Performance Parameters and Error Sources for Translation Stages

Movement along a single plane—vertical, horizontal, or even rotational—is called translation. There are several ways to move a stage or platform in this manner.

Horizontal translation stages are designed specifically to move components in a single, linear direction that is nominally perpendicular to gravitational force. Vertical translation stages are designed specifically to move components in a linear direction that is nominally parallel to gravitational force.

Vertical translation (elevation) can be accomplished in several ways. For example, horizontal stages may be mounted with an "L" bracket and used in place of a vertical stage, but in this case performance may be compromised. The most popular precision vertical translator is shown in figure 8.1. It uses a micrometer to drive a pivoting cam. This cam takes the horizontal motion of the micrometer and converts it to a vertical motion. The cam lifts a top plate which is constrained by a bearing assembly to travel only vertically. The component that needs to be moved is mounted on the top plate.

FLATNESS, STRAIGHTNESS, AND UNCERTAINTY

With a translation stage, any deviation from purely linear motion introduces positioning error. The three major types of error in a horizontal translation stage are illustrated in figure 8.2.

Flatness is a term used to refer to the variation in the vertical (z) direction over the length of travel. The variation may come from machining inaccuracies in the bearing structure, dirt and contamination, or arcuate motion.

Straightness is defined as the variation in the horizontal (y) direction over the length of travel. This variation may result from bending and misalignment of the bearing ways, in addition to the causes mentioned above.

Position uncertainty is caused by various sources, including backlash, friction, and stiction. Increasing the amount of friction, by applying additional load to the device, will likewise decrease resolution and increase the degree of position uncertainty in most positioners.

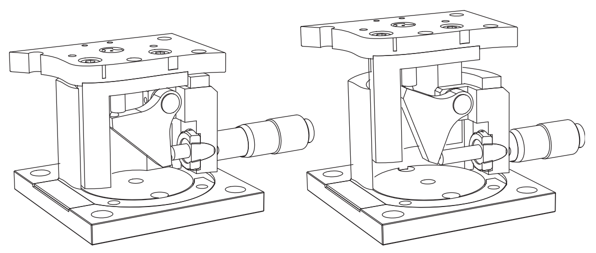

Figure 8.1 **Micrometer- and cam-driven vertical (z-axis) stage**

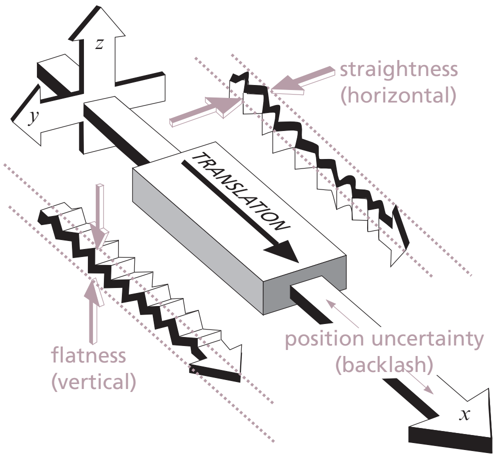

Figure 8.2 **Major sources of error in a horizontal translation stage**

ACCURACY

Accuracy is the absolute deviation between desired and actual position. Ideally, motion is constrained to just one axis in a translation stage. Any deviation is caused by way assembly runout errors. These errors can result in translation in the y or z axes or rotation about θx (roll), θy (pitch), or θz (yaw). Errors in flatness (z-runout) and straightness (y-runout) are generally the consequence of underlying angular errors.

ANGULAR DEVIATION

Angular deviation, which is always present to some degree, can greatly affect the position of a component mounted to a stage. Pitch errors are common in bearing stages owing to the overhanging nature of the load at the two extremes of travel. This pitch error produces a corresponding runout error in the z axis.

REPEATABILITY

Repeatability is the error within which a given position can be reproduced. Unidirectional repeatability, measured by approaching a position from a single direction, hides errors caused by backlash and hysteresis effects. Bidirectional repeatability, measured by approaching a position from opposing directions, includes these effects and provides a more meaningful specification.

RESOLUTION

Resolution is defined as the smallest increment of movement that a stage can make. Resolution can be enhanced by using finer pitch micrometers or adjustment screws, using larger adjustment knobs, and minimizing friction and backlash. Meaningful resolution should be measured by motion of the total stage system, not just the drive mechanism. Friction and stiction ultimately are the limiting factors in determining the degree of resolution. The lower the friction is the finer will be the degree of resolution that can be achieved. It follows that increasing the amount of friction on a positioner will adversely affect the degree of resolution.

ABBÉ ERROR

Abbé error, illustrated in figure 8.3, is the linear positional error caused by the combination of the axes of measurement being offset from the plane of motion and an angular error in that motion. Abbé error has the worst impact on linear positioning accuracy. Post-mounted components on translation stages typically experience an Abbé error which increases as the distance between stage bearings and the mounted component increases. An angular error in θy (pitch) of a stage will result in a positional error in y and an axis shift in z of a post-mounted component. Sources of Abbé error include way curvature, preload variation along a way, insufficient preload, contamination between the bearings and way surfaces, and torsional compliance caused by external forces acting on the load and overhanging components. Abbé error can be minimized by keeping the axis of measurement as close to the plane of motion as possible.

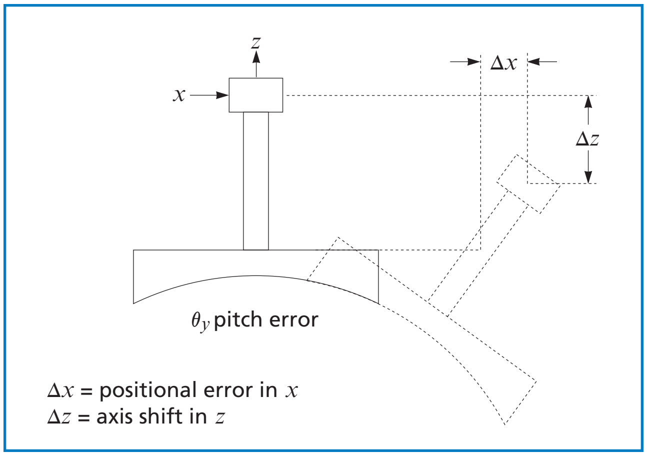

Figure 8.3 **Abbé error**

Components mounted on long posts experience the most Abbé error.

ARCUATE MOTION ERROR

This type of motion error occurs in stages where the design of the stage is based on a flexure mechanism. Typically, the flexure is fixed at one end while pressure is applied to it at the other. This means that the resulting displacement is actually associated with movement on a curved arc. In other words, any movement in a given plane will produce a secondary displacement in a direction that is perpendicular to the principal plane. In this case, as the moving platform is displaced in the longitudinal direction, it also tends to move toward the base of the fixed block. This undesirable displacement in the direction perpendicular to the intended direction of translation is referred to as the arcuate displacement or error.

COSINE ERROR

Cosine error is the result of an angular misalignment between the motion of the translation stage and that of the actuator (or other accuracy-determining component). The magnitude of the error, equal to the actuator travel times $(1 - \cos\theta)$ where θ is the actuator misalignment, has a negligible effect on the overall accuracy of the stage. For example, if a translation stage with 25 mm of travel has an actuator with a 1-degree misalignment, this results in an error of just 3.8 µm over the entire range of travel.