PZ 106E User Manual

Capacitive Sensors

D-015, D-050, D-100

Release 2.2.0

Product Description
and
Operating Notes

This document is valid for the following Products:

D-015.x0	**Capacitive Sensor, 15 µm nominal range**
D-050.x0	**Capacitive Sensor, 50 µm nominal range**
D-100.x0	**Capacitive Sensor, 100 µm nominal range**

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1 Introduction

Closed-loop position control of piezoelectric-driven stages offers stable, drift-free and hysteresis-free motion, high virtual stiffness and long-term position stability. The key element for position servo-control is the sensor measuring the stage position. The sensor's accuracy determines to a high degree the resolution and the quality of the total position control system. Therefore high-resolution sensors with appropriate evaluation electronics have to be used to achieve best performance of the position control system.

This manual describes handling and operation of capacitive sensors. Compared with other sensor types, capacitive sensors provide excellent resolution, long-term and temperature stability. The measurement range of up to 300 micrometers is sufficient for most piezoelectric positioning applications.

Excitation and readout of capacitive sensors requires sophisticated, low-noise electronics. Most PI servo-controllers, both digital and analog, are available with circuitry for capacitive sensors. In this manual, the E-509.CxA module, designed for use in the E-500 chassis, is used in several examples. For details, see the manual for the controller you are using.

For information on the excitation and readout electronics, see the manual for the servo-controller you are using (e.g. E-509.CxA or E-665.CR).

2 Model Survey

Capacitive Sensors consist of two parts, called plates: the probe and the target. The following models each consist of a matched set of probe and target plates.

Model*	Material*	Active Area	Nominal Range
D-015.00	Alu	16.6 mm^2	15 µm
D-050.00	Alu	67.7 mm^2	50 µm
D-100.00	Alu	113.1 mm^2	100 µm

*Invar and Stainless Steel versions as well as customized sensors are available on request.

In addition, a number of PI products have integrated capacitive sensors, such as the P-721.CLQ PIFOC Microscope Objective Nanopositioner.

3 Mounting Instructions

If you are using a PI stage with integrated capacitive sensors, the information on proper mounting and handling can be skipped.

If you have ordered a complete mechanical system, the sensors are aligned and the positions of both probe and target plate are adjusted before shipment. There should be no need for further mechanical or electrical adjustments.

If you intend to mount the sensor plates in your own system, you must align both parallelism and distance.

Note: A Capacitive Sensor consists of a matched pair of one PROBE and one TARGET plate. The pair used to tune the E-509 module to best performance should also be used in the application. For best accuracy, you should not mix up different probes and targets.

If you mix up PROBE and TARGET, the sensor system will work, but results will not be as accurate as specified.

For non-morphologic reasons, the *Probe* is usually connected to the *stationary* plate, the *Target* to the *moving* plate!

The following considerations must be taken into account while designing the mechanical flats for mounting capacitive sensors.

1. The sensor consists of two parts, the PROBE and TARGET plates. Either the probe or the target is mounted on the moving part of the positioning system while the other plate is connected to the base of the stage (generally the TARGET is the moving part!). Note: The target has yellow cable, the probe has blue or brown cable.
2. Standard E-509 Servo-Control Modules expect the sensor signal to increase when the PZT element expands and vice versa.
3. The plates of the capacitive sensor must be mounted parallel to each other with minimum angular displacement. Errors in parallelism can be caused by improper alignment of the mounting flats or may be caused by angular tilting during stage moves. Such alignment errors can influence the linearity and gain factor.
4. Because the mounting distance of the sensor is very critical, you must assure axial alignment of the plate distance. Small deviations from the nominal distance may be compensated by a zero-adjust potentiometer, usually accessable on the front panel of the controller.

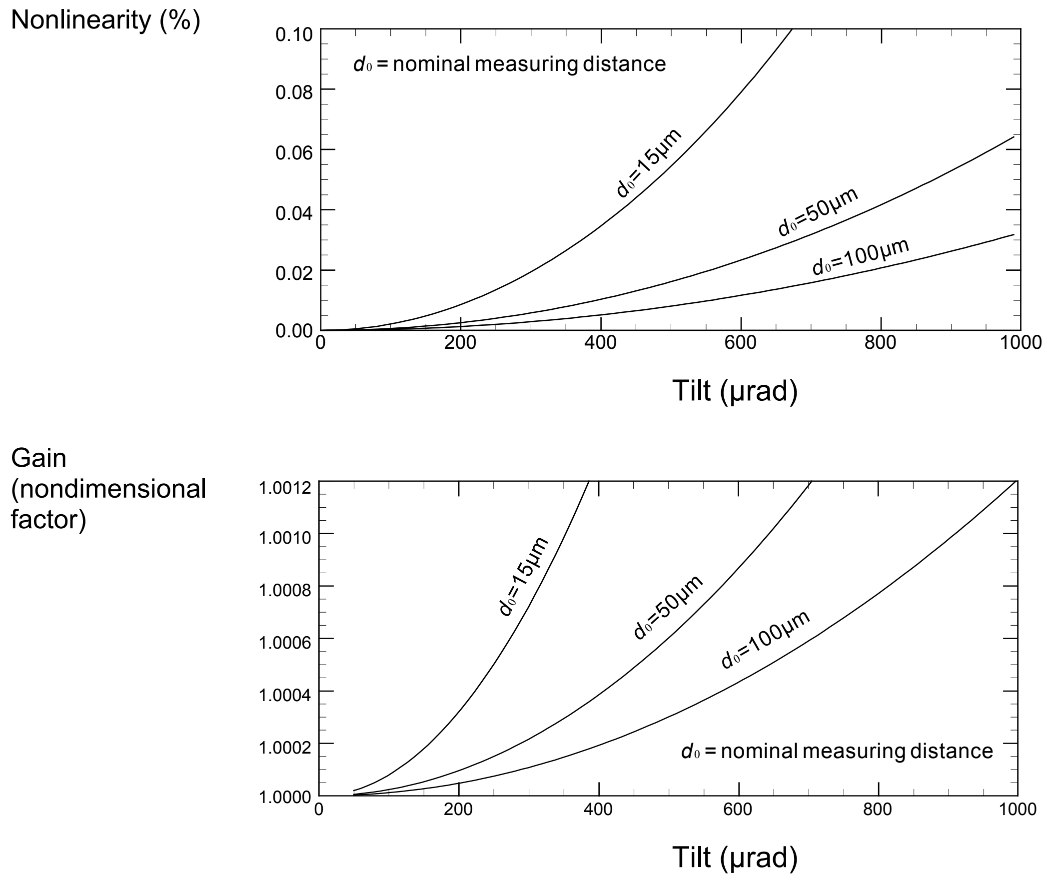

Fig. 1: Influence of angular misalignment on linearity (top) and gain (bottom).

3.1 Mounting Distances

A capacitive sensor has to be mounted such that the minimum measurement distance is 50% of the nominal range d_0 and the maximum distance is 1.5 times the nominal range, e.g. if a sensor has a nominal range of 100 µm, the zero position distance is 100 µm, the minimum (closest) position is 50 µm and the maximum position is 150 µm. Mounting the sensor plates with larger or smaller separtation will narrow the useable measurement range.

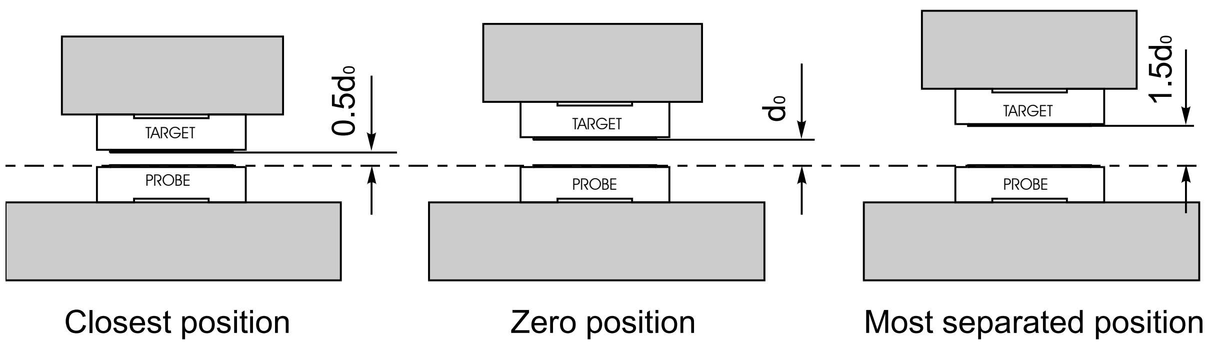

Fig. 2:Mounting distance of capacitive sensors

3.2 Influence of Temperature

The accuracy of a capacitive sensor depends also on its geometry (flatness, mounting parallelity and centricity). Temperature variations cause slight bending of the sensing surfaces if the materials of the sensor and mounting flat have different temperature coefficients. Best results can be achieved if both materials A and B are the same:

> Note:
>
> The best (flattest) probe surface can be obtained if both materials A and B have the same coefficient of thermal expansion

If the sensor is mounted on a surface with a different thermal expansion coefficient, deviations from the ideal flatness have to be considered:

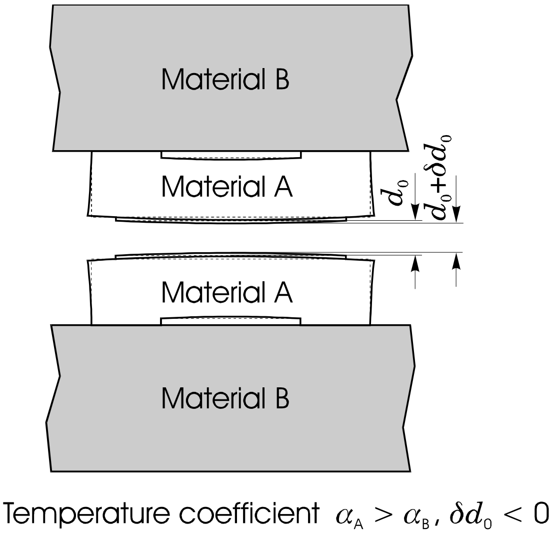

Fig. 3:

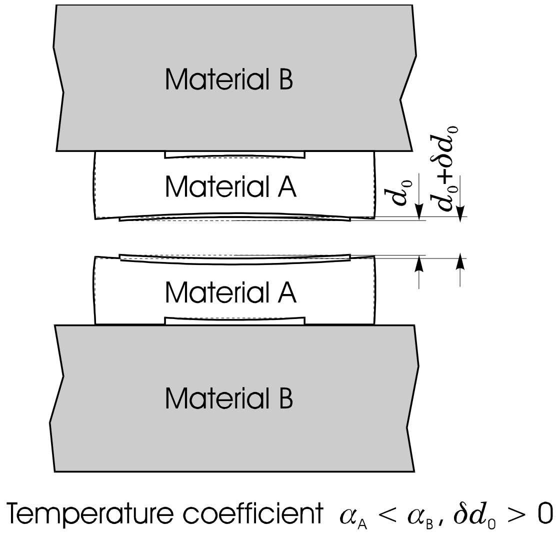

Fig. 4:

4 Mechanical Zero-Point

If your capacitive sensors were installed by PI, then they should have been calibrated before shipment and should not need to be readjusted.

4.1 Definition

The mechanical zero position of the sensor plates is the position (distance) where the capacitance of the sensor equals the capacitance of the associated reference capacitor (10 pF, 4.7 pF or 3.3 pF, depending on the value installed or configured).

4.2 How to Recognize the Mechanical Zero Position

Assuming the sensor is connected to an E-509 controller, at the mechanical zero position the monitor output signal is 0 V when the zero adjust potentiometer (on the front panel) is full CCW (counterclockwise). At the closest plate distance, the monitor output signal is -5 V, at the farthest distance +5 V. The *nominal measurement range* is the range between the closest and farthest separation of the plates.

Capacitive sensors can also be used with servo-controllers expecting a unipolar input from 0 to +10 V, such any of PI's analog controllers based on the E-802 servo-control submodule. Then, the zero-adjust must be set to an offset of +5 V (close to the center position), so that the sensor output falls in the 0 to +10 range.

4.3 Adjusting the Mechanical Zero

Mechanical zero adjustment is one of the basic calibration operations. It affects all subsequent calibrations.

1. Make sure that servo-control mode is set to OFF at the controller you are using.
2. Turn the sensor-processing electronics ZERO potentiometer (usually on the controller front panel) full counterclockwise (CCW).
3. Mechanically adjust the position of the sensor parts (Target and Probe) so that the sensor monitor signal is -5 V at the closest distance and +5 V at the most-separated position.
4. With the plates at their closest distance, turn the ZERO potentiometer clockwise (CW) until the monitor reading is about 0 V.Now the sensor output signal range is 0-10V, as required by most PI controllers (e.g. E-509).

5 Technical Data

5.1 Specifications

PARAMETER	D-015.00			D-050.00			D-100.00			UNITS
	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
NOISE (1) f = 100 Hz		1.2	1.75		4.0	5.8		8.0	11.7	$pm/\sqrt{Hz}$
LINEARITY (1)		0.05	0.1		0.05	0.1		0.05	0.1	%
EXPANSION (2) Aluminum Thickness Area Invar Thickness Area		 180 -0.75 16 -0.06	 220 -0.06		 180 -2.5 16 -0.2	 220 -0.2		 240 -5 20 -0.4	 270 -0.4	nm/°C
INFLUENCE OF AIR (2) Sensor Air pressure P_A Humid partial pressure P_q Temperature			 0.013 -1.7 0.042			 0.043 -5.7 0.14			 0.086 -11.4 0.28	 nm/hPa pm/hPa nm/°C
RESONANT FREQUENCY (2)	20			20			20			kHz

(1) Values were taken with E-509.C1A.

(2) Expected from design-based calculations

5.2 Capacitance/Distance Relation

The sensor probe and target plates form an air-capacitor. Its capacitance value depends on the separation of the plates and is compared with an internal reference capacitor of C_r=10 pF. Changes of the distance d between the two plates cause a change in capacitance and the resulting signal is related to the deviation from the nominal distance d_0.

At the nominal distance, the capacitance of the sensor equals the capacitance of the internal reference capacitor. The resulting sensor electronics output voltage U_{out} is 0 V (with standard setting), with most controllers, it can be monitored at a SENSOR-MONITOR output terminal on the device.

$$U_{out} = 10\text{V} \times \left(\frac{d}{d_0} - 1\right)$$

If the distance between the sensor plates becomes smaller, the monitor signal becomes negative and will reach -5 V at the minimum measurement position, which is 50% of the nominal range (d=0.5d_0). At the maximum measurement position, 150% of the nominal range (d=1.5d_0), the monitor signal reaches +5 V.

5.3 Resolution

The resolution of a capacitive sensor is limited by electronic noise in the signal processing electronics. The length and trace of the connecting cables may also influence the signal noise. Mechanical imperfections in manufacturing and mounting of the sensor plates may cause non-linearities, but will not significantly affect the resolution.

Using E-509.C1A signal processing boards, the system-inherent noise density of about 1.15 $\mu\text{V}/\sqrt{\text{Hz}}$ is the real limitation of resolution.

5.4 Features in Control Electronics

E-509 electronics provide a linearization option to compensate for inhomogeneities of the electric field. Influences caused by mechanical errors, e.g. through deviations in the plane parallelism can also be compensated to first order effects. Parallelism of plate mounting is an important factor for non-linearities.

The sensor processing module, in conjunction with the special linearization circuit, ensures very good linearity, low background noise and excellent long-term stability.

For multi-channel applications, there are synchronization options to preventbeat interference.

When connecting the electronics, note that:

The PROBE plate has a blue or brown cable or is labeled with "P".

The TARGET plate has a yellow cable or is labeled with "T".

6 Dimensions

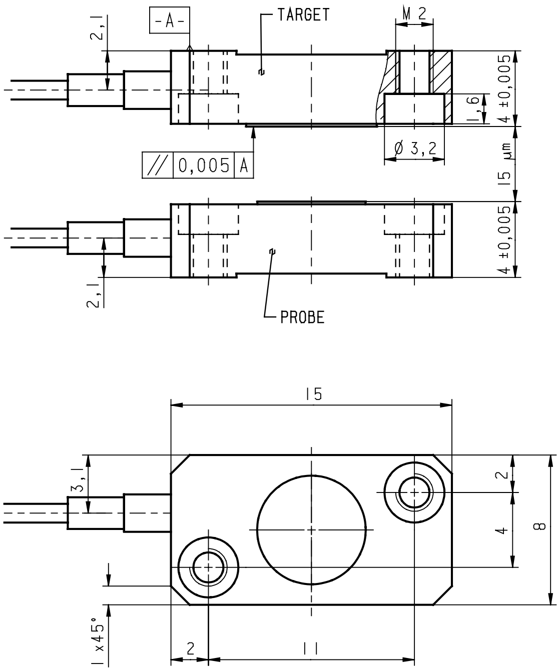

Fig. 5: D-015.00

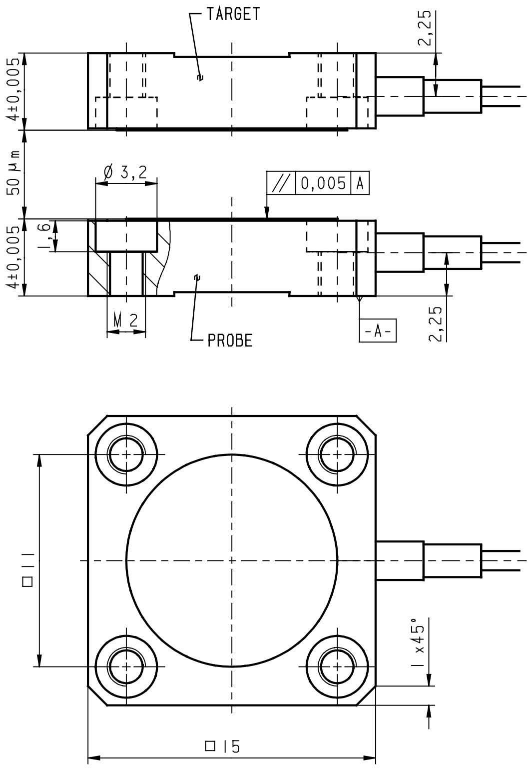

Fig. 6: D-050.00

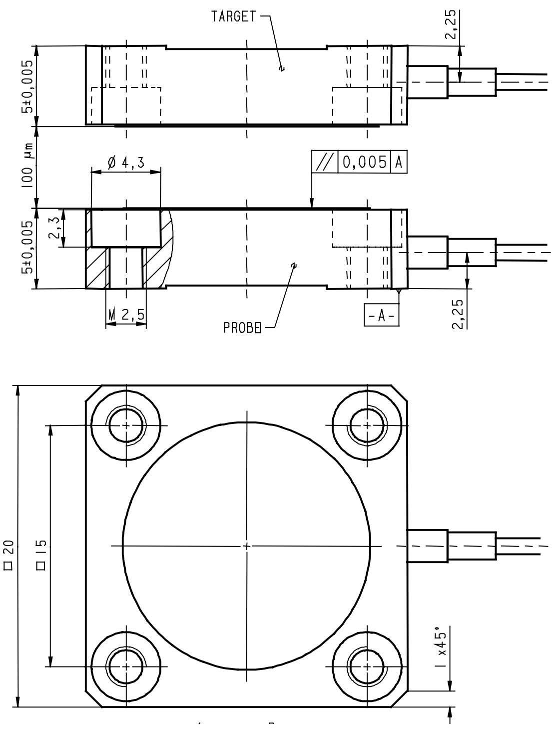

Fig. 7: D-100.00

Notes:

TARGET has yellow cable

PROBE has blue or brown cable.

Dimensions in mm, decimal places separated by commas in drawings