

# Mechanisms of Positioning

A key element of a translation stage is its bearing structure. The design goals for these mechanisms involve having the highest possible load capacity with the lowest possible amount of friction and the most accurate desired path. Since a single design could not meet all the goals at once, several different mechanisms have evolved. Traditional bearing designs for long-travel stages include dovetail slides, ball bearings, and crossed-roller bearings. Flexures are the best choice for short-travel ultrahigh precision positioning. All of these are discussed below.

## DOVETAIL SLIDES

Dovetail slides (see figure 8.4) can be very simple and effective in systems requiring long travel and for applications involving heavy loads. They are less appropriate for high-precision systems because of their degree of resolution and precision. Stiction limits positional resolution and also provides a means whereby stored residual stress can be spontaneously released, causing creep and drift. Friction often imposes large forces upon the drive mechanism, exacerbating any stiction effects present in the drive. Finally, a dovetail slide depends on effective, whole-surface lubrication. The stage floats with a consequent lack of microscopic definition and is generally not suitable for high-precision applications.

## BALL BEARINGS

Ball-bearing stages (see figure 8.5) replace the friction of sliding motion used in dovetail slides by a lower friction rolling motion. A linear array of spherical balls is held between V-grooves or rails with a cage that prevents adjacent balls from touching one another. To minimize wobble, the rails are forcefully preloaded to apply pressure uniformly along the bearing. Because there is a very small area of contact between the ball and rail, small microscopic bumps influence stage motion. To eliminate play and wobble, all small irregularities must be effectively smoothed out by applying preload.

Bearings require lubrication to prevent seizing and reduce friction and stiction, thereby minimizing metal-to-metal contact. The balls make point contact with the rails, limiting their load-bearing capacity. To be effective, preload must be fairly high. This leads to some problems: friction and stiction are increased, and the preload may be temperature dependent. With aging, the preload may relax, causing lubricant to leak from the balls and rail. If this type of stage is abused—for example if the stage is dropped from a height—the ball bearings will indent the rails, causing permanent damage. It is generally not recommended to use ball-bearing slides for high-load applications. Ball bearings with point loading do have significant advantages including relatively low cost and resistance to contamination. The bearings have a self-cleaning action whereby any tiny dirt or dust particles are simply pushed clear by the rolling and squeezing action of the ball bearings.

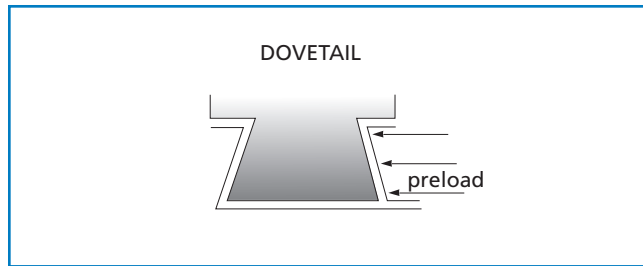


Figure 8.4 Dovetail slide

## CROSSED-ROLLER BEARINGS

Crossed-roller bearing stages (see figure 8.6) replace balls with small cylindrical steel rollers. The rollers are held apart from one another by a cage to prevent adjacent rollers from touching. By having the axis of rotation alternate or cross at 90 degrees, the stage can be preloaded and will operate at any angle. Point loading of the ball bearing is changed to a line contact with the roller bearing. Thus, because of the larger load-bearing surfaces (line rather than point), crossed-roller bearings can have a higher preload applied, carry greater loads, and meet very tight run-out specifications. The line contact type of mechanism also makes them much more resistance to damage from shock loads. However, the ability of these bearings to accept higher preloads means that preloading setscrews are subjected to much higher stress. This increases the problem of long-term creep and relaxation of the preload clamping force. Also, higher load-bearing capacity is achieved at the expense of higher friction and stiction.

Unlike the case of the ball bearings and flexure type of motion mechanisms, contamination is a particular problem with crossed-roller bearings. Dirt is rolled over and trapped on the rollers and tracks, continuously building up and grinding into the surface. The resulting increase in friction and stiction further limits ultimate resolution and leads to erratic motion with time. Crossed-roller bearing stages need to be protected from dust and dirt contaminants or have their bearings, and associated parts, cleaned and relubricated from time to time.

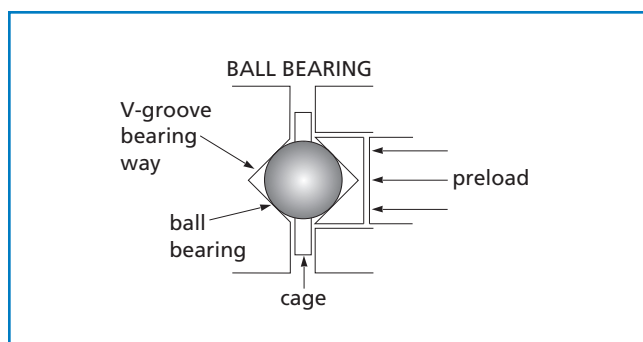


Figure 8.5 Ball bearing

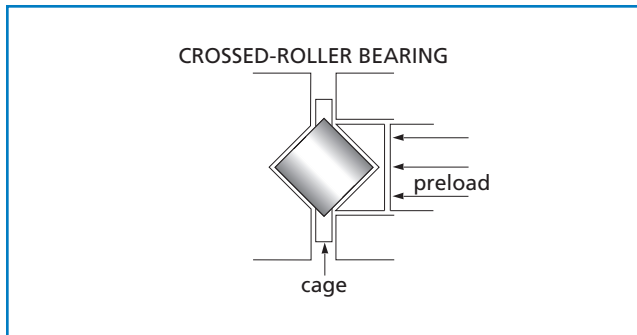


Figure 8.6 Crossed-roller bearing

### FLEXURES

The term *flexure* embraces a number of stictionless positioning devices which rely upon the elastic deformation of solid materials. A flexure may be as small as a quartz fiber or have a thickness of several millimeters. The principle aim is to achieve low stiffness in the direction of the required motion and high stiffness in all other directions without introducing undue stress and friction.

Flexures can be used in translation stages as well as in mirror mounts. When used in translation stages, a simple flexure normally approximates straight-line movement with a circular path, so there is a second-order cross coupling between axes. This is called arcuate motion. The stage platform moves toward the base as it is displaced longitudinally (see figure 8.7).

Flexure stages offer high stiffness and resistance to shock and rely on elastic deformation of a solid material; therefore, there is essentially no friction or stiction as there is in bearing designs. Both friction and stiction in a flexure stage are so small that they are not measurable, attributable only to interatomic interactions. In addition to having no internal friction, flexures have high stiffness and relatively high load capacity and resistance to shock, coupled with low sensitivity to vibration. The limitation of these devices in any application is that the travel is typically no more than 10 to 15 percent of the major dimension of the device, or the angle of rotation is only a few degrees (less than 15 degrees). Flexures are without equal when ultimate performance is a goal and the application can accept certain constraints.

### Principle of Operation of the Flexure

The flexure element constrains the stage in two axes so that the resulting motion occurs only in the desired direction. In the other axes, the flexure is rigid. The rigidity of the flexure in directions other than the axis of motion can be configured as required by strapping or stiffening the flexure to produce a rigid link with small regions of flexibility near the clamping points. If this semirigid link is sufficiently wide, then the resistance to twisting is greatly increased. Furthermore, strapped or stiffened flexures do not have the freedom to vibrate sympathetically at low frequencies since the only regions permitted to flex are typically about 0.5 mm wide and 30 mm long.

Use of a suitable return spring allows the flexure stage to be preloaded against the drive spindle. The net friction of the system is solely that remaining in the drive itself. Consequently, adding a piezoelectric actuator produces an electronically controllable stage with a resolution in the order of tens of nanometers or less.

With standard flexures, any movement in a given plane will produce a secondary displacement perpendicular to the principal plane (i.e., a moving platform tends to move toward the base of the fixed block as it is displaced longitudinally). This occurs because the flexures are fixed, and all displacements are actually associated with movement on an arc.

For many positioning applications, arcuate motion is not a problem, and the prime consideration is precision alignment and orientation in one direction. When precise movement is required in only one plane, special linearized compound flexures, which eliminate arcuate movement, are available. These consist of four continuous spring strips which are clamped at their ends and centers, as shown in figure 8.8.

Attaching the strips on both sides of the moving platform constrains the platform to linear motion. Mounting the moving platform in a saddle which also can move, and constraining its motion with similarly attached flexures, doubles the range of linear motion and increases the stiffness of the device.

Flexure technology provides the capability to design stages and component holders that are completely free from hysteresis, creep, drift, friction, and stiction. The positioning and alignment capability of a flexure device is limited only by the actuator mechanism.

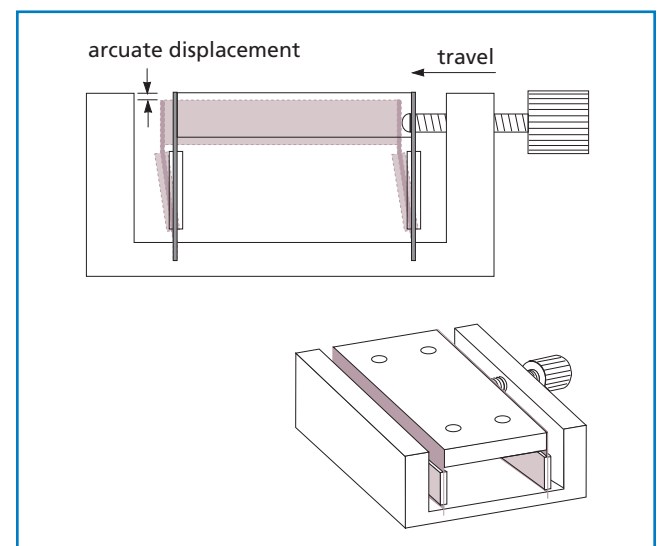


Figure 8.7 Simple flexure arrangement showing strapping of the flexures and arcuate motion

Figure 8.9 compares the resolution of various stage and actuator technologies. A high-resolution thumbscrew or micrometer actuator provides precision travel from many millimeters down to around 1  $\mu\text{m}$ . A differential micrometer provides 50 nm of resolution over a range of 300  $\mu\text{m}$ , and a piezoelectric actuator provides movement and resolution from around 100  $\mu\text{m}$  down to the region of 1 nm.



Single-axis compound-flexure stage

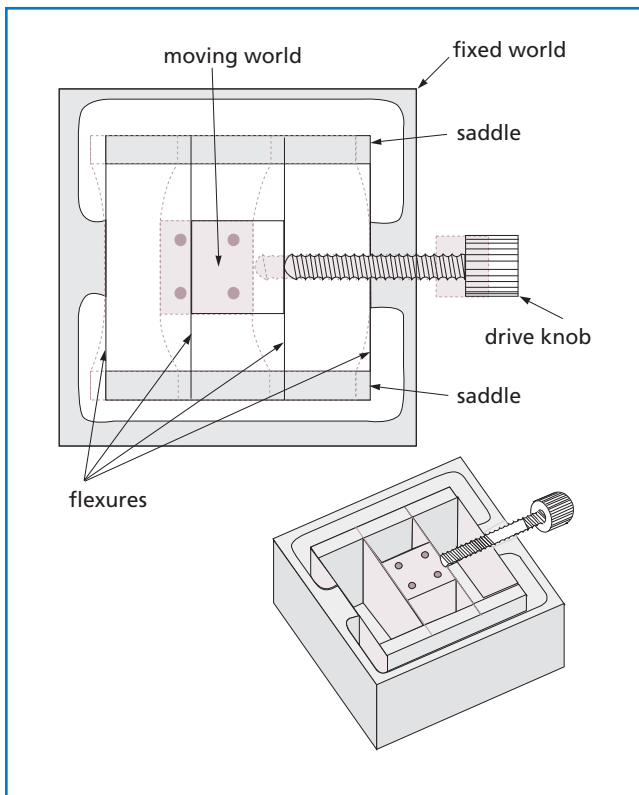


Figure 8.8 Compound-flexure arrangement providing rectilinear translation without arcuate motion

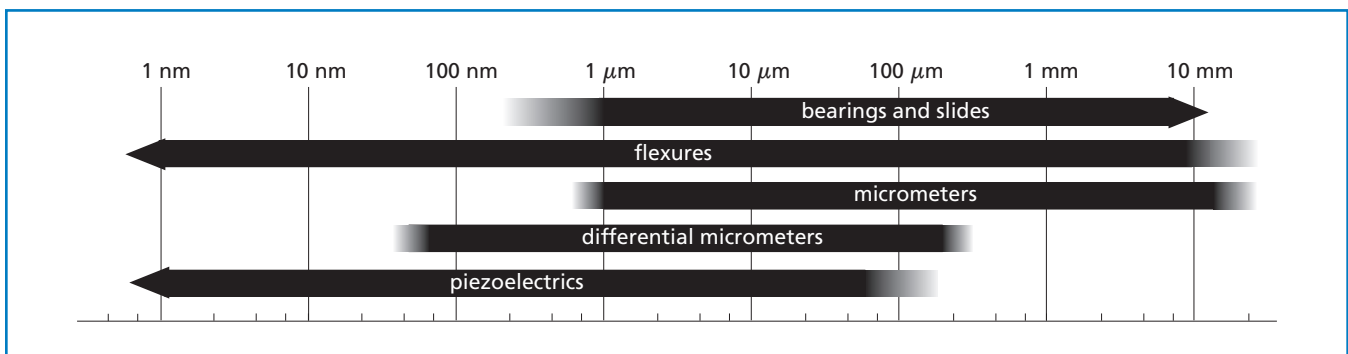


Figure 8.9 Comparison of the resolution properties achievable by various motion and drive technologies