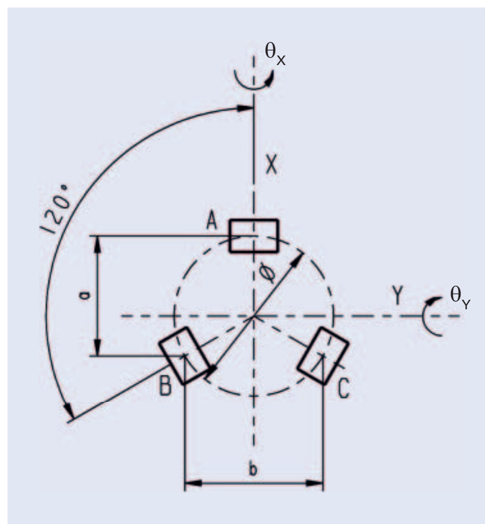
Kinematics of Multi-Axis Tip/Tilt Systems

Piezo tip/tilt mirror systems from PI are based on parallel kinematics with a single movable platform for all directions of motion. The systems achieve a higher linearity than can be attained by switching two single-axis systems in succession, as is the case with galvanoscanners, for example, and therefore, are very compact.



Arrangement of the actuators of a tripod piezo drive

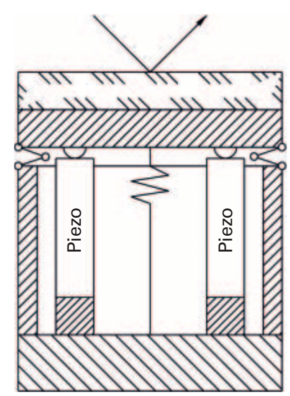
The tilt angle and the travel in Z are calculated using the following formulas:

$$\theta_Y = 2A - \frac{(B+C)}{2a}$$

$$\theta_X = \frac{(B-C)}{b}$$

$$Z = \frac{(A+B+C)}{3}$$

A, B, C is the linear displacement of the relevant actuators.



Principle of a tilt system with differential piezo drive

Piezo-actuated tip/tilt mirrors and platforms are suitable both for highly dynamic operation, such as tracking, scanning, image stabilization, elimination of drift and vibration, and for static positioning of optical systems and samples.

They allow for an optical beam deflection up to 100 mrad, extremely short response times from milliseconds to microseconds and resolutions down to nanoradians.

PI offers a large range from compact systems for laser beam steering up to large units used for astronomy.

Tip/Tilt System with Tripod Piezo Drive

The platform is driven by three piezo actuators that are located in 120° angles to one another. By means of coordinate transformation, the motion can be split among the different actuators.

In addition to tilting, the platform may also be used linearly in Z direction, which is important, for example, for correcting optical path lengths (phase shifters).

Tip/Tilt System with Differential Piezo Drive (Tetrapod)

The platform is driven by two pairs of piezo actuators located in 90° angles to one another. Four actuators are controlled differentially in pairs, depending on the tilt direction. The tilt axes θ_X and θ_Y are arranged orthogonally so that a coordinate transformation is not necessary.

This concludes in an excellent stability in linear and angular positioning for a wide temperature range.

Just as the tripod, the differential version guarantees an optimum angular stability over a large temperature range. For position controlled versions, the differential evaluation of two sensors per axis provides an improved linearity and resolution.

Dynamics of a Piezo Tip/Tilt Mirror

The maximum operating frequency of a piezo tip/tilt system strongly depends on its mechanical resonant frequency. The properties of amplifier, controller and sensor are also important. To estimate the effective resonant frequency of the system – a combination of platform and mirror – it is necessary to calculate the moment of inertia of the mirror substrate first.

Moment of inertia of a rotationally symmetric mirror:

$$I_M = m\left[\frac{2R^2 + H^2}{12} + \left(\frac{H}{2} + T\right)^2\right]$$

Moment of inertia of a rectangular mirror:

$$I_M = m\left[\frac{L^2 + H^2}{12} + \left(\frac{H}{2} + T\right)^2\right]$$

with:

m = mirror weight [g]

I_M = moment of inertia of a mirror [g × mm²]

L = mirror length orthogonally to tilt axis [mm]

H = mirror thickness [mm]

T = distance of pivot point to platform surface (see technical data of individual models) [mm]

R = mirror radius [mm]

The resonant frequency of the system is calculated with resonant frequency of the platform (see technical data) and moment of inertia of the mirror substrate using the following formula:

$$f' = m \frac{f_0}{\sqrt{1 + I_M/I_0}}$$

Resonant frequency of a piezo tip/tilt system with mirror

with:

f' = resonant frequency of platform with mirror [Hz]

f_0 = resonant frequency of platform without mirror [Hz]

I_0 = moment of inertia of platform (see technical data) [g × mm²]]

I_M = moment of inertia of mirror [g × mm²]

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