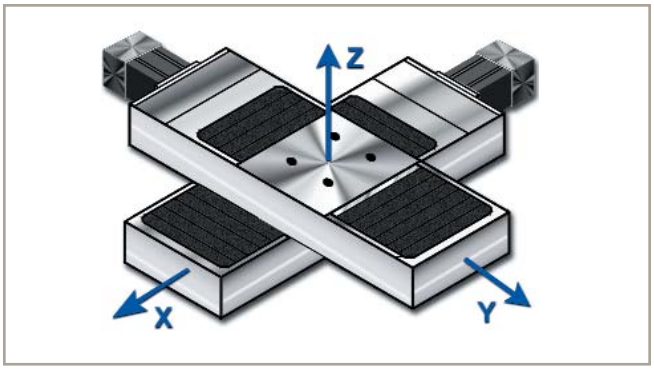
Linear Stage Terminology

There are many factors that affect the capabilities of a linear stage to position accurately in three-dimensional space. Abbe errors, straightness, flatness, pitch, roll, yaw, hysteresis, backlash, orthogonal alignment, encoder errors, mounting surface, and cantilevered loading all contribute to positioning errors in three-dimensional space.

Note: The Specification tables in this catalog contain values for stage positioning accuracy. This specification reflects the positioning capabilities of the stage in the direction of travel only. These values should not be taken as a representation of the positioning capabilities of the stage in three-dimensional space when configured as part of a multi axis configuration. When two or more positioning stages are assembled in a multi-axis configuration, additional factors will cause positioning errors in three-dimensional space.

For discussion purposes, the following sections will reference a set of two translation stages assembled into an X-Y assembly. The lower stage in the assembly is aligned so that the stage travels in a horizontal plane in the X-axis direction in three-dimensional space (X-axis). The upper stage is assembled on the first stage and travels in a horizontal plane in the Y-axis direction in three-dimensional space (Y-axis).



Abbe Error — Displacement error caused by angular errors in bearing ways and an offset distance between the point of interest and the drive mechanism (ball screw) or feedback mechanism (linear encoder).

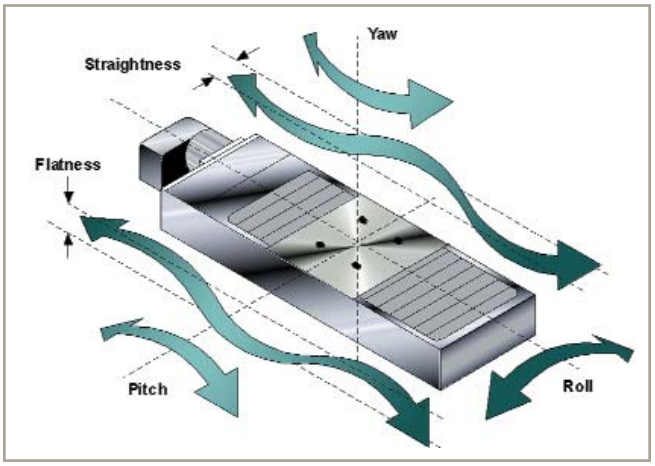
Straightness — Straightness is a deviation from the true line of travel perpendicular to the direction of travel in the horizontal plane. For the stage assembly listed above, a straightness deviation in the travel of the X-axis stage will cause a positioning error in the Y direction. A straightness deviation in the travel of the Y-axis stage will cause a positioning error in the X direction.

Flatness (a.k.a. vertical straightness) — Flatness is a deviation from the true line of travel perpendicular to the direction of travel in the vertical plane. For the stage assembly shown, a flatness deviation in the travel of the X-axis or Y-axis stage will cause a positioning error in the Z direction.

Pitch — Pitch is a rotation around an axis in the horizontal plane perpendicular to the direction of travel. If the position of interest being measured is not located at the center of rotation, then the pitch rotation will cause an Abbe error in two dimensions. For the X-axis, a pitch rotation will cause an Abbe error in both the X and Z direction. For the Y-axis, a pitch rotation will cause an Abbe error in both the Y and Z direction. The magnitude of these errors can be determined by multiplying the length of the offset distance by the sine and 1-cosine of the rotational angle.

Example: X-axis

Pitch Angle (Φ) = *10 arc sec (.0027°)*
Offset Distance (D) = *25 mm (1 in)*
Error • direction = *D • (1 - cos (.0027°))*
= *25 mm • (1-cos (.0027°)*
= *0.00003 µm*
Error z direction = *D • sin Φ*
= *25 mm • sin (.0027°)*
= *1.18 µm*



Roll — Roll is a rotation around an axis in the horizontal plane parallel to the direction of travel. If the position of interest being measured is not located at the center of rotation, then the roll rotation will cause an Abbe error in two dimensions. For the X-axis, a roll rotation will cause an Abbe error in both the Y and Z direction. For the Y-axis, a roll rotation will cause an Abbe error in both the X and Z direction. The magnitude of these errors can be calculated by multiplying the length of the offset distance by the sine and cosine of the rotational angle.

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Yaw — Yaw is a rotation around an axis in the vertical plane perpendicular to the direction of travel. If the position of interest being measured is not located at the center of rotation, then the yaw rotation will cause an Abbe error in two dimensions. For X- or Y-axis stages, yaw rotation will cause an Abbe error in both the X and Y direction. The magnitude of these positioning errors can be calculated by multiplying the length of the offset distance by the sine and cosine of the rotational angle.

Hysteresis Error — Hysteresis error is a deviation between the actual and commanded position at the point of interest caused by elastic forces in the motion system. Hysteresis also affects bi-directional repeatability. Accuracy and repeatability errors caused by hysteresis for Aerotech linear positioning stages are included in the stage specification tables. Elastic forces in the machine base, load, and load coupling hardware are not accounted for and must also be examined and minimized for optimal performance.

Backlash Error — Backlash error is an error in positioning caused by the reversal of travel direction. Backlash is the portion of commanded motion that produces no change in position upon reversal of travel direction. Backlash is caused by clearance between elements in the drive train. As the clearance increases, the amount of input required to produce motion is greater. This increase in clearance results in increased backlash error. Backlash also affects bi-directional repeatability. Accuracy and repeatability errors caused by backlash for Aerotech linear positioning stages are accounted for in the stage specification tables. Linear motor-based stages are direct drive and therefore have zero backlash.

Encoder Error — Imperfections in the operation of the encoder such as absolute scale length, non-uniform division of the grating scale, imperfections in the photo-detector signal, interpolator errors, hysteresis, friction, and noise can affect the positioning capabilities of the linear translation stage. The accuracy and repeatability information in the specification tables takes all of these errors into account except absolute scale length. Absolute scale length is affected by thermal expansion of the encoder scale. Temperature considerations must be accounted for during system design and specification.

Orthogonal Alignment — For the two stages to travel precisely along the X and Y axes, the line of travel for the Y-axis must be orthogonal to the line of travel of the X-axis. If the two travel lines are not orthogonal, Y-axis travel creates a position error in the X direction. The maximum value of this error can be determined by multiplying the travel length of the stage by the sine of the angular error.

Example:

Orthogonality Error	*= 5 arc sec (0.0014°)*
Travel Length (L)	*= 400 mm (16 in)*
Error	*= L • sin θ*
	= 400 mm • sin (0.0014°)
	= 9.8 µm

Machine Base Mounting Surface – The machine base plays an important role in the performance of the linear translation stage. Aerotech stages typically require that the surface of the machine must have a localized flatness deviation of less than 5 µm (0.0002 in) to guarantee the stage specification. Mounting the stage to a machine base with flatness deviations greater than the specification can deflect the stage. Distortion in an Aerotech translation stage can cause pitch, roll, yaw, flatness, and straightness deviations greater than the specifications listed.

Cantilevered Loading – When a cantilevered load is placed on a translation stage, moment loads are created. Shear and bending forces induce deflection in the stage structural elements. In an X-Y assembly, the cantilevered load, acting on the lower axis, increases as the load traverses to the extremes of the upper axis. A position error in the Z direction occurs due to a combination of Y-axis deflection and X-axis roll.