Fast Steering Mirrors / Active Optics
Single and Multi-Axis Piezo Steering Mirrors for Industry & Research
Selection Guide: Piezo Steering Mirrors

Fast Steering Mirrors (FSM), Tip/Tilt Platform & Active Optics

Piezo-driven tip/tilt platforms and scanners (steering mirrors, beam deflectors, phase shifters) provide higher accelerations and bandwidth than other actuators such as voice-coils or galvos. All are flexure-guided for zero friction and stiction and excellent guiding accuracy. Multiaxis models are parallel-kinematic designs with coplanar axes. Open- and closed-loop models with strain gauge and capacitive sensors (highest precision) are available.

PI FSM’s provide resolution down to nanoradians and excellent position stability. They can perform optical beam steering over ranges of up to 120 mrad, and have extremely low response times (milliseconds to microseconds). They are ideal for dynamic operation (e.g. tracking, scanning, drift and vibration cancellation) as well as static positioning of optics and samples.

<table>
<thead>
<tr>
<th>Models</th>
<th>Description</th>
<th>Axes</th>
<th>Tilt Angle / opt Deflection (mrad)</th>
<th>Linear Travel (µm)</th>
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<tr>
<td>S-310, S-316</td>
<td>Clear aperture, 5 models, open- and closed-loop, Z-actuators and Z/tip/tilt versions, for optics to 1” diameter</td>
<td>1 &amp; 3</td>
<td>0.6 / 1.2 or 1.2 / 2.4</td>
<td>6 / 12</td>
<td>SGS</td>
<td>2-94</td>
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<td>S-325</td>
<td>3-axis (tripod) Z/tip/tilt platform for optics to 1” diameter</td>
<td>3</td>
<td>5 / 10</td>
<td>30</td>
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<td>S-334</td>
<td>Ultra-compact 2-axis FSM with largest optical deflection to 120 mrad. With 10 mm mirror</td>
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<td>60 / 120</td>
<td></td>
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<td>S-330</td>
<td>High-dynamics tip/tilt FSM with two orthogonal axes, for optics to 2” diameter. 3 models</td>
<td>2</td>
<td>2 / 4, 5 / 10, 10/ 20</td>
<td>–</td>
<td>SGS</td>
<td>2-88</td>
</tr>
<tr>
<td>S-224, S-226</td>
<td>With mirror, compact, very fast, available with sensor or without</td>
<td>1</td>
<td>to 2.2 / 4.4</td>
<td>–</td>
<td>SGS</td>
<td>2-96</td>
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<tr>
<td>S-303</td>
<td>Phase Shifters. Extremely precise, 25 kHz resonant frequency, optional sensors</td>
<td>1</td>
<td>–</td>
<td>3</td>
<td>Capacitive</td>
<td>2-96</td>
</tr>
<tr>
<td>S-323</td>
<td>Z/tip/tilt platform, high dynamics</td>
<td>2</td>
<td>3 / 6</td>
<td>30</td>
<td>Capacitive</td>
<td>2-96</td>
</tr>
<tr>
<td>P-541.Z</td>
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<td>3</td>
<td>1</td>
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<td>P-528</td>
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<td>3</td>
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<td>Capacitive</td>
<td>2-46</td>
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<tr>
<td>N-510</td>
<td>Tripod Z-tip/tilt Nanopositioning Platform</td>
<td>3</td>
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<td>1300</td>
<td>Linear encoder</td>
<td>1-17</td>
</tr>
</tbody>
</table>

More tip/tilt piezo stages see p. 2-25 ff
Notes on specifications see p. 2-97 ff
Piezo Tip/Tilt Mirrors Fundamentals

Single Axis Designs

Single-Axis Systems / Scanners
Two designs of single-axis (θz) tilt platforms are available:

I. Single-Flexure, Single-Actuator Tilt Platform
Examples: S-224 and S-226.

The platform is supported by one flexure and pushed by one linear piezo actuator (see Fig. 1). The flexure determines the pivot point and doubles as a preload for the piezo actuator. The advantages of the single-flexure, single-actuator design are the straightforward construction, low cost and small size. If angular stability over a wide temperature range is a critical issue, the differential piezo drive is recommended.

II. Differential-Piezo-Drive Tilt Platform
This design features two piezo actuators operating in push/pull mode supporting the platform (see Fig. 2). The actuators are wired in a bridge which is supplied with a constant and a variable drive voltage. The case features integrated zero-friction, zero-stiction flexures which assure excellent guiding accuracy.

The differential design exhibits excellent angular stability over a wide temperature range. With this arrangement, temperature changes only affect the vertical position of the platform (piston motion) and have no influence on the angular position. In the closed-loop models, availability of two sensor signals permits better linearity and resolution.

A variety of single- and multi-axis implementations is possible.

Multi-Axis Tip/Tilt Systems / Scanners

PI offers two standard designs, both using parallel kinematics. Parallel kinematics systems have the following advantages over serial systems: only one moving platform, fixed pivot point, better dynamics, smaller form-factor. In addition, the design offers better linearity than attainable with two single-axis systems (e.g. two galvoscanners) in a stacked configuration.

I. Piezo Tripod Z/Tip/Tilt Platform
Examples: S-315 and S-316, S-325.

The platform is supported by three piezo actuators spaced at 120° intervals. Because expansion of an individual actuator affects both θx and θy, more complex control algorithms are required.

With coordinate transformation, platform position commands can be resolved into targets for individual actuators (see the equations and Fig. 3 for details). The piezo tripod has one advantage over the differential drive: in addition to tilt motion, it allows active vertical control (piston motion) of the platform—an important feature for applications involving optical path-length adjustment (phase-shifting).

Also, the design allows for a central clear aperture, ideal for transmitted-light applications. As with the differential drives, temperature changes have no effect on the angular stability.

II. Differential-Piezo-Drive Tip/Tilt Platform

The platform is driven by two pairs of piezo actuators arranged at 90° angles. Each pair is controlled as a unit in push-pull mode. The four actuators are connected in a bridge circuit and supplied with one fixed and two variable voltages. Because each actuator pair is parallel to one of the orthogonal tip/tilt axes θx and θy, no coordinate transformation is required.

Like the piezo tripod design, the differential drive exhibits excellent angular stability over a wide temperature range. In the closed-loop models, availability of two sensor signals permits better linearity and resolution.

A variety of single- and multi-axis implementations is possible.
Dynamic Behavior of Piezo Steering Mirrors

The maximum operating frequency of a tilt platform is heavily dependent on its mechanical resonant frequency. The performance characteristics of the amplifier, servocontroller and sensors are also very important. To estimate the effective resonant frequency of the tilt mirror system (platform + mirror), the moment of inertia of the mirror substrate must first be calculated.

Moment of inertia of a rotationally symmetric mirror:

\[ I_M = m \left( \frac{3R^2 + H^2}{12} + \left( \frac{H}{2} + T \right) \right) \]

Moment of inertia of a rectangular mirror:

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

where:

- \( m \) = mirror mass [g]
- \( I_M \) = moment of inertia of the mirror [g · mm²]
- \( L \) = mirror length perpendicular to the tilt axis [mm]
- \( H \) = mirror thickness [mm]
- \( T \) = distance, pivot point to platform surface (see technical data table for individual model) [mm]
- \( R \) = mirror radius [mm]

Using the resonant frequency of the unloaded platform (see individual technical data table) and the moment of inertia of the mirror substrate, the system resonant frequency is calculated according to the following equation:

Resonant frequency of a tilt platform/mirror system

\[ f' = \frac{f_0}{\sqrt{1 + I_M/I_0}} \]

where:

- \( f' \) = resonant frequency of platform with mirror [Hz]
- \( f_0 \) = resonant frequency of unloaded platform [Hz]
- \( I_0 \) = moment of inertia of the platform (see technical data table for the individual model) [g · mm²]
- \( I_M \) = moment of inertia of the mirror [g · mm²]

For more information on static and dynamic behavior of piezo actuators, see pp. 2-196 ff.
Resolution in large earthbound telescopes is limited by atmospheric turbulence and vibrations. During the last 15 years PI has designed several large-aperture tip/tilt systems for image stabilization. Piezoelectrically driven active secondary mirrors can improve the effective resolution up to 1000% by correcting for these image shifts in real time, especially during long integrations with weak light sources.

**Momentum Compensation**
Due to the inertia of the large mirrors and the high accelerations required to correct for image fluctuations, significant forces can be induced in the telescope structure, causing unwanted vibrations. PI has developed momentum compensation systems integrated into the tip/tilt platforms which cancel undesirable vibrations and thus offer significantly better stabilization than uncompensated systems.

**High-Resolution Linear Actuators**
273 PI actuators are used for tip/tilt/piston movement of segmented mirror panels in the SALT Telescope. Features: 16 nm design resolution; 0.15 μm minimum incremental motion; non-rotating tip, compact design.
Active Optics / Steering Mirrors

Fast Steering Mirrors: Why Piezo?

- Faster and more precise than conventional actuators
- Better stability through differential drive designs
- Stiff mechanical interface, 1 DOF only
- Tip/tilt & piston movements
- Up to Ø50 cm apertures

Applications of Fast Steering Mirrors

- Fast beam steering, alignment, switching
- Image resolution enhancement (pixel multiplication, dithering)
- Optical path length stabilization
- Vibration cancellation (laser systems, imaging)
- Interferometry, Fabry-Perot filters
- Image stabilization, high speed background subtraction

- Laser beam stabilization (resonators, optical setups)
- Laser beam scanning (lithography, optical setups)
- Laser beam steering and tracking (telecommunication satellites, etc.)
- Bore-sight systems
- Dynamic error correction (e.g. in polygon scanning mirrors)
- Mass storage device testing and manufacture
Piezo nanopositioning systems are significant investments and PI believes in optimizing the performance of every customer’s system. PI individually tests every stage and optimizes the static and dynamic performance for the customer’s application. The metrology test protocol is part of the system’s delivery package. It shows the customer what the performance of the system was at the time of delivery and which system components belong together. For PI every metrology procedure and its recording is a quality assurance instrument, and only nanopositioning systems which meet their specifications will leave the premises.

Furthermore, PI makes significant continuing investments in improved-quality, high-performance nanometrology equipment so that we can deliver better value to our customers. Because a nanomechanism can only be as accurate as the equipment it was tuned and tested with, PI closed-loop stages are measured exclusively with prestigious Zygo interferometers. PI’s nanometrology metrology laboratories are seismically, electromagnetically and thermally isolated, with temperatures controlled to better than 0.25 °C / 24 hrs. We are confident that our metrology capabilities and procedures are the benchmark for the industry.

An S-334 long-range 2-axis fast steering mirror measured with a Moeller Wedel autocollimator

An S-340 2-axis fast steering mirror platform measured with a Zygo interferometer
S-330 Piezo Tip/Tilt-Platform

High-Dynamics, Large-Angle Piezo Tip/Tilt Platforms for Fast Steering Mirrors

These flexure-guided, piezoelectric platforms can provide higher accelerations than other implementations, enabling step response times in the sub-millisecond range. Closed-loop and open-loop versions with 3 different tilt ranges up to 10 mrad (20 mrad optical deflection) are available.

Parallel-kinematics design for improved stability, linearity and dynamics

PI piezo tip/tilt mirror systems are based on a parallel-kinematics design with coplanar axes and a single moving platform. Two pairs of differential-driven piezo actuators are employed to provide the highest possible angular stability over a wide temperature range. Compared to stacked, two-stage piezo or galvo scanners, the single-platform design provides several advantages: smaller package size, identical dynamic performance in both axes, faster response and better linearity. It also prevents polarization rotation.

Resolution to 20 mrad, Excellent Position Stability
Optical Beam Deflection to 20 mrad (>1°)
Higher Dynamics, Stability & Linearity Through Parallel-Kinematics Design
Sub-Millisecond Response
For Mirrors up to 50 mm Diameter
Closed-Loop Versions for Better Linearity
Excellent Temperature Stability

Application Examples

- Image processing / stabilisation
- Interlacing, dithering
- Laser scanning / beam steering
- Optics
- Optical filters / switches
- Beam stabilization

Ordering Information

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Controller</th>
<th>Connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-330.2SL</td>
<td>High-Dynamics Piezo Tip/Tilt Platform, 2 mrad, SGS, LEMO Connector</td>
<td>E-616</td>
<td>LEMO Connector</td>
</tr>
<tr>
<td>S-330.2SD</td>
<td>High-Dynamics Piezo Tip/Tilt Platform, 2 mrad, SGS, Sub-D Connector</td>
<td>E-616</td>
<td>Sub-D Connector</td>
</tr>
<tr>
<td>S-330.8L</td>
<td>High-Dynamics Piezo Tip/Tilt Platform, 10 mrad, Open-Loop, LEMO Connector</td>
<td>E-616</td>
<td>LEMO Connector</td>
</tr>
<tr>
<td>S-330.4SL</td>
<td>High-Dynamics Piezo Tip/Tilt Platform, 5 mrad, SGS, LEMO Connector</td>
<td>E-616</td>
<td>LEMO Connector</td>
</tr>
<tr>
<td>S-330.8SD</td>
<td>High-Dynamics Piezo Tip/Tilt Platform, 10 mrad, SGS, Sub-D Connector</td>
<td>E-616</td>
<td>Sub-D Connector</td>
</tr>
<tr>
<td>S-330.8OL</td>
<td>High-Dynamics Piezo Tip/Tilt Platform, 10 mrad, Open-Loop, LEMO Connector</td>
<td>E-616</td>
<td>LEMO Connector</td>
</tr>
</tbody>
</table>

S-330 piezo tip/tilt platforms are fast and compact tip/tilt units, providing precise angular motion of the top platform around two orthogonal axes. They provide a high-bandwidth, position feedback signal to the controller. The sensors are connected in a bridge configuration to eliminate thermal drift, and assure optimal position stability. Open-loop systems are also available.

Circuit diagram and cable configuration of the S-330.xSL closed-loop versions.

The S-330.xSD models feature a single Sub-D connector and can be operated by the E-616 controller.
Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.
S-334 Miniature Piezo Tip/Tilt-Mirror

Fast Steering Mirror with up to 120 mrad Deflection

**Ordering Information**

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Description</th>
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</thead>
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<tr>
<td>S-334.2SD</td>
<td>High-Dynamics Piezo Tip/Tilt Platform, 50 mrad, SGS, Sub-D Connector, incl. Mirror</td>
</tr>
<tr>
<td>S-334.2SL</td>
<td>High-Dynamics Piezo Tip/Tilt Platform, 50 mrad, SGS, LEMO Connector, incl. Mirror</td>
</tr>
</tbody>
</table>

**Application Examples**

- Image processing / stabilization
- Interlacing, dithering
- Laser scanning / beam steering
- Optics
- Optical filters / switches
- Scanning microscopy
- Beam stabilization

**Miniature Design**

- Optical Beam Deflection to 120 mrad (~ 6.8°)
- Coplanar Axes & Fixed Pivot Point Eliminate Polarization Rotation
- Factory Installed Mirror
- Millisecond Response, Resolution to 0.5 μrad
- Closed-loop Position Servo-Control for High Accuracy
- For Mirrors up to 12.5 mm (0.5”) Diameter
- Frictionless, High-Precision Flexure Guiding System
- Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy

S-334 piezo tip/tilt mirrors / scanners provide extremely large deflection angles in a miniaturized package. These fast steering mirror systems are based on a sophisticated parallel-kinematics design with two coplanar, orthogonal axes and a fixed pivot point.

**Large Tip/Tilt Ranges with Excellent Motion Characteristics**

The novel flexure/lever design with minimized inertia allows for the exceptionally large tip/tilt range of 60 mrad (50 mrad in closed-loop operation, which is equivalent to 100 mrad optical beam deflection) and very fast response in the millisecond range. These parameters make the system unique in the market of piezo driven tip/tilt mirror systems.

**Sub-Microradian Resolution**

In addition to the large angles and the high dynamics the S-334 provides sub-micro-radian resolution. The integrated high-resolution, full-bridge strain gauge sensors (SGS) provide absolute position control, excellent repeatability and high linearity, typically better than 0.25% over the entire travel range.

**Differential Drive for Improved Stability and Dynamics**

The S-334 is based on a parallel-kinematics design with coplanar axes and a single moving platform. Two pairs of differentially-driven piezo actuators are employed to provide the highest dynamics and position stability over a wide temperature range.

Compared to stacked, (two-stage), piezo or galvo scanners, the single-platform design provides several advantages: smaller package size, identical dynamic performance in both axes, faster response and better linearity. It also prevents polarization rotation.

**High Reliability and Long Lifetime**

The compact S-334 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and provide better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free, not subject to wear and offer extraordinary reliability.

**Factory Installed Mirror**

The S-334 is equipped with a factory-installed mirror 10 mm in diameter and 2 mm thick (flatness λ/5, reflectivity >98% from 500 nm to 2 μm).
Technical Data

<table>
<thead>
<tr>
<th>Model</th>
<th>S-334.2SL</th>
<th>S-334.2SD</th>
<th>Units</th>
<th>Tolerance</th>
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<tbody>
<tr>
<td>Active Axes</td>
<td>θx, θy, θz</td>
<td>θx, θy, θz</td>
<td>mrad</td>
<td>min. (+20 %/-0 %)</td>
</tr>
<tr>
<td>Motion and positioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated sensor</td>
<td>SGS</td>
<td>SGS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*Open-loop tilt angle at -20 to +120 V</td>
<td>60</td>
<td>60</td>
<td>mrad</td>
<td></td>
</tr>
<tr>
<td>*Closed-loop tilt angle</td>
<td>50</td>
<td>50</td>
<td>mrad</td>
<td></td>
</tr>
<tr>
<td>Open-loop resolution</td>
<td>0.5</td>
<td>0.5</td>
<td>μrad</td>
<td>typ.</td>
</tr>
<tr>
<td>Closed-loop resolution</td>
<td>5</td>
<td>5</td>
<td>μrad</td>
<td>typ.</td>
</tr>
<tr>
<td>Linearity</td>
<td>0.05</td>
<td>0.05</td>
<td>%</td>
<td>typ.</td>
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<tr>
<td>Repeatability</td>
<td>5</td>
<td>5</td>
<td>μrad</td>
<td>typ.</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Resonant frequency under load (with standard mirrors)</td>
<td>1.0</td>
<td>1.0</td>
<td>kHz</td>
<td>±20 %</td>
</tr>
<tr>
<td>Resonant frequency with 12.5 mm diam. x 2 mm glass mirror</td>
<td>0.8</td>
<td>0.8</td>
<td>kHz</td>
<td>±20 %</td>
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<tr>
<td>Load capacity</td>
<td>0.2</td>
<td>0.2</td>
<td>N</td>
<td>Max.</td>
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<tr>
<td>Distance of pivot point to platform surface</td>
<td>6</td>
<td>6</td>
<td>mm</td>
<td>±1 mm</td>
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<tr>
<td>Platform moment of inertia</td>
<td>1530</td>
<td>1530</td>
<td>g x mm²</td>
<td>±20 %</td>
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<tr>
<td>Standard mirror (mounted)</td>
<td>diameter: 10 mm, thickness: 2 mm, BK7, λ/5, R &gt; 98 % (λ = 500 nm to 2 μm)</td>
<td>diameter: 10 mm, thickness: 2 mm, BK7, λ/5, R &gt; 98 % (λ = 500 nm to 2 μm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive properties</td>
<td></td>
<td></td>
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<tr>
<td>Ceramic type</td>
<td>PICMA® P-885</td>
<td>PICMA® P-885</td>
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<tr>
<td>Electrical capacitance</td>
<td>6</td>
<td>6</td>
<td>μF</td>
<td>±20 %</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Operating temperature range</td>
<td>-20 to 80</td>
<td>-20 to 80</td>
<td>°C</td>
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</tr>
<tr>
<td>Material casing</td>
<td>Titanium</td>
<td>Titanium</td>
<td></td>
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</tr>
<tr>
<td>Mass</td>
<td>0.065</td>
<td>0.065</td>
<td>kg</td>
<td>±5 %</td>
</tr>
<tr>
<td>Cable length</td>
<td>2</td>
<td>2</td>
<td>m</td>
<td>±10 mm</td>
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<tr>
<td>Sensor / voltage connection</td>
<td>LEMO connector</td>
<td>25-pin sub-D connector</td>
<td></td>
<td></td>
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<tr>
<td>Recommended controller / amplifier</td>
<td>Modular piezo controller system E-500 (p. 2-144) with amplifier module E-503.00S (three channels) (p. 2-146) or 1 x E-505.00S and 2 x E-505 (high speed applications) (p. 2-147) and E-509 servo controller (p. 2-152) Open-loop: E-663 three channel amplifier (p. 2-136)</td>
<td>E-616 controller for tip/tilt mirror systems (p. 2-132)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
S-325 Piezo Z / Tip/Tilt Platform
High-Speed Tripod System for Mirrors and Optics

Optical Beam Deflection to 10 mrad, Resolution to 50 nrad
Piston Movement up to 30 μm (for Path Length Adjustment)
Compact Tripod Design with Coplanar Axes Eliminates Polarization Rotation
Sub-Millisecond Responsiveness
Closed-Loop Versions for Higher Precision
For Mirrors up to 25 mm (1”) Diameter
Frictionless, High-Precision Flexure Guiding System
Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy

The S-325 Z/tip/tilt platforms and actuators provide high speed and precise movement of the platform in two tilt axes as well as sub-nanometer linear resolution with sub-millisecond response. The design is based on a parallel-kinematics direct-drive piezo tripod (see p. 2-83), and they are especially optimized for industrial applications where 1.000.000.000 motion cycles have to be performed without failure or performance degradation. The systems are designed for mirrors and optics up to 25 mm in diameter and can be mounted in any orientation.

The tripod drive offers optimum angular stability over a wide temperature range. Compared to stacked, (two-stage), piezo or galvo scanners, the single platform design provides several advantages: smaller package size, identical size, identical dynamic performance in all axes, faster response and better linearity. It also prevents polarization rotation.

All three piezo linear actuators can be driven individually (for tip/tilt movement) or in parallel (for vertical movement) by a three-channel amplifier.

High Resolution, Stability and Dynamics
The S-325 offers piston movement of up to 30 μm (ideal for path length adjustment) and mechanical tilt up to 5 mrad (equivalent to 10 mrad optical beam deflection). The zero-friction piezo drives and flexure guidance allow sub-nanometer linear resolution and sub-microradian angular resolution.

Open-Loop and Closed-Loop Operation
In open-loop mode, the platform linear motion is roughly proportional to the applied voltage. The S-325.30L open-loop model is ideal for high-bandwidth, high-resolution applications where the absolute angular position is of secondary importance (e.g. for tracking) or where feedback is provided by an external sensor (e.g. CCD, PSD). The S-325.3SL model is equipped with high-resolution strain gauge sensors and provides absolute position control, high linearity and high repeatability. The new E-616 controller/driver module (see p. 2-132) is ideally suited for tip/tilt OEM applications.

Ordering Information

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>S-325.3SD</td>
<td>High-Dynamics Piezo Z/Tilt Platform, 5 mrad, 30 μm, SGS, Sub-D Connector</td>
</tr>
<tr>
<td>S-325.3SL</td>
<td>High-Dynamics Piezo Z/Tilt Platform, 5 mrad, 30 μm, SGS, LEMO Connector</td>
</tr>
<tr>
<td>S-325.30L</td>
<td>High-Dynamics Piezo Z/Tilt Platform, 5 mrad, 30 μm, Open-Loop, LEMO Connector</td>
</tr>
</tbody>
</table>

Application Examples

- Image processing / stabilization
- Optical trapping
- Laser scanning / beam steering
- Laser tuning
- Optical filters / switches
- Optics
- Beam stabilization

S-325 cable configuration (top: S-325.30L, bottom: S-325.3SL)
High Reliability and Long Lifetime

The compact S-325 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and provide better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free, not subject to wear and offer extraordinary reliability.

Technical Data

<table>
<thead>
<tr>
<th>Model</th>
<th>S-325.30L</th>
<th>S-325.3SL</th>
<th>S-325.3SD</th>
<th>Units</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active axes</td>
<td>Z, $\alpha_x$, $\alpha_y$</td>
<td>Z, $\alpha_x$, $\alpha_y$</td>
<td>Z, $\alpha_x$, $\alpha_y$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Motion and positioning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated sensor</td>
<td>–</td>
<td>SGS</td>
<td>SGS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open-loop travel, 0 to +100 V</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>$\mu$m</td>
<td>min. (+20%/-0%)</td>
</tr>
<tr>
<td>Open-loop tilt/tilt angle, 0 to +100 V</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>mrad</td>
<td>min. (+20%/-0%)</td>
</tr>
<tr>
<td>Closed-loop travel</td>
<td>–</td>
<td>30</td>
<td>30</td>
<td>$\mu$m</td>
<td></td>
</tr>
<tr>
<td>Closed-loop tilt/tilt angle</td>
<td>–</td>
<td>4</td>
<td>4</td>
<td>mrad</td>
<td></td>
</tr>
<tr>
<td>Open-loop resolution</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>nm</td>
<td>typ.</td>
</tr>
<tr>
<td>Open-loop tilt/tilt angle resolution</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>mrad</td>
<td>typ.</td>
</tr>
<tr>
<td>Closed-loop linear resolution</td>
<td>–</td>
<td>0.6</td>
<td>0.6</td>
<td>nm</td>
<td>typ.</td>
</tr>
<tr>
<td>Closed-loop tilt/tilt resolution</td>
<td>–</td>
<td>0.1</td>
<td>0.1</td>
<td>mrad</td>
<td>typ.</td>
</tr>
<tr>
<td><strong>Mechanical properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unloaded resonant frequency</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>kHz</td>
<td>±20%</td>
</tr>
<tr>
<td>Resonant frequency (with 25 x 8 mm glass mirror)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>kHz</td>
<td>±20%</td>
</tr>
<tr>
<td>Distance of pivot point to platform surface</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>mm</td>
<td>±0.5 mm</td>
</tr>
<tr>
<td>Platform moment of inertia</td>
<td>515</td>
<td>515</td>
<td>515</td>
<td>g • mm²</td>
<td>±20%</td>
</tr>
<tr>
<td><strong>Drive properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceramic type</td>
<td>PICMA® P-885</td>
<td>PICMA® P-885</td>
<td>PICMA® P-885</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical capacitance</td>
<td>9.3</td>
<td>9.3</td>
<td>9.3</td>
<td>$\mu$F</td>
<td>±20%</td>
</tr>
<tr>
<td>Dynamic operating current coefficient</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>$\mu$A / (Hz • mrad)</td>
<td>±20%</td>
</tr>
<tr>
<td><strong>Miscellaneous</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>-20 to 80</td>
<td>-20 to 80</td>
<td>-20 to 80</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Material casing</td>
<td>Aluminum</td>
<td>Aluminum</td>
<td>Aluminum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>0.065</td>
<td>0.065</td>
<td>0.065</td>
<td>kg</td>
<td>±5%</td>
</tr>
<tr>
<td>Cable length</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>m</td>
<td>±10 mm</td>
</tr>
<tr>
<td>Sensor / voltage connection</td>
<td>LEMO</td>
<td>LEMO</td>
<td>Sub-D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
S-310 – S-316 Piezo Z/Tip/Tilt Scanner
High-Speed System with Clear Aperture

Application Examples
- Image processing / stabilization
- Interferometry
- Laser scanning / beam steering
- Laser tuning
- Optical filters / switches
- Beam stabilization

where feedback is provided by an external sensor (e.g. CCD, PSD). The S-316.10 model is equipped with high-resolution strain gauge sensors and provides absolute position control, high linearity and high repeatability.

Available Versions
- S-310.10, S-314.10
  Open-loop Z-platforms; all three piezo linear actuators are electrically connected in parallel, providing vertical positioning (piston movement) of the top ring. Only one drive channel is required.
- S-311.10, S-315.10
  Open-loop Z/Tip/Tilt positioners; all three piezo linear actuators can be driven individually (or in parallel) by a three-channel amplifier. Vertical (piston movement) positioning and tip/tilt positioning are possible.
- S-316.10
  Closed-loop Z/Tip/Tilt positioner. All three piezo linear actuators are equipped with strain gauge position feedback sensors and can be driven individually (or in parallel) by a three-channel amplifier with a position servo-controller. Vertical positioning (piston movement) and tip/tilt positioning are possible. The integrated position feedback sensors provide sub-microradian resolution and high repeatability.

Ordering Information
- S-310.10
  Piezo Actuator, Clear Aperture, 6 μm, LEMO Connector
- S-311.10
  Piezo Z/Tip/Tilt Platform, Clear Aperture, 600 μrad, 6 μm, LEMO Connector
- S-314.10
  Piezo Actuator, Clear Aperture, 12 μm, LEMO Connector
- S-315.10
  Piezo Z/Tip/Tilt Platform, Clear Aperture, 1.2 mrad, 12 μm, SGS, LEMO Connector
- S-316.10
  Piezo Z/Tip/Tilt Platform, Clear Aperture, 1.2 mrad, 12 μm, SGS, Sub-D Connector

The tripod design features optimum angular stability over a wide temperature range. The systems are designed for mirrors and optics up to 25 mm in diameter and can be mounted in any orientation; the clear aperture is ideal for transmitted-light applications (e.g. for optical filters).

Open-Loop and Closed-Loop Operation
In open-loop mode, the tip/tilt angle is roughly proportional to the applied voltage. The S-310 to S-315 open-loop models are ideal for high-speed, high resolution applications where the absolute angular position is of secondary importance (e.g. for tracking) or...
High Reliability and Long Lifetime

The compact S-310 - S-316 systems are equipped with pre-loaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and provide better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free, not subject to wear and offer extraordinary reliability.

Technical Data

<table>
<thead>
<tr>
<th>Model</th>
<th>S-310.10</th>
<th>S-314.10</th>
<th>S-311.10</th>
<th>S-315.10</th>
<th>S-316.10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active axes</td>
<td>Z</td>
<td>Z</td>
<td>Z, θx, θy</td>
<td>Z, θx, θy</td>
<td>Z, θx, θy</td>
</tr>
</tbody>
</table>

**Resolution of PI piezo tip/tilt platforms is not limited by friction or stiction. Noise equivalent motion with E-503 amplifier (p. 2-146).**

*Mechanical tilt, optical beam deflection is twice as large. For maximum tilt range, all three piezo actuators must be biased at 50 V. Due to the parallel-kinematics design linear travel and tilt angle are interdependent. The values quoted here refer to pure linear / pure angular motion (equations p. 2-84).*
**S-323 Piezo Z/Tip/Tilt Platform**

High Dynamics & Stability Nanopositioning System with Direct Metrology

- Optical Beam Deflection to 6 mrad
- Sub-μrad Resolution for High Positioning Stability
- Position Servo-Control with Capacitive Sensors
- Frictionless, High-Precision Flexure Guiding System
- System Combination with Digital Controllers for Highest Linearity

<table>
<thead>
<tr>
<th>Model</th>
<th>Active axes</th>
<th>Travel range</th>
<th>Resolution</th>
<th>Unloaded resonant frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-323.3CD</td>
<td>Z, θx, θy</td>
<td>30 μm, ±1.5 mrad</td>
<td>0.1 nm, ±0.05 μrad</td>
<td>1.7 kHz</td>
</tr>
</tbody>
</table>

**S-303 Piezo Phase Shifter**

Highest Dynamics and Stability with Capacitive Feedback Sensor

- 25 kHz Resonant Frequency for Sub-Millisecond Dynamics
- Capacitive Sensor Option for Highest Linearity and Stability
- 3 μm Travel Range
- Compact Size: 30 mm Diameter x 10 mm
- Aperture with Open-Loop Versions
- Invar Option for Highest Thermal Stability

<table>
<thead>
<tr>
<th>Model</th>
<th>Active axes</th>
<th>Closed-loop/ open-loop travel @ -20 to +120V</th>
<th>Closed-loop/ open-loop resolution</th>
<th>Unloaded resonant frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-303.CD (closed-loop)/ S-302.0L (open-loop)</td>
<td>Z</td>
<td>2 / 3 μm</td>
<td>0.03 nm</td>
<td>25 kHz</td>
</tr>
</tbody>
</table>

**S-224 -S-226 Piezo Tilt-Mirror**

Fast Steering Mirror Combines Highest Dynamics and Compact Design

- Optical Beam Deflection to 4.4 mrad
- Sub-μrad Resolution, Sub-Millisecond Response
- Frictionless, High-Precision Flexure Guiding System
- Includes BK7 Mirror
- Optional Position Feedback Sensor
- Outstanding Lifetime Due to PICMA® Piezo Actuators

<table>
<thead>
<tr>
<th>Model</th>
<th>Active axes</th>
<th>Open-loop tilt angle @ 0 to +100V</th>
<th>Closed-loop/ open-loop resolution</th>
<th>Unloaded resonant frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-224.00 (open-loop)/ S-226.00 (closed-loop)</td>
<td>θx</td>
<td>2.0 / 2.2 mrad</td>
<td>0.05 / 0.1 μrad</td>
<td>9 kHz</td>
</tr>
</tbody>
</table>
Details on Specifications for Active Optics / Steering Mirrors

Motion and Positioning

Performance specifications are valid for room temperature (22° ±3 °C) and closed-loop systems are calibrated at this temperature (specifications for other operating temperatures on request). Recalibration is recommended for operation at a significantly higher or lower temperature. Custom designs for ultra-low or ultra-high temperatures on request.

Integrated feedback sensor
Absolute measuring capacitive and strain gauge (SGS) sensors are used to provide position information to the controller. For details see the tutorial “Piezoelectrics in Positioning” section (see p. 2-187).

Open-loop linear travel @ 0 to 100 V
Typical open-loop travel at 0 to 100 V operating voltage. Max. recommended operating voltage range is -20 to +120 V (extremes for short durations only).

Closed-loop linear travel
Travel provided in closed-loop operation. PI piezo amplifiers have an output voltage range of -20 to +120 V or -30 to +135 V to provide enough margin for the servo-controller to compensate for load changes, etc.

Open-Loop Tilt Angle @ 0 to 100 V
Typical open-loop tilt angle at 0 to 100 V operating voltage. For differential-drive tilt platforms, 0° is reached at 50 V drive voltage, the maximum negative angle at 0 V and the maximum positive angle at 100 V. Max. operating voltage range is -20 to +120 V (outside 0 to 100 V for short durations only).

Closed-Loop Travel
Tilt provided in closed-loop operation at room temperature. PI piezo amplifiers have an output voltage range of -20 to +120 V or -30 to +135 V to provide enough margin for the controller to compensate for load changes etc.

Open-loop / closed-loop resolution
Resolution of piezo flexure stages is basically infinitesimal because it is not limited by stiction or friction. Instead of resolution, the noise-equivalent motion is specified. Values are typical results (RMS, 1 σ), measured with E-503 amplifier module in E-500/501 chassis.

Full-range repeatability (typ.)
Typical values in closed-loop mode (RMS, 1 σ). Repeatability is a percentage of the total distance or angle traveled. For small ranges, repeatability is significantly better.

Pitch / Yaw / Roll / Rotational Runout
Typical rotational off-axis error; sometimes associated with a particular motion axis, as in “Rotational runout (Z motion)”.

Straightness / Flatness / Crosstalk
Typical linear off-axis error; sometimes associated with a particular motion axis, as in “Crosstalk (Z motion)”.  

Mechanical Properties

Stiffness
Static large-signal stiffness of the piezo mechanics in operating direction at room temperature. Small-signal stiffness and dynamic stiffness may differ because of effects caused by the active nature of piezoelectric material, compound effects, etc. For details see the tutorial “Piezoelectrics in Positioning” section (see p. 2-189 ff).

Unloaded resonant frequency
Lowest tilt resonant frequency around active axis without mirror attached to platform (does not specify the maximum operating frequency). For details see the tutorial “Piezoelectrics in Positioning” Section (see p. 2-192 ff).

Resonant frequency with mirror
Example of how a load (mirror) attached to the platform affects the resonant frequency (calculated data). See “Dynamic Behavior” (p. 2-84) for further details.
Drive Properties

Electrical capacitance
The piezo capacitance values indicated in the technical data tables are small-signal values (measured at 1 V, 1000 Hz, 20 °C, no load). Large-signal values at room temperature are 30 to 50% higher. The capacitance of piezo ceramics changes with amplitude, temperature, and load, up to 200% of the unloaded, small-signal capacitance at room temperature. For detailed information on power requirements, refer to the amplifier frequency-response graphs in the “Piezo Drivers / Servo Controllers” (see p. 2-99 ff) section of this catalog.

Dynamic Operating Current Coefficient (DOCC)
Average electrical current supplied by the amplifier required to drive a piezo actuator per unit frequency and unit displacement (sine-wave operation). For example, to find out if a selected amplifier can drive a given piezo tilt platform at 50 Hz with 300 μrad amplitude, multiply the DOCC coefficient by 50 and 300 and check if the result is less than or equal to the output current of the selected amplifier. For details see the tutorial “Piezoelectrics in Positioning” (see p. 2-195 ff) section.

Miscellaneous

Operating temperature range
Typically -20 to +80 °C, the temperature range indicates where the piezo stage may be operated without damage. Performance specifications are valid for room temperature (22 °C) and closed-loop systems are calibrated for optimum performance at this temperature (specifications for other operating temperatures on request). Recalibration is recommended for operation at a significantly higher or lower temperature. Custom designs for ultralow or ultra-high temperatures on request.

Material
Flexure stages are usually made of anodized aluminum or stainless steel. Small amounts of other materials may be used internally (for spring preload, piezo coupling, mounting, thermal compensation, etc.).

Al: Aluminum
N-S: Non-magnetic stainless steel
S: Ferromagnetic stainless steel
I: Invar
T: Titanium

Voltage connection
Standard operating voltage connectors are LEMO and sub-D type connectors.

LEMO connector: LEMO FFA, 00.250, male. Cable: coaxial, RG 178, Teflon coated, 1 m

Sensor connection
Standard sensor connectors are LEMO and sub-D type connectors.

Sub-D special connectors contain both piezo voltage and sensor connections.

For extension cables and adapters, see “Accessories” (p. 2-188 ff), in the “Piezo Drivers / Servo Controllers” Section.