, the benefits can significantly outweigh the reduction in capacity. As the linear bearings discussed have tremendous stiffness and typically have applied loads that are a very small percentage of their capacity, the opportunity to improve bearing performance is substantial. While these bearing designs have diverse applications, they are appropriate to high performance motion systems demanding high acceleration, velocity, positioning accuracy, repeatability, or a combination of criteria. Clearly, there is measurable performance advantages that demonstrate the benefits of the technology.