

E-710

**High-Speed Digital NanoAutomation®
Piezo Controllers**



E-710.6CD 6-axis digital piezo controller shown with custom Super Invar 6-DOF piezo flexure NanoPositioning stage.

Ordering Information

- E-710.3CD**
Digital Piezo Controller, 3 Axes, Sub-D-Special Connector, RS-232 & IEEE-488 Interface
- E-710.4CL**
Digital Piezo Controller, 4 Axes, Lemo Connectors, RS-232 & IEEE 488 Interface
- E-710.4CD**
Digital Piezo Controller, 4 Axes, Sub-D Connector, RS-232 & IEEE 488 Interface
- E-710.P3D**
Digital Piezo Controller, 3 + 1 Axes, Sub-D-Connectors, RS-232, IEEE-488 & High-Speed PIO Interface
- E-710.P4L**
Digital Piezo Controller, 4 Axes, LEMO Connectors, RS-232, IEEE 488 & High-Speed PIO Interface
- E-710.P4D**
Digital Piezo Controller, 4 Axes, Sub-D Connectors, RS-232, IEEE 488 & High-Speed PIO Interface
- E-710.6CD**
Digital Piezo Controller, 6 Axes, Sub-D-Special Connectors RS-232 & IEEE 488 Interface

- Options**
- E-710.SCN**
Dynamic Digital Linearization Upgrade
- E-710.3x3**
Extension Cable Piezo NanoPositioning Stage/E-710.3CD Controller, 3 m
- E-710.3x5**
Extension Cable Piezo NanoPositioning Stage/E-710.3CD Controller, 5 m
- E-710.1x3**
Extension Cable 3m, E-750 / E-710 to Piezo Flexure Stage, 1 Channel Sub-D

Custom Designs for Volume Buyers

- **For Piezo NanoPositioners with Capacitive Feedback Sensors**
- **3-, 4- & 6-Channel Versions**
- **32-Bit Digital Filters**
- **Polynomial Linearization**
- **Coordinate Transformation for Parallel Kinematics / Parallel Metrology Systems**
- **Optional Dynamic Digital Linearization (Firmware Option) Improves Scanning Linearity**
- **AutoCalibrate Function for Easy Controller / Stage Interchangeability**
- **Fast RS-232 and IEEE 488 Interfaces**
- **Optional High-Speed Parallel Port Interface**
- **Extensive Software Support**

E-710 digital piezo controllers/drivers are the most advanced and flexible controllers for piezo nanopositioning and scanning stages on the market. Based on powerful 32-bit DSPs (digital signal processor) they control up to six-degrees of freedom with integrated power amplifiers for multilayer PZT drives (-20 to 110 V) and

signal conditioning electronics for two-plate capacitive position sensors. E-710 controllers represent a major advance over conventional multi-axis controllers because the sensor and output channels of two or more axes can participate in an internal coordinate transformation for multi-axis parallel-kinematics positioning systems with parallel-motion metrology, e.g. the P-500 series on page 2-32.

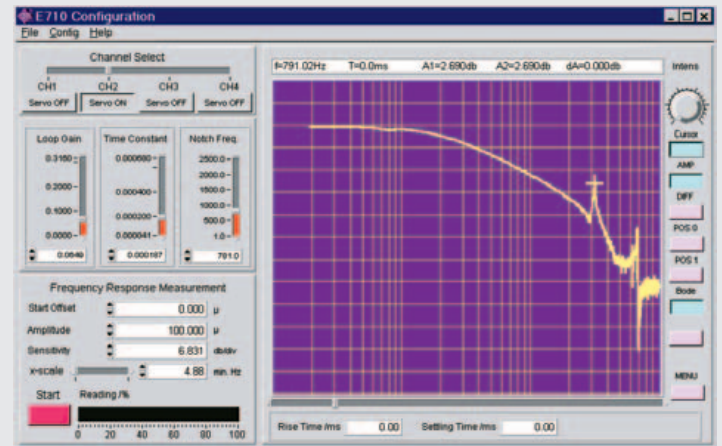
Parallel Motion Metrology "Sees" all Controlled Degrees of Freedom Simultaneously

Parallel-kinematics nanopositioning systems with parallel-metrology position feedback are superior to stacked or nested multi-axis positioning systems. They allow active trajectory control, automatic crosstalk and runout compensation and provide direct, non-contacting position information, measuring motion exactly where it matters (rather than measuring the strain in the drive system, a technique common in lower-precision

positioning systems relying on the feedback of piezo resistive sensors).

Integrated Linearization Systems

E-710-controlled nanopositioning systems boast outstanding linearity, achieved by PI's proprietary ILS (Integrated Linearization System) and additional digital polynomial linearization. The ILS, part of the E-710's capacitive position sensor signal conditioning circuitry, compensates for influences caused by non-parallelism of the sensor plates. The digital polynomial linearization is calibrated for each individual nanopositioning system and can improve linearity to 0.001% over the full travel range.



E-710 data acquisition and analysis functions (Bode plots, etc.) help optimize performance of NanoPositioning systems.



PZT Actuators
PZT Flexure NanoPositioners
PZT Active Optics / Steering Mirrors
Tutorial: Piezoelectrics...
Capacitive Position Sensors
PZT Control Electronics
MicroPositioners / Hexapod Systems
Photonics Alignment & Packaging Systems
Motor Controllers
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Dynamic Digital Linearization

System Analysis—Advanced Software Tools

The E-710 comes with the NanoCapture software featuring advanced functions for measuring-system response, step-and-settle and Bode plots. All positioning commands use standard units such as micrometers or microradians, for easy programming. In addition, all control parameters are non-volatile, user-accessible and can be easily modified and optimized. Fully programmable low-pass & notch filters round out the E-710.

Integrated Wave Generator & Look-up Table

The implementation of a wave generator for all E-710 models allows the synchronous driving of several axes with a mathematical function or with a user-defined random signal stored in a lookup table containing 65,535 points. Programmable trigger inputs and outputs facilitate synchronization with external events.

Communication / Interfaces

E-710 controllers are equipped with fast RS-232 and IEEE 488 interfaces. The optional parallel port I/O (PIO) interface allows the fastest possible position setting/reading (20,000 positions per second bypassing the command parser).

Dynamic Digital Linearization Improves Scanning Linearity up to 3 Orders of Magnitude

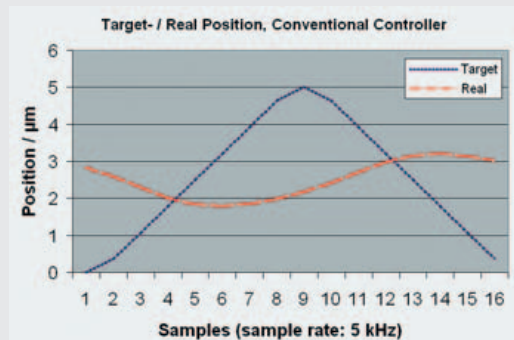
Control theory predicts that conventional PID (proportional

integral derivative) servo motion controllers exhibit phase lag and tracking errors in dynamic operation (due to the fact that a PID controller needs to see an error first before a reaction occurs, and also due to the nonlinear nature of PZT material). Depending on the controller settings and specs of the nanopositioning system driven, tracking errors (the difference between the commanded position and actual position) can reach double-digit percentage values even at

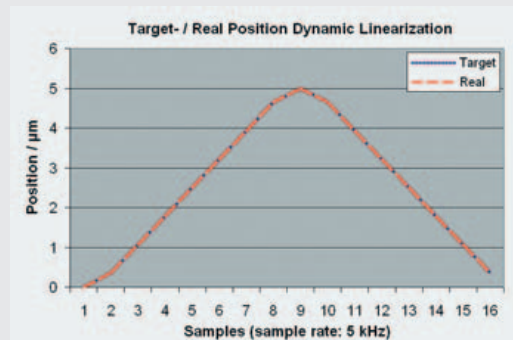
moderate scanning rates. Consequently, scanning stages often cannot be driven at the desired rates, or the acquired data has poor linearity.

The new E-710.SCN Dynamic Digital Linearization upgrade (standard for the E-710.6CD 6-axis controller, optional for the 3- and 4-channel versions) solves this problem. This PI-exclusive technology is a breakthrough for scanning applications, reducing phase lag and nonlinearity to indiscernible levels, even with high-

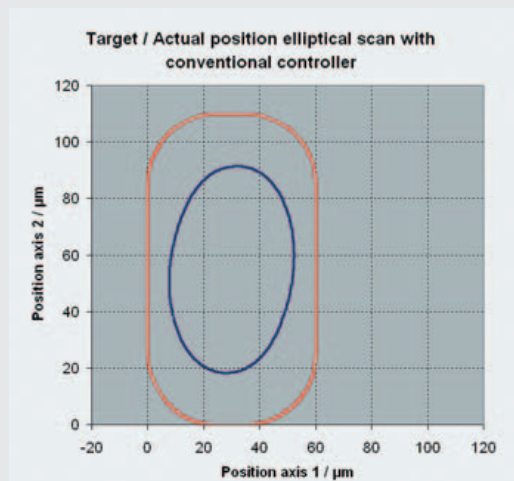
frequency dynamic actuation under load. The effect is an improvement in linearity (and usable bandwidth) of up to three orders of magnitude, resulting in significantly increased throughput. Dynamic Digital Linearization works both in single-axis and multi-axis applications (see graphs).



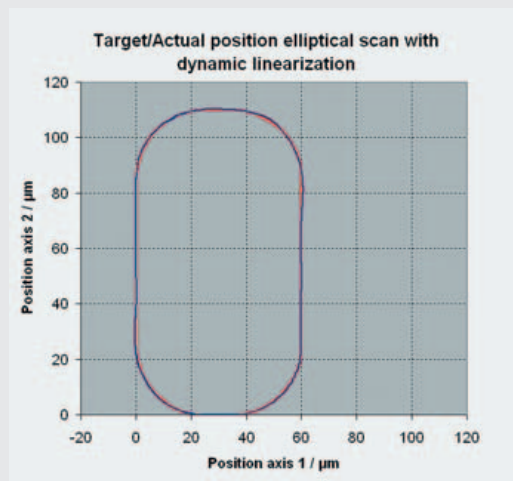
Triangular scanning signal at 312 Hz. There is a significant difference (2.6 μm max.) between target and real position with the conventional PID motion controller.



Triangular scanning signal at 312 Hz, with the E-710 with dynamic digital linearization. The difference between the target position and the actual motion is indiscernible. The maximum error is only 7 nanometers.



Elliptical scan in a laser micro-drilling application with XY piezo scanning stage, conventional controller, 60 msec/rev. The outer curve ellipse describes the target position, the inner ellipse shows the actual motion at the stage.



Same scan as before, with dynamic digital linearization. Target and actual data can hardly be discerned.

Extensive Software Support

The E-710 controller comes with a variety of software tools as well as LabView™ drivers and DLL's for easy setup, system analysis and integration.

NanoCapture™ Software for E-710 Digital Piezo Controllers

- **Allows Optimization of all Servo Parameters**
- **Measures System Response, Step and Settle, Resonant Frequency, Bode Plots**
- **Increases Throughput**
- **Wave Generator: Defines and Simulates Waveforms and Reports Wave Generation Results**

The NanoCapture™ software provided with the E-710 digital piezo controller is a versatile tool for system response analysis and optimization and for the definition and generation of waveforms.

Advanced Analysis Tools

In addition to standard functions for the operation of piezo NanoPositioning systems, NanoCapture™ features advanced measuring and analysis functions for resonant frequency, overshoot, step-and-settle, Bode plots, etc. These features are specifically useful when the mechanical properties of a factory-calibrated system are changed at the operating site by parameters such as an increased or reduced payload, a different orientation or different damping conditions.

In this case, parameters such as servo-gain, notch-filter frequency, or the position sensor's zero point, etc. need to be adjusted to maintain optimum system response and stability. NanoCapture™ supports the operator in determining system resonant frequency, rise time, and settling time by analyzing the dynamic position feedback data from the NanoPositioning system's integrated capacitance sensors (no other metrology or measur-

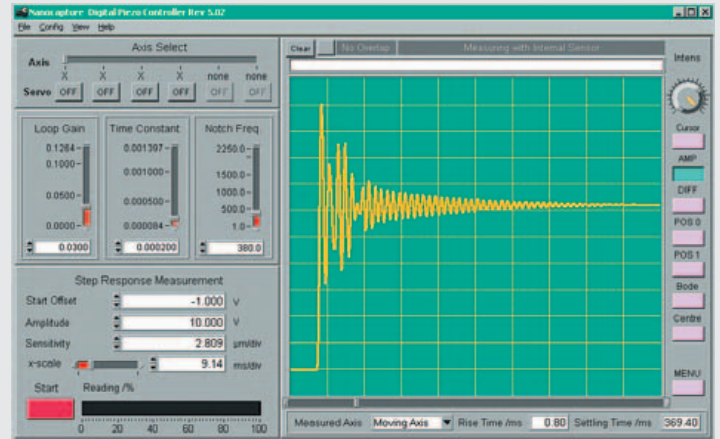
ing instruments are required!). Based on this data, servo parameters are easily adjusted for optimized settling under any load condition.

Wave Generator Handling

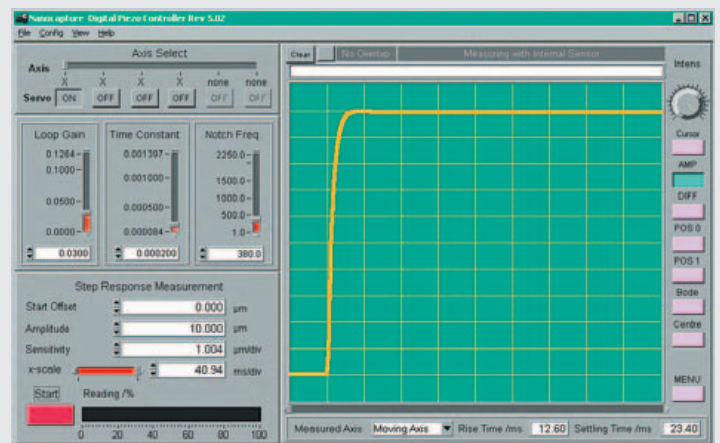
In addition to its system analysis and optimization functionalities, the NanoCapture™ software allows convenient handling of the wave generator feature of the E-710 controller:

- **Rapidly perform simple waveforms as well as circular trajectories with two axes**
- **Design complex waveforms**
- **Save defined wave segments to the controller**

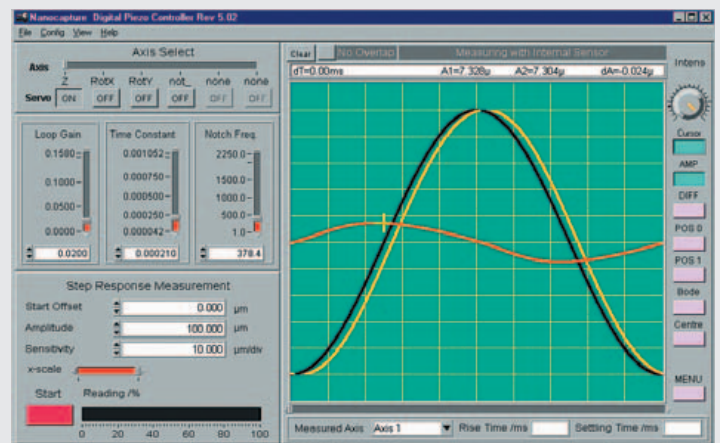
The NanoCapture™ software also permits the user to see the effects of the E-710.SCN Dynamic Digital Linearization upgrade on the position accuracy of repetitive functions such as scans.



Step response of a (poorly damped), open-loop NanoPositioning system. Data acquisition with E-710 and NanoCapture™ software.



Closed-loop response of a NanoPositioning system with optimized servo settings. Data acquisition with E-710 and NanoCapture™ software.



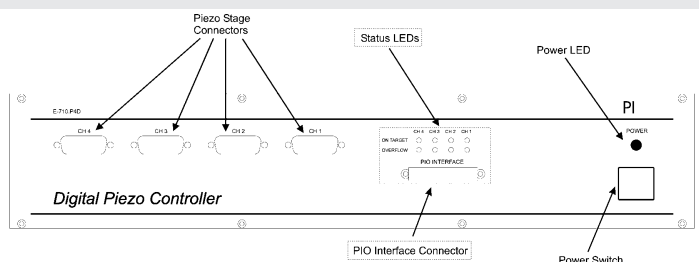
E-710 internal wave generator. Data acquisition with E-710 and NanoCapture™ software.

PZT Control Electronics

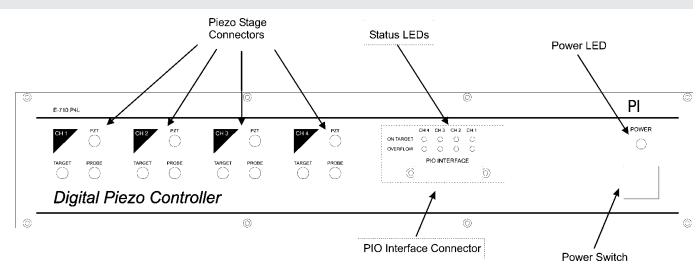
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Technical Data

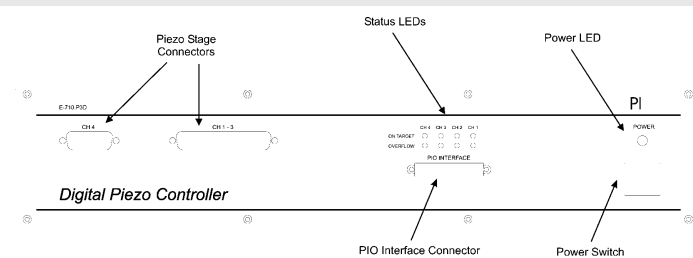
Model	E-710.3CD	E-710.4CD / E-710.4CL / E-710.P3D / E-710.P4D / E-710.P4L	E-710.6CD
Function	Digital NanoAutomation® PZT controller and power amplifier	Digital NanoAutomation® PZT controller and power amplifier	Digital NanoAutomation® PZT controller and power amplifier
Axes	3	4	6
Sensor	Capacitive sensors	Capacitive sensors	Capacitive sensors
Processor	DSP 32-bit floating point, 33 MHz	DSP 32-bit floating point, 33 MHz	2 x DSP 32-bit floating point, 33 MHz
Sampling interval	50 µs (sensor), 200 µs (servo-loop, 4 axes)	50 µs (sensor), 200 µs (servo loop, 4 axes)	40 µs (sensor), 200 µs (servo-loop, 6 axes)
Effective Resolution DAC	20-bit	20-bit	20-bit
Maximum output power	25 W / channel	25 W / channel	25 W / channel
Average output power	6 W / channel	6 W / channel	6 W / channel
Peak output current < 20 ms	200 mA / channel	200 mA / channel	200 mA / channel
Average output current > 20 ms	60 mA / channel	60 mA / channel	60 mA / channel
Current limitation	Short-circuit proof	Short-circuit proof	Short-circuit proof
Output voltage	-20 to +110 V	-20 to +110 V	-20 to +110 V
PZT voltage output sockets	3-channel sub-D special	3-ch. + 1ch. sub-D, special (models E-710.P3D only), 4x 1-ch. Sub-D, special (models E-710.4CD and E-710.P4D only)	LEMO ERN.00.250.CTL (E-710.xxL only) 2x 3-channel sub-D special
Sensor sockets	3-channel sub-D, special	3-ch. + 1 ch. sub-D, special (models E-710.P3D only), 4x 1-ch. Sub-D, special (models E-710.4CD and E-710.P4D only) LEMO PSA.00.250.CTAC22 (models E-710.xxL only)	2x 3-channel sub-D, special
Interfaces	RS-232 and IEEE 488	RS-232 and IEEE 488, all models (for ASCII command structure) PIO (models E-710.Pxx only)	RS-232 and IEEE 488, all models (for ASCII command structure)
Software	PZT Control, NanoCapture, LabView™ Drivers, DLLs	PZT Control, NanoCapture, LabView™ Drivers, DLLs	PZT Control, NanoCapture, LabView™ Drivers, DLLs
Dimensions	450 x 105 x 390 mm	450 x 105 x 390 mm	450 x 105 x 390 mm
Weight	7 kg	7 kg	7 kg
Power consumption (max)	60 W	60 W	60 W
Operating voltage	90-120 or 220-264 VAC, 50-60 Hz	90-120 or 220-264 VAC, 50-60 Hz	90-120 or 220-264 VAC, 50-60 Hz



Connectors of E-710.4CD and E-710.P4D. PIO interface and status LEDs present on the E-710.P4D version only.



Connectors of E-710.4CL and E-710.P4L. PIO interface and status LEDs present on the E-710.P4L version only.



Connectors of E-710.3CD and E-710.P3D. PIO interface, status LEDs and 4th-channel connector present on the E-710.P3D version only.