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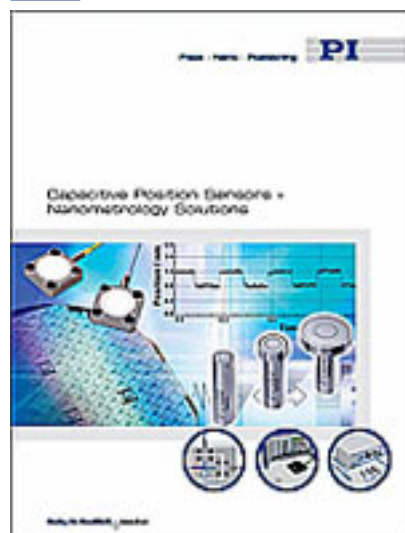
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NEW!



[PI Capacitive Position Sensors, Metrology Solutions Brochure](#)

Capacitive Gauge Sensors for Nanometrology



Capacitive gauges (capacitance sensors) are the nanometrology system of choice for the most demanding precision positioning, scanning and measurement applications. PI capacitive sensors ensure highest resolution, linearity and longterm stability. These absolute-measuring, non-contact devices detect motion at sub-nanometer levels directly (direct metrology). They provide accuracy, linearity, resolution, stability and bandwidth superior to conventional sensors such as LVDTs, strain gauge type sensors (piezo resistive sensors), and incremental encoders (glass scale type encoders).

[>> Download the Capacitive Sensors Brochure](#)

For the ultimate performance the D-015 - D-100 two plate sensor series are available. The new single-probe D-510 series provide similar precision and feature an integrated LEMO connector for easy mounting and replacement in the field.

[>> Read on or jump to the Capacitance Sensor Selection Guide](#)

New Single-Probe Capacitive Position Gauge for Nanometrology Applications

The new D-510 family of PISeca™ capacitive displacement gauges performs high-precision, non-contact measurements of geometric quantities representing displacement, separation, position, length or other linear dimension against any kind of electrically conductive target. These single-probe nanometrology sensors combine superior resolution and linearity with very high bandwidth for dynamic measurements.



[>> D-510 Single-Probe Capacitive Position Gauge for Nanometrology Applications](#)

Features & Advantages

- Sub-Nanometer Resolution, Measuring Ranges to 500 μm
- Absolute, Non-Contact Measurement of Distance / Motion / Vibration
- Multi-Axis Measurements Possible
- Excellent Measuring Linearity to 0.1 %
- Plug & Play: Easy Setup and Integration
- Very Temperature Stable
- Bandwidth to 10 kHz
- Guard-Ring Electrode Design for Better Sensor Linearity
- ILS Linearization System in the Signal Conditioner Electronics Improves Output Signal Linearity
- All Systems Factory Calibrated for Highest Possible Linearity / Accuracy

Higher Linearity through Guard-Ring Capacitor and ILS Electronics

Not all capacitive sensors are created equal. Because the sensor design has a strong influence on the linearity, PI uses a special guard-ring electrode to shield the sensor electrode from boundary effects. This ensures a homogeneous electric field in the measurement zone and results in higher measuring linearity. In addition, the E-852 sensor signal conditioning electronics are equipped with the PI proprietary ILS linearization circuit.

Easy Installation & Setup

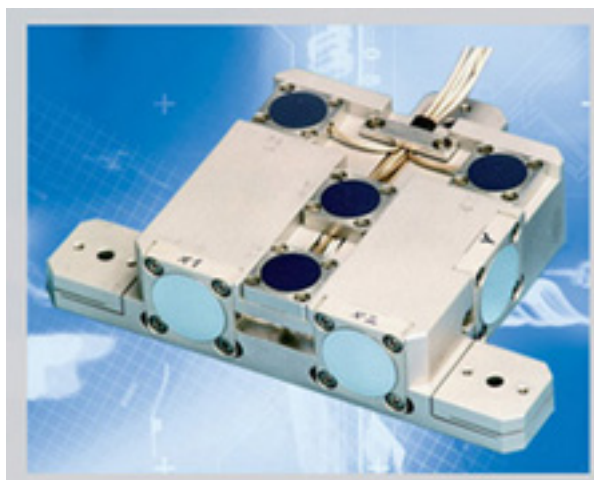
The capacitive gauges are plug and play units. A high cable with a performance LEMO connector plugs directly into the sensor head for easy installation or replacement in the field. Installation is further facilitated by a display in the E-852 signal conditioner sensor electronics that indicates the optimum distance between probe and target.

[>> E-852 Signal Conditioner Electronics for D-510](#)

Direct Metrology, Parallel Metrology Configurations

The capacitance sensors offered by PI are the most accurate measuring systems for nanopositioning applications currently on the market. In contrast to high-resolution sensors measuring deformation in the drive train, like strain gauge or piezoresistive sensors, capacitive sensors are non-contact, direct-metrology devices—a fact which gives them many advantages:

- Better Phase Fidelity
- Higher Bandwidth
- No Periodic Error
- Non-Contacting
- Ideal for Parallel Metrology
- Higher Linearity
- Better Reproducibility
- Higher Long-Term Stability



Capacitive position sensors in an ultra-high-accuracy, six-axis nanopositioning system designed by PI for the German Institute of Standards (PTB). Application: scanning microscopy

Capacitive sensors are especially well-suited for parallel metrology configurations. In multi-axis nanopositioning systems, parallel metrology means that the controller monitors all controlled degrees of freedom relative to "ground" (the fixed frame) and uses each actuator to compensate the undesired off-axis motion of the others automatically ([active trajectory control](#)). As a result, it is possible to keep deviations in the sub-nanometer and sub-microradian range.

Resolution

Resolution on the order of picometers is achievable with short-range, two-electrode capacitive position sensors. Theoretical measurement resolution is limited only by quantum noise. In practical applications, stray radiation, electronics-induced noise and geometric effects are the limiting factors. For example, with the 100 μm range, a D-100.00 capacitive probe and E-509.C1A electronics, the effective noise factor is 0.02 nm/ $\sqrt{\text{Hz}}$. This translates to 0.2 nm at 100 Hz bandwidth. The maximum standard bandwidth (jumper selectable) is 3 kHz.

Figure 1 shows a D-015, 15 μm capacitive position sensor and an interferometer, both measuring nanometer-range actuator cycles. The graphs clearly show the superior resolution of the capacitive position sensing technique.



D-050 Capacitance Sensor Probes.

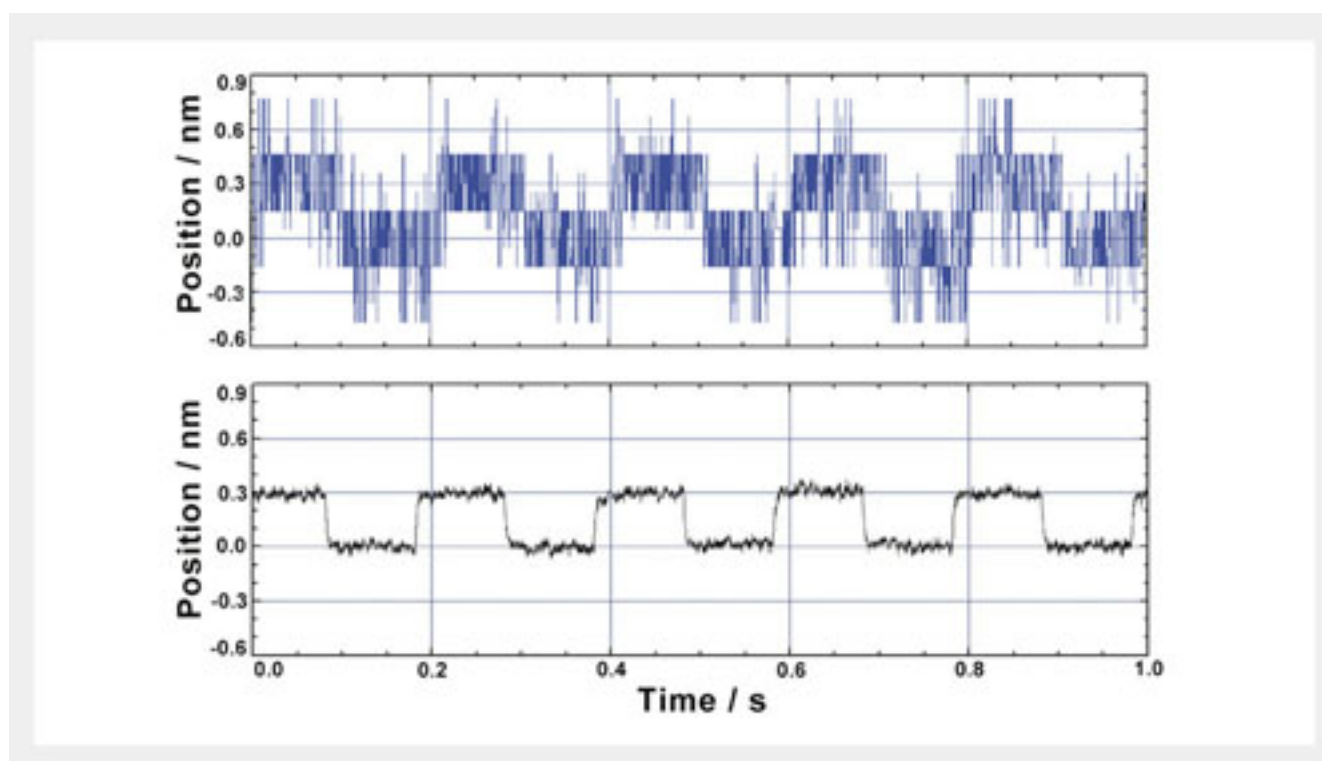


Fig 1. Piezo nanopositioning system making 0.3 nm steps, measured with PI capacitive sensor (lower curve) and with a highly precise laser interferometer. The capacitive sensor provides significantly higher resolution than the interferometer

[>> Read on or jump to the Capacitance Sensor Selection Guide](#)

Stability and Linearity of PI Capacitive Position Sensors

PI capacitive position sensor electronics incorporate a proprietary design providing superior linearity, low sensitivity to cable capacitance, low background noise and low drift.

The Integrated Linearization System (ILS) compensates for influences caused by errors, such as non-parallelism of the plates. When used with PI digital controllers (which add polynomial linearization techniques) a positioning linearity of up to 0.003 % is achievable.

Figure 2 shows the linearity of a P-752.11C piezo flexure nanopositioning stage with integrated capacitive position sensor operated in closed-loop mode with an analog controller. All errors contributed by the mechanics, PZT drive, sensors and electronics are included in the resulting linearity of better than 0.02 %. Even higher linearity is achievable with PI digital controllers, [see the E-710](#).

The exceptional long-term stability of the PI capacitive position sensor and electronics design is shown in Figure 3.

Fig 2. Linearity of a P-752.11C, 15 μm piezo nanopositioning stage operated with E-500/E-509.C1 control electronics. The travel range is 15 μm , the gain 1.5 $\mu\text{m}/\text{V}$. Linearity is better than 0.02 %; even higher linearity is achievable with PI digital controllers

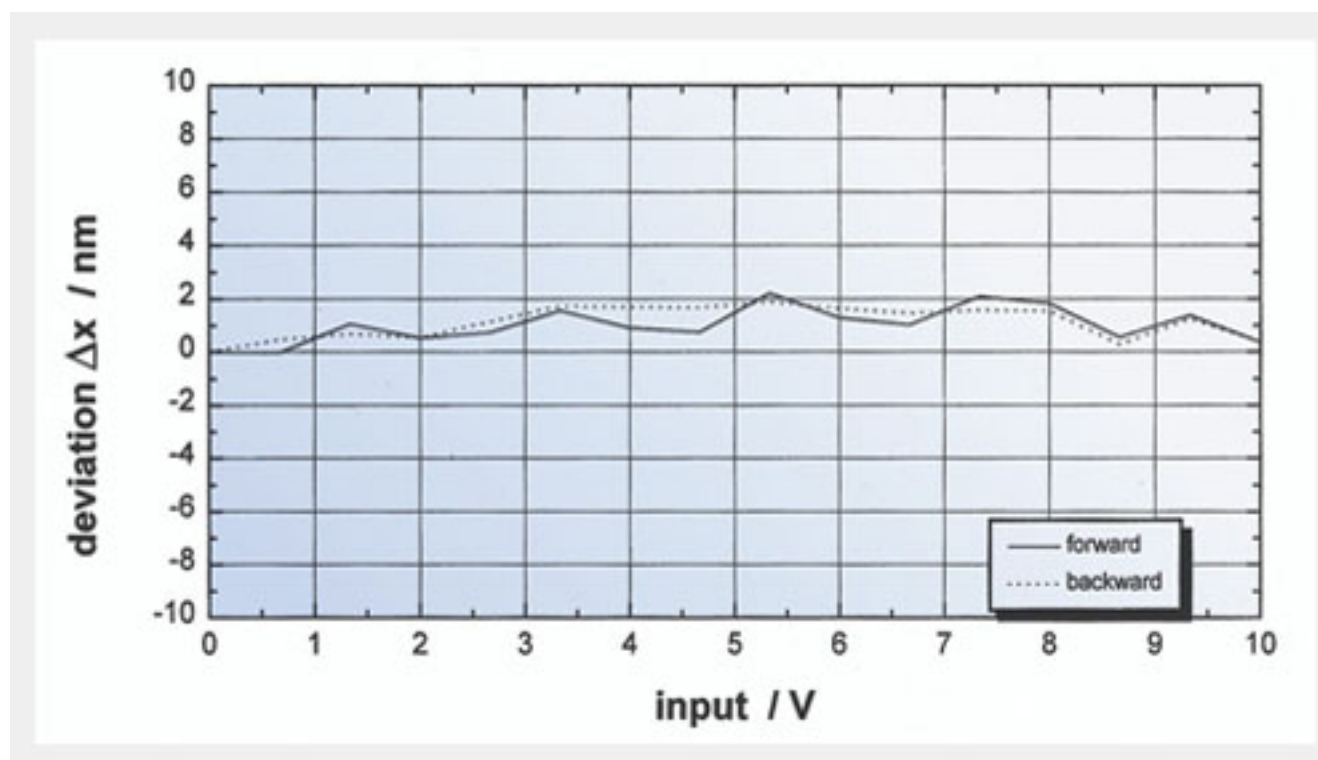


Fig. 2

Fig 3. Measurement stability of an E-509.C1 capacitive position sensor control board with 10 pF reference capacitor over 3.5 hours (after controller warm-up).

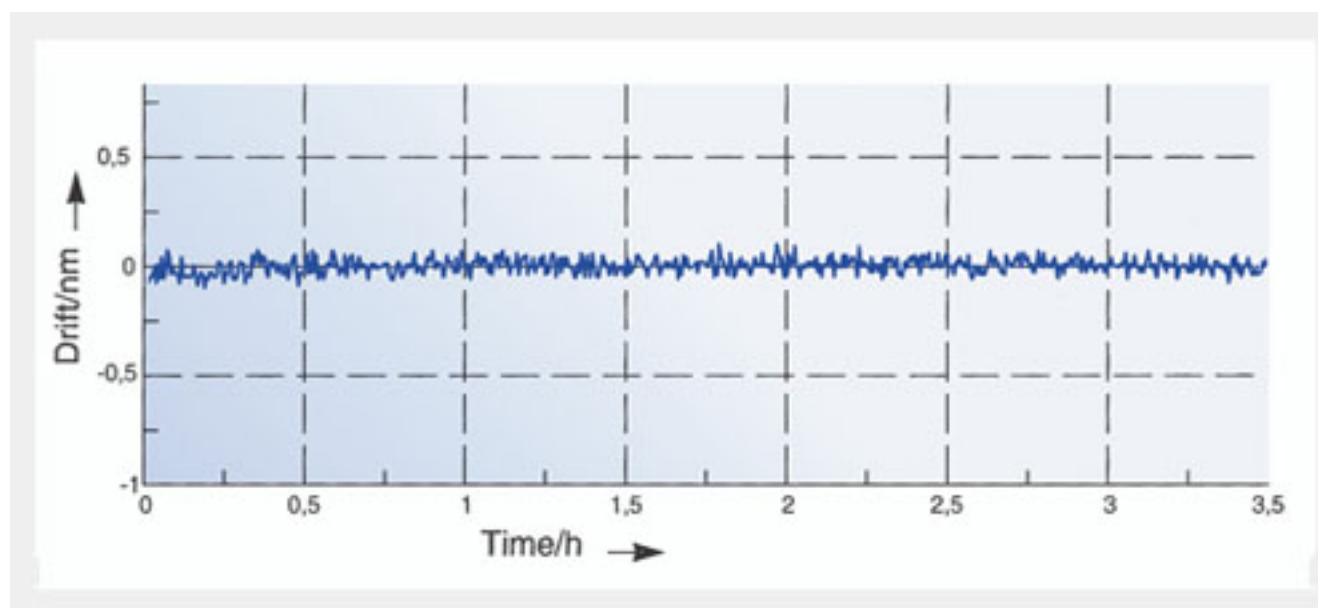


Fig. 3

[>> Read on or jump to the Capacitance Sensor Selection Guide](#)

[>> E-852 Signal Conditioner Electronics for D-510](#)

Special Design Eliminates Cable Influences



When measuring distance by detection of capacitance changes, fluctuations in the cable capacitance can have an adverse effect on accuracy. This is why most capacitive measurement systems only provide satisfactory results with short, well-defined cable lengths.

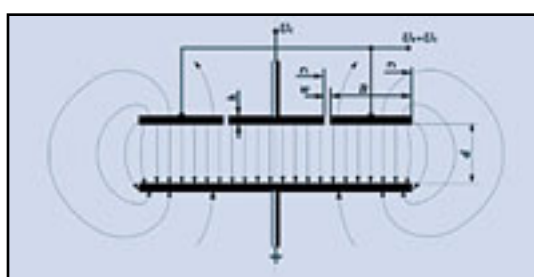
PI Systems use a special design which eliminates cable influences, permitting use of cable lengths of up to 3 m without difficulty. For optimum results, we recommend calibration of the sensor-actuator system in the [PI Metrology Lab](#).

Signal Paths to 15 Meters

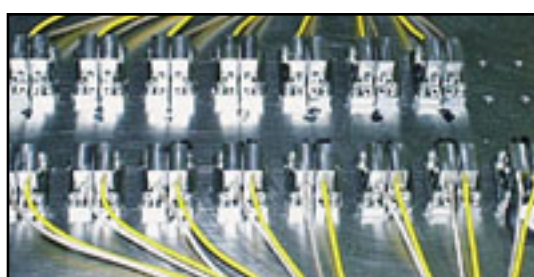
Longer distances between sensor and electronics can be spanned with special, loss-free, digital transmission protocols.

A remote sensor interface box is available for the [E-710](#) digital nanopositioning controller.

Features & Advantages, Applications



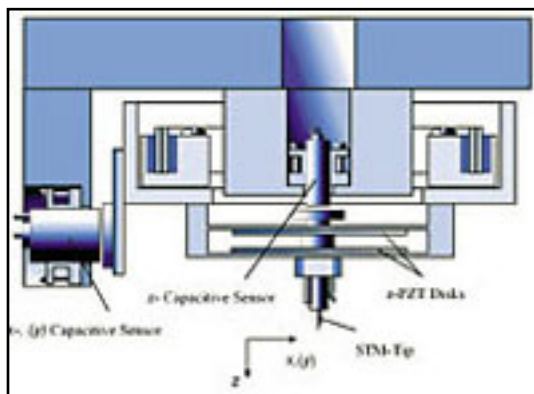
Two-plate capacitive sensor working principle.



Quality control and long-term stability testing of capacitive displacement sensors at PI.



Custom, 7-channel, capacitive position sensor electronics.



Working principle of STM (scanning tunneling microscope) with integrated capacitive position sensors

Properties of PI Sensors

- Highest resolution (0.01 nanometer) of all commercially available position sensors
- Measuring ranges of up to 1 mm
- Ideal for parallel metrology applications
- Linearity to 0.003%
- Extremely high long-term stability (better than 0.1 nm / 3 hours)
- Vacuum compatible
- Bandwidth to 10 kHz
- Invar versions for highest temperature stability ($5 \times 10^{-6} / K$)
- Multi-channel digital electronics available
- Compatible with PI nanopositioning system servo-controllers
- Two-plate and single-plate sensors
- Custom models

Reasons for Choosing PI

- Over 30 years experience in designing ultra-high-precision mechanics
- In-house design & manufacture of sensors and electronics
- State-of-the-art equipment for simulation, production and testing
- State-of-the-art metrology lab with multiple thermal, acoustic and seismic isolation for meaningful sub-nanometer measurements
- In-house controller development
- PI has the most-experienced nanopositioning systems development and production teams in the field
- ISO-9001 certified since 1994

Capacitance Sensor Selection Guide

Models*	Standard Range [μm]*	Extended Range [μm]*	Material*	Notes
D-510.020	20	100	Al	Single plate, easy setup, E-852 compact signal conditioner / controller . Sub-nanometer-resolution. Other materials on request
D-510.050	50	250	Al	
D-510.100	100	500	Al	
D-015.00	15	45	Al	Dual Plate. Highest Precision. Sub-Nanometer-resolution. Other materials on request
D-050.00	50	150	Al	
D-100.00	100	300	Al	

*Custom dimensions, sensors, designs for volume buyers.
 We manufacture a variety of capacitance sensors specifically for use in our nan positioning systems (see selection guide below)



➤ [Get the new hardbound, 500 page PI Catalog](#)

P-541.Z	Low-profile Z-stage, 80 x 80 mm aperture.	Z	100	Capacitive / SGS
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>> Closed-Loop Single-Axis Piezo Stages with Direct Metrology Sensors
(Direct metrology provides increased accuracy)

Models*	Description	Axes	Travel [µm]	Sensor
P-622.Z - P-622.Z	PIHera® Z-axis piezo stages, compact, very accurate, long travel range.	Z	50, 100, 250	Capacitive
P-772	Nanopositioning piezo stage, very compact, fast and accurate	X	10	Capacitive
P-750	High-load nanopositioning piezo stage, very good guidance, high stiffness.	X	75	Capacitive / LVDT
P-752	Nanopositioning piezo stage. Very fast and accurate, outstanding guiding accuracy.	X	15, 30	Capacitive
P-753	Nanopositioning piezo stage and actuator in one, very compact, fast and accurate.	Z & X	12, 25, 38	Capacitive
P-620.1 - P-625.1	PIHera® piezo nanopositioners, compact, very accurate, long travel ranges, excellent value	X (XY, Z)	50, 100, 250, 500	Capacitive

>> Multi-Axis Stages, Modular piezo Stages (Serial Kinematics)

Models*	Description	Axes	Travel [µm]	Sensor
P-620.2 - P-625.2	PIHera® XY piezo nanopositioners, Very compact & accurate (direct metrology), long travel range.	XY (Z, XYZ)	50, 100, 250, 500	Capacitive

>> Multi-Axis Stages, Parallel Kinematics / Parallel Metrology
(Parallel kinematics and parallel metrology allow active trajectory control, better dynamics and higher multi-axis precision)

Models*	Description	Axes	Travel [µm]	Sensor
P-615	NanoCube® 350C XYZ piezo alignment system, clear aperture, ideal for fiber alignment.	XYZ	to 350 / Axis	Capacitive
P-363	PicoCube® high-precision system for AFM, SPM, nanomanipulation; 50 picometer resolution.	XY, XYZ	5 / Axis	Capacitive
P-541 P-542	Low profile XY scanning stage 80 x 80 mm aperture.	XY	to 200 in XY	Capacitive
P-733	XY piezo scanning stage 50 x 50 mm aperture, vacuum versions available.	XY	100 x 100	Capacitive
P-733.2DD / P-733.3DD	High-speed scanning stage, XY and XYZ versions, ideal for tasks like scanning microscopy.	XY, XYZ	30 x 30 (x10)	Capacitive
P-734	XY nanoscanning stage, extremely flat and straight (1 – 2 nm); 56 x 56 mm clear aperture..	XY	100 x 100	Capacitive
P-517 - P-527	Multi-axis stage 66 x 66 mm clear aperture, custom model with 6 degrees of freedom available.	XY, XYZ, XYθ _z	to 200 in XY, 10 in Z, to 2 mrad	Capacitive
P-561.3DD	PIMars™ XYZ scanning stages, faster, direct drive, excellent guidance, 66 x 66 mm clear aperture.	XY, XYZ	45 XY, 11 Z	Capacitive
P-561 - P-563	PIMars™ multi-axis stages; travel range to 300 x 300 x 300 µm , 66 x 66 mm clear aperture, custom model with 6 degrees of freedom available.	XY, XYZ	to 300 x 300 x 300	Capacitive
P-587	6-axis-nanopositioning stage.	XYZ, θ _x θ _y θ _z	up to 800 / 10 mrad	Capacitive
P-518 - P-558	Z-axis and tip/tilt platforms clear aperture	Z, θ _x θ _y	to 200 in Z, 4 mrad	Capacitive

>> Z-Axis and Tip/Tilt Platforms
mirrors see "Active Optics / Steering Mirrors" section

Models*	Description	Axes	Travel [µm]	Sensor
P-541.Z	Low-profile Z-stage, 80 x 80 mm aperture.	Z & Z, Tip/Tilt	100	Capacitive / SGS
P-518 - P-558	Z-axis and tip/tilt platforms 66 x 66 mm clear aperture	Z & Z, Tip/Tilt	to 200 in Z, 4 mrad	Capacitive
P-620.Z - P-622.Z	PIHera® Z-axis nanopositioners, compact, very accurate, long travel range.	Z	50, 100, 250	Capacitive

>> Scanning (Microscopy) Stages with Clear Aperture

Models*	Description	Axes	Travel [µm]	Sensor
P-725	PIFOC® objective nanofocusing system, compact, light-weight, long travel ranges, QuickLock mounting system, direct metrology	Z	100, 250, 400	Capacitive
P-541.Z	Low-profile Z-stage, 80 x 80 mm aperture	Z & Z, Tip/Tilt	100	Capacitive / SGS
P-518 - P-558	Z-axis and tip/tilt platforms clear aperture Tip/Tilt	Z & Z	to 200 in Z, 4 mrad	Capacitive

P-541 P-542	Low profile XY scanning stage 80 x 80 mm aperture	XY	to 200 in XY	Capacitive / SGS
P-733	XY piezo scanning stage 50 x 50 mm aperture, vacuum versions available.	XY	100 x 100	Capacitive
P-733.2DD , P-733.3DD	High-speed scanning stage, XY and XYZ versions, ideal for tasks like scanning microscopy	XY, XYZ	30 x 30 (x10)	Capacitive
P-734	XY nanoscanning stage, extremely flat and straight (1 – 2 nm); 56 x 56 mm clear aperture.	XY	100 x 100	Capacitive
P-517 , P-527	Multi-axis stage 66 x 66 mm clear aperture, custom model with 6 degrees of freedom available.	XY, XYZ, XY θ_z	to 200 in XY, 20 in Z, to 4 mrad	Capacitive
P-561 - P-563	PIMars™ multi-axis stages; travel range. to 300 x 300 x 300 μm , 66 x 66 mm clear aperture, custom model with 6 degrees of freedom available	XY, XYZ	to 300 x 300 x 300	Capacitive

>> 6-Axis Parallel Kinematics Stages

Models*	Description	Axes	Travel [μm]	Sensor
P-587	6-axis-nanopositioning stage	XYZ, $\theta_x\theta_y\theta_z$	up tp 800 / 10 mrad	Capacitive

>> Objective Nanofocusing Systems / Z-Stages

Models*	Description	Axes	Travel [μm]	Sensor
P-725	PIFOC®. objective nanofocusing system, compact, light-weight, long travel ranges, QuickLock mounting system, direct metrology.	Z	100, 250, 400	Capacitive
P-721.CDQ P-721.LLQ	PIFOC®. Piezo-Z objective nanofocusing system, very fast and accurate, with QuickLock mounting system, direct metrology.	Z	100	Capacitive / LVDT

Selection Guide: Piezo Stages with Integrated Capacitance Sensors



* Ask about custom sizes, sensors or special designs.
Capacitive and LVDT sensors are direct metrology devices.
Capacitive sensors provide the highest accuracy, bandwidth and linearity.