

PZ 149E User Manual

S-330 Tip/Tilt Platform

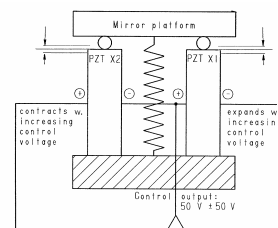
Release: 1.1.0 Date: 2007-07-24



This document describes the following product(s):

- S-330.2SL, S-330.4SL, S-330.8SL
High-dynamics piezo tip/tilt platforms, SGS, LEMO connector, travel 2, 5, and 10 mrad* respectively
- S-330.2SD, S-330.4SD, S-330.8SD
High-dynamics piezo tip/tilt platforms, SGS, Sub-D connector, travel 2, 5, and 10 mrad* respectively
- S-330.20L, S-330.40L, S-330.80L
High-dynamics piezo tip/tilt platforms, open-loop, LEMO connector, travel 2, 5, and 10 mrad* resp.

*Values are mechanical travel in closed-loop mode; optical beam deflection is twice mechanical travel



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Declaration of Conformity

according to ISO / IEC Guide 22 and EN 45014

Manufacturer:	Physik Instrumente (PI) GmbH & Co. KG	
Manufacturer's Address:	Auf der Römerstrasse 1 D-76228 Karlsruhe, Germany	

The manufacturer hereby declares that the product,

Product Name: **Tip/Tilt Platform**
Model Numbers: **S-330**
Product Options: **all**

when operated with a complying controller from PI,
complies with the following European directives:

73/23/EWG, Niederspannungsrichtlinie / 73/23/EEC, Low voltage
directive

89/336/EWG, EMV- Richtlinie / 89/336/EEC, EMC-Directive

98/37/EG, Maschinenrichtlinie / 98/37/EC, Machinery Directive

The applied standards certifying the conformity are listed below.

Electromagnetic Emission: EN 61000-6-3, EN 55011

Electromagnetic Immunity: EN 61000-6-1

Safety (Low Voltage Directive) : EN 61010-1

Safety of Machinery: EN 12100

15 July, 2007
Karlsruhe, Germany



Dr. Karl Spanner
President

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This manual has been provided for information only and product specifications are subject to
change without notice.

About This Document

Users of This Manual

This manual is designed to help the reader to install and operate the S-330 Tip/Tilt Platform. It assumes that the reader has a fundamental understanding of basic servo systems, as well as motion control concepts and applicable safety procedures.

The manual describes the physical specifications and dimensions of S-330 Tip/Tilt Platforms as well as the software and hardware installation procedures which are required to put the associated motion system into operation.

Updated releases are available for download from www.pi.ws or email: contact your PI Sales Engineer or write info@pi.ws.

Conventions

The notes and symbols used in this manual have the following meanings:

WARNING

Calls attention to a procedure, practice or condition which, if not correctly performed or adhered to, could result in injury or death.



CAUTION

Calls attention to a procedure, practice, or condition which, if not correctly performed or adhered to, could result in damage to equipment.



NOTE

Provides additional information or application hints.

Related Documents

The motion controller and the software tools which may be delivered with S-330 Tip/Tilt Platform are described in their own manuals. Updated releases are available for download from www.pi.ws or email: contact your PI Sales Engineer or write info@pi.ws.

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1 Introduction

S-330 piezo platforms are fast and compact tip/tilt units providing precise angular motion of the top platform around two coplanar, orthogonal axes. These flexure-guided platforms can provide high accelerations, enabling step response times in the sub-millisecond range.

On closed-loop versions, high-resolution, absolute measuring strain gauge sensors (SGS) are applied to appropriate places on the drive train and feed the platform position information back to a piezoelectric controller. The sensors are connected in a full-bridge configuration to eliminate thermal drift; they assure optimal position stability and rapid response with nanometer resolution.

Both open- and closed-loop versions in 3 different tilt ranges up to 10 mrad (20 mrad optical deflection) are available.

1.1 Features

- Resolution to 20 nrad, Excellent Position Stability
- Coplanar Rotation Axes, Single Moving Platform
- Optical Beam Deflection to 20 mrad ($>1^\circ$)
- 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

1.2 Parallel Kinematics

These PI piezo tip/tilt platforms are based on a parallel-kinematics design with coplanar rotational axes and a single moving platform driven by two pairs of differential actuators. The advantage is jitter-free, multi-axis motion with excellent temperature stability. The single pivot-point design also avoids the drawback of polarization rotation, common with stacked systems like galvo-scanners.

1.3 Operation

S-330 tip/tilt platforms must be operated in conjunction with three highly stable piezo amplifiers, and the closed-loop versions with electronics including a servo-controller for each motion axis. See Section 4 “Drive Electronics” for more information.

The electronics can in general be controlled in a number of different ways, including manual control (via 10-turn potentiometers), low-voltage control signals (perhaps from a DAQ-board in a PC), or convenient high-level ASCII commands from a host PC. See the documentation of the electronics for more details. All electronics, including analog controllers, have comprehensive software available, and all documentation can be freely downloaded from www.pi.ws.

1.4 Superior Lifetime

Highest possible reliability is assured by the use of awardwinning PICMA[®] multilayer piezo actuators. PICMA[®] actuators are the only ceramic encapsulated actuators on the market, which makes them uniquely resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.



Fig. 1: S-330.2SL, S-330.4SL and S-330.8SL tip/tilt platforms

1.5 Models Available

Travel ranges in parentheses are optical beam deflection angles and are thus twice the mechanical tip/tilt value.

S-330.2SL	High-dynamics piezo tip/tilt platform, 2 (4) mrad, SGS, LEMO Connector
S-330.2SD	High-dynamics piezo tip/tilt platform, 2 (4) mrad, SGS, Sub-D Connector
S-330.20L	High-dynamics piezo tip/tilt platform, 2 (4) mrad, Open-Loop, LEMO Connector
S-330.4SL	High-dynamics piezo tip/tilt platform, 5 (10) mrad, SGS, LEMO Connector
S-330.4SD	High-dynamics piezo tip/tilt platform, 5 (10) mrad, SGS, Sub-D Connector
S-330.40L	High-dynamics piezo tip/tilt platform, 5 (10) mrad, Open-Loop, LEMO Connector
S-330.8SL	High-dynamics piezo tip/tilt platform, 10 (20) mrad, SGS, LEMO Connector
S-330.8SD	High-dynamics piezo tip/tilt platform, 10 (20) mrad, SGS, Sub-D Connector
S-330.80L	High-dynamics piezo tip/tilt platform, 10 (20) mrad, Open-Loop, LEMO Connector

1.6 Safety Precautions

CAUTION

Be careful when mounting

Never use the hole on the platform's surface for mounting an object.

Never put anything in the flexure gaps of the body.

Do not clamp the body since this can block the flexure guiding system.

Calibrated System

If you purchased a motion system consisting of tip/tilt platform and controller, do not interchange parts or channels; they are matched and calibrated together. Respect the assignment of the platform's supply voltage and sensor channels to the individual controller channels, as indicated by the serial numbers on the labels affixed to the devices.



Resonance Can Cause Permanent Damage

The system must never be operated close to the resonant frequency or permanent damage can result. If you hear or see resonant behavior, switch off the unit immediately.

1.7 Prescribed Use

Based on its design and realization, the S-330 Tip/Tilt Platform is intended precision positioning of small payloads about two rotation axes when connected to a compatible PI piezo motion controller. It is a laboratory apparatus as defined by DIN EN 61010 and meets the following minimum specifications for safe operation (any more stringent specifications in the technical data table, p. 16, e.g. operating temperature -20°C to 80°C , are of course, also met):

- Indoor use only
- Altitude up to 2000 m
- Temperature range 5°C to 40°C
- Max. relative humidity 80% for temperatures up to 31°C , decreasing linearly to 50% relative humidity at 40°C
-

2 Quick Start

2.1 Mounting

You can mount the object to be positioned (for example, a mirror) on the platform using glue.

CAUTION

Never use the hole on the platform surface for mounting an object.

Never put anything in or across the gaps (flexure guiding system) of the body.

Do not clamp the body since this can block the flexure guiding system.



The platform can be mounted in any orientation. If you mount it on a vertical plane, however, the maximum “sideways” force limitation of 1 N will limit the load capacity accordingly.

By default, the platform metal case is not connected electrically. You should ground the mechanics if so required.

2.2 Connecting to Controller and Starting

The following instructions describe starting the S-330 tip/tilt platform using PI’s E-500-series control electronics (E-500 or E-501 chassis including either an E-616 amplifier/controller or an E-503.00S amplifier module and, when using the closed-loop model, an E-509.S3 servo-control module). If you use other modules from the E-500 series the steps are the same, but the connections details may differ. In this case please consult “Drive Electronics” Section on p. 12 for further information.



CAUTION

Calibrated System

If you purchased a motion system consisting of tip/tilt platform and controller, do not interchange parts or channels; they are matched and calibrated together. Respect the assignment of the platform's supply voltage and sensor channels to the individual controller channels, as indicated by the serial numbers on the labels affixed to the devices.

Resonance Can Cause Permanent Damage

The system must never be operated close to the resonant frequency or permanent damage can result. If you hear or see resonant behavior, switch off the unit immediately. See "Dynamic Behavior" Section on p. 14 for more details.

- 1 Make sure the control electronics is switched off.
- 2 Closed-loop, sub-D-connector models (S-330.xSD):
Connect the sub-D connector to the PZT+Sensor socket of the control electronics and go to Step 4.
- 3 LEMO-connector models (S-330.xxL):
 - a) Connect the drive cables from the S-330 tip/tilt platform to the E-503.00S amplifier module.

The drive voltage cables have brown connectors and are labeled "CH 1", "CH 2" and "CH 3". They must be plugged into the corresponding output sockets of the amplifier module.

NOTE

Do not mix up the cables while connecting, since the amplifier channels are connected internally so as to supply the platform channels 1 and 2 with variable drive signals, while channel 3 is supplied with a constant and very stable voltage of +100 volts.

- b) Closed-loop models (S-330.xSL) only: Connect the sensor cables from the tip/tilt platform to the E-509.S3 servo-control module.

The two sensor cables with 4-pin connectors labeled "CH1" and "CH2" must be plugged into the corresponding sockets of the servo-control module (labeled "SERVO 1" and "SERVO 2").

- 4 Switch on the control electronics.
Consult the E-500 User Manual, and, if you have an E-516 or E-616 module installed, the corresponding User Manual for information on commanding the S-330 tip/tilt platform. If you have and E-509 servo-control module, consult also its User Manual.

3 Working Principle

3.1 Design

The tip/tilt platform is mounted on four LVPZT stacks, located at the corners of a square. Tilting around one axis requires synchronized movement of two diagonally opposite LVPZT actuators. To ensure that one actuator will contract by exactly the same amount as the other expands, the actuator pairs are individually matched at the factory. The actuators in each pair are then connected electrically in differential push-pull mode, eliminating Z-axis freedom.

NOTE

With this design the pivot point is fixed and the same for both rotation axes. Whether you choose to measure the angles in vertical planes or in planes perpendicular to the platform depends on the requirements of your application.

Because the symmetrical design of the tip/tilt platform system, temperature changes will not effect the angular orientation but only the Z-axis position (axial thermal drift). Most applications are much less sensitive to this kind of instability as long as the angular orientation remains stable.

The closed-loop versions are equipped with two pairs of strain gauge position feedback sensors operated in a bridge circuit for ultra-high resolution and angular stability. These sensors permit angular movements to be executed with sub- μ rad resolution and repeatability.

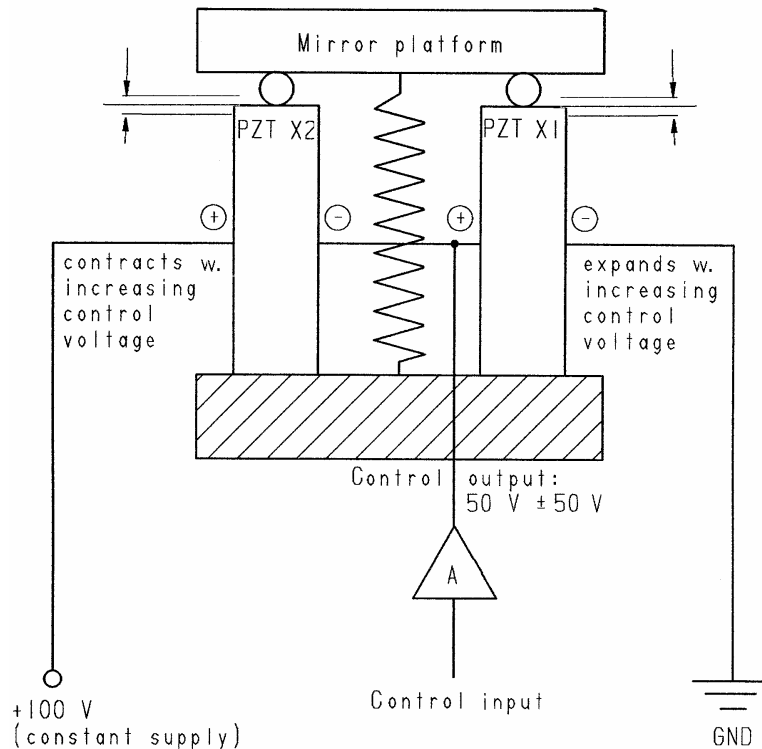


Fig. 2: S-330 Differential-drive tip/tilt platform, working principle (only Axis-1 tip motion shown)

3.2 Operating Voltages

Each tilt axis of the tip/tilt platform system requires one controlled operating voltage in the range of 0 to +100 volts and one constant voltage of +100 V. At the zero position (tilt angle zero) both actuators of a pair are expanded to 50% of their maximum expansion (i.e. to 7.5 μm). Control voltages below 50 volts cause tilting in one direction, above 50 volts, tilting in the other. Operation over an extended range of -20 to +120 V is possible, but excursions above 100 V and below -20 V should be kept of short duration.

3.3 Motion Polarities

The diagram below shows the relative positions of the four PZT stacks and makes the relative rotation polarities clear.

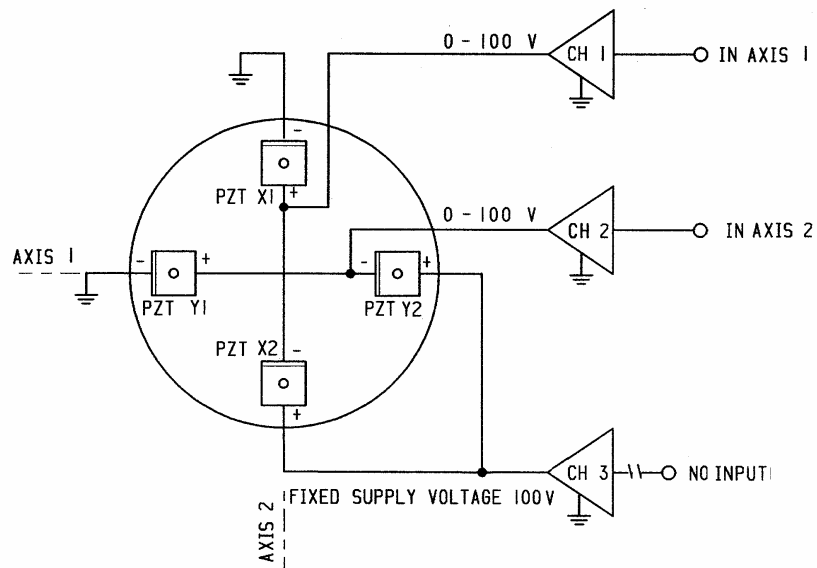


Fig. 3 S-330 viewed from above with Axis 1 (controlled by channel 1) running left and right.

Keeping in mind that the grounded PZTs expand with increasing input, it can be seen that if after a positive Axis 1 tilt, you look “uphill” across the platform, a subsequent positive Axis 2 tilt would go up to the left and down to the right. Conversely, facing “uphill” after a positive Axis 2 tilt, a positive Axis 1 tilt would go down to the left and up to the right.

4 Drive Electronics

4.1 Sub-D-Connector Versions (S-330.xxD)

Versions with the sub-D connector can be connected directly to the E-616 Amplifier/Controller.

4.2 LEMO-Connector Versions (S-330.xxL)

LEMO-connector versions can be controlled by the following combinations of E-500-series modules:

Amplifier (choice of the following, always required):

E-503.00S	Amplifier module special connected for differential-drive LVPZT tip/tilt platforms; 2 channels with variable drive signals (output sockets "CH1" and "CH2") plus 100 V fixed output (output socket "CH3")
2 x E-505.00 1 x E-505.00S	Single Channel modules. With two E-505.00 modules on the left and one E-505.00S on the right, "CH1" of the platform must be connected to the leftmost module, "CH2" to the center module and "CH3" to the E-505.00S

NOTE

On amplifiers for differential-drive tip/tilt mirrors, the DC-offset potentiometer for channel 3, if present at all, is disabled and the output is clamped internally to +100 volts. The analog input of this channel is also disabled. External control voltages thus must be supplied to the CONTROL INPUT sockets of CH1 and CH2.

Controller (required in addition to amplifier for closed-loop operation):

E-509.S3	Position servo-control module for SGS sensors; channel 1 and 2 (labeled "SERVO 1" and "SERVO 2") must be used with the platforms sensor cables "CH1" and "CH2" accordingly
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Display Module (displays position or voltage of axes, not required):

E-515.03	3½-digit LED position or voltage display for each of 3 channels (channel 3 not used)
E-515.01	3½-digit LED position or voltage display, 1 channel (2 modules needed for 2-axis display)

Computer Interface and Display Module (replaces display above, allows digital computer operation^{*}):

E-516.i3	Computer Interface and Display Module, 3 channels, (channel 3 not used)
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^{*} Computer-generated analog signals can, of course, be used to control any S-330, with or without an E-516. For certain National Instrument DAQ cards operating with LabVIEW in a PC, PI provides an Analog Driver Set which makes the high-level PI General Command Set available over an analog interface. See the controller documentation, which should include Technical Note E500T0011 with complete instructions and the password for downloading the Analog Drivers. They are under E-500 in the download section of www.pi.ws. The associated documentation is available without password.

5 Dynamic Behavior

In addition to the amplifier, controller and sensor bandwidths, the maximum operating frequency of a tilt platform depends on its mechanical resonant frequency. 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:

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

Moment of inertia of a rectangular mirror:

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

where:

- m = Mirror mass [g]
- I_M = Moment of inertia of the mirror [$g \cdot mm^2$]
- 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 Technical Data table on p. 16) 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, p. 9) [$g \cdot mm^2$]
- I_M = Moment of inertia of the mirror [$g \cdot mm^2$]

For more information on static and dynamic behavior of piezo actuators, see the "Tutorial" section of the PI Catalog.

6 Old Equipment Disposal

In accordance with EU directive 2002 / 96 / EC (WEEE), as of 13 August 2005, electrical and electronic equipment may not be disposed of in the member states of the EU mixed with other wastes.

To meet the manufacturer's product responsibility with regard to this product, Physik Instrumente (PI) GmbH & Co. KG will ensure environmentally correct disposal of old PI equipment that was first put into circulation after 13 August 2005, free of charge.

If you have such old equipment from PI, you can send it to the following address postage-free:

Physik Instrumente (PI) GmbH & Co. KG
Auf der Römerstr. 1
76228 Karlsruhe, Germany



7 Technical Data

Models	S-330.20L S-330.40L S-330.80L	S-330.2SL	S-330.4SL	S-330.8SL	S-330.2SD S-330.4SD S-330.8SD		
Active axes	θ_x, θ_y	θ_x, θ_y	θ_x, θ_y	θ_x, θ_y	θ_x, θ_y		
Motion and positioning							
Integrated sensor	-	4x SGS	4x SGS	4x SGS	4x SGS		
Open-loop tilt angles ⁸ for -20 to +120 V	see SL version	3.5	7	15	see SL version	mrad	min.
Closed-loop tilt angle θ_x, θ_y	-	2	5	10	see SL version	mrad	
Open-loop angular resolution ¹ in θ_x, θ_y	see SL version	0.02	0.1	0.2	see SL version	μ rad	typ.
Closed-loop angular resolution ¹ in θ_x, θ_y	-	0.05	0.25	0.5	see SL version	μ rad	typ.
Repeatability ² in θ_x, θ_y	-	0.15	0.5	1	see SL version	μ rad	typ.
Mechanical properties							
Unloaded resonant frequency ⁵ in θ_x, θ_y	see SL version	3.7	3.3	3.1	see SL version	Hz	$\pm 20\%$
Resonant frequency under load ⁶ in θ_x and θ_y	see SL version	2.6 (with glass mirror, 25 mm diam., 8 mm thick)	1.6 (with glass mirror, 25 mm diam., 8 mm thick)	1.0 (with glass mirror, 25 mm diam., 8 mm thick)	see SL version	Hz	$\pm 20\%$
Distance, pivot point to platform surface	6	6	6	6	6	mm	± 1 mm
Inertia, of mirror	1530	1530	1530	1530	1530	g x mm ²	$\pm 20\%$
Drive properties							
Ceramic type	PICMA [®]	PICMA [®]	PICMA [®]	PICMA [®]	PICMA [®]		
Electrical Capacitance	12.5 per axis	3 per axis	6 per axis	12.5 per axis	12.5 per axis	μ F	$\pm 20\%$
Dynamic operating current coefficient ⁴ (DOCC)		0.22 per axis				$\frac{\mu A}{Hz \times mrad}$	$\pm 20\%$

Models	S-330.20L S-330.40L S-330.80L	S-330.2SL	S-330.4SL	S-330.8SL	S-330.2SD S-330.4SD S-330.8SD		
Miscellaneous							
Operating temperature range ¹	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material case	Stainless steel, non-magnetic	Stainless steel, non-magnetic	Stainless steel, non-magnetic	Stainless steel, non-magnetic	Stainless steel, non-magnetic		
Platform material	Invar	Invar	Invar	Invar	Invar		
Mass	see SL version	0.2	0.38	0.7	see SL version	kg	±5%
Cable length	1.5	1.5	1.5	1.5	1.5	m	±10 mm
Sensor connection	-	2x Lemo connector (SGS sensor)	2x Lemo connector (SGS sensor)	2x Lemo connector (SGS sensor)	Sub-D connector, 25-pin		
Voltage connection	3x Lemo connector (low voltage)	3x Lemo connector (low voltage)	3x Lemo connector (low voltage)	3x Lemo connector (low voltage)	Sub-D connector, 25-pin		
Recommended controller / amplifier	E-616:	E-500 modular control system E-501.00 chassis, E-503.00S amplifier, E-509.S3 servo-controller and optional E-516 interface module For high-dynamics applications with E-500.00 chassis and one E-505.00S and two E-505.00 amplifiers					
Mirror mounting							
Standard mirror, mounted	BK7, λ/5, R > 98% (λ = 500 nm to 2 μm)	BK7, λ/5, R > 98% (λ = 500 nm to 2 μm)	BK7, λ/5, R > 98% (λ = 500 nm bis 2 μm)	BK7, λ/5, R > 98% (λ = 500 nm to 2 μm)	BK7, λ/5, R > 98% (λ = 500 nm to 2 μm)		
Mirror diameter	10 mm	10 mm	10 mm	10 mm	10 mm	mm	max.
Mirror thickness	2 mm	2 mm	2 mm	2 mm	2 mm	mm	max.

- 1 Resolution of PZT tip/tilt platforms is not limited by friction or stiction. Value is typical (RMS, 1σ) noise-equivalent motion with E-503 amplifier module.
- 2 Full-Range Repeatability: Typical values, closed-loop mode. Since repeatability is a percentage of the angle traveled, repeatability is significantly better for small ranges.
- 3 Small-signal value (measured at 1 V, 1000 Hz, 20°C, no load); large-signal values at room temperature are 30 to 50% higher. The capacitance of PZT 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 curves in the "PZT Control Electronics" section of the PI Catalog.
- 4 Dynamic Operating Current Coefficient in μA per hertz and μrad. Example: Sinusoidal scan of 100 μrad at 10 Hz requires approximately 0.22 mA drive current.
- 5 Unloaded Resonant Frequency: Lowest tilt resonant frequency around an active axis without mirror (well above the maximum operating frequency). For more resonance considerations, see "Tutorial" in the PI Catalog.
- 6 Resonant Frequency with Mirror: Example of how a load (mirror) affects the (calculated) resonant frequency.



- 7 Standard range, other temperature ranges on request. Closed-loop systems are calibrated for optimum performance at room temperature. Recalibration is recommended if operation is at a significantly higher or lower temperature.
- 8 Mechanical tilt, optical beam deflection is twice as large. Special version with 10 mrad available on request.

7.1 Connectors

7.1.1 Sub-D Versions

The S-330.xxD versions are equipped with a single sub-D25m plug carrying both the piezo voltages and the sensor signals. This connector interfaces directly with the E-616 Amplifier/Controller module. The pinout is as shown below:

Pin	Signal
1	SGS3-B1
14	SGS3-B2
2	Not used
15	Not used
3	SGS2-B1
16	SGS2-B2
4	SGS-REF
17	SGS-GND
5	SGS1-B1
18	SGS1-B2
6	SGS-REF
19	SGS-GND
7	Connected to GND in plug*
20	GAIN1
8	-15 V
21	GAIN2
9	+15 V
22	GAIN3
10	GND
23	PZT1-GND
11	PZT1-OUT
24	PZT2-GND
12	PZT2-OUT
25	PZT3-GND
13	PZT3-OUT

* Sensed by E-616, which then outputs a constant 100 V on PZT3-OUT

7.1.2 LEMO Versions

The S-330.xxL versions are equipped with LEMO connectors for the individual piezo voltages and sensor signals, including a third piezo cable for the constant-voltage, 100 V, reference supply. The open-loop versions (S-330.x0L) have no sensor cables.

The piezo supply voltage cables are labeled “CH 1”, “CH 2” and “CH 3”, whereby CH3 connects to the constant 100 V supply.

The sensor cables (if present) have 4-pin connectors and are labeled “CH 1” and “CH2”.

Always connect the cables as labeled during calibration.

7.2 Dimensions

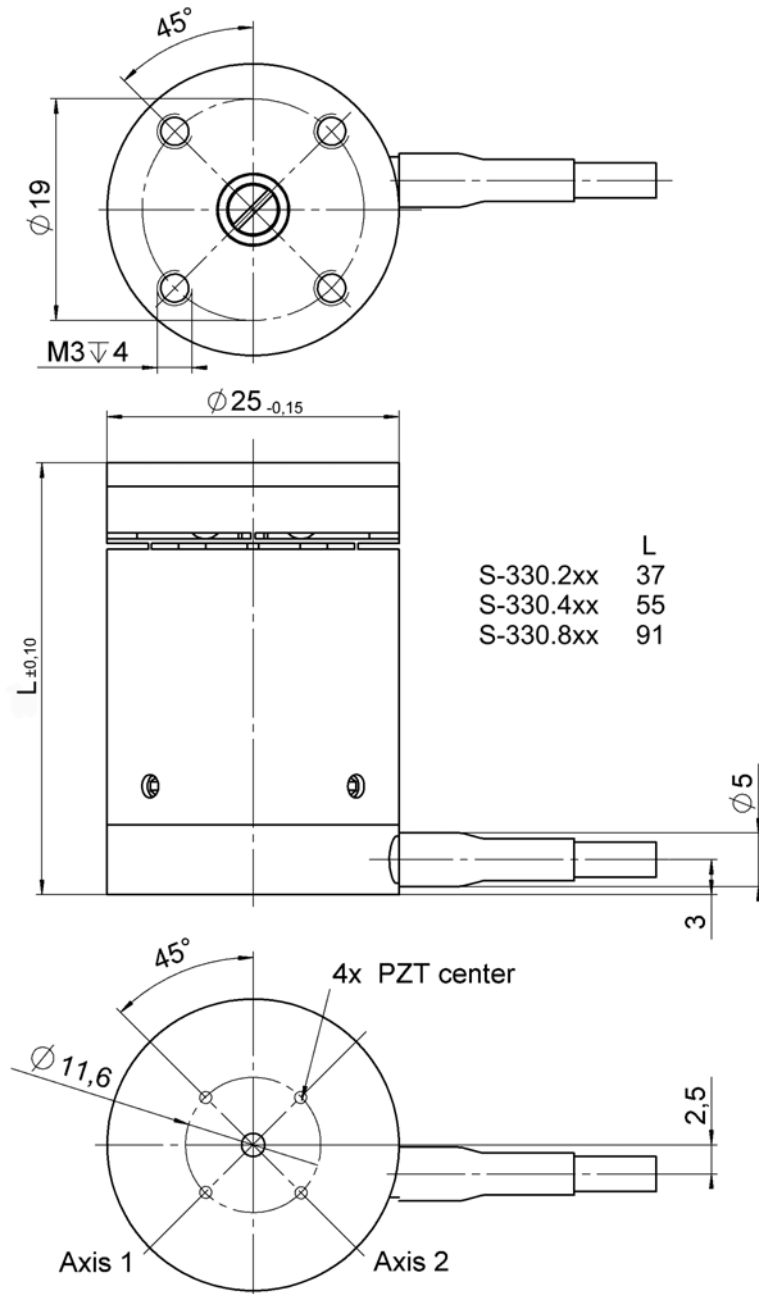


Fig. 4: S-330 dimensions in mm, decimal places separated by a comma in drawings

