



PZ 96E User Manual

S-310, S-311, S-314, S-315, S-316

Tilt Platforms and Z-axis Positioners

Release 1.10



Product Description and Operating Notes

This document is valid for the following products:

S-310.10	Z-Platform, open-loop
S-314.10	Z-Platform, open-loop
S-311.10	Tip-tilt / Z-Platform, open-loop
S-315.10	Tip-tilt / Z-Platform, open-loop
S-316.10	Tip-tilt / Z-Platform, closed-loop

Release: *1.10*
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0. Manufacturer Declarations

Certification

Physik Instrumente (PI) GmbH & Co. KG certifies that this product met its published specifications at the time of shipment.

Warranty

This PI product is warranted against defects in materials and workmanship for a period of one year from date of shipment. Duration and conditions of warranty for this product may be superseded when the product is integrated into (becomes a part of) other PI products. During the warranty period, PI will, at its option, either repair **or** replace products which prove to be defective.

Limitation of Warranty

The foregoing warranty shall not apply to defects resulting from improper or inadequate maintenance by the Buyer, Buyer supplied products or interfacing, unauthorised modification or misuse, operation outside of the environmental specifications for the product, or improper site preparation or maintenance.

The design and connection of any circuitry to this product is the sole responsibility of the Buyer. PI does not warrant the Buyer's circuitry or malfunctions of PI products that result from the Buyer's circuitry. In addition, PI does not warrant any damage that occurs as a result of the Buyer's circuit or any defects that result from Buyer-supplied products.

No other warranty is expressed or implied. PI specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

Warnings

- **Shock Hazard:** Voltages up to 130 V can be present on PZT connectors.
- **PZT Damage:** Most piezo actuators can be destroyed by uncontrolled oscillation near the mechanical resonant frequency. If you observe resonance while configuring your system, switch off power to the actuators concerned immediately. Remember that any mass mounted on the platform will reduce the resonant frequency dramatically.

1. Introduction

The S-310 to S-316 Z-positioners and multi-axis tip/tilt platforms are fast and compact units based on the triple-piezo-drive-supported platform design. All offer piston movement up to 12 μm and all but the S-310 and S-314 offer tip/tilt motion up to $\pm 600 \mu\text{rad}$ with sub-msec response and settling.

1.1. Features

- 10 mm Clear Aperture
- Triple-PZT-Actuator-Supported Platform
- Tilt Range up to $\pm 600 \mu\text{rad}$
- Piston Movement up to 12 μm
- Open- and Closed-Loop Versions
- For Optics, Mirrors or Other Components



Fig. 1: S-314.10 Z-Platform (open-loop)

1.2. Description

S-310 to S-316 tilt platforms are equipped with three low-voltage (0 to 100 V) piezoelectric linear drives spaced at 120° intervals. Control of the tip/tilt versions is complicated because expansion of an individual PZT actuator can affect both θ_x and θ_y rotation. External coordinate transformation (software or hardware) is required to allow platform position commands in θ_x and θ_y coordinates, and that hardware or software will determine how the tip/tilt angles are defined. See the equations and Fig. 2 on page 7 for examples.

The triple-piezo-actuator design exhibits excellent angular stability over a wide temperature range. Temperature changes only affect the vertical position of the platform (piston motion) and have no influence on the angular position. The units can be mounted in any orientation.

In open-loop operation, the position of each actuator roughly corresponds to the drive voltage (see the discussion on p. 7 for calculating vertical position / platform angle as a function of actuator extension and see the "Tutorial: Piezoelectrics in Positioning" in the PI catalog or at www.pi.ws for more on the behavior of open-loop PZTs).

The open-loop models (S-310 to S-315) are ideal for applications where the position is controlled by an external loop based on data provided by a sensor (e.g. quad cell, CCD chip). The closed-loop version (S-316.10) offers absolute position control, high linearity and repeatability based on the internal high-resolution feedback sensor.

2. Model Survey

Several different versions are available:

- S-310.10 Open-loop Z-actuator;** 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-314.10 Open-loop Z-actuator;** same as S-310.10 but with twice the travel range.
- S-311.10 Open-loop Z, tip/tilt positioner;** 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-315.10 Open-loop Z, tip/tilt positioner;** same as S-311.10 but with twice the tip/tilt and piston travel range.
- 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/ position servo-controller. Vertical positioning (piston movement) and tip/tilt positioning are possible. The integrated position feedback sensors provide sub- μ rad resolution and repeatability (with PI control electronics).

3. Quick Start

3.1. Mounting

You can mount the object to be positioned (for example, a mirror) on the platform using glue or three screws with M2.5 threads.

Warnings

- Mounting screws longer than 3 mm may damage the internal flexure system.
- Do not overtighten mounting screws.
- Some models have visible assembly screws covered with sealing laquer. These screws must not be disturbed. Damage to the seal will void the warranty.

The platform can be mounted in any orientation.

By default, the platform metal case is floating. You should ground the mechanics if so required.

3.2. Connecting to Controller

S-310 to S-316 platforms are used with position control electronics consisting of amplifier and—in case of closed loop operation—a PZT servo controller (see the Technical Data table on page 9 for required devices). Make sure there is no voltage on the PZT output of the amplifier when you connect the platform to the controller. The best way to do so is to switch the controller off.

The connections that need to be made between platform and controller/amplifier are listed in the table below. For further information on connecting the platform to the controller, on controller setup and operation, refer to the User Manual of the appropriate controller, and to any associated software manuals.

The Z-axis-only S-310 and S-314 platforms have only one connector for connecting to the PZT output socket of the amplifier. Their three PZTs are electrically connected in parallel.

S-311, S-315 and S-316 platforms have three connectors for connecting to the PZT output socket of the amplifier, each connector cable is labeled with the PZT channel number. With these platforms all three PZTs can be driven individually. The three sensor connector cables of S-316 are each labeled with the sensor channel number. The correct PZT- and sensor-channel assignment must be observed when connecting the unit to the controller.

The following table summarizes the connections that need to be made with the controller*.

Model	Actuator/Positioner connector(s)	Controller connector(s) for connecting with the actuator/positioner**
S-310.10, S-314.10 open-loop Z-actuator	PZT drive voltage: 1 LEMO connector (male)	PZT drive voltage: 1 output socket on the amplifier module labeled "PZT"
S-311.10, S-315.10 open-loop Z, tip/tilt positioner	PZT drive voltage: 3 LEMO connectors (male); cables labeled "CH1," "CH2," "CH3"	PZT drive voltage: 3 output sockets on the amplifier module(s) labeled "PZT".*
S-316.10 closed-loop, Z, tip/tilt positioner	PZT drive voltage: 3 LEMO connectors (male); cables labeled "CH1," "CH2," "CH3"	PZT drive voltage: 3 output sockets on the amplifier module(s) labeled "PZT"*
	Sensors: 3 LEMO connectors (female) cables labeled "CH1", "CH2," "CH3"	Sensors: 3 input sockets on the PZT-servo-controller module(s) labeled "SENSOR"*

* If calibrated at PI, the channel numbers will be indicated.

** Amplifier/controller modules for OEM applications may be provided with other connection facilities. For detailed information about connecting to position control electronics for OEM applications refer to the respective manuals.

3.3. Testing

Before powering up the controller, check the system connections carefully.

Warnings

- **Shock Hazard:** Voltages up to 130 V can be present on PZT connectors.
- **PZT Damage:** Most piezo actuators can be destroyed by uncontrolled oscillation near the mechanical resonant frequency. If you observe resonance while configuring your system, switch off power to the actuators concerned immediately. Remember that any mass mounted on the platform will reduce the resonant frequency dramatically.

Power up the controller and perform a few test moves to make sure the system is working properly. Consult the controller/amplifier manual to determine the best way to do this.

4. Operating Considerations

4.1. Travel Range

For maximum tilt range of the tip/tilt versions, the zero tip/tilt position must that with all three piezo actuators biased at 50 V.

Be aware that all three PZT actuators move down to the bottom limit of the travel range when you switch the amplifier off.

Linear travel and tilt angle are interdependent (see the discussion of tilt angles on page 7 for more information). The travel-range and tilt-angle values quoted in the documentation (see Technical Data table on page 9) refer to pure linear or pure angular motion.

4.2. Power Requirements

In dynamic applications it is important to avoid exceeding the power-output capability of the amplifier. You can check this using the dynamic operating current coefficient of the PZTs (DOCC) which is given in μA per Hz and μm in the Technical Data table on p. 9:

Multiply the PZT's DOCC by the desired frequency and displacement. For calculations involving tilt motion, first calculate the corresponding motion of each actuator using the equations that describe your geometry, then use the DOCC to get the power requirements.

Example S-314.10: Sinusoidal scan of 10 μm at 10 Hz requires approximately 1.5 mA drive current (DOCC = 15 μA per Hz and μm).

The result has to be less than or equal to the average output current of the selected amplifier. For further information please refer to the "Tutorial" section of the PI Catalog, in particular page 4-32, or consult the same material at www.pi.ws → Products → Tutorial, (<http://www.physikinstrumente.de/products/prdetail.php?secid=4-32>).

4.3. 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 a tip/tilt system (platform + payload), the moment of inertia of the payload must also be considered.

Moment of inertia of a rotationally symmetric payload (e.g. round 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 payload (e.g. rectangular mirror):

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

where:

m = Payload Mass [g]

I_M = Moment of inertia of the payload [$\text{g}\cdot\text{mm}^2$]

L = Payload length perpendicular to the tilt axis [mm]

H = Payload thickness [mm]

T = Distance, pivot point to platform surface (see technical data table on p. 9 for individual model) [mm]

R = Payload radius [mm]

Using the resonant frequency of the unloaded platform (see Technical Data table, p. 9) and the moment of inertia of the payload, the system resonant frequency is calculated according to the following equation:

Resonant frequency of a tip/tilt platform system (including payload):

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

where:

f' = Resonant frequency of platform with payload [Hz]

f_0 = Resonant frequency of unloaded platform [Hz]

I_0 = Moment of inertia of the unloaded platform (see technical data table) [$g \cdot mm^2$]

I_M = Moment of inertia of the payload [$g \cdot mm^2$]

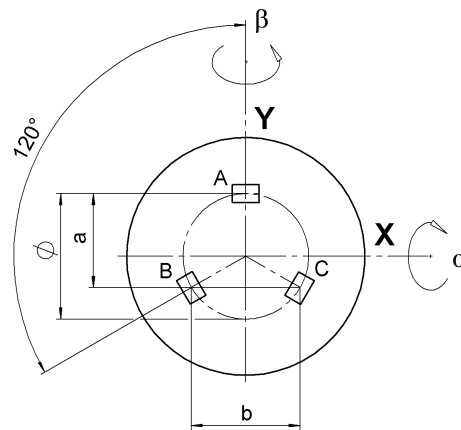
For more information on static and dynamic behavior of piezo actuators, see the "Tutorial" section of the PI Catalog, in particular pages 4-27 ff, or consult the same material at www.pi.ws → Products → Tutorial, (<http://www.physikinstrumente.de/products/section4/content.php>).

5. Working Principle

The three PZT actuators which support the platform are arranged symmetrically around the centerpoint (see Fig. 2 at right). As you can see in Fig. 3 on p. 12, they come labeled as channels 1, 2 and 3, clockwise from the cable exit point.

There are many ways to define the axes and tip/tilt angles. The definitions you use will depend on the geometry of your application.

The geometry and formulas shown in Fig. 2 are based on a system with the Y-axis passing through one of the actuators (designated A) and the tilt angles measured around **fixed** axes (i.e. the angles are measured in



$$a = \frac{b}{2} \sqrt{3}, \quad \varnothing = \frac{2b}{3} \sqrt{3}$$

Fig. 2 Triple-piezo-drive tip/tilt platform geometry, viewed from above. A, B, C are the three PZT drives.

vertical planes, not planes necessarily perpendicular to the platform). For this example, the formulas below would be used to calculate α and β . These formulas show the relationship between the displacement of each actuator (from the bottom limit of the travel range = extension at 0 V) and the tip/tilt angles (in radians). It

uses the $\sin \alpha = \alpha$ approximation, making it valid for small angles, covering the full travel range of the device.

$$\begin{aligned}\alpha &= [A - \frac{1}{2}(B+C)] / a \\ \beta &= (B-C) / b \text{ with } A = \text{constant} \\ Z &= (A+B+C) / 3\end{aligned}$$

where A, B, and C are the linear displacements of the corresponding piezo actuators (between 0 and 12 μm), α and β are the tilt motions in radians measured around fixed axes, Z is the linear displacement of the platform centerpoint.

Equation 1: Triple-piezo-drive relation

Example

S-315 and S-316 Tilt Platforms

$$\emptyset = 13.9 \text{ mm}$$

$$a = 10.4 \text{ mm}$$

$$b = 12.0 \text{ mm}$$

A, B, C actuator range: 0 to 12 μm

$$\alpha_{\min} = [A_{\min} - \frac{1}{2}(B_{\max} + C_{\max})] / a = -12 \mu\text{m} / 10.4 \text{ mm} = -1.15 \text{ mrad}$$

$$\alpha_{\max} = [A_{\max} - \frac{1}{2}(B_{\min} + C_{\min})] / a = 12 \mu\text{m} / 10.4 \text{ mm} = 1.15 \text{ mrad}$$

$$\beta_{\min} = (B_{\min} - C_{\max}) / b = -12 \mu\text{m} / 12.0 \text{ mm} = -1 \text{ mrad}$$

$$\beta_{\max} = (B_{\max} - C_{\min}) / b = 12 \mu\text{m} / 12.0 \text{ mm} = 1 \text{ mrad}$$

$$Z = 0 \text{ to } 12 \mu\text{m}$$

6. Technical Data

Models	S-310.10	S-314.10	S-311.10	S-315.10	S-316.10	Units	Notes
Active axes	Z	Z	Z, θ_x , θ_y	Z, θ_x , θ_y	Z, θ_x , θ_y		
* Open-loop tilt angle @ 0 to 100 V	-	-	± 300	± 600	± 600	$\mu\text{rad} \pm 20\%$	A2
* Closed-loop tilt angle \geq	-	-	-	-	± 600	μrad	A3
Open-loop linear travel @ 0 to 100 V	6	12	6	12	12	$\mu\text{m} \pm 20\%$	A5
Closed-loop linear travel \geq	-	-	-	-	12	μm	A6
Integrated feedback sensor	-	-	-	-	3 x strain gauge		B
Closed-loop *** angular resolution \leq	-	-	-	-	± 0.05	μrad	C1
Closed-loop / open-loop *** linear resolution \leq	- / 0.1	- / 0.2	- / 0.1	- / 0.2	0.2 / 0.4	nm	C1
Stiffness (Z)	20	10	20	10	10	N/ $\mu\text{m} \pm 20\%$	D1
Electrical capacitance	0.7	1.4	3 x 0.23	3 x 0.45	3 x 0.45	$\mu\text{F} \pm 20\%$	F1
** Dynamic operating current coefficient (DOCC)	15	15	3 x 5	3 x 5	3 x 5	$\mu\text{A}/(\text{Hz} \times \mu\text{m})$	F2
Diameter (max.) of mounted mirrors/optics	25	25	25	25	25	mm	
Unloaded resonant frequency (f_0)	9.5	5.5	9.5	5.5	5.5	kHz $\pm 20\%$	G2
Resonant frequency w/ $\varnothing 15 \times 4$ mm glass mirror	6.5	4.4	5.5	4.1	4.1	kHz $\pm 20\%$	G3
Resonant frequency w/ $\varnothing 20 \times 4$ mm glass mirror	6.1	4.2	4.4	3.4	3.4	kHz $\pm 20\%$	G3
Distance, pivot point to platform surface (T)	-	-	5	5	5	mm	
Platform moment of inertia	-	-	150	150	150	gmm^2	
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	$^{\circ}\text{C}$	H2
Voltage connection	1 x VL, 2 m cable	1 x VL, 2 m cable	3 x VL, 2 m cable	3 x VL, 2 m cable	3 x VL, 2 m cable		J1
Sensor connection	-	-	-	-	3 x L, 2 m cable		J2
Weight (w/o cables)	45	55	45	55	55	g $\pm 5\%$	
Material (case / platform)	N-S / N-S	N-S / N-S	N-S / N-S	N-S / N-S	N-S / N-S		L
Length (L)	19.5	28.5	19.5	28.5	28.5	mm	
Recommended amplifier/controller	Low- and Medium-Power Applications: E-500 (E-501) chassis + E-503 (three-channel amp.) + optional E-515/E-516 display/interface. Alternatively, E-663 (3-channel amplifier) or E-610.00 OEM amplifier module						

Notes

*For maximum tilt range, all three piezo actuators must be biased at 50 V. Linear travel and tilt angle are interdependent. The values quoted here refer to pure linear / pure angular motion about fixed axes, actuators starting from the center positions. See discussion on page 8 for more information.

**Dynamic Operating Current Coefficient in μA per Hertz and mm (per actuator). Example S-314.10: Sinusoidal scan of 10 mm at 10 Hz requires approximately 1.5 mA drive current. For tilt calculation see the Power Requirements section, p. 6.

***Noise equivalent motion with E-503 amplifier.

A2 Open-Loop Tilt Angle @ 0 to 100 V

Typical open-loop tilt angle at 0 to 100 V operating voltage. Max. operating voltage range is -20 to +120 V, (outside 0 – 100 V for short durations only). For details see "Lifetime of PZTs" in the "Tutorial" section of the PI catalog or at www.pi.ws → Products → Tutorial.

A3 Closed-Loop Tilt Angle

Tilt provided in closed-loop operation. PI LVPZT amplifiers have an output voltage range of -20 to +120 V to provide enough margin for the controller to compensate for load changes etc.

A5 Open-Loop Linear Travel @ 0 to 100 V

Typical open-loop travel at 0 to 100 V operating voltage. Max. operating voltage range is -20 to +120 V, (outside 0 – 100 V for short durations only). For details see "Lifetime of PZTs" in the "Tutorial" section of the PI catalog.

A6 Closed-Loop Linear Travel

Travel provided in closed-loop operation. PI LVPZT amplifiers have an output voltage range of -20 to +120 V to provide enough margin for the controller to compensate for load changes etc.

B Integrated Feedback Sensor

Absolute-measuring SG (strain gauge) sensors are used to provide position information to the controller. For details see the "Tutorial: Piezoelectrics in Positioning" section of the PI catalog.

C1 Closed-Loop / Open-Loop Resolution

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

D1 Stiffness

Static large-signal stiffness of the PZT ceramic at room temperature. Small-signal stiffness and dynamic stiffness may differ because of effects caused by the active nature of the piezo material, compound effects, etc. Further details see "Tutorial" section of the PI catalog.

F1 Electrical Capacitance

The PZT 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 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.

F2 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 DOC 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 in the "Tutorial: Piezoelectrics in Positioning" section of the PI catalog.

G2 Unloaded Resonant Frequency (f_0)

Lowest tilt resonant frequency around active axis without mirror attached to platform (is above the maximum operating frequency). For further details see the "Tutorial: Piezoelectrics in Positioning" section of the PI catalog.

G3 Resonant Frequency with Mirror

Example of how a load (mirror) attached to the platform affects the resonant frequency (calculated data). See "Dynamic Behavior" in the PI catalog for further details.

H2 Operating Temperature Range

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.

J1 Voltage Connection

Typical operating voltage connectors are LEMO-type connectors. VL (Voltage Low):

LEMO FFA.00.250, male. Cable: coaxial, RG 178, Teflon coated. For extension cables and adapters, see "Accessories" in the "PZT Control Electronics" section of the PI catalog.

J2 Sensor Connection

Typical sensor connectors are LEMO-type connectors. L: LEMO FFA.0S.304, female. Cable: PUR. For extension cables and adapters, see "Accessories" in the "PZT Control Electronics" section of the PI catalog.

L Material (Case/Platform)

Al: aluminum, N-S: non-magnetic stainless steel, S: ferromagnetic stainless steel, I: invar. Small amounts of other materials may occur internally for spring preload, piezo coupling, mounting, etc.

7. Dimensions

Dimensions in mm, decimal places separated by commas in drawings

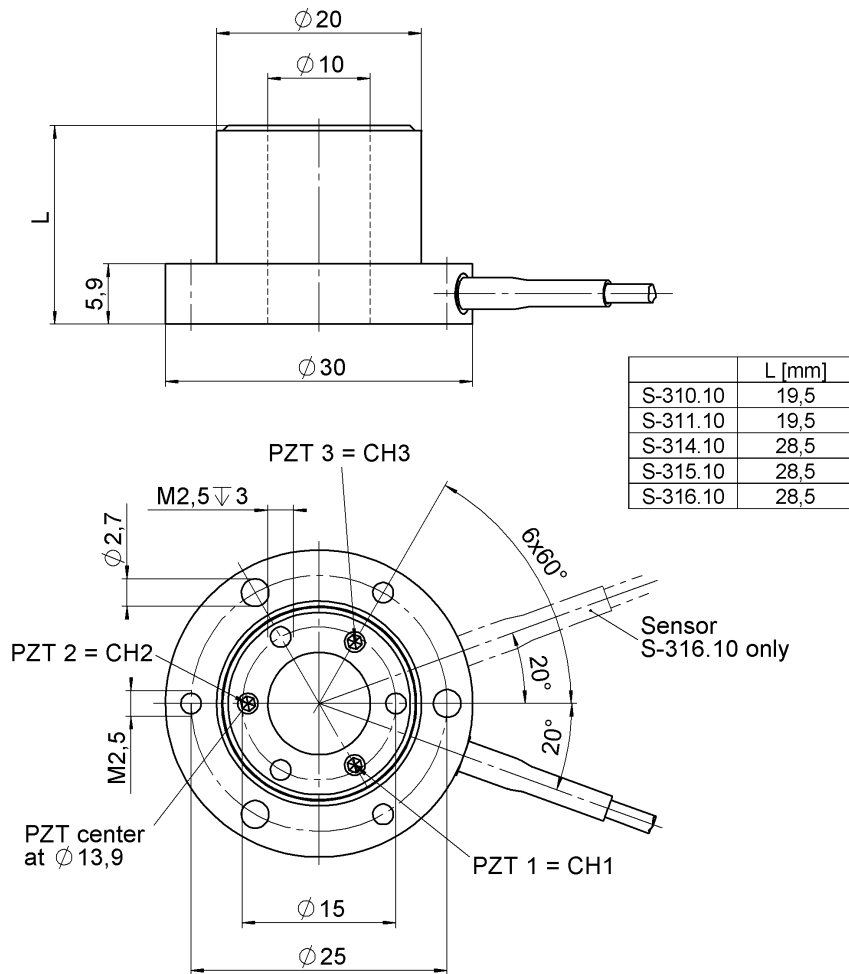


Fig. 3: S-31x.10 Tip-tilt / Z-Platforms

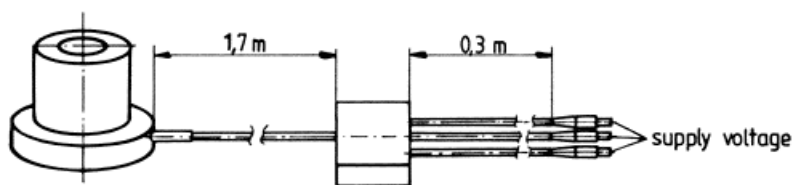


Fig. 5: S-311.10 and S-315.10 Tip-tilt / Z-Platform (open-loop); cables labeled with PZT channel numbers

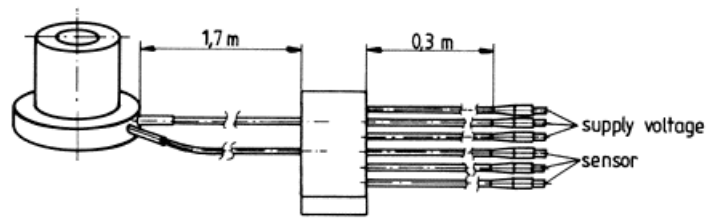


Fig. 6: S-316.10 Tip-tilt / Z-Platform (closed-loop); cables labeled with PZT channel numbers and sensor channel numbers