Piezotechnology

Piezo Ceramic Actuators and Custom Subassemblies

Who We Are

PI Ceramic is the piezo ceramic division of Physik Instrumente (PI), the world-leading manufacturer of ultra-high-precision piezo nanopositioning systems. Based on knowledge and expertise gained in more than 40 years of continuous research and manufacturing of piezoelectric material and components, PI Ceramic is a world-class supplier of high-performance piezoelectric actuator and transducer components and subassemblies.

PI Ceramic is also the only company to provide the ultra-reliable PICMA® monolithic piezo ceramic actuators. No other supplier of piezo ceramic actuators is better placed to design and produce innovative actuator solutions for today's and tomorrow's high-tech applications.

The PI Ceramic state-of-the-art facility in Lederhose, Germany hosts an extensive manufacturing operation, R&D laboratories and administration center

Contents

PI Ceramic Strengths

Clean room production guarantees the highest reliability

- **State-of-the-Art Piezo Assemblies, Transducers and Subsystems**
- **Design & Manufacture of Key Components for Capital Equipment & Research**
- **Custom and Standard Solutions**
- **Short Delivery Through Highly Flexible Processing**
- **All Key Technologies and Equipment In-House**
- **ISO 9001-2000 Quality Certified**

Key Markets and Applications

PI Ceramic delivers piezoelectric solutions for all important high-tech markets:

- Semiconductors
- Industrial Automation
- Precision Machining
- Life Sciences
- Medical Instrumentation
- Telecommunications
- Remote Sensing
- Vibration Cancellation
- Defense Industry
- Aerospace Engineering

PI Ceramic is a solutions-based company. Our engineers are continually developing new ideas and concepts, geared to bringing emerging technologies and products to market.

In addition to a large range of standard piezoelectric actuator components, we specialize in the rapid design and delivery of custom parts and subassemblies manufactured to our customers' specifications. Our design and manufacturing processes are optimized for medium production quantities of high-performance, key component parts, such as those used in capital equipment and research. Our flexibility allows us to produce custom parts at a very attractive price, even in small quantities.

PI Ceramic's 6840 square meter (73600 square foot) facility features the latest equipment for ceramic design, engineering and manufacturing. To support our own equipment and experienced staff, and to maintain our leading position in the industry, we maintain a number of alliances with universities and research facilities. PI Ceramic has been an ISO 9001 certified manufacturer since 1997.

PI Ceramic
TÜV CERT
ISO 9001
Since 1997


Ceramic tape casting equipment for PICMA® mulilayer actuator production


Mounting custom actuator subassemblies for a semi-conductor application

Our Mission

"Long-term business relationships, reliability, open and friendly communication with customers and suppliers are of the essence for PI Ceramic and all members of the worldwide PI group and far more important than short-term gain."

Dr. Karl Spanner, President

Our mission is to satisfy customers by providing the highest benefit for their applications with standard or custom-engineered solutions. This is achieved by close contact between our design and application engineers and your designers—from the early prototype phase to the finished product and beyond.

Customer Relationships

PI Ceramic employees cultivate close working relationships with our clients. We are committed to professionalism, total customer satisfaction, and quality service delivery.
PI Ceramic's priority is helping our customers succeed by sustaining their competitive edge in existing and new technologies. Their success is PI Ceramic's success.

State-of-the-art ceramic spray dryer ensures the highest piezoceramics quality

PI Ceramic History

1880	Discovery of piezoelectric activity by J. and P. Curie
1890	First porcelain manufacturing company in Hermsdorf, Germany (10 miles from the PI Ceramic factory)
1918	HESCHO Trust, 1000 employees, world-leader in electro-ceramics at the time
1931	First ceramic capacitor
1945	KWH (Keramische Werke Hermsdorf) founded
1952	First PZT materials (PIEZOLAN™) manufactured at KWH
1989	KWH is split into different companies
1992	PI and employees of KWH found PI Ceramic (2000 square meters, 21500 sq.ft.)
2000	PI Ceramic employs 70 people
2002	PI Ceramic expands factory to 6840 square meters (73600 square feet)
2003	PICMA® actuator technology introduced
2006	125 people are employed at PIC

Equipment for fully automated screen printing of electrodes on piezoelectric and dielectric ceramics

Handling robot for piezo-ceramic components

Piezoelectric Components

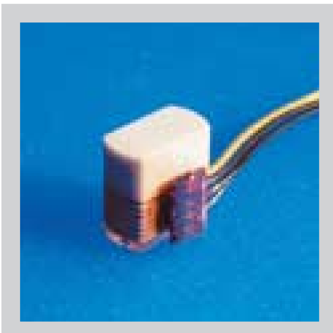
Applications

- Actuators
- Ultrasonic Transducers/Sensors
- Sonar Technology
- Medical Applications

		mm
Discs	OD Thickness	1 - 80 min 0.2
Rings	OD/ID Thickness	3 - 50 0.2 - 15
Tubes	OD/ID L	1 - 80 max. 50
Plates	L/W TH	1 - 70 min 0.2
Shear Plates	L/W Thickness	2 - 20 max. 15

(A combination of extreme values is not possible!)

PICA™-Stack Piezoelectric Actuators



Applications

- NanoPositioning
- High-Load Positioning
- Active Vibration Cancellation
- Smart Structures
- Precision Mechanics
- Chip Manufacturing and Testing
- Laser Tuning

see PICA™-Stack, PICA™-Power and PICA™-Thru datasheets, pages 16, 18, 20

Variety of piezo ceramic stacks

PZT Actuator for Structural Deformation / Vibration Damping in Aerospace Applications

Technical Data

Displacement	up to 300 µm
Blocking force	up to 80 kN
Static load	up to 100 kN
Operating voltage range	0 to1000 V
Operating temperature range	-20 to +85/150 °C (cryogenic on request)
Dynamic reliability	more than 10^9 cycles
Cross section shapes	cylindrical, tubular, rectangular
Length	up to 300 mm

PICMA® Monolithic Multilayer Actuators

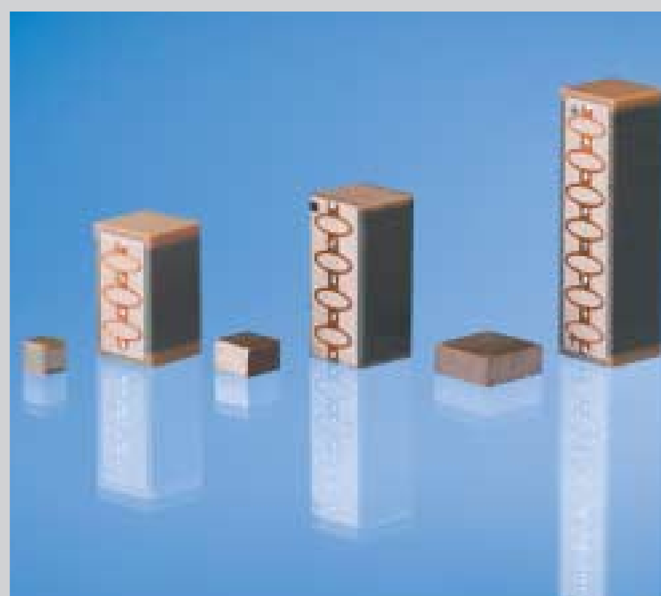
Special Features

- Low Operating Voltage
- No Polymer Coating
- Ceramic Insulation
- 100 % Ultra-High Vacuum Compatible
- Sub-nm Resolution
- Sub-ms Response Time

Applications

- NanoPositioning
- Precision Mechanics
- Semiconductor Equipment
- Valves
- Laser Applications
- Telecommunication

see PICMA® datasheets
pages 13, 14, 15



PICMA® Monolithic Actuators are the only ceramic insulated piezo actuators available. They provide higher reliability than other monolithic actuators and exhibit no measurable outgassing

Technical Data

Cross section	2x2 to 10x10 mm²
Displacement	up to 40 µm / single stack
Blocking force	up to 5 kN
Operating voltage	max. 120 V
Operating temperature	- 40 to +150 °C

PICA™-Shear Actuators (X, XY and XYZ)

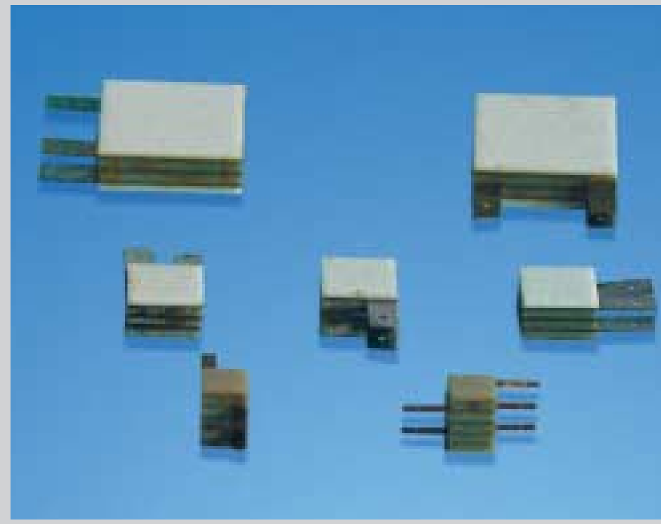
Special Features

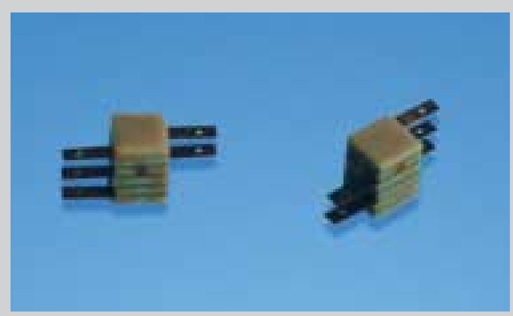
- Low Operating Voltage
- Special Polymer Insulation
- 100 % UHV Compatible
- Sub-nm Resolution
- Sub-ms Response Time

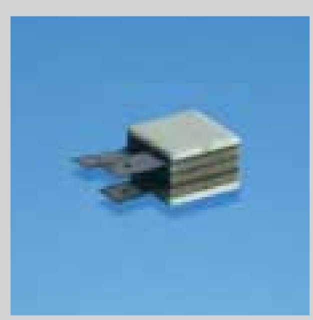
Applications

- NanoPositioning
- Piezo-Motors
- Semiconductor Equipment
- Laser Applications

see PICA™ Shear Actuators datasheet, page 22







Technical Data

Cross section	3x3 to 16x16 mm²
Displacement	up to 10 µm
Operating voltage	typ ±250 V
Operating temperature	-40 to +150 °C (cryogenic on request)

Piezoelectric Bender Actuators

Applications

- Micropositioning
- Pneumatic Valve Control
- Telecommunication
- Optical Switches
- Ink Jet Printers

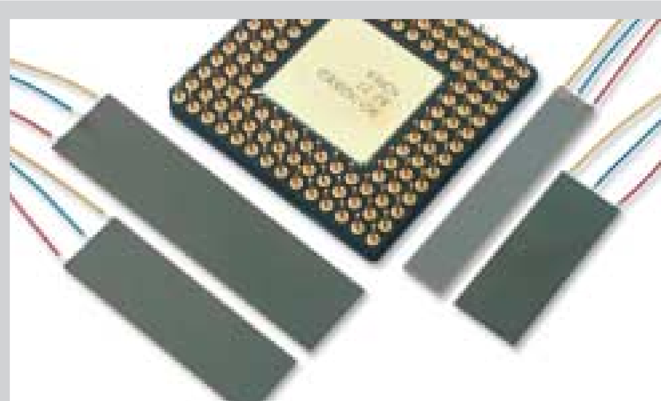
Variety of custom benders (HV design)

PI Ceramic Multilayer Benders are excellent actuators for pneumatic valves

Special Features

- Low Operating Voltage
- No Polymer Coating
- Full Ceramic Actuator
- 100 % UHV Compatible
- µm Resolution
- ms Response Time

see PICMA® Bender datasheet, page 24

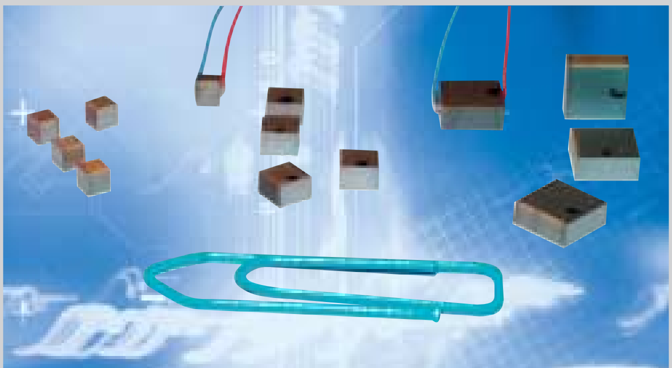


Technical Data

Displacement	up to 2 mm
Blocking force	up to 2.5 N
Operating voltage	max. 60 V (max. 300 (500) V, HV design)

PL022 · PL033 · PL055

PICMA® Chip Monolithic Multilayer Piezo Actuators



PICMA® Chip actuators are the smallest ceramic-encapsulated multilayer piezo actuators available. Standard cross-sections range from 2 x 2 to 5 x 5 mm

- **Ceramic Encapsulation for Extended Lifetime**
- **Ultra-Compact, from 2 x 2 x 2 mm**
- **High Curie Temperature**
- **Ideal for Dynamic Operation**
- **Sub-Millisecond Response / Sub-Nanometer Resolution**
- **UHV Compatible to 10^{-9} hPa**
- **Superior Lifetime**

Ultra-Compact Monolithic Piezo Actuators

PICMA® Chip actuators are small monolithic multilayer piezo actuators. Providing sub-nanometer resolution and sub-millisecond response, they are ideally suited to high-level dynamic applications. PICMA® actuators consist of a highly reliable ceramic-encapsulated PZT block with solderable terminations, and come in standard sizes as small as 2 x 2 x 2 mm.

Application Examples

- Static and dynamic nanopositioning
- Laser tuning
- Micro-dispensing
- Interferometry
- Life sciences
- Photonics

Optimized PZT Ceramics, Humidity Resistance

PICMA® actuators are made from a ceramic material in which the piezoceramic properties such as stiffness, capacitance, displacement, temperature stability and lifetime are optimally combined. The monolithic, ceramic-encapsulated design provides better humidity protection than polymer-film insulation.

Long Lifetime and High Performance—Ideal for Dynamic Operation

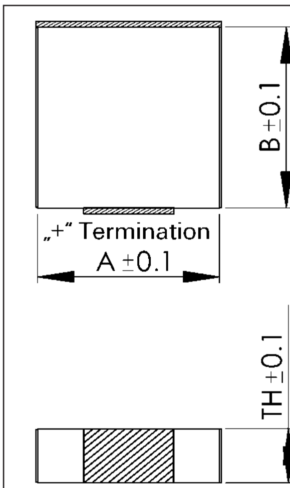
PICMA® Chip actuators are superior to conventional actuators in high-endurance situations, where they show substantially longer lifetimes both in static and dynamic operation, even in harsh environments. Due to their high resonant frequency, these actuators are ideally suited for dynamic operation with light loads; an external preload is recommended for dynamic operation with larger loads. The high Curie temperature of 320 °C provides a usable temperature range extending up to 150 °C, well above the 80 °C limit of conventional multilayer actuators. At the low end, operation down to a few Kelvin is possible (with reduction in performance specifications).

Optimum UHV Compatibility—No Outgassing

The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (no outgassing / high bakeout temperatures of up to 150 °C).

Amplifiers, Drivers & Controllers

PI offers a wide range of control electronics for piezo actuators from low-power drivers to multi-channel, closed-loop, digital controllers. Of course, PI also designs custom amplifiers and controllers.



Dimensions in mm.

Technical Data / Product Order Numbers

Order number*	Dimensions A x B x TH in mm	Displacement [µm @ 100 V] ±20%	Blocking force [N]	Electrical capacitance [nF] ±20%	Resonant frequency [kHz]
PL022.30	2 x 2 x 2	2.2	> 120	25	> 300
PL033.30	3 x 3 x 2	2.2	> 300	50	> 300
PL055.30	5 x 5 x 2	2.2	> 500	250	> 300

* For optional wire leads change order number extension to .x1 (e.g. PL022.31)
Resonant frequency measured at 1 V_{pp}, capacitance measured at 1 V_{pp}, 1 kHz.

Recommended preload for dynamic operation 15 to 30 MPa
Max. operating voltage: -20 to +100 V
Max. operating temperature: 150°C
Standard Mechanical Interface: ceramic (top & bottom)
Standard Electrical Interface: solderable termination
Available Options: special mechanical interfaces, etc.
Other specifications on request.

P-882 – P-888

PICMA® High-Performance Monolithic Multilayer Piezo Actuators

PICMA® piezo actuators are currently available with cross-sections of 2 x 3, 3 x 3, 5 x 5, 7x7 and 10 x 10 mm

- **Award-Winning Technology**
- **Low Operating Voltage**
- **Superior Lifetime Even Under Extreme Conditions**
- **Very Large Operating-Temperature Range**
- **High Humidity Resistance**
- **Excellent Temperature Stability**
- **High Stiffness**
- **UHV Compatible to 10^{-9} hPa**
- **Sub-Millisecond Response & Sub-Nanometer Resolution**

Increased Lifetime and Higher Performance

PICMA® (PI Ceramic Monolithic Actuator) piezo actuators are characterized by their high performance and reliability, even in extremely harsh environments. They are superior to conventional multilayer actuators in industrial applications and high-endurance situations, where they show substantially longer lifetimes both in static and dynamic operation.

Application Examples

- Precision mechanics and mechanical engineering
- Nanopositioning / high-speed switching
- Active and adaptive optics
- Vibration cancellation
- Pneumatic & hydraulic valves
- Metrology / interferometry
- Life sciences, medicine and biology

New Production Process, Optimized PZT Ceramics

PICMA® piezo actuators are made from a ceramic material in which the piezoceramic properties such as stiffness, capacitance, displacement, temperature stability and lifetime are optimally combined. The actuators' monolithic design and special electrode structure was made possible by advances in production technology. This development is just one reflection of the more than 40 years experience PI & PI Ceramic have with thousands of industrial PZT applications.

Increased Lifetime Through Humidity Resistance

The monolithic ceramic-encapsulated design provides better humidity protection than polymer-film insulation. Diffusion of water molecules into the insulation layer, is greatly reduced by the use of cofired, outer ceramic encapsulation.

High-Level Dynamic Performance—Very Wide Temperature Range

The high Curie temperature of 320 °C gives PICMA® actuators a usable temperature range extending up to 150 °C. This means that they can be operated in hotter environments, or they can be driven harder in dynamic operation. With conventional multilayer actuators, heat generation—which is proportional to operating frequency—either limits the operating frequency or duty cycle in dynamic operation, or makes ungainly cooling provisions necessary.

At the low end, operation down to a few Kelvin is possible (with reduction in performance specifications).

PICMA® actuator with optional wire leads and rounded top piece for decoupling lateral forces optional

Optimum UHV Compatibility—No Outgassing

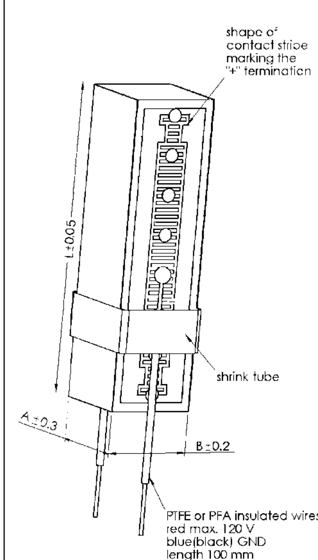
The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (no outgassing / high bakeout temperatures, up to 150 °C)

Ideal for Closed-Loop Operation

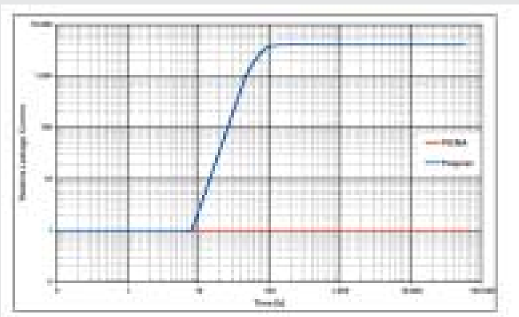
The ceramic surface of the actuators is extremely well suited for use with resistive or optical fiber strain gauge sensors. Such sensors can be easily applied to the actuator surface and exhibit significantly higher stability and linearity than with conventional polymer-insulated actuators.

Amplifiers, Drivers & Controllers

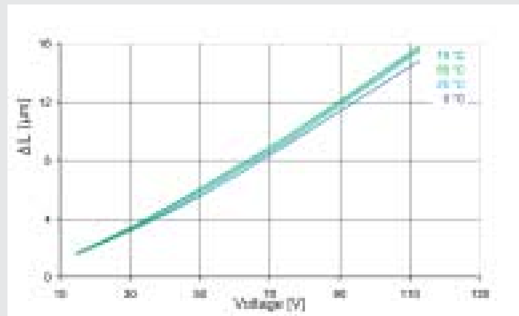
PI offers a wide range of control electronics for piezo actuators from low-power drivers to multichannel, closed-loop, digital controllers. Of course, PI also designs custom amplifiers and controllers.



PICMA® dimensions, in mm



PICMA® piezo actuators (bottom curve) compared with conventional multilayer actuators with polymer insulation (top curve). PICMA® actuators are not affected by the high-humidity test conditions. Conventional piezo actuators exhibit increased leakage current after only a few hours. Leakage current is an indication of insulation quality and expected lifetime.
Test conditions: U = 100 V_{DC}; T = 25 °C; Relative Humidity = 70%



The displacement of PICMA® actuators exhibits very low temperature dependence. This, in combination with their low heat generation, makes PICMA® actuators optimal for dynamic operation. (Operating frequency f = 200 Hz)

Technical Data / Product Order Numbers

Order number*	Dimensions A x B x L [mm]	Nominal displacement [µm @ 100 V]	Max. displacement [µm @ 120 V]	Blocking force [N @ 120 V]	Stiffness [N/µm]	Electrical capacitance [µF] ±20%	Resonant frequency [kHz] ±20%
P-882.10	2 x 3 x 9	6.5 ±20%	8 ±20%	190	24	0.13	135
P-882.30	2 x 3 x 13.5	11 ±20%	13 ±20%	210	16	0.22	90
P-882.50	2 x 3 x 18	15 ±10%	18 ±10%	210	12	0.31	70
P-883.10	3 x 3 x 9	6.5 ±20%	8 ±20%	290	36	0.21	135
P-883.30	3 x 3 x 13.5	11 ±20%	13 ±20%	310	24	0.35	90
P-883.50	3 x 3 x 18	15 ±10%	18 ±10%	310	18	0.48	70
P-885.10	5 x 5 x 9	6.5 ±20%	8 ±20%	800	100	0.6	135
P-885.30	5 x 5 x 13.5	11 ±20%	13 ±20%	870	67	1.1	90
P-885.50	5 x 5 x 18	15 ±10%	18 ±10%	900	50	1.5	70
P-885.90	5 x 5 x 36	32 ±10%	38 ±10%	950	25	3.1	40
P-887.30	7 x 7 x 13.5	11 ±20%	13 ±20%	1700	130	2.2	90
P-887.50	7 x 7 x 18	15 ±10%	18 ±10%	1750	100	3.1	70
P-887.90	7 x 7 x 36	32 ±10%	38 ±10%	1850	50	6.4	40
P-888.30	10 x 10 x 13.5	11 ±20%	13 ±20%	3500	267	4.3	90
P-888.50	10 x 10 x 18	15 ±10%	18 ±10%	3600	200	6.0	70
P-888.90	10 x 10 x 36	32 ±10%	38 ±10%	3800	100	13.0	40

Recommended preload for dynamic operation 15 to 30 MPa

* For optional PTFE insulated wires, pigtail length 100 mm, change order number extension to .x1 (e.g. P-882.11).

Unloaded (longitudinal) resonant frequency measured at 1 V_{pp}; capacitance at 1 V_{pp}, 1 kHz.

Standard PZT ceramic type: PIC 252 (modified PIC 255)

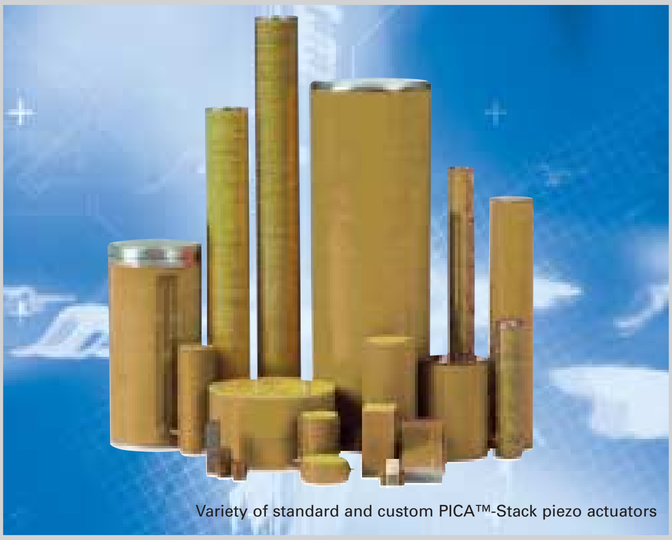
Max. operating voltage: -20 to +120 V
Max. operating temperature: -40 to +150 °C

Standard Mechanical Interface: ceramic (top & bottom)
Standard Electrical Interface: solderable pads

Available Options: strain gauge sensors, special mechanical interfaces, etc.
Other specifications on request.
Specifications subject to change without notice.

P-007 – P-056

PICA™-Stack Piezoceramic Actuators—Versatile Piezoelectric Power


Variety of standard and custom PICA™-Stack piezo actuators

- **High Load Capacity to 100 kN**
- **High Force Generation to 80 kN**
- **Large Cross Sections to 56 mm Diameter**
- **Variety of Shapes**
- **Extreme Reliability >10^9 Cycles**
- **Proven and Flexible Design**
- **Sub-Nanometer-Resolution / Sub-Millisecond-Settling-Time**
- **Vacuum-Compatible Versions**

PICA™-Stack piezo ceramic actuators are offered in a large variety of standard shapes and sizes with additional custom designs to suit any application.

Ultra-High Reliability, High Displacement, Low Power Requirements

PICA™-Stack actuators are specifically designed for high-duty-cycle applications. With our extensive applications knowledge, gained over several decades, we know how to build performance that does not come at the price of reliability. All materials used are specifically matched for robustness and lifetime. Endurance tests on PICA™ actuators prove consistent performance, even after billions (1,000,000,000) of cycles. The combination of high displacement and low electrical capacitance provides for excellent dynamic behavior with reduced driving power requirements.

Application Examples

- Nanopositioning
- High-load positioning
- Precision mechanics
- Semiconductor manufacturing and testing
- Laser tuning
- Switching
- Smart structures (adaptronics)

Flexibility: PI Ceramic's Strength

All manufacturing processes at PI Ceramic are set up for flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

- Custom Materials
- Custom Voltage Ranges
- Custom Geometries (Circular, Rectangular, Triangular, Layer Thickness ...)
- Custom Displacement
- Custom Load / Force Ranges
- Custom Flat or Spherical Endplates (Alumina, Glass, Sapphire, ...)
- Extra-Tight Length Tolerances
- Integrated Piezoelectric Sensor Discs
- Special High / Low Temperature Versions
- Vacuum Compatible Versions

Short Leadtime, Standard & Custom Designs

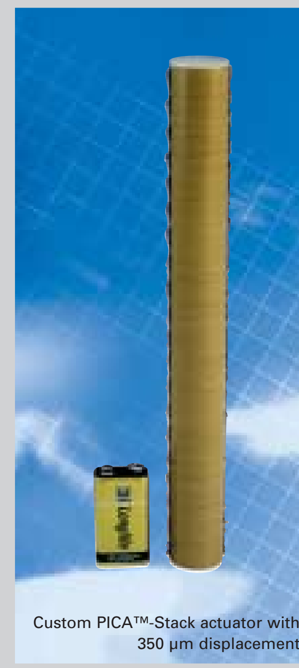
Because all piezoelectric materials used in PICA™ actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding. All standard and custom PICA™-Stack actuators are delivered with performance test sheets.

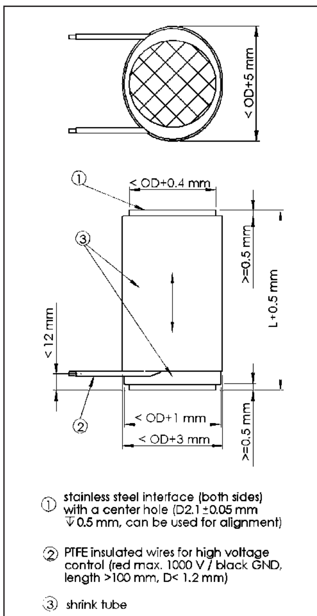
Amplifiers, Drivers & Controllers

PI offers a wide range of control electronics for piezo actuators, from low-power drivers to multi-channel, closed-loop, digital controllers. Of course, PI also designs custom amplifiers and controllers.

Notes

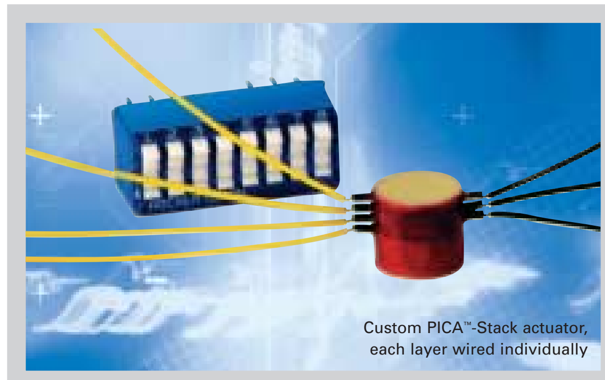
PICA™-Stack actuators are delivered with metal endcaps for improved robustness and reliability. Adherence to the mounting and handling guidelines (see p. 1-48) will help you obtain maximum performance and lifetime from your piezo actuators.
See PI main catalog page 1-40 *ff.* for preloaded actuators.


Custom PICA™-Stack actuator with 350 µm displacement



PICA™-Stack dimensions, see technical data table for further information

Custom PICA™-Stack actuators with rectangular cross-sections



Custom PICA™-Stack actuator, each layer wired individually

Technical Data / Product Order Numbers

Order number	Displacement [µm] -10/+20%	Diameter D [mm]	Length L [mm] ±0.5	Blocking force [N]	Stiffness [N/µm]	Capacitance [nF] ±20%	Resonant frequency [kHz]
P-007.00	5	7	8	650	130	11	126
P-007.10	15	7	17	850	59	33	59
P-007.20	30	7	29	1000	35	64	36
P-007.40	60	7	54	1150	19	130	20
P-010.00	5	10	8	1400	270	21	126
P-010.10	15	10	17	1800	120	64	59
P-010.20	30	10	30	2100	71	130	35
P-010.40	60	10	56	2200	38	260	20
P-010.80	120	10	107	2400	20	510	10
P-016.10	15	16	17	4600	320	180	59
P-016.20	30	16	29	5500	190	340	36
P-016.40	60	16	54	6000	100	680	20
P-016.80	120	16	101	6500	54	1300	11
P-016.90	180	16	150	6500	36	2000	7
P-025.10	15	25	18	11000	740	400	56
P-025.20	30	25	30	13000	440	820	35
P-025.40	60	25	53	15000	250	1700	21
P-025.80	120	25	101	16000	130	3400	11
P-025.90	180	25	149	16000	89	5100	7
P-025.150	250	25	204	16000	65	7100	5
P-025.200	300	25	244	16000	54	8500	5
P-035.10	15	35	20	20000	1300	700	51
P-035.20	30	35	32	24000	810	1600	33
P-035.40	60	35	57	28000	460	3300	19
P-035.80	120	35	104	30000	250	6700	11
P-035.90	180	35	153	31000	170	10000	7
P-045.20	30	45	33	39000	1300	2800	32
P-045.40	60	45	58	44000	740	5700	19
P-045.80	120	45	105	49000	410	11000	10
P-045.90	180	45	154	50000	280	17000	7
P-050.20	30	50	33	48000	1600	3400	32
P-050.40	60	50	58	55000	910	7000	19
P-050.80	120	50	105	60000	500	14000	10
P-050.90	180	50	154	61000	340	22000	7
P-056.20	30	56	33	60000	2000	4300	32
P-056.40	60	56	58	66000	1100	8900	19
P-056.80	120	56	105	76000	630	18000	10
P-056.90	180	56	154	78000	430	27000	7

Recommended preload for dynamic operation 15 to 30 MPa

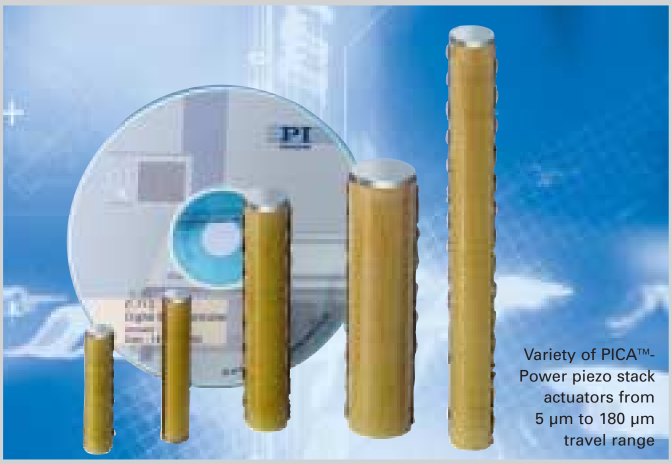
Unloaded (longitudinal) resonant frequency measured at 1 V_{pp}; capacitance at 1 V_{pp}, 1 kHz; blocking force at 1000 V.

Standard PZT ceramic type: PIC 151
Operating voltage range: 0 to 1000 V
Operating temperature range: -20 to +85 °C
Standard mechanical interface (top & bottom): steel plates, 0.5 - 2 mm thick (depends on model)
Standard electrical interface: two PTFE-insulated wires, pigtail length 100 mm
Available options: integrated piezo force sensor or strain gauge sensors, non magnetic, vacuum compatible, etc.

Other specifications on request.

P-010.xxP – P-056.xxP

PICA™-Power High-Level Dynamics Piezo Actuators



Variety of PICA™-Power piezo stack actuators from 5 µm to 180 µm travel range

- **Operating Temperature to 150 °C**
- **Temperature Sensor PT1000 Applied**
- **High Load Capacity to 80 kN**
- **Large Cross-Sections to 56 mm Diameter**
- **Extreme Reliability >10^9 Cycles**
- **Sub-Nanometer Resolution / Sub-Millisecond Settling Time**
- **Ultra-High-Vacuum-Compatible Versions to 10^{-9} hPa**
- **Non-Magnetic Versions**

PICA™-Power-series piezoceramic stack actuators are offered in a large variety of standard shapes and sizes, with additional custom designs to suit any application.

Application Examples

- Nanopositioning
- Active vibration damping and cancellation
- High-load positioning
- Precision machining
- Semiconductor manufacturing and testing
- Laser tuning
- Switching
- Smart structures (adaptronics)

Extra-High Reliability for High-Level Dynamics, High-Temperature Applications

Based on the PIC 255 material, PICA™-Power actuators are optimized for high-temperature working conditions and high-duty-cycle dynamic applications. With our extensive applications knowledge, gained over several decades, we know how to build performance that does not come at the price of reliability. All materials used are specifically matched for robustness and lifetime. Endurance tests on PICA™-Power actuators prove consistent performance, even after billions (1,000,000,000) of cycles.

Flexibility: PI Ceramic's Strength

All manufacturing processes at PI Ceramic are set up for flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

- Custom Materials
- Custom Voltage Ranges
- Custom Geometries (Circular, Rectangular, Triangular, Layer Thickness ...)
- Custom Displacement
- Custom Load / Force Ranges
- Custom Flat or Spherical Endplates (Alumina, Glass, Sapphire, ...)
- Extra-Tight Length Tolerances
- Integrated Piezoelectric Sensors
- Custom UHV Versions
- Clear Aperture Available

Short Leadtime for Standard & Custom Designs

Because all piezoelectric materials used in PICA™-Power actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding. All standard and custom PICA™-Power actuators are delivered with performance test sheets.

Amplifiers, Drivers & Controllers

PI offers a wide range of piezo control electronics, from low-power drivers to the ultra-high-performance E-480 power amplifier delivering 2000 W of dynamic power.

For closed-loop positioning applications, a variety of analog and digital controllers is also available. The modular E-500 system can be upgraded from an amplifier to a servo-controller and offers a variety of computer interfaces.

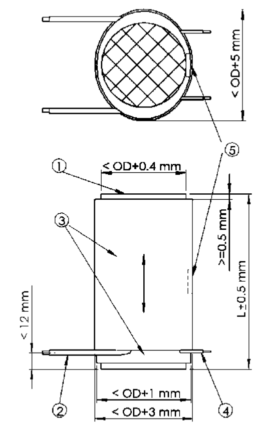
Of course, PI also designs custom amplifiers and controllers.

Notes

See PI main catalog page 1-40 *ff.* for preloaded actuators.

OEM-PICA™-Power actuators are available with cross sections to 56 mm

Custom preloaded PICA™-Power piezo actuator with forced-air cooling



1. stainless steel interface (both sides) with a center hole (D2.1 ±0.05 mm ∇ 0.5 mm, can be used for alignment)
2. PTFE insulated wires for high voltage control (red max. 1000 V / black GND, length >100 mm, D< 1.2 mm)
3. shrink tube
4. temperature sensor wires (PTFE insulated, yellow/yellow, length >100 mm, D< 0.7 mm)
5. temperature sensor PT 1000 (centered)

PICA™-Power actuator dimensions, see technical data table for further information

Technical Data / Product Order Numbers

Order number	Displacement [µm] -10/+20%	Diameter D [mm]	Length L [mm] ±0.5	Blocking force [N]	Stiffness [N/µm]	Capacitance [nF] ±20%	Resonant frequency [kHz]
P-010.00P	5	10	9	1200	240	17	129
P-010.10P	15	10	18	1800	120	46	64
P-010.20P	30	10	31	2100	68	90	37
P-010.40P	60	10	58	2200	37	180	20
P-010.80P	120	10	111	2300	19	370	10
P-016.10P	15	16	18	4500	300	130	64
P-016.20P	30	16	31	5400	180	250	37
P-016.40P	60	16	58	5600	94	510	20
P-016.80P	120	16	111	5900	49	1000	10
P-016.90P	180	16	163	6000	33	1600	7
P-025.10P	15	25	20	9900	660	320	58
P-025.20P	30	25	33	12000	400	630	35
P-025.40P	60	25	60	13000	220	1300	19
P-025.80P	120	25	113	14000	120	2600	10
P-025.90P	180	25	165	14000	80	4000	7
P-035.10P	15	35	21	18000	1200	530	55
P-035.20P	30	35	34	23000	760	1200	34
P-035.40P	60	35	61	26000	430	2500	19
P-035.80P	120	35	114	28000	230	5200	10
P-035.90P	180	35	166	29000	160	7800	7
P-045.20P	30	45	36	36000	1200	2100	32
P-045.40P	60	45	63	41000	680	4300	18
P-045.80P	120	45	116	44000	370	8800	10
P-045.90P	180	45	169	45000	250	13000	7
P-056.20P	30	56	36	54000	1800	3300	32
P-056.40P	60	56	63	66000	1100	6700	18
P-056.80P	120	56	116	68000	570	14000	10
P-056.90P	180	56	169	70000	390	21000	7

Recommended preload for dynamic operation 15 to 30 MPa

Unloaded (longitudinal) resonant frequency measured at 1 V_{pp}; capacitance at 1 V_{pp}, 1 kHz; blocking force at 1000 V.

Standard PZT ceramic type: PIC 255
Operating voltage range: 0 to 1000 V
Operating temperature range: -20 to +150 °C
Standard mechanical interface (top & bottom): steel plates, 0.5 to 2 mm thick (depends on model)
Standard electrical interfaces: PTFE insulated wires, pigtail length 100 mm
Available options: integrated piezo sensor or strain gauge sensors, non-magnetic, UHV, etc.

Other specifications on request.

P-010.xxH · P-016.xxH · P-025.xxH

PICA™-Thru Piezo Stack Actuators with Aperture

PICA™-Thru piezo stack actuators with clear aperture

- **Clear Aperture for Transmitted-Light Applications**
- **Large Cross-Sections Available to 56 mm Diameter**
- **Variety of Shapes and Options**
- **Extreme Reliability >10⁹ Cycles**
- **Proven and Flexible Design**
- **Sub-Nanometer Resolution / Sub-Millisecond Settling-Time**
- **Vacuum Compatible and Nonmagnetic Versions**

PICA™-Thru actuators are hollow piezo stack actuators, offered in a large variety of standard shapes and sizes with additional custom designs to meet all customer requirements. They combine the advantage of a clear aperture with the strength and force generation of stack actuators. These tubular devices are high-resolution linear actuators for static and dynamic applications.

Application Examples

- Optics
- Image stabilization
- Laser tuning
- Laser treatment
- Precision mechanics
- Confocal microscopy
- Micropositioning

Ultra-High Reliability, High Displacement, Low Power Requirements

PICA™ piezo actuators are specifically designed for high-duty-cycle applications. With our extensive applications knowledge, gained over several decades, we know how to build performance that does not come at the price of reliability. All materials used are specifically matched for robustness and lifetime. Endurance tests on PICA™ actuators prove consistent performance, even after billions (1,000,000,000) of cycles. The combination of high displacement and low electrical capacitance provides for excellent dynamic behavior with reduced driving-power requirements.

Flexibility: PI Ceramic's Strength

All manufacturing processes at PI Ceramic are set up for flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

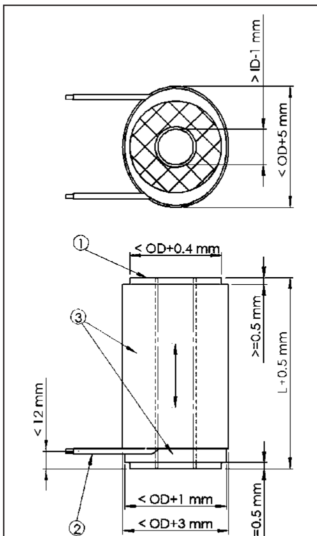
- Custom Materials
- Custom Voltage Ranges
- Custom Geometries
- Custom Displacement
- Custom Load / Force Ranges
- Custom Endplates (Alumina, Glass, Sapphire, ...)
- Extra-Tight Length Tolerances
- Integrated Piezoelectric Sensor Discs
- Low-Temperature Versions
- Vacuum Versions

Short Leadtime for Standard & Custom Designs

Because all piezoelectric materials used in PICA™ actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding. All standard and custom PICA™ actuators are delivered with performance test sheets.

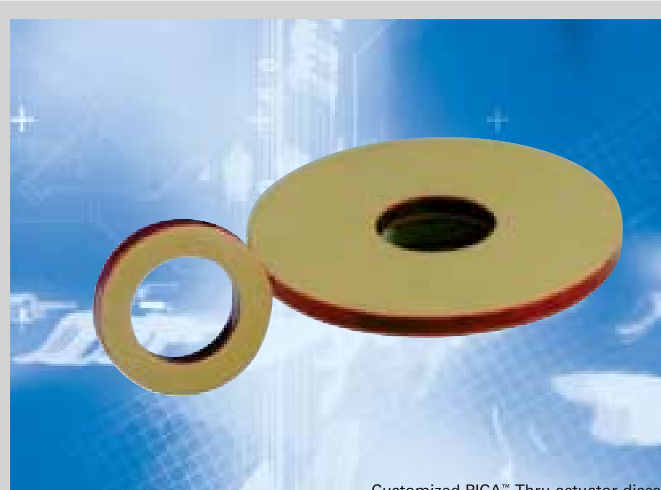
Amplifiers, Drivers & Controllers

PI offers a wide range of control electronics for piezo actuators from low-power drivers to multi-channel, closed-loop, digital controllers. Of course, PI also designs custom amplifiers and controllers.

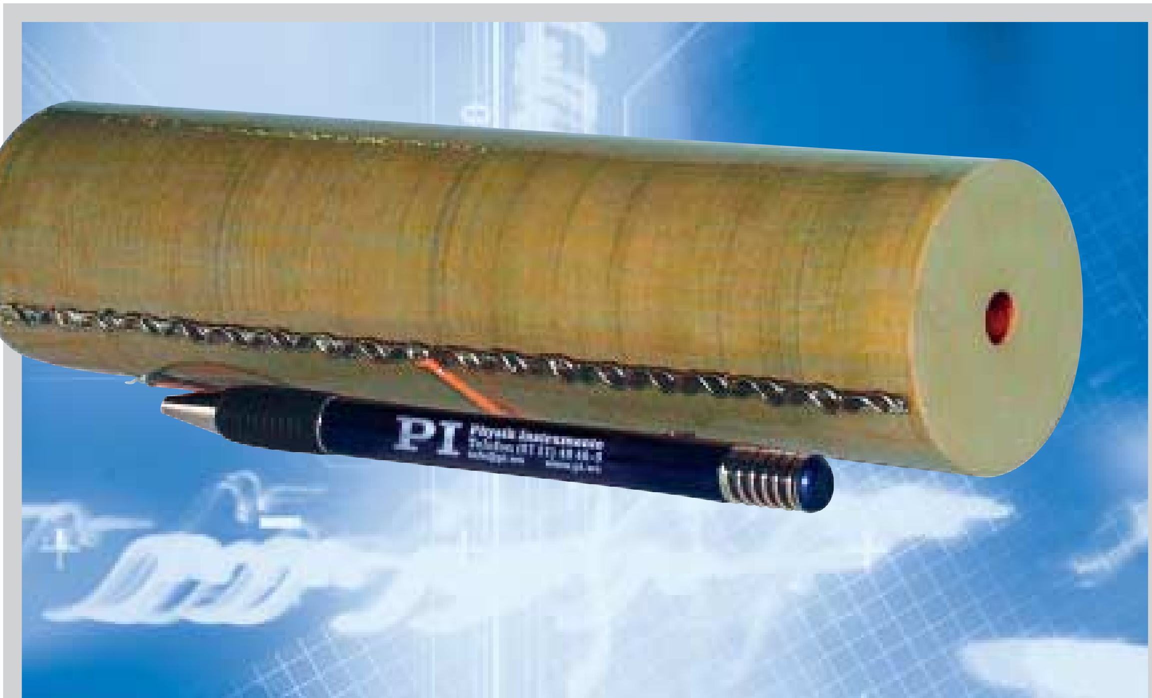


① ceramic interface (both sides)
② PTFE insulated wires for high voltage control (red max. 1000 V / black GND, length >100 mm, D< 1.2 mm)
③ shrink tube

PICA™-Thru piezo actuator dimensions, see technical data table for further information.



Customized PICA™-Thru actuator discs



Custom PICA™-Thru piezo actuator with 56 mm outside diameter and 8 mm inner diameter, 250 µm displacement. Pen for size comparison

Technical Data / Product Order Numbers

Order number	Displacement [µm] -10/+20%	Diameter OD [mm]	Diameter ID [mm]	Length L [mm] ±0.5	Blocking force [N]	Stiffness [N/µm]	Capacitance [nF] ±20%	Resonant frequency [kHz]
P-010.00H	5	10	5	7	1200	230	15	144
P-010.05H	10	10	5	12	1300	130	29	84
P-010.10H	15	10	5	15	1700	110	40	67
P-010.15H	20	10	5	21	1500	76	59	48
P-010.20H	30	10	5	27	1800	59	82	39
P-010.30H	40	10	5	40	1600	40	120	28
P-010.40H	60	10	5	54	1800	29	180	20
P-016.00H	5	16	8	7	2900	580	42	144
P-016.05H	10	16	8	12	3400	340	83	84
P-016.10H	15	16	8	15	4100	270	120	67
P-016.15H	20	16	8	21	3800	190	170	48
P-016.20H	30	16	8	27	4500	150	230	39
P-016.30H	40	16	8	40	4000	100	340	28
P-016.40H	60	16	8	52	4700	78	490	21
P-025.10H	15	25	16	16	7400	490	220	63
P-025.20H	30	25	16	27	8700	290	430	39
P-025.40H	60	25	16	51	9000	150	920	22
P-025.50H	80	25	16	66	9600	120	1200	17

Recommended preload for dynamic operation 15 to 30 MPa

Unloaded (longitudinal) resonant frequency measured at 1 V_{pp}; capacitance at 1 V_{pp}, 1 kHz; blocking force at 1000 V.

Standard PZT ceramic type: PIC 151
Operating voltage range: 0 to 1000 V
Operating temperature range: -20 to +85 °C
Standard mechanical interface (top & bottom): ceramic, 0.5 - 2 mm thick
Standard electrical interface: two PTFE-insulated wires, pigtail length 100 mm
Available options: integrated piezo sensor or strain gauge sensors, vacuum compatible, etc.

Other specifications on request.

P-111 – P-151

PICA™-Shear Piezo Actuators—Compact Multiaxis Motion


Custom made PICA™-Shear actuators

- **Compact Multiaxis Actuators**
- **X, XY, XZ and XYZ Versions**
- **High Resonant Frequencies**
- **Extreme Reliability >10⁹ Cycles**
- **Picometer-Resolution / Sub-Millisecond Settling Time**
- **Optional UHV-Compatible Versions to 10^{-9} hPa on request**
- **Non-Magnetic and Clear Aperture Versions**

PICA™-Shear series multi-axis piezo actuators are made only by PI Ceramic. These devices are extremely compact and feature sub-namometer resolution and ultra-fast response. They are available in a variety of geometries providing displacements to 10 µm.

High Stiffness under High Duty Cycles

PICA™-Shear actuators exhibit high stiffness, both parallel and perpendicular to the motion direction. Based on the piezoelectric shear effect, PICA™-Shear X and XY actuators show almost twice the displacement amplitudes of conventional piezo actuators at the same electric field. Consequently they can be made smaller and have higher resonant frequencies. This results in reduced power requirements for a given induced displacement in dynamic X- and Y-axis operation.

Application Examples

- Nanopositioning
- Precision mechanics
- Active vibration cancellation
- Semiconductor manufacturing and testing
- Laser tuning
- Atomic force microscopy
- Switching
- Scanning applications
- Linear motors

Ultra-High Reliability, High Displacement, Low Power Requirements

PICA™ actuators are specifically designed for high-duty-cycle applications. All materials used are specifically matched for robustness and lifetime. Endurance tests proved consistent performance even after billions (1,000,000,000) of cycles. The combination of high displacement and low electrical capacitance provides for excellent dynamic behavior with reduced driving power requirements.

Flexibility: PI Ceramic's Strength

All manufacturing processes at PI Ceramic are set up for flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

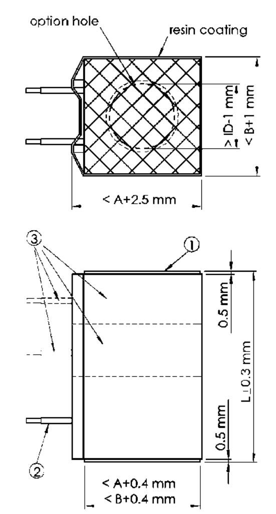
- Optional Vacuum Versions to 10^{-9} hPa
- Non-Magnetic Designs
- Clear Aperture
- Custom Endplates (Alumina, Glass, ...)
- Extra-Tight Length Tolerances, to 0.02 mm
- Optical Surface Quality
- Custom Geometries
- Custom Displacement
- Custom Load / Force Ranges
- Low-Temperature Designs, Down to Liquid-He
- Combination with Piezoelectric Shear Sensors (no Pyroelectric Effect)

Short Leadtime for Standard & Custom Designs

Because all piezoelectric materials used in PICA™ actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding. All standard and custom PICA™ actuators are delivered with performance test sheets.

Amplifiers, Drivers & Controllers

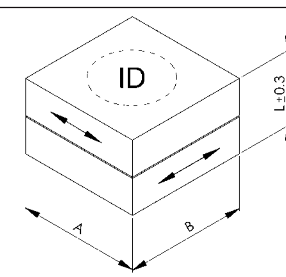
The E-507.36 amplifier module is recommended for operation of PICA™-Shear actuators.



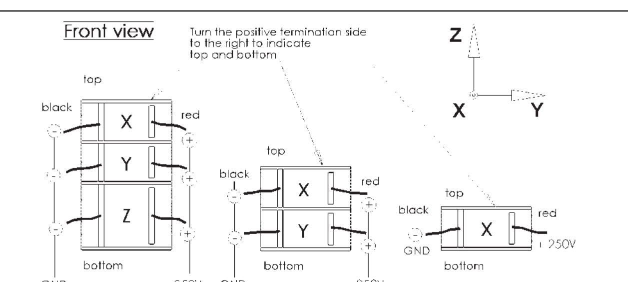
① ceramic interface (both sides)

② PTFE insulated wires for high voltage control (red +250 V / black GND, length >100 mm, D<0.7 mm), axial position centered at the termination line of the stack element

③ number of axis elements and wires is dependent on stack type



PICA™-Shear actuator dimensions, in mm. See technical data table for explanation of A, B, L



Axis and lead assignment for PICA™-Shear actuators

Technical Data / Product Order Numbers

Order number	Active axes	Displacement [µm] -10/+20% @ -250 to 250 V	Cross section A x B / ID [mm]	Length L [mm] ±0.3	Max. shear load [N]	Axial stiffness [N/µm]	Capacitance [nF] ±20%	Resonant frequency [kHz]
P-111.01	X	1*	3 x 3	3.5	20	70	0.5	330
P-111.03	X	3*	3 x 3	5.5	20	45	1.5	210
P-111.05	X	5	3 x 3	7.5	20	30	2.5	155
P-121.01	X	1*	5 x 5	3.5	50	190	1.4	330
P-121.03	X	3*	5 x 5	5.5	50	120	4.2	210
P-121.05	X	5	5 x 5	7.5	40	90	7	155
P-141.03	X	3*	10 x 10	5.5	200	490	17	210
P-141.05	X	5	10 x 10	7.5	200	360	28	155
P-141.10	X	10	10 x 10	12	200	230	50	100
P-151.03	X	3*	16 x 16	5.5	300	1300	43	210
P-151.05	X	5	16 x 16	7.5	300	920	71	155
P-151.10	X	10	16 x 16	12	300	580	130	100
P-112.01	XY	1 x 1*	3 x 3	5	20	50	0.5 / 0.5	230
P-112.03	XY	3 x 3*	3 x 3	9.5	10	25	1.5 / 1.5	120
P-122.01	XY	1 x 1*	5 x 5	5	50	140	1.4 / 1.4	230
P-122.03	XY	3 x 3*	5 x 5	9.5	40	70	4.2 / 4.2	120
P-122.05	XY	5 x 5	5 x 5	14	30	50	7 / 7	85
P-142.03	XY	3 x 3*	10 x 10	9.5	200	280	17 / 17	120
P-142.05	XY	5 x 5	10 x 10	14	100	190	28 / 28	85
P-142.10	XY	10 x 10	10 x 10	23	50	120	50 / 50	50
P-152.03	XY	3 x 3*	16 x 16	9.5	300	730	43 / 43	120
P-152.05	XY	5 x 5	16 x 16	14	300	490	71 / 71	85
P-152.10	XY	10 x 10	16 x 16	23	100	300	130 / 130	50
P-123.01	XYZ	1 x 1 x 1*	5 x 5	7.5	40	90	1.4 / 1.4 / 2.9	155
P-123.03	XYZ	3 x 3 x 3*	5 x 5	15.5	10	45	4.2 / 4.2 / 7.3	75
P-143.01	XYZ	1 x 1 x 1*	10 x 10	7.5	200	360	5.6 / 5.6 / 11	155
P-143.03	XYZ	3 x 3 x 3*	10 x 10	15.5	100	170	17 / 17 / 29	75
P-143.05	XYZ	5 x 5 x 5	10 x10	23	50	120	28 / 28 / 47	50
P-153.03	XYZ	3 x 3 x 3*	16 x 16	15.5	300	450	43 / 43 / 73	75
P-153.05	XYZ	5 x 5 x 5	16 x 16	23	100	300	71 / 71 / 120	50
P-153.10	XYZ	10 x 10 x 10	16 x 16	40	60	170	130 / 130 / 230	30
P-153.10H	XYZ	10 x 10 x 10	16 x 16 / 10	40	20	120	89 / 89 / 160	30
P-151.03H	X	3*	16 x 16 / 10	5.5	200	870	30	210
P-151.05H	X	5	16 x 16 / 10	7.5	200	640	49	155
P-151.10H	X	10	16 x 16 / 10	12	200	400	89	100

* Tolerances ±30%
Unloaded (longitudinal) resonant frequency measured at 1 V_{pp}, capacitance at 1 V_{pp}, 1 kHz.
Standard PZT ceramic type: PIC 255.
Operating voltage range: ±250 V
Operating temperature range: -20 to +85 °C
Standard mechanical interface (top & bottom): ceramic plates
Available options: non-magnetic, UHV, low temperature, clear aperture, vacuum, etc.
Other specifications on request.

PL112 – PL140

PICMA® Multilayer Piezo Bender Actuators

Bender actuators with optional wire leads (order number extension .x1); microprocessor for size comparison

- Ceramic Encapsulation
- Positioning Range up to 2 mm
- Fast Response (<10 msec)
- Nanometer-Range Resolution
- Low Operating Voltage
- Vacuum-Compatible Versions
- Available with Integrated Position Sensor
- Special OEM and Bench-Top Amplifiers/Drivers Available

PICMA®-series multilayer bender piezo actuators provide a deflection of up to 2 mm, forces up to 2 N (200 grams) and response times in the millisecond range. These multilayer piezoelectric components are manufactured from ceramic layers of only about 50 µm thickness. They feature internal silver-palladium electrodes and ceramic insulation applied in a cofiring process. The benders have two outer active areas and one central electrode network dividing the actuator in two segments of equal capacitance, similar to a classical parallel bimorph.

Application Examples

- Wire bonding
- Pneumatic valves
- Fiber optic switches
- Beam deflection
- Micropositioning
- Acceleration sensors

Advantages

PICMA® Bender piezo actuators offer several advantages over classic bimorph components manufactured by gluing together two ceramic plates (0.1 to 1 mm thick). The main advantage is the drastically reduced (by a factor of 3 to 10) operating voltage of only 60 V. The reduced voltage allows smaller drive electronics and new applications, such as in medical equipment. Additionally, these devices offer improved humidity resistance due to the ceramic encapsulation.

Long Lifetime and High Performance—Ideal for Dynamic Operation

PICMA® Bender actuators are superior to conventional actuators in high-endurance situations. They show substantially longer lifetimes both in static and dynamic operation, even in harsh environments. Diffusion of water molecules into the insulation layer is greatly reduced by the use of cofired, outer ceramic encapsulation.

The high Curie temperature of 320 °C gives PICMA® actuators a usable temperature range extending up to 150 °C, well above the 80 °C limit of conventional multilayer actuators. At the low end, operation down to a few Kelvin is possible (with reduction in performance specifications).

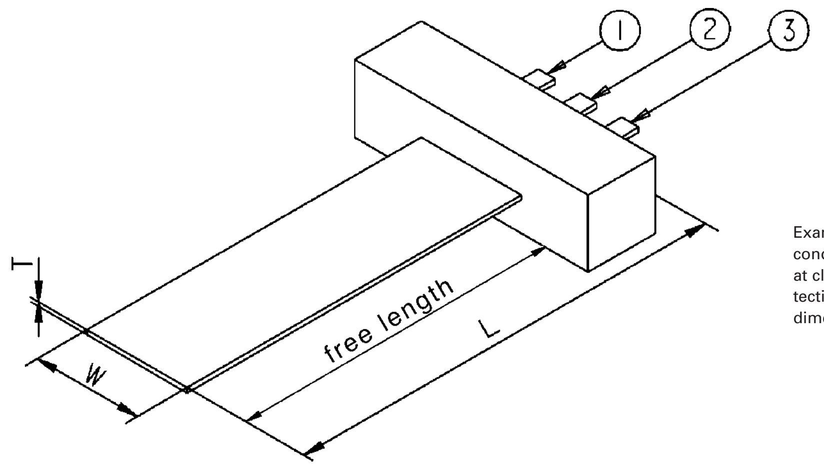
Optimum UHV Compatibility—No Outgassing

The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (no outgassing / high bakeout temperatures, up to 150 °C).

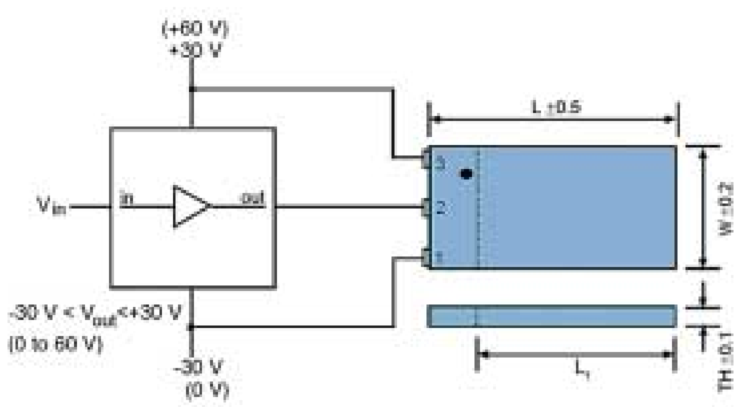
Amplifiers, Drivers & Controllers

PI offers a wide range of standard amplifiers and controllers for piezo actuators. The E-650.00 and E-650.OE drivers were specifically designed to operate PICMA® Bender actuators. For closed-loop positioning applications, a variety of analog and digital controllers is available. Of course, PI also designs custom amplifiers and controllers.

Custom closed-loop bender actuator with strain gauge sensor applied for position measurement



Example for recommended clamp: non-conducting material with rounded edges at clamping interface (for ceramic protection). Not included. See table for dimensions L, W and T



Full differential voltage control.
Pin assignment:
1: -30 V [or GND]
2: -30 V to +30 V [or 0 to 60 V]
3: +30 V [or +60 V]

Max. operating frequency should not exceed 30 % of specified resonant frequency

Technical Data / Product Order Numbers

Order number*	Operating voltage [V]	Nominal *** displacement [µm] ±20%	Free *** length (L_f) [mm]	Dimensions L x W x T [mm]	Blocking *** force [N]	Electric capacitance [µF] ±20%	Resonant *** frequency [Hz]
PL112.10**	0 - 60	±80	12	17.8 x 9.6 x 0.65	±2.0	2 x 1.1	>1000
PL122.10	0 - 60	±250	22	25.0 x 9.6 x 0.65	±1.1	2 x 2.4	660
PL127.10	0 - 60	±450	27	31.0 x 9.6 x 0.65	±1.0	2 x 3.4	380
PL128.10**	0 - 60	±450	28	35.5 x 6.3 x 0.75	±0.5	2 x 1.2	360
PL140.10	0 - 60	±1000	40	45.0 x 11.0 x 0.60	±0.5	2 x 4.0	160

* For optional 100 mm wire leads change order number extension to .x1 (e.g. PL 112.11).
*** All parameters depend on actual clamping conditions and applied load.

Operating temperature: -20 °C to + 85 °C (** max. 150 °C)
Low temperature option available
Closed-loop option on request (strain-gauge-sensor)

Other specifications on request.
Specifications subject to change without notice.
Capacitance measured at 1 V_{pp}, 1 kHz. Unloaded ("free bending") resonant frequency measured at 1 V_{pp}.

PT120 – PT140

Piezoceramic Tubes

Selection of PT piezoceramic tubes

- **Standard & Custom Sizes**
- **For OEM Applications**
- **XYZ-Positioning**
- **Sub-Nanometer Resolution**
- **Large Diameters to 80 mm**
- **Wall Thickness as Small as 0.3 mm**

PT-series piezoceramic tubes are used in a wide range of applications from microdispensing to scanning microscopy. These monolithic components contract laterally (radially) and longitudinally when a voltage is applied between their inner and outer electrodes. Multi-electrode tubes are available to provide XYZ motion for use in manipulation and scanning microscopy applications. PI also provides ultra-high-linearity, closed-loop scanning stages for SPM and nanomanipulation.

Application Examples

- Micropositioning
- Scanning microscopy (STM, AFM, etc.)
- Fiber stretching / modulation of optical path length
- Micro pumps / ink-jet printing
- Micromanipulators
- Ultrasonic and sonar applications

Precision and Flexibility: PI Ceramic's Strength

PT piezo tubes are manufactured to the tightest tolerances. We can provide tubes with diameters as small as 0.8 mm (inner-diameter) and tolerances as tight as 0.025 mm.

All manufacturing processes at PI Ceramic are set up for flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

- Custom Materials
- Custom Voltage Ranges
- Custom Geometries
- Custom Displacement
- Extra-Tight Tolerances
- Applied Sensors
- Special High / Low Temperature Versions
- Ultra-High-Vacuum Versions

Short Leadtime for Standard & Custom Designs

Because all piezoelectric materials used in PT tube actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding. All standard and custom actuators are delivered with performance test sheets.

Amplifiers, Drivers & Controllers

PI offers a wide range of control electronics for piezo actuators from low power drivers to multi-channel, closed-loop, digital controllers.

Design
Dimensions: max. L: 50 mm
max. OD: 80 mm
min. wall thickness: 0.30 mm

Electrodes: fired silver-plated inside and outside as standard; thin film electrodes (e.g. copper-nickel or gold) as outer electrodes optional

Options: single or double wrapped, circumferential bands or quartered outer electrodes

Polarization: inner electrode positive potential

Tube actuators are not designed to withstand large forces (see PICA™-Thru actuators), but their high resonant frequencies make them especially suitable for dynamic operation with light loads.

XY scanning tubes with quartered outer electrodes; see table for specifications

Useful Equations

Axial contraction and radial displacement of piezo tube actuators can be estimated by the following equations:

(Equation 1)

$$\Delta L \approx d_{31} \cdot L \cdot \frac{U}{d}$$

where:
d_{31} = strain coefficient (displacement normal to polarization direction) [m/V]
L = length of the ceramic tube [m]
U = operating voltage [V]
d = wall thickness [m]

(Equation 2)

$$\Delta d \approx d_{33} \cdot U$$

where:
Δd = change in wall thickness [m]
d_{33} = strain coefficient (field and displacement in polarization direction) [m/V]
U = operating voltage [V]

Typical values for d_{31} and d_{33} are -200 pm/V and 500 pm/V, respectively.

The radial contraction is the superposition of the increase in wall thickness and the tangential contraction; it can be estimated by the following equation:

(Equation 3)

$$\frac{\Delta r}{r} \approx d_{31} \frac{U}{d}$$

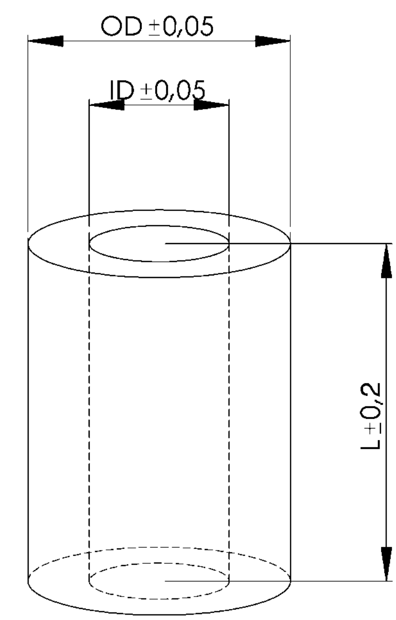
where:
r = tube radius
d_{31} = strain coefficient (displacement normal to polarization direction) [m/V]
U = operating voltage [V]
d = wall thickness [m]

The quartered electrodes option makes XY scanning possible. These scanner tubes, which flex in X and Y, are widely used in scanning-probe microscopes. The scan range of these components is estimated by:

(Equation 4)

$$\Delta x \approx \frac{2\sqrt{2} \cdot d_{31} \cdot L^2 \cdot U}{\pi \cdot ID \cdot d}$$

where:
Δx = scan range in X and Y (for symmetrical electrodes) [m]
d_{31} = strain coefficient (displacement normal to polarization direction) [m/V]
U = symmetric operating voltage [V]
L = length [m]
ID = inner diameter [m]
d = wall thickness [m]



PT Tube dimensions, in mm (see table for further information)

Technical Data / Product Order Numbers

Order number	Dimensions L x OD x ID**	Max. operating voltage [V]	Electrical capacitance [nF ±20%]	Axial contraction µm @ max. V	Radial contraction µm @ max. V	XY deflection [µm @ ±200 V]
PT120.00	20 x 2.2 x 1.0	500	3	5		
PT130.00	30 x 3.2 x 2.2	500	10	9	0.9	
PT130.90	30 x 3.2 x 2.2	500	12	9	0.9	
PT130.94*	30 x 3.2 x 2.2	±200	4 x 2.4	9	0.9	±18
PT130.10	30 x 6.35 x 5.35	500	18	9	1.8	
PT130.14*	30 x 6.35 x 5.35	±200	4 x 3.8	9	1.8	±9
PT130.20	30 x 10.0 x 9.0	500	36	9	3	
PT130.24*	30 x 10.0 x 9.0	±200	4 x 8.5	9	3	±6
PT130.30	30 x 10.0 x 8.0	1000	18	9	3	
PT130.40	30 x 20.0 x 18.0	1000	35	9	6	
PT140.70	40 x 40.0 x 38.0	1000	70	15	12	

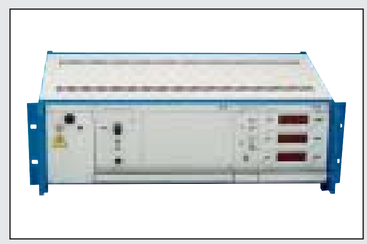
All models available with 40 mm length, except PT120.00
Other specification on request
* Quartered electrodes for XY deflection
** OD, ID ±0.05 mm all models except PT120 / PT 130.00 (±0.1 mm)

Piezo Drivers, Power Amplifiers, Controllers

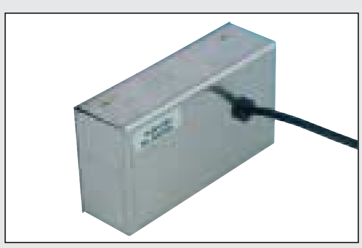
Examples

PI offers a wide variety of standard & custom amplifiers, drivers and closed-loop controllers for piezo actuators and nanopositioning systems. A few examples are given below. See the Physik Instrumente (PI) NanoPositioning catalog and website (www.pi.ws) for more information.

E-500 Modular Piezo Control Systems. See PI Catalog

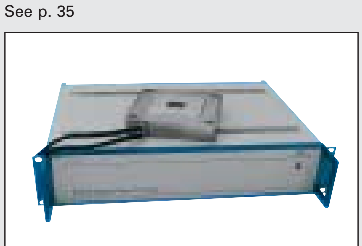


E-480.00 High-Power Amplifier with Energy Recovery (2000 W, 1100 V). See PI Catalog



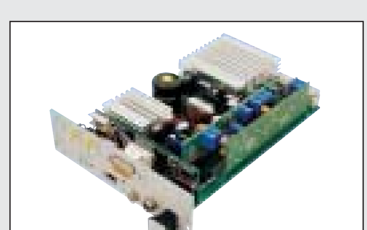
E-461 Amplifier Module (0.3 W, 1000 V). See p. 35

E-650.00 Amplifier for Multilayer Bender Actuators (+/- 30 V, 18 W). See p. 29



E-710.6CD 6-axis digital piezo controller shown with custom Super Invar 6-DOF piezo flexure NanoPositioning stage (110 V, 25 W, 3 to 6 Channels). See PI Catalog

E-420 Power Amplifier Module (500 W peak power, 1100 V). See p. 36



E-621 Amplifier & Servo-Controller Module with High-Speed RS-232 Interface (120 V, 14 W). See PI Catalog

E-650

Piezo Drivers for Multilayer Bender Actuators

E-650.OE LVPZT Amplifier Module for Multilayer Bender Actuators, OEM Version

E-650.00 LVPZT Amplifier for Multilayer Bender Actuators

Ordering Information

E-650.00
LVPZT Amplifier for Multilayer Bender Actuators, Bench-Top

E-650.OE
LVPZT Amplifier Module for Multilayer Bender Actuators, OEM Version

Ask about custom designs!

- **Specifically Designed to Drive Multilayer Bimorph Actuators**
- **Bench-Top and OEM Versions**
- **Up to 18 W Peak Power**
- **LCD Voltage Display**
- **Output Voltage ±30 V or 0 to 60 V and Separate Fixed Voltage**

E-650.00 is a bench-top piezo driver, especially designed for low-voltage, multilayer PZT bender actuators (bimorphs) such as the PL122 to PL140. It is equipped with a special circuit that can provide one fixed voltage and a variable voltage in the range of 0 to 60 V (±30 V). The driver can output and sink a peak current of 300 mA. The E-650.00 can be operated in two ways:

I. Manual Control:

Output voltage can be set by a 10-turn DC-offset potentiometer* in E-650.OE in the range of 0 to 60 V.

II. External Control:

Output voltage is controlled by an analog signal applied to the BNC input, ranging from 0 to 10 V. Multiplying by the gain factor of 6, an output voltage range of 0 to 60 V results. The DC-offset potentiometer* can be used to bias the control input voltage.
A $3\,^1/_2$-digit LCD display shows the output voltage.
The E-650.OE is the OEM version of the E-650.00. It provides peak output power of 8 W. All inputs and outputs are via 8 header pins located on the bottom of the module. The E-650.OE is designed to be mounted on a circuit board. The electronics are fully enclosed in a metal case.

* not included in E-650.OE

Technical Data

Models	E-650.00	E-650.OE
Function	Power amplifier	Power amplifier
Channels	1	1
Maximum output power	18 W	8 W
Average output power	6 W	4 W
Peak output current <5 ms	300 mA	140 mA
Avg. output current >5 ms	100 mA	60 mA
Current limitation	Short-circuit proof	Short-circuit proof
Voltage gain	6 ±0.1	6 ±0.1
Polarity	positive	positive
Control input voltage	0 to +10 V	0 to +10 V
Display	$3^1/_2$-digit LCD	-
Output voltage	0 to 60 V or ±30 V, one additional fixed voltage of 60 V	0 to 60 V or ±30 V, one additional fixed voltage of 60 V
DC-offset setting	0 to 60 V at output, with 10-turn pot (E-650.00 only)	0 to 60 V at output, with 10-turn pot (E-650.00 only)
Input impedance	100 kΩ	100 kΩ
Frequency response	600 Hz @ 1000 nF load, 6 kHz @ no load	200 Hz @ 1000 nF load, 3 kHz no load
Control input socket	BNC	header pins
PZT voltage output socket	9-pin Sub-D	header pins
Dimensions	160 x 125 x 50 mm	70 x 42 x 30 mm
Weight	0.7 kg (w/o P/S)	0.15 kg
Operating voltage	90-240 VAC, 50-60 Hz, (external switching P/S, included)	+/- 15 V, 315 mA max., stabilized
Operating temperature range	0 to +50 °C	0 to +50 °C

E-831 – E-841 – E-842

OEM Piezo Driver and Power Supply Modules

E-831.02 amplifier module

- **Cost Effective Piezo Driver**
- **Small Size**
- **Low Noise, High Stability**
- **Easy-to-Use**
- **Full Overcurrent, Short-Circuit and Temperature Protection**
- **Power-up/down Without Voltage Spikes**

The E-831.02 OEM piezo driver module is a very compact, cost-effective, single-channel, 4-quadrant power amplifier for low-voltage piezoelectric actuators.

It provides a peak output power of 12 W and average power of 2 W (expandable to 5 W with external heat sink). The E-831.02 is a high-precision amplifier with a fixed gain of 10.0 and outputs voltages in the range of -20 to 120 V for control input signals ranging from of -2 to 12 V. The output is fully compensated for the capacitive loads of up to 10 µF typical of PI's low-voltage PZTs such as PICMA® piezo actuators. For monitoring purposes, the output voltage is internally divided by 100 and provided at a special monitor pin.

Because piezo actuators require virtually no power in steadystate operation and the power consumption depends on the operating frequency, high-powered amplifiers are not required for many applications. With a peak output current of 100 mA (sink/source) the E-831 is well-suited for switching applications and fast transitions where the capacitive load (the piezo actuator) needs to be charged as quickly as possible. The small-signal bandwidth is about 3 kHz.

E-841.05 power supply module

Power Supplies for E-831.02

The E-841.05 (input voltage range 10 to 30V) and E-842.05 (input voltage range 30 V to 72 V) switched power supply modules provide all the operating voltages (±15 V, -26 V and +127 V DC) required by the E-831.02 amplifier module. Both models supply enough power for up to three E-831.02 amplifiers with a total output power of 5 W.

A sync. input on the power supply allows synchronization of the internal switching frequency with an external clock (185 to 220 kHz) for elimination of interference in AC-driven position sensors or DACs.

Easy Implementation

E-831 and E-841/E-842 modules are enclosed in metal cases with solderable pins for PCB mounting. They are designed to work together without additional components.

Triple Safety

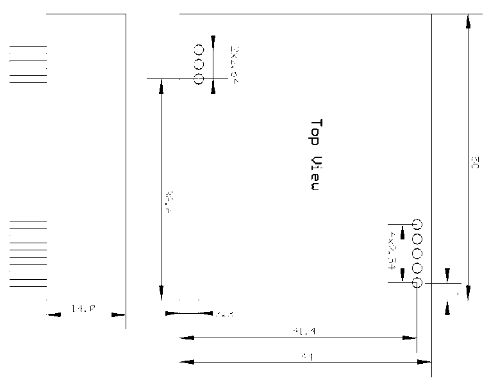
The E-831 amplifier is short-circuit proof with both a low-speed current limiter of 50 mA and a high-speed (8 msec) current limiter of 100 mA. When the case temperature rises above 70 °C (can be reached after a few minutes with maximum current) an internal temperature sensor shuts down the output stage until the temperature drops below 60 °C. This operation mode is indicated by the active-high TEMP-OFL TTL status line.

Ordering Information

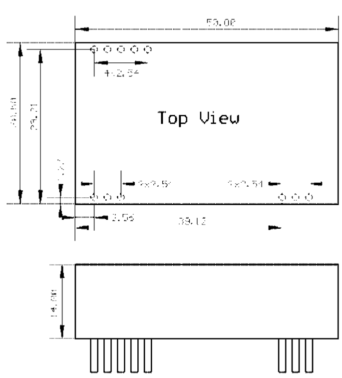
E-831.02
Single-Channel Piezo Driver Module for LVPZTs

E-841.05
Power Supply Module for E-831, Input 10 to 30 V

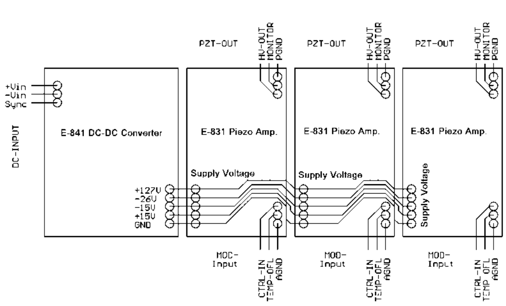
E-842.05
Power Supply Module for E-831, Input 30 to 72 V



Tiny: E-841.05/E-842.05 dimensions in mm



Tiny: E-831.02 dimensions in mm, decimal places separated by commas in drawings



Scheme for a three-channel amplifier consisting of an E-841 power supply and three E-831 amplifiers

Technical Data E-831.02

Models	E-831.02
Function:	Single-channel piezo amplifier module
Output voltage range:	from [U+ - 6 V] (121 V for U+ = 127 V) to [U- + 8 V] (-20 V for U- = 28 V)
Gain	10 ±0.1
Max. output current:	100 mA for 8 ms (sink/source)
Max. average current:	50 mA for 3 min without heatsink
Output protection:	short-circuit protected, the module is overload protected to 70 °C case temperature
Max. output power:	2 W without ext. heatsink 5 W with ext. heatsink or forced airflow
Control input range:	-2 to +12 V
Input impedance:	100 kΩ
Dynamic current requirements:	depend on load, amplitude and slew rate
Cut off frequency:	3.5 kHz, no load
Operating temperature range:	+5° to +50° Celsius
Operating voltages: (all currents without dynamic load)	+15 V / 20 mA (14 to16 V) -15 V / 20 mA (-14 th -16 V) +127 V / 1.8 mA +125 to 135 V) -26 V / 1.8 mA (-24 to -30 V)
Case	Metal shielded case, size: 50 x 30 x 14 mm
Soldering pins	1 mm diameter, 4 mm length

Technical Data E-84x.05

Models	E-841.05, E-842.05
Function:	Power Supply Module for E-831
Output voltages:	+127 V, 30 mA; -26 V, 30 mA; +15 V, 50 mA; -15 V, 50 mA
Max. output Power:	8 W
Max. average Power	8 W with forced air flow (5 W without)
Output protection:	short-circuit protected (1 min.)
Input voltage:	10 - 30 V (E-841.05); 30 - 72 V (E-842.05)
Quiescent current:	70 mA @15 V; 35 mA @30 V; 15 mA @72 V
Max. input current:	1000 mA (E-841.05 @ 10V); 200 mA (E-842.05 @ 72V)
Power-on, peak current:	1500 mA
Switching frequency	100 kHz typical
External clock frequency:	200 kHz (185 - 220 kHz possible)
Synchronization signal:	preferred TTL-level with duty cycle 50 %; operating from 1.8 V_{pp} and offsets within ±7 V
Output ripple:	<100 mV_{pp}
Operating temperature range:	5° to +50° Celsius (with power derating above 40 °C)
Case	Metal shielded case, size: 50 x 44 x 14 mm
Soldering pins	1 mm diameter, 4 mm length

E-507

HVPZT Piezo Amplifier Module

- **Up to 400 W Peak Power**
- **Output Voltage Range -3 to -1100 V & Bipolar**
- **±250 V for Shear Actuators**

The E-507.00 is a piezo driver module for high-voltage PZTs. It can output and sink a peakcurrent of 50 mA and an average current of 13 mA. The E-507.00 can be operated in two ways:

I. Manual Control:

The output voltage can be set by a 10-turn, DC-offset potentiometer in the range of -3 to -1000 Volts.

II. External Control:

Out-put voltage is controlled by an analog signal applied to the BNC input ranging from 0 to 11 Volts. Multiplying by the gain factor of -100, an output voltage range of -3 to -1100 Volts results. The DC-offset potentiometer adds a DC bias to the input, allowing continuous shifting of the input range between 0 V to +10 V and -10 V to 0 V (see page 6-52).

For computer-controlled operation, an E-516.i3 20-bit DAC interface/display module can be used (requires E-500/E-501 chassis). See graph for frequency response with selected HVPZTs.

E-507.OE is the high current OEM version of E-507.00, especially designed for switching applications. It can output a peak-current of 400 mA for 5 msec. The E-507.OE is not equipped with a DC-offset potentiometer.

E-507.36 is designed for systems or actuators requiring an operation voltage range of -250 V to +250 V, such as the P-363 PicoCube® (see page 2-72) or the P-111 – P-151 PicaShear™ actuators.

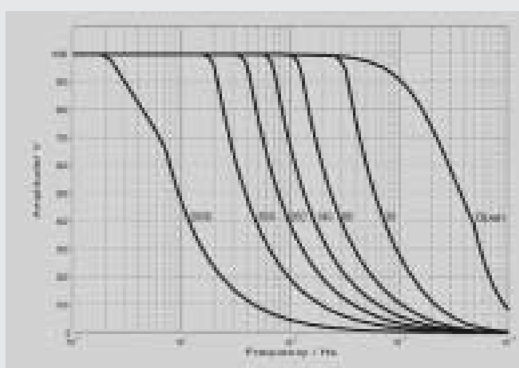
Ordering Information

E-507.00
HVPZT Amplifier Module,
-3 to -1100 V

E-507.OE
HVPZT Amplifier Module, OEM,
400 mA Peak Current

E-507.36
HVPZT Amplifier Module,
-250 to +250 V

Ask about custom designs!



E-507.00, frequency response with various PZT loads. Values shown are capacitance in nF measured in actual PZT

Technical Data

Models	E-507.00	E-507.OE	E-507.36
Function	Power amplifier	Power amplifier	Power amplifier
Channels	1	1	1
Maximum output power	50 W (see page 6-52)	400 W (see page 6-52)	50 W (see page 6-52)
Average output power	13 W	13 W	13 W
Peak output current <5 ms	50 mA	400 mA	100 mA
Average output current >5 ms	12 mA	12 mA	24 mA
Current limitation	Short-circuit proof	Short-circuit proof	Short-circuit proof
Voltage gain	-100 ±1, +100 ±1 (selectable)	-100 ±1	-50 ±1
Polarity	Negative/positive/bipolar (jumper selectable)	Negative	Bipolar
Control input voltage	0 to +11 V, 0 to -11 V (jumper selectable)	0 to +11 V	-5 to +5 V
Output voltage	-3 to -1100 V (-780 to +260, -550 to +550, -260 to +780, +3 to +1100 V, jumper selectable)	-3 to -1100 V	-250 to -250 V
DC-offset setting	-3 to -1100 V at output with 10-turn pot.	-	500 V range at output with 10 turn pot.
Input impedance	100 kΩ	100 kΩ	100 kΩ
Control input sockets	BNC	DIN 41612, 32 pin, rear; SMB, front	BNC
PZT voltage output sockets	LEMO ERA.0A.250.CTL	LEMO ERA.0A.250.CTL	LEMO ERA.0A.250.CTL
Dimensions	One 14T slot wide, 3H high	One 14T slot wide, 3H high	One 14T slot wide, 3H high
Weight	0.75 kg	0.75 kg	0.75 kg
Operating voltage	Requires E-530/E-531 power supply (E-500/E-501 system)	Requires E-530/E-531 power supply (E-500/E-501 system)	Requires E-530/E-531 power supply (E-500/E-501 system)

E-461

HVPZT Piezo Drivers

E-461.00

E-461.OE

- **Single Channel Piezo Driver**
- **12 V Battery or P/S Operation**
- **Output Voltage Range -10 to -1000 V**

The E-461.00 piezo driver is a low-cost amplifier for high-voltage PZTs. It can output a peak current of 0.5 mA and an average current of 0.3 mA. Because the unit requires an operating current of only 80 mA @ 12 V, battery operation is possible.

The E-461.OE is the OEM version of the E-461.00 amplifier. The OEM module does not provide manual controls. All input connections are via 6 header pins located on the bottom. The HV output is via a coaxial cable with LEMO connector (ERA.0A.250.CTL). The module is designed for mounting on circuit boards. The electronics are fully enclosed in a metal case. The E-461.00 and E-461.OE can be operated in 2 ways:

I. Manual Control:

Output voltage can be set by a DC-offset potentiometer (not supplied with E-461.OE) in the range of -10 to -1000 V.

II. External Control:

Output voltage is controlled by an analog signal in the range of 0 to 10 V, applied to the BNC input. Multiplying by the gain factor of -100, an output voltage range of -10 to -1000 V results. The DC-offset potentiometer adds a DC bias to the input, allowing continuous shifting of the input range between 0 V to +10 V and -10 V to 0 V (see PI main catalog page 6-52).

The E-461.00 and E-461.OE are not equipped with active discharge circuitry but a 5 Mh/ 3.9 nF RC network. Therefore, PZT discharge times will differ from charge times. If dynamic (>1 Hz) PZT operation is required, please consider the E-463 or E-507 amplifiers (see PI main catalog page 6-40 and page 6-23).

Ordering Information

E-461.00
HVPZT Piezo Driver

E-461.OE
HVPZT Piezo Driver Module, OEM Version

Ask about custom designs!

Technical Data

Models	E-461.00	E-461.OE
Function	Power amplifier	Power amplifier
Channels	1	1
Maximum output power	0.5 W	0.5 W
Average output power	0.3 W	0.3 W
Peak output current <5 ms	0.5 mA	0.5 mA
Average output current >5 ms	0.3 mA	0.3 mA
Current limitation	Short-circuit proof	Short-circuit proof
Voltage gain	-100 ±1	-200 ±1
Polarity	negative	negative
Control input voltage	0 to +10 V	0 to +5 V
Output voltage	-10 to -1000 V	-10 to -1000 V
DC-offset setting	-10 to -1000 V at output with 1-turn pot.	-
Input impedance	10 kΩ	1 MΩ
Frequency response	Static and quasi static applications only	Static and quasi-static applications only
Control input socket	BNC	Header pins
PZT voltage output socket	LEMO ERA.0A.250.CTL	LEMO ERA.0A.250.CTL
Dimensions	160 x 90 x 60 mm	67 x 41 x 20 mm
Weight	0.5 kg	0.25 kg
Operating voltage	10 to 15 VDC, stabilized	10 to 15 VDC, stabilized
Max. operating current	80 mA	80 mA
Operating temperature range	0 to +60 °C	0 to +60 °C
Power supply	optional (3.5 mm jack socket)	-

E-470 – E-471 – E-472 – E-420

High-Power, Modular HVPZT Piezo Amplifiers / Controllers

E-471.00 Configuration example: E-471.00 HVPZT amplifier, with optional E-509.S1 PZT servo-controller (strain gauges) and E-516 20-bit DAC interface/display

- **550 W Peak Power**
- **Output Voltage -3 to -1100 V & Bipolar**
- **1- and 2-Channel Versions**
- **Optional Position Servo-Control Modules**
- **Optional RS-232 & IEEE 488 Interface Module & Display**

The E-470 series high-power amplifier/controllers are specifically designed to drive high-capacitance PZT actuators. They are based on the E-420 4-quadrant amplifier module, which can output and sink a peak current of 500 mA and an average current of 100 mA in a voltage range of -3 to -1100 V (positive or bipolar range, jumper selectable). OEM, 19” rackmount, bench-top, and two-channel versions are available, some with servo-control module and display (see Ordering Information for standard combinations).

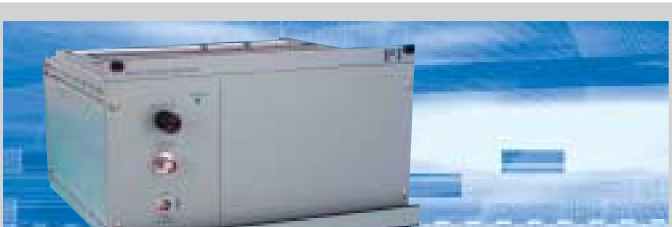
Standard versions can be operated in two ways:

I. Manual Control:

The output voltage can be set by a 10-turn, DC-offset potentiometer in the range of -3 to -1000 Volts

II. External Control:

Output voltage is controlled by an analog signal applied to the BNC input, ranging from 0 to 11 Volts. Multiplying by the gain factor of -100, an output voltage range of -3 to -1100 Volts results. The DC-offset potentiometer adds a DC bias to the input, allowing continuous shifting of the input range between 0 V to +10 V and -10 V to 0 V (see PI main catalog page 6-52).
See graph for frequency response with selected HVPZTs.



E-420.00 HVPZT amplifier module

Upgrades

The E-471.00 version allows installation several upgrade options for enhanced versatility (see Ordering Information).

Two additional modes are possible with versions having the E-509 Sensor & Servo-Controller Module upgrade:

I. Manual Closed-Loop Operation

Displacement of the PZTs can be set by a 10-turn DC-offset potentiometer in the range of zero to nominal displacement.

II. External Closed-Loop Operation

Displacement of the PZT is controlled by an analog signal in the range of 0 to +10 V, applied to the BNC input. The controller is calibrated in such a way that 10 V corresponds to maximum nominal displacement and 0 V corresponds to 0 displacement. The DC-offset potentiometer can be used to add an offset voltage of 0 to 10 V to the input signal.

Notes

Important Calibration Information: Please read details see PI main catalog page 6-53.

Ordering Information

E-470.00
HVPZT Amplifier, 550 W, -3 to -1100 V, Bench-Top

E-471.00
HVPZT Amplifier, Controller & Interface / Display Upgrade Possible, 550 W, -3 to -1100 V, 19”

E-472.00
HVPZT Amplifier, 2 Channels, 550 W, -3 to -1100 V, Bench-Top, 19”

E-420.00
HVPZT Amplifier Module, 550 W, -3 to -1100 V, Integrated P/S

Upgrades for E-471

E-509.C1A
PZT Sensor-Controller Module (Capacitive Sensor)

E-509.L1
PZT Sensor / Controller Module (LVDT Sensor)

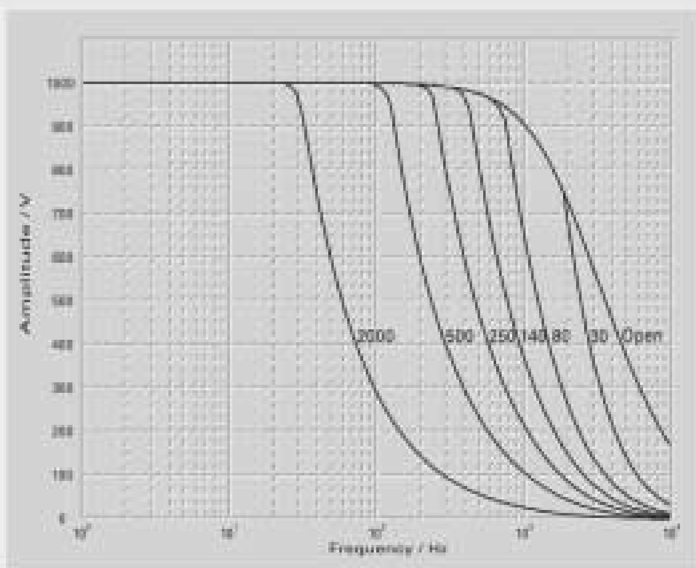
E-509.S1
PZT Sensor / Controller Module (Strain Gauge Sensor)

Computer Interface and Display Module (see PI main catalog page 6-26)

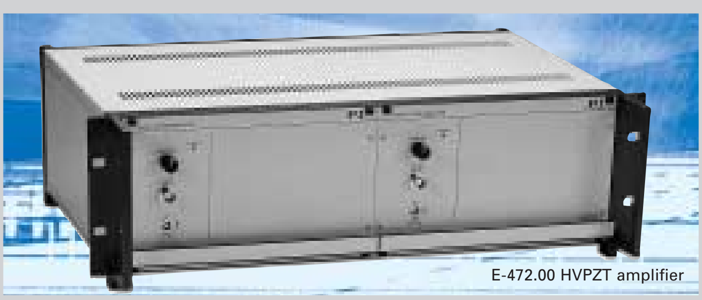
E-516.i31
20-bit DAC Interface/Display Module, IEEE 488 / RS-232 Voltage & Position Display Module (see PI main catalog page 6-26)

E-515.01
Display Module for PZT Voltage and Displacement Sensor & Servo-Controller Modules for Closed-Loop PZT Operation (see PI main catalog page 6-28)

Ask about custom designs!



E-420, E-470, E-471, E-472, frequency response with various PZT loads. Values shown are capacitance in nF, measured in actual PZT



E-472.00 HVPZT amplifier

Technical Data

Models	E-470.00, E-471.00, E-472.00, E-420.00
Function	power amplifier (servo-controller option for E-471)
Channels	1 (E-472: 2)
Maximum output power	550 W / channel (see page 6-52)
Average output power	110 W / channel
Peak output current <50 ms:	500 mA / channel
Average output current >50 ms	100 mA / channel
Current limitation	short-circuit proof
Voltage gain	-100 ±1, +100 ±1 (selectable)
Polarity	Negative/positive/bipolar (jumper selectable)
Control input voltage	0 to +11 V, 0 to -11 V (jumper selectable)
Output voltage	-3 to -1100 V (-780 to +260, -550 to +550, -260 to +780, +3 to +1100 V, jumper selectable)
DC-offset setting	-3 to -1100 V at output with 10-turn pot.
Input impedance	100 kΩ / 1 nF
Control input sockets	BNC
PZT voltage output sockets	LEMO ERA.0A.250.CTL
Dimensions	236 x 132 x 296 mm + handles (E-470); 450 x 132 x 296 mm + handles (E-471, E-472); 215 x 123 x 185 mm (E-420) (see page 6-10)
Weight	5.2 kg (E-470); 7.6 kg (E-471); 10.1 kg (E-472); 2.5 kg (E-420)
Operating voltage	90-120 / 220-264 VAC, 50-60 Hz

E-660

LVPZT Piezo Drivers

Ordering Information

E-660.00
LVPZT Piezo Driver

E-660.OE
LVPZT Piezo Driver Module, OEM Version

Ask about custom designs!

- **Single-Channel Piezo Driver**
- **12 V Battery or P/S Operation**
- **Output Voltage Range 5 to 100 V**

The E-660.00 piezo driver is a low-cost amplifier for low-voltage PZTs. It can output and sink a peak current of 20 mA and an average current of 10 mA. The E-660 is designed for static and low-level dynamic PZT applications. Because an operating current of only 150 mA @ 12 V is required, battery operation is possible.

E-660.OE is the OEM version of the E-660.00 amplifier. The OEM module does not provide manual controls. All inputs and outputs are via 8 header pins located on the bottom of the E-660.OE. The module is designed to be mounted on circuit boards. The electronics are fully enclosed in a metal case. The E-660.00 and E-660.OE can be operated in two ways:

I. Manual Control:

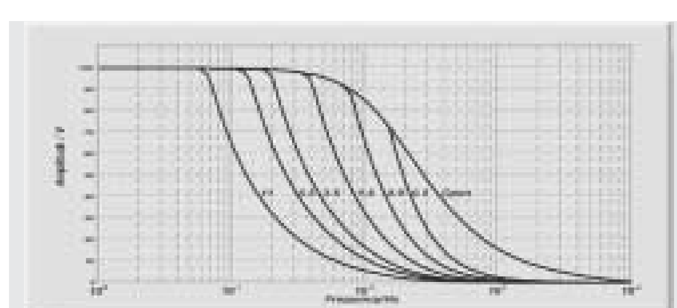
Output voltage can be set by a DC-offset potentiometer (not supplied with E-660.OE) in the range of 5 to 100 V.

II. External Control:

Output voltage is controlled by an analog signal in the range of 0 to 10 V, applied to the BNC input (E-660.00). Multiplying by the gain factor of 10, an output voltage range of +5 to +100 V results. The DC-offset potentiometer adds a DC bias to the input, allowing continuous shifting of the input voltage range between 0 V to +10 V and -10 V to 0 V (see PI main catalog page 6-52).

Technical Data

Models	E-660.00	E-660.OE
Function	Power amplifier	Power amplifier
Channels	1	1
Output power	2 W	2 W
Output current	20 mA	20 mA
Current limitation	Short-circuit proof	Short-circuit proof
Voltage gain	10 ±0.1	10 ±0.1
Polarity	Positive	Positive
Control input voltage	0 to +11 V	0 to +10 V
Output voltage	5 to 110 V	5 to 100 V
DC offset setting	5 to 110 V with 1-turn pot.	-
Input impedance	100 kΩ	100 kΩ
Control input socket	BNC	header pins
PZT voltage output socket	LEMO ERA.00.250.CTL	header pins
Dimensions	150 x 195 x 75 mm	93 x 45 x 28 mm
Weight	0.5 kg	0.25 kg
Operating voltage	12 to 15 VDC, stabilized	12 to 15 VDC, stabilized
Max. Operating current	150 mA	150 mA
Operating temperature range	0 to +50 °C	0 to +50 °C
Power supply	Optional (3.5 mm jack socket)	-



E-660, frequency response with various PZT loads. Values shown are capacitance values are in µF, measured in actual PZT

Tutorial

Advantages of Piezoelectric Actuators

Unlimited Resolution

A piezoelectric actuator can produce extremely fine position changes down to the sub-nanometer range. The smallest changes in operating voltage are converted into smooth movements. Motion is not influenced by striction/friction or threshold voltages.

Large Force Generation

Piezoelectric actuators can generate a force of several 10,000 N. PI Ceramic offers units that can bear loads up to several tons and position within a range of more than 100 µm with sub-nanometer resolution.

Rapid Response

Piezoelectric actuators offer the fastest response time available. Microsecond time constants and acceleration rates of more than 10,000 g's can be obtained.

No Magnetic Fields

Piezoelectric actuators are especially well-suited for applications where magnetic fields cannot be tolerated. For extreme requirements, PI Ceramic is able to deliver assemblies which have no measurable remnant magnetism.

Low Power Consumption

The piezoelectric effect directly converts electrical energy into motion, absorbing electrical energy during movement only. Static operation, even holding heavy loads, does not consume power.

No Wear and Tear

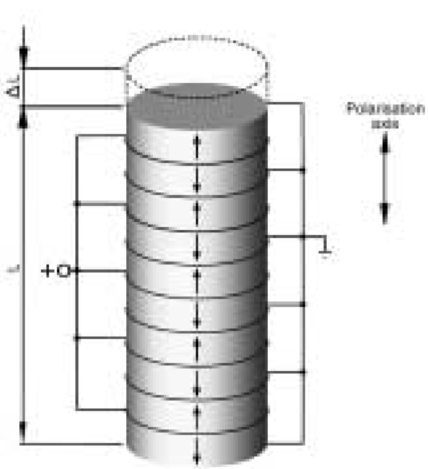
A piezoelectric actuator has neither gears nor rotating shafts. Its displacement is based on pure solid-state effects and exhibits no wear and tear. PI Ceramic has conducted endurance tests on actuators in which no change in performance was observed after several billion cycles.

Vacuum and Clean-Room Compatible

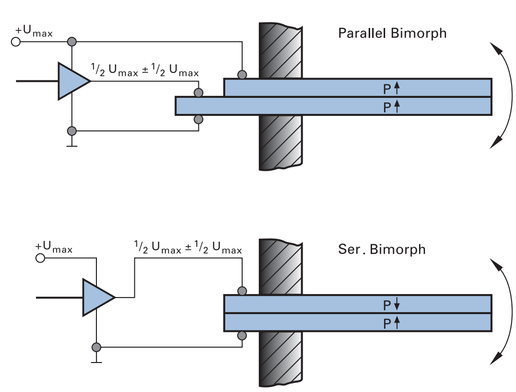
Piezoelectric actuators employ ceramic elements that do not need any lubricants and exhibit no wear or abrasion. This makes them clean-room compatible and ideally suited for ultra-high-vacuum applications.

Operation at Cryogenic Temperatures

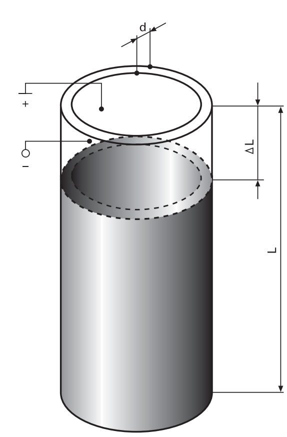
The piezoelectric effect is based on electric fields and functions down to almost zero kelvin, albeit at reduced specifications.



Design of a PZT stack actuator



Parallel bimorph and serial bimorph



Tube design

Fundamentals of Piezoelectric Actuators

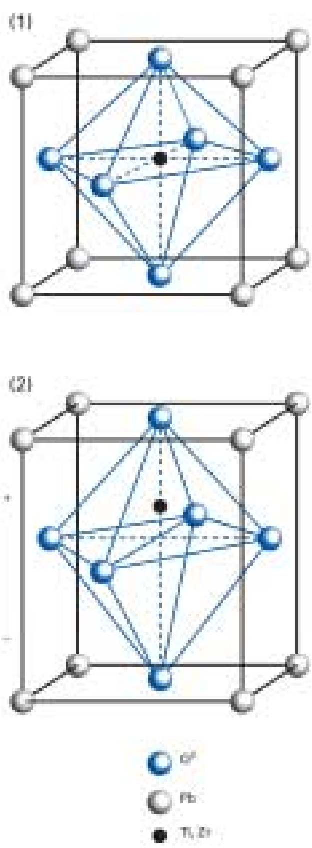
Introduction

PI Ceramic piezoelectric actuators offer today´s motion engineer and scientist a practical way to achieve extremely high positioning accuracy, shortest possible response times, best dynamic operation and largest forces in a wide variety of applications. Presently piezoelectric actuator based motion systems increasingly replace classical motion technologies—improving products in terms of miniaturization, precision and throughput. In addition, the unique features of piezoelectric actuators will trigger the development of motion equipment that could not even exist without this technology.

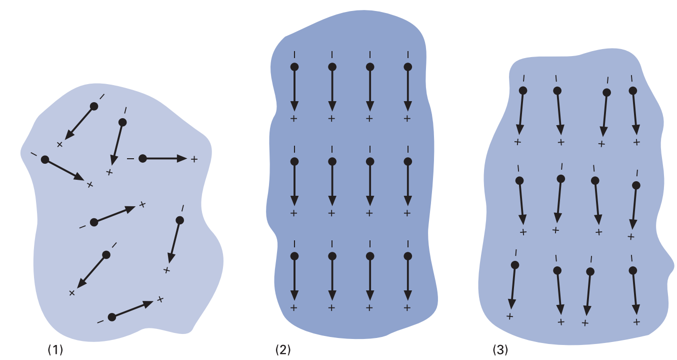
PI Ceramic, a member of the PI Group, offers the largest selection worldwide of research- and industrial-reliability piezoelectric actuators. In addition to the standard Piezoelectric products presented in this short catalog, we focus on custom designs tailored to our customer´s requirements.

The highly vertically integrated structure of the PI Group allows control of each manufacturing step, beginning at the raw material up to finished NanoPositioning systems, including electronic drivers, amplifiers and controllers. This comprehensive development and manifacturing know-how of electromechanical components and systems is unique in the world.

Since the piezoelectric effect exhibited by natural monocrystalline materials such as quartz, tourmaline, Rochelle salt, etc. is very small, polycrystalline piezoelectric ceramic materials, such as lead (plumbum) zirconate titanate (PZT), with improved properties have been developed. PZT ceramics are available in many variations and are by far the most widely used materials for piezoelectric actuator applications today.



PZT unit cell: 1) Perovskite-type lead zirconate titanate (PZT) unit cell in the symmetric cubic state above the Curie temperature
2) Tetragonally distorted unit cell below the Curie temperature



The poling process in ferroelectric ceramics. Electric dipoles: (1) unpoled ferroelectric ceramic, (2) during and (3) after poling (piezoelectric ceramic)

Applications for Piezoelectric Actuators

- Optics and Photonics
- Precision Mechanics
- Life Sciences, Medicine, Biology
- Vibration Cancellation
- Adaptronics
- Mechanical Engineering
- Measuring Technologies
- Microelectronics
- Disk Drive

Piezoelectric Actuator Materials

Below the so called Curie temperature T_C (see Table 1) the ionic lattice structure in the PZT crystallites becomes distorted and asymmetric (with an axis of polarity) and, additionally, exhibits spontaneous polarization. One result is that the discrete PZT crystallites become piezoelectric. However, the statistical distribution of the grain orientations in the ceramic will cause the macroscopic behavior to be non-piezoelectric.

An additional property, the ferroelectric nature of the PZT material, will help to solve this problem. When an intense electric field is applied to the ceramic, the different lattice orientations of the individual ceramic grains can be permanently altered. As a result of this ''poling process'' the ceramic is accorded a net orientation of its internal, spontaneous polarization in the direction of the poling field and shows an overall piezoelectric effect. For some PZT ceramics, it is necessary to perform the poling process at elevated temperatures.

Table 1 shows the specifications of different PI Ceramic PZT materials.

The types PIC 151 and PIC 255 are the PI Ceramic standard actuator materials which are used for the PICA™-Stack and PICA™-Power actuators. These materials show the highest piezoelectric deformation constants, d_{33}, d_{31} and d_{15} (see Table 1) and, consequently, the largest induced strain values at comparable fields. These compositions incorporate all our long-term experience in piezo-electronic actuator development, manufacturing and application.

PIC 151 PIC 151 is a modified lead zirconate titanate (PZT) ceramic with high permittivity, coupling factor and charge constant. It is thus well-suited for PICA™-Stack actuators and bender applications. Due to the high coupling factor and the low mechanical quality factor it is also recommended for low fregquency and pulsed ultrasonic applictions.

PIC 255 PIC 255 is a modified lead zirconate titanate (PZT) with a high curie temperature, coupling factor and charge constant. The material is optimized for actuator application under dynamic or high-temperature working conditions. Because of its high coercive field, PIC 255 can be used for bipolar-driving-mode applications as well as for PICA™-Shear actuators. Due to its high coupling efficiency, low mechanical quality factor and low temperature coefficient, it is also well suited low-power ultrasonic transducers, non-resonant boardband devices, sensors for load and sound transducers and is preferred for vacuum applications.

PIC 252 PIC 252 is a low-sintering modification of PIC 255, especially used for multilayer actuators. It is recommended for dynamic and/or high-temperature operating conditions due to its high curie temperature and low permittivity. This material will replace the currently used ceramic type in the near future.

Table 1: PI Ceramic Standard PZT Materials [in extracts]

Parameter	Unit		PIC 151	PIC 155	PIC 255	PIC 181	PIC 241	PIC 300
Density	p	g/cm³	7.8	7.8	7.8	7.8	7.8	7.8
Curie Temperature	T_C	°C	250	345	350	330	270	370
Relative Dielectric Permittivity	$\varepsilon_{33}^T/\varepsilon_0$		2400	1450	1750	1200	1500	1050
	$\varepsilon_{11}^T/\varepsilon_0$		1980	1400	1650	1500	1550	950
Dielectric Dissipation Factor	$\tan\delta$	10^{-3}	20	20	20	5	5	3
Electromechanical Coupling Factor	k_p		0.62	0.62	0.62	0.56	0.55	0.48
	k_t		0.53	0.48		0.46	0.46	0.43
	k_{31}		0.38	0.35	0.35	0.32	0.32	0.25
	k_{33}		0.69	0.69	0.69	0.66	0.64	0.46
Mechanical Quality Factor	Qm		100	80	80	2000	1200	1400
Frequency Constant	N_p	H_{zm}	1950	1960	2000	2270	2190	2350
	N_1	H_{zm}	1500	1500	1420	1640	1590	1700
	N_3	H_{zm}	1750	1780		2010	1550	1700
	N_t	H_{zm}	1950	1990	2000	2110	2140	2100
Piezoelectric Deformation	d_{31}	pm/V	-210	-165	-180	-120	-130	-80
(Charge) Coefficient	d_{33}	pm/V	500	360	400	265	290	155
	d_{15}	pm/V			500	475	265	155
Piezoelectric Voltage Coefficient	g_{31}	10^{-3} Vm/N	-11.5	-12.9	-11.3	-11.2	-9.8	-9.5
	g_{33}	10^{-3} Vm/N	22	27	25	25	21	16
Elastic Compliance Coefficient	s_{11}^E	10^{-12} m²/N	15.0	15.6	16.1	11.8	12.6	11.1
	s_{33}^E	10^{-12} m²/N	19.0	19.7	20.7	14.2	14.3	11.8
Elastic Stiffness Coefficient	c_3^D	10^{10} N/m²	10.0	11.1	13.4	16.6	13.8	16.4
Temperature Coefficient	$TC\varepsilon_{33}$	10^{-3}/K	6	6	4	3	3	2

This data was measured according to EN50324 I/II.

PICMA® and PICA™: Cofired and Stacked Piezoelectric Actuators

Two main types of piezo actuators are available: cofired PICMA® actuators requiring about 120 volts for full motion, and glued PICA™-Stack actuators, requring up to 1000 volts for full extension.

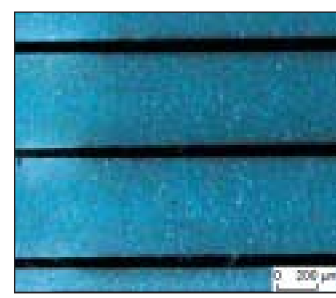
The maximum electrical field which can be recommended for reliable operation of PZT ceramics is on the order of 1 to 2 kV/mm. To keep the operating voltage within practical limits, actuators consist of thin layers of electroactive ceramic material which are electrically connected in parallel. The net positive displacement is the sum of the displacements of the individual layers. The thickness of the individual layers determines the maximum operating voltage of the actuator.

Glued PICA™-Stack piezoelectric actuators consist of separate ceramic discs with a thickness of 0.2 to 1.0 mm. These values, which are limited by the manufacturing technology, result in nominal driving voltages of up to 1000 V. In contrast, PICMA® actuators are manufactured using a cofiring technology. This advanced process allow for multilayer designs which have individual layer thicknesses of just 20 to 100 µm. Hence PICMA® actuators require nominal voltages of only 40 to 200 V.

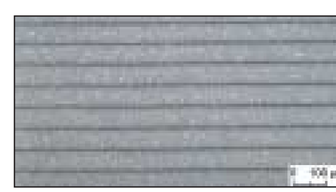
Both types of piezoelectric actuators can be used for many applications: PICMA® actuators facilitate drive electronics design and can be produced at reasonable costs in standard sizes and large quantities. Due to its manufacturing technology, PICA™-Stack actuators can be designed with larger cross-sections for high-load applications. They can easily lift weights of up to several tons. Additionally, the PICA™-Stack technology is very flexible in terms of special actuator shapes and sizes.

Polymer coated stacked actuator (PICA™-Stack) and ceramic insulated cofired actuator (PICMA®)

Comparison of a long-travel, high-load piezoelectric actuator and a compact actuator for small loads



Layers in a stacked piezoelectric actuator



Layers in cofired monolithic piezoelectric actuator

Displacement Modes of Piezoelectric Actuators

For small electric driving signals the displacement ΔL of a bulk ceramic material sample can be calculated from the following equation:

(Equation 1)

$\Delta L_j = S_j L_0 = d_{ij} E_i L_0$

where:

S_j: *mechanical strain in direction j (strain in defined as relative length change, ΔL/L) [dimensionless]*

L_0: *material thickness in field direction [m]*

E_i: *electrical field in direction i [V/m]*

d_{ij}: *piezoelectric deformation coefficient [pm/V]*

The maximum allowable field strength in piezo actuators is between 1 and 2 kV/mm in the polarization direction.

Exceeding the maximum voltage may cause dielectric breakdown and irreversible damage to the piezo actuator.

Stacks can be built with aspect ratios up to 12:1 (length:diameter). Longer travel ranges can be achieved by mechanical amplification techniques.

Equation 1 is applicable for small electric signals only, because the piezoelectric deformation coefficients, d_{ij}, for PZT ceramics show strong electric field dependency. In fact, the coefficient value can increase by a factor of 1.5 to 2 compared to the small-signal value in Table 1 when the nominal voltage of the actuator is applied. This increase leads to a very high large-signal deformation coefficient d_{15} of 1100 pm/V at an amplitude of 250 V for PICA™-Shear actuators, which are made of PIC 255.

Commonly used stack actuators achieve a relative displacement of up to 0.2 %. Displacement of piezoceramic actuators is primarily a function of the applied electric field strength E, the length L of the actuator, the forces applied to it and the properties of the piezoelectric material used. The material properties can be described by the piezoelectric strain coefficients d_{ij}. These coefficients describe the relationship between the applied electric field and the mechanical strain produced.

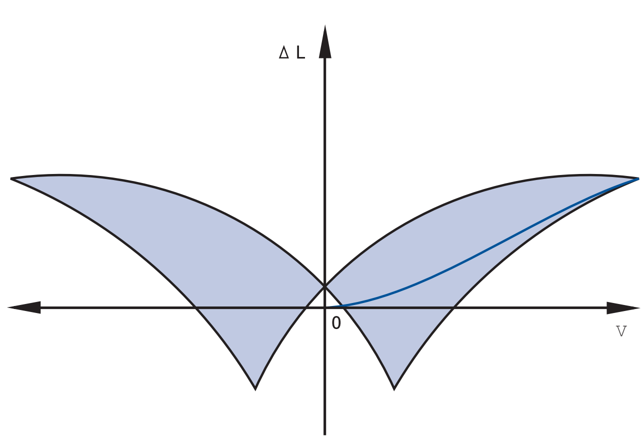
The change in length, ΔL, of an unloaded single-layer piezo actuator can be estimated by the following equation:

(Equation 2)

$\Delta L = S \cdot L_o \approx \pm E \cdot d_{ij} \cdot L_o$

where:

S	=	*strain (relative length change ΔL/L, dimensionless)*
L_0	=	*ceramic length [m]*
E	=	*electric field strength [V/m]*
d_{ij}	=	*piezoelectric coefficient of the material [m/V]*



Typical response of a "soft PZT" actuator to a bipolar drive voltage. When a certain threshold voltage negative to the polarization direction is exceeded, reversal of polarization can occur

Displacement Modes of Piezoelectric Actuators (cont.)

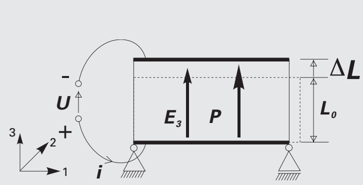
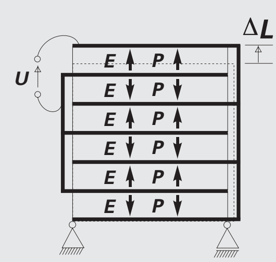
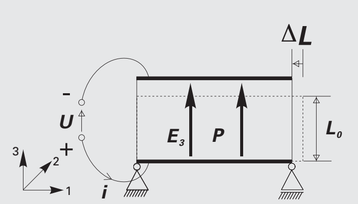
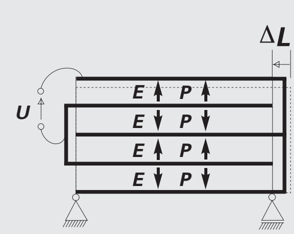
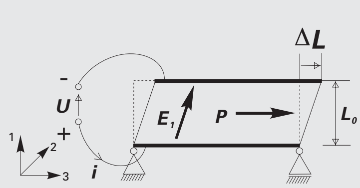
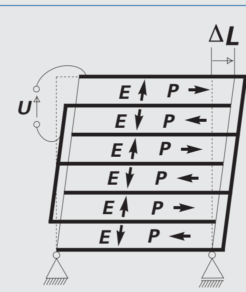
Table 2 illustrates the different piezoelectric actuator displacement modes for PZT ceramics.

By convention, index 3 is always aligned in the poling direction of the material. The small-signal values of the relevant piezoelectric deformation coefficients d_{33}, d_{31} and d_{15} for the different actuator materials can be found in Table 1.

The longitudinal mode is used for most linear actuators in this catalog. In this mode, the electric field, the poling direction as well as the mechanical strain or displacement, have the same orientation. Keep in mind that the longitudinal deformation is always accompanied by a transverse deformation. When driven with a positive voltage U_3, the material expands in the longitudinal direction while at the same time shrinking in the transverse direction, as can be seen from the material deformation figures in Table 2. Whether the actuator is of a longitudinal or transverse type depends only on the displacement which is used. The shear mode is different, because in the electric field and the poling direction are perpendicular to each other. The PICA™-Shear actuators use the shear displacement in the poling direction.

To get the displacements of the individual layers in a multilayer actuator to add while using the appropriate electrical contact configuration, the poling orientations of adjacent layers have to alternate (see Table 2).

Table 2: Piezoelectric actuator modes in PZT ceramics

Mode	Material deformation	Multilayer actuator configuration	Remarks
Longitudinal	 relevant deformation coefficient: d_{33}		The longitudinal mode is the most important. It is used for PICMA®-, PICA™-Stack-, PICA™-Thru-, PICA™-Power- and the Z-axis of PICA™-Shear actuators.
Transverse	 relevant deformation coefficient: d_{31}		This mode is used for standard bending actuators (bimorphs or trimorphs) as well as for pure contractors and tubes.
Shear	 relevant deformation coefficient: d_{15}		This mode is used for the X- and Y-axes of the PICA™-Shear actuators.

where:

E_i vector component of the electric field

P polarization direction

U applied voltage

i current

ΔL induced displacement

Note:

PI piezo actuators and stages are designed for high reliability in industrial applications. The travel, voltage and load ranges in the technical data tables can actually be used in practice. They have been collected over many years of experience in piezo actuator production and in numerous industrial applications.

In contrast to many other piezo suppliers, PI has its own piezo ceramic development and production facilities together with the necessary equipment and knowhow. The goal is always reliability and practical usefulness. Maximizing isolated parameters, such as expansion or stiffness, at the cost of piezo lifetime might be interesting to an experimenter, but has no place in practical application.

When selecting a suitable piezo actuator or stage, consider carefully the fact that “maximum travel” may not be the only critical design parameter.

Hysteresis (Open-Loop Piezo Operation)

Hysteresis is observable in open-loop operation; it can be reduced by charge control and virtually eliminated by closed-loop operation (see PI main catalog page 4-31 *ff.*).

Open-loop piezo actuators exhibit hysteresis in their dielectric and electromagnetic large-signal behavior. Hysteresis is based on crystalline polarization effects and molecular effects within the piezoelectric material.

The amount of hysteresis increases with increasing voltage (field strength) applied to the actuator. The “gap” in the voltage/displacement curve typically begins around 2 % (small-signal) and widens to a maximum of 10 % to 15 % under large-signal conditions. The highest values are attainable with shear actuators in d_{15} mode.

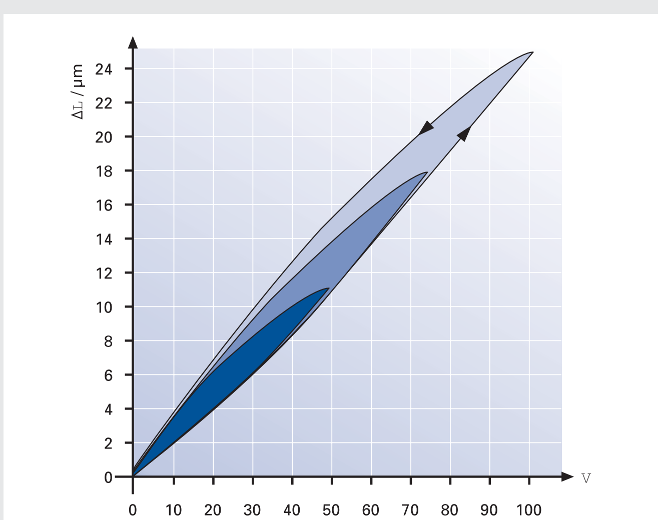
For example, if the drive voltage of a 50 µm piezo actuator is changed by 10 %, (equivalent to about 5 µm displacement) the position repeatability is still on the order of 1 % of full travel or better than 1 µm.

The smaller the move, the smaller the uncertainty. Hysteresis must not be confused with the backlash of conventional mechanics. Backlash is virtually independent of travel, so its relative importance increases for smaller moves.

For tasks where it is not the absolute position that counts, hysteresis is of secondary importance and open-loop actuators can be used, even if high resolution is required.

In closed-loop piezo actuator systems hysteresis is fully compensated. PI offers these systems for applications requiring absolute position information, as well as motion with high linearity, repeatability and accuracy in the nanometer and sub-nanometer range (see PI main catalog page 4-31 *ff.*).

Example: Piezoelectrically driven fiber aligners and tracking systems derive the control signal from an optical power meter in the system. There, the goal is to maximize the optical signal level as quickly as possible, not to attain a predetermined position value. An open-loop piezo system is sufficient for such applications. Advantages like unlimited resolution, fast response, zero backlash and zero stick/slip effect are most welcome, even without position control.



Hysteresis curves of an open-loop piezo actuator for various peak voltages. The hysteresis is related to the distance moved, not to the nominal travel range

Creep / Drift (Open-Loop Piezo Operation)

The same material properties responsible for hysteresis also cause creep or drift. Creep is a change in displacement with time without any accompanying change in the control voltage. If the operating voltage of a piezo actuator is changed, the remnant polarization (piezo gain) continues to change, manifesting itself in a slow change of position. The rate of creep decreases logarithmically with time (see below). The following equation describes this effect:

(Equation 3)

$$\Delta L(t) \approx \Delta L_{t=0.1}\left[1+\gamma\cdot \lg\left(\frac{t}{0.1}\right)\right]$$

Creep of PZT motion as a function of time.

where:

t	=	*time [s]*
$\Delta L(t)$	=	*change in position as a function of time*
$\Delta L_{t=0.1}$	=	*displacement 0.1 seconds after the voltage change is complete [m].*
γ	=	*creep factor, which is dependent on the properties of the actuator (on the order of 0.01 to 0.02, which is 1 % to 2 % per time decade).*

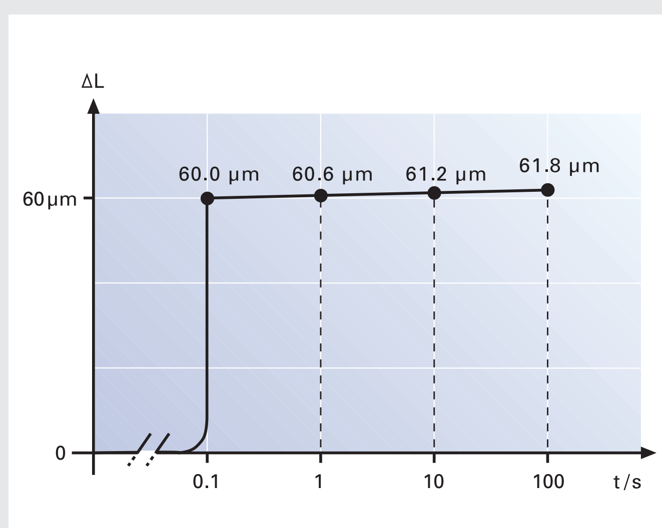
In practice, maximum creep (after a few hours) can add up to a few percent of the commanded motion.

Aging

Aging refers to reduction in remnant polarization; it can be an issue for sensor or charge-generation applications (direct piezo effect). With actuator applications it is negligible, because repoling occurs every time a higher electric field is applied to the actuator material in the poling direction.

Note

For periodic motion, creep and hysteresis have only a minimal effect on repeatability.



Creep of open-loop PZT motion after a 60 µm change in length as a function of time. Creep is on the order of 1 % of the last commanded motion per time decade

Fundamentals of Piezomechanics

Forces and Stiffness

Maximum Applicable Forces (Compressive Load Limit, Tensile Load Limit)

The mechanical strength values of PZT ceramic material (given in the literature) are often confused with the practical long-term load capacity of a piezo actuator. PZT ceramic material can withstand pressures up to 250 MPa (250 x 10^6 N/m^2) without breaking. This value must never be approached in practical applications, however, because depolarization occurs at pressures on the order of 20 % to 30 % of the mechanical limit. For stacked actuators and stages (which are a combination of several materials) additional limitations apply. Parameters such aspect ratio, buckling, interaction at the interfaces, etc. must be considered.

The load capacity data listed for PI actuators are conservative values which allow long lifetime.

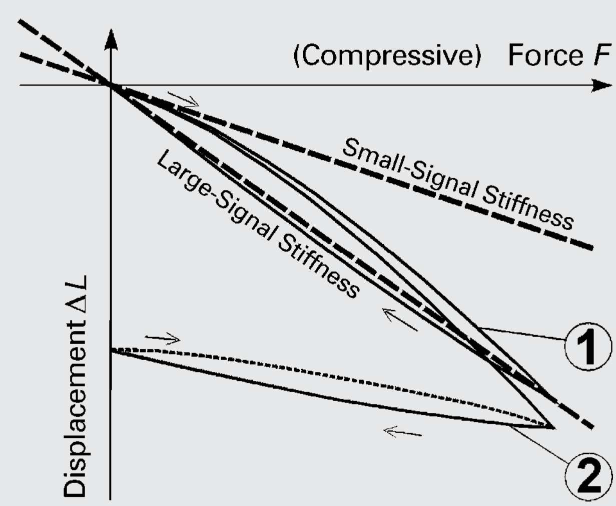
Tensile loads of non-preloaded piezo actuators are limited to 5 % to 10 % of the compressive load limit. PI offers a variety of piezo actuators with internal spring preload for increased tensile load capacity. Preloaded elements are highly recommended for dynamic applications.

The PZT ceramic is especially sensitive to shear forces; they must be intercepted by external measures (flexure guides, etc.).

Stiffness

Actuator stiffness is an important parameter for calculating force generation, resonant frequency, full-system behavior, etc. The stiffness of a solid body depends on Young's modulus of the material. Stiffness is normally expressed in terms of the spring constant k_T, which describes the deformation of the body in response to an external force.

This narrow definition is of limited application for piezoceramics because the cases of static, dynamic, large-signal and small-signal operation with open and shorted electrodes must all be distinguished. The poling process of piezoceramics leaves a remnant strain in the material which depends on the magnitude of polarization. The polarization is affected by both the applied voltage and external forces. When an external force is applied to poled piezoceramics, the dimensional change depends on the stiffness of the ceramic material and the change of the remnant strain (caused by the polarization change). The equation $\Delta L_N = F/k_T$ is only valid for small forces and small-signal conditions. For larger forces, an additional term, describing the influence of the polarization changes, must be superimposed on the stiffness (k_T). Since piezo ceramics are active materials, they produce an electrical response (charge) when mechanically stressed (e.g. in dynamic operation). If the electric charge cannot be drained from the PZT ceramics, it generates a counterforce opposing the mechanical stress. This is why a piezo element with open electrodes appears stiffer than one with shorted electrodes. Common voltage amplifiers with their low output impedances look like a short circuit to a piezo actuator.



Quasi-static characteristic mechanical stress/strain curves for piezo ceramic actuators and the derived stiffness values. Curve 1 is with the nominal operating voltage on the electrodes, Curve 2 is with the electrodes shorted (showing ceramics after depolarization)

Mechanical stressing of piezo actuators with open electrodes, e.g. open wire leads, should be avoided, because the resulting induced voltage might damage the stack electrically.

Note

There is no international standard for measuring piezo actuator stiffness. Therefore stiffness data from different manufacturers cannot be compared without additional information.

Force Generation

In most applications, piezo actuators are used to produce displacement. If used in a restraint, they can be used to generate forces, e.g. for stamping. Force generation is always coupled with a reduction in displacement. The maximum force (blocked force) a piezo actuator can generate depends on its stiffness and maximum displacement. At maximum force generation, displacement drops to zero.

(Equation 4)

$$F_{max} \approx k_T \cdot \Delta L_0$$

Maximum force that can be generated in an infinitely rigid restraint (infinite spring constant).

where:

ΔL_0 = *max. nominal displacement without external force or restraint [m]*

k_T = *piezo actuator stiffness [N/m]*

In actual applications the spring constant of the load can be larger or smaller than the piezo spring constant. The force generated by the piezo actuator is:

(Equation 5)

$$F_{max\ eff} \approx k_T \cdot \Delta L_0 \left(1- \frac{k_T}{k_T+k_S}\right)$$

Effective force a piezo actuator can generate in a yielding restraint

where:

ΔL_0 = *max. nominal displacement without external force or restraint [m]*

k_T = *piezo actuator stiffness [N/m]*

k_S = *stiffness of external spring [N/m]*

Example

What is the force generation of a piezo actuator with nominal displacement of 30 µm and stiffness of 200 N/µm? The piezo actuator can produce a maximum force of 30 µm x 200 N/µm = 6000 N When force generation is maximum, displacement is zero and vice versa (see below for details).

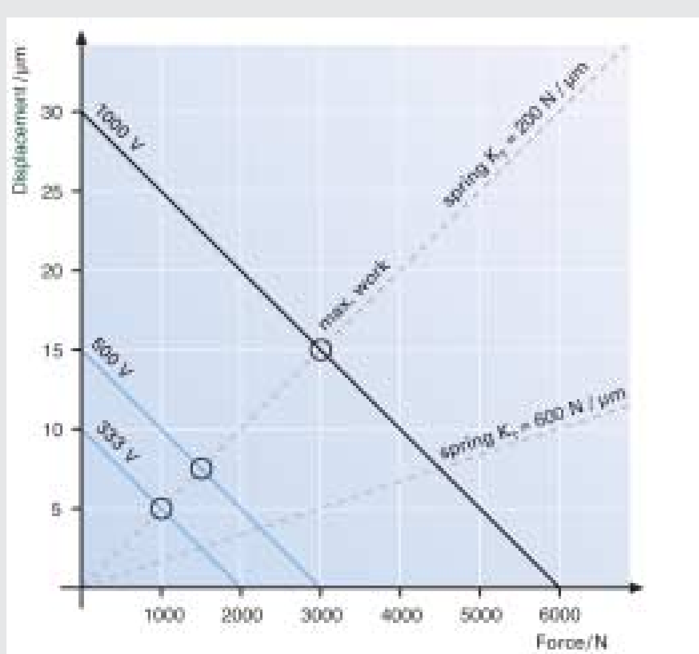
Example

A piezo actuator is to be used in a nano imprint application. At rest (zero position) the distance between the piezo actuator tip and the material is 30 microns (given by mechanical system tolerances). A force of 500 N is required to emboss the material.

Q: Can a 60 µm actuator with a stiffness of 100 N/µm be used?

A: Under ideal conditions this actuator can generate a force of 30 x 100 N = 3000 N (30 microns are lost motion due to the distance between the sheet and the piezo actuator tip). In practice the force generation depends on the stiffness of the metal and the support. If the support were a soft material, with a stiffness of 10 N/µm, the piezo actuator could only generate a force of 300 N onto the metal when operated at maximum drive voltage. If the support were stiff but the material to be embossed itself were very soft it would yield and the piezo actuator still could not generate the required force. If both the support and the metal were stiff enough, but the piezo actuator mount was too soft, the force generated by the piezo would push the actuator away from the material to be embossed.

The situation is similar to lifting a car with a jack. If the ground (or the car's body) is too soft, the jack will run out of travel before it generates enough force to lift the wheels off the ground.



Force generation vs. displacement of a piezo actuator (displacement 30 µm, stiffness 200 N/µm). Stiffness at various operating voltages. The points where the dashed lines (external spring curves) intersect the piezo actuator force/displacement curves determine the force and displacement for a given setup with an external spring. The stiffer the external spring (flatter dashed line), the less the displacement and the greater the force generated by the actuator. Maximum work can be done when the stiffness of the piezo actuator and external spring are identical

Displacement and External Forces

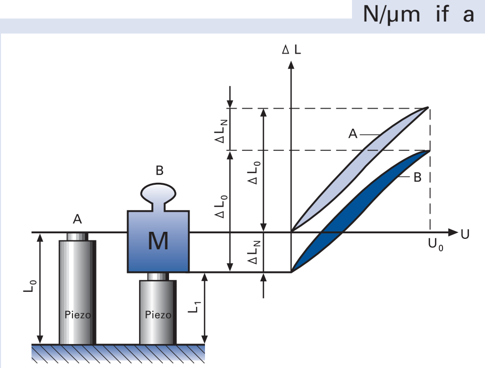
Like any other actuator, a piezo actuator is compressed when a force is applied. Two cases must be considered when operating a piezo actuator with a load:

a) The load remains constant during the motion process.

b) The load changes during the motion process.

Note

To keep down the loss of travel, the stiffness of the preload spring should be under 1/10 that of the piezo actuator stiffness. If the preload stiffness were equal to the piezo actuator stiffness, the travel would be reduced by 50 %. For primarily dynamic applications, the resonant frequency of the preload must be above that of the piezo actuator.



Case a: Zero-point offset with constant force

a Constant Force

Zero-point is offset

A mass is installed on the piezo actuator which applies a force F = M · g (M is the mass, g the acceleration due to gravity).
The zero-point will be shifted by $\Delta L_N \approx F/k_T$, where k_T is the stiffness of the actuator.
If this force is below the specified load limit (see product technical data), full displacement can be obtained at full operating voltage.

(Equation 6)

$$\Delta L_N \approx \frac{F}{k_T}$$

Zero-point offset with constant force

where:

ΔL_N = *zero-point offset [m]*
F = *force (mass x acceleration due to gravity) [N]*
k_T = *piezo actuator stiffness [N/m]*

Example

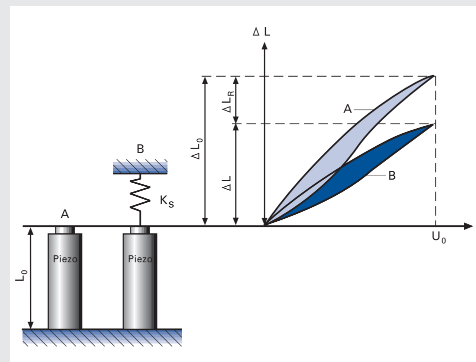
How large is the zero-point offset of a 30 µm piezo actuator with a stiffness of 100 N/µm if a load of 20 kg is applied, and what is the maximum displacement with this load?

The load of 20 kg generates a force of 20 kg x 9.81 m/s² = 196 N. With a stiffness of 100 N/µm, the piezo actuator is compressed slightly less than 2 µm. The maximum displacement of 30 µm is not reduced by this constant force.

b Changing Force

Displacement is reduced

For piezo actuator operation against an elastic load different rules apply. Part of the displacement generated by the piezo effect is lost due to the elasticity of the piezo element. The total available displacement can be related to the spring stiffness by the following equations:



Case b: Effective displacement of a piezo actuator acting against a spring load

(Equation 7)

$$\Delta L \approx \Delta L_0 \left(\frac{k_T}{k_T + k_S} \right)$$

Maximum displacement of a piezo actuator acting against a spring load.

(Equation 8)

$$\Delta L_R \approx \Delta L_0 \left(1 - \frac{k_T}{k_T + k_S} \right)$$

Maximum loss of displacement due to external spring force. In the case where the restraint is infinitely rigid ($k_s = \infty$), the piezo actuator can produce no displacement but acts only as a force generator.

where:

ΔL = *displacement with external spring load [m]*
ΔL_0 = *nominal displacement without external force or restraint [m]*
ΔL_R = *lost displacement caused by the external spring [m]*
k_s = *spring stiffness [N/m]*
k_T = *piezo actuator stiffness [N/m]*

Example

Q: What is the maximum displacement of a 15 µm piezo translator with a stiffness of 50 N/µm, mounted in an elastic restraint with a spring constant k_S (stiffness) of 100 N/µm?

A: Equation 7 shows that the displacement is reduced in an elastic restraint. The spring constant of the external restraint is twice the value of the piezo translator. The achievable displacement is therefore limited to 5 µm (1/3 of the nominal travel).

Dynamic Forces

Every time the piezo drive voltage changes, the piezo element changes its dimensions. Due to the inertia of the piezo actuator mass (plus any additional load), a rapid move will generate a force acting on (pushing or pulling) the piezo. The maximum force that can be generated is equal to the blocked force, described by:

(Equation 9)

$$F_{max} \approx \pm k_T \cdot \Delta L_0$$

Maximum force available to accelerate the piezo mass plus any additional load. Tensile forces must be compensated, for example, by a spring preload.

where:

F_{max} = *max. force [N]*

ΔL_0 = *max. nominal displacement without external force or restraint [m]*

k_T = *piezo actuator stiffness [N/m]*

The preload force should be around 20 % of the compressive load limit. The preload should be soft compared to the piezo actuator, at most 10 % the actuator stiffness.

In sinusoidal operation peak forces can be expressed as:

(Equation 10)

$$F_{dyn} = \pm 4\pi^2 \cdot m_{eff} \left(\frac{\Delta L}{2}\right) f^2$$

Dynamic forces on a piezo actuator in sinusoidal operation at frequency f.

where:

F_{dyn} = *dynamic force [N]*

m_{eff} = *effective mass [kg],*

ΔL = *peak-to-peak displacement [m]*

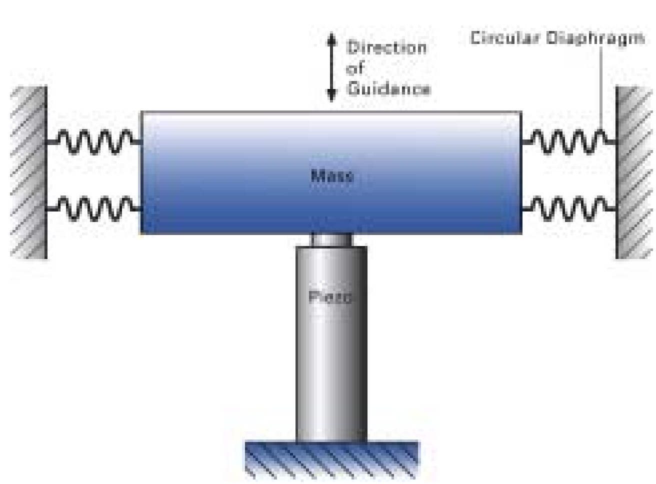
f = *frequency [Hz]*

The maximum permissible forces must be considered when choosing an operating frequency.

Example:
Dynamic forces at 1000 Hz, 2 m peak-to-peak and 1 kg load reach approximately ±40 N.

Note

A guiding system (e.g. diaphragm type) is essential when loads which are heavy or large (relative to the piezo actuator diameter) are moved dynamically. Without a guiding system, there is a potential for tilt oscillations that may damage the piezoceramics.



Recommended guiding for large masses

Resonant Frequency

In general, the resonant frequency of any spring/mass system is a function of its stiffness and effective mass. Unless otherwise stated, the resonant frequency given in the technical data tables for actuators always refer to the unloaded actuator with one end rigidly attached. For piezo positioning systems, the data refers to the unloaded system firmly attached to a significantly larger mass.

(Equation 11)

$$f_0 = \left(\frac{1}{2\pi}\right)\sqrt{\frac{k_T}{m_{eff}}}$$

Resonant frequency of an ideal spring/mass system.

where:

f_0 = *resonant frequency of unloaded actuator [Hz]*

k_T = *piezo actuator stiffness [N/m]*

m_{eff} = *effective mass (about 1/3 of the mass of the ceramic stack plus any installed end pieces) [kg]*

Note:
In positioning applications, piezo actuators are operated well below their resonant frequencies. Due to the non-ideal spring behavior of piezoceramics, the theoretical result from the above equation does not necessarily match the real-world behavior of the piezo actuator system under large signal conditions. When adding a mass M to the actuator, the resonant frequency drops according to the following equation:

(Equation 12)

$$f_0' = f_0\sqrt{\frac{m_{eff}}{m'_{eff}}}$$

Resonant frequency with added mass.

m'_{eff} = *additional mass $M + m_{eff}$.*

The above equations show that to double the resonant frequency of a spring-mass system, it is necessary to either increase the stiffness by a factor of 4 or decrease the effective mass to 25 % of its original value. As long as the resonant frequency of a preload spring is well above that of the actuator, forces it introduces do not significantly affect the actuator's resonant frequency.

The phase response of a piezo actuator system can be approximated by a second order system and is described by the following equation:

(Equation 13)

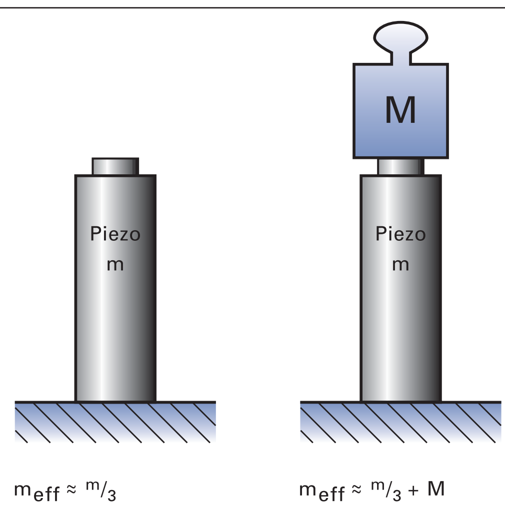
$$\varphi \approx 2 \cdot \arctan\left(\frac{f}{f_0}\right)$$

where:

φ = *phase angle [deg]*

F_{max} = *resonant frequency [Hz]*

f = *operating frequency [Hz]*



Effective mass of an actuator fixed at one end

How Fast Can a Piezo Actuator Expand?

Fast response is one of the characteristic features of piezo actuators. A rapid drive voltage change results in a rapid position change. This property is especially welcome in dynamic applications such as scanning microscopy, image stabilization, switching of valves/shutters, shock-wave generation, vibration cancellation systems, etc.

A piezo actuator can reach its nominal displacement in approximately 1/3 of the period of the resonant frequency, provided the controller can deliver the necessary current. If not compensated by appropriate measures (e.g. notch filter, InputShaping®, see PI main catalog page 4-33) in the servo-loop, such rapid expansion will be accompanied by significant overshoot.

(Equation 14)

$$T_{min} \approx \frac{1}{3f_0}$$

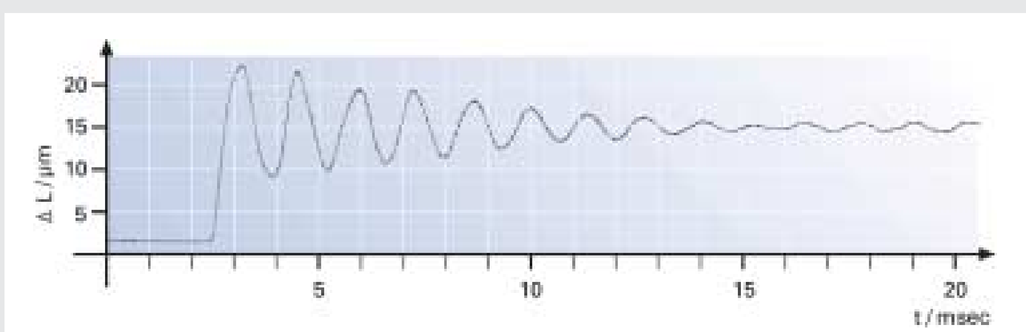
Minimum rise time of a piezo actuator (requires an amplifier with sufficient output current and slew rate).

where:

T_{min} = time [s]

f_0 = resonant frequency [Hz]]

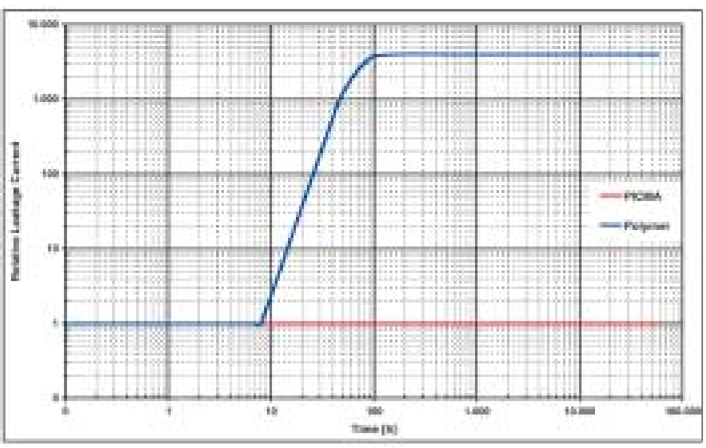
Example: A piezo translator with a 10 kHz resonant frequency can reach its nominal displacement within 30 µs.



Response of an undamped, lever-amplified piezo actuator (low resonant frequency) to a rapid drive-voltage change. This behavior can be prevented by intelligent control techniques or position servo-control

Lifetime of PI Ceramic Piezoelectric Actuators

The lifetime of a piezoelectric actuator is not limited by wear and tear. All PI Ceramic piezo actuators are specifically designed for high-duty-cycle applications. All materials used are matched for robustness and lifetime. Endurance tests on PI Ceramic actuators prove consistent performance, even after billions (1,000,000,000) of cycles. There is no generic equation to determine the lifetime because of the many parameters such as temperature, humidity, voltage, acceleration, load, operating frequency, insulation materials, etc. which have an influence.



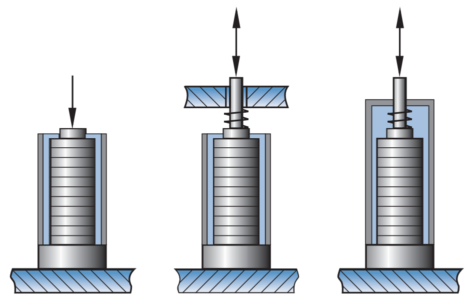
PICMA® piezo actuators (bottom curve) compared with conventional multilayer actuators with polymer insulation (top curve). PICMA® Actuators are not affected by the high-humidity test conditions. Conventional piezo actuators exhibit increased leakage current after only a few hours. Leakage current is an indication of insulation quality and expected lifetime. Test conditions: $U = 100\ V_{DC}$; $T = 25$ °C; Relative Humidity = 70 %

PICMA®-type actuators have advantages over other piezo actuators, especially in humid environments. Their monolithic, ceramic-insulated design blocks the diffusion of water molecules into the insulation layer, the major cause of dielectric breakdown.

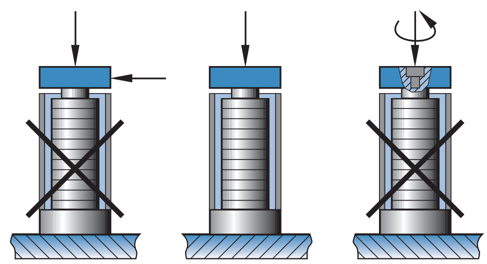
PI Ceramic invests considerable energy in investigating and continually improving actuator lifetime. The design of the piezoelectric actuators in this catalog reflect several decades of experience in with thousands of industrial piezo actuator applications. Another result of this experience are the "Handling Precautions" in the following section.

Please contact your PI sales & application engineer for further information on lifetime and handling issues.

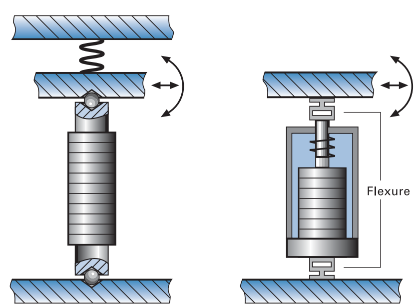
Lifetime of PI Ceramic Piezoelectric Actuators (cont.)



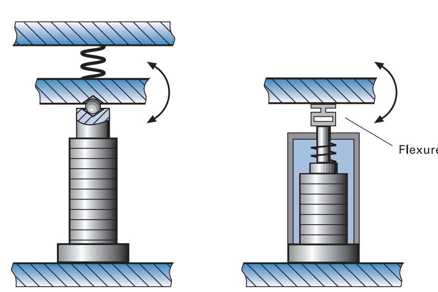
No pulling force without preload



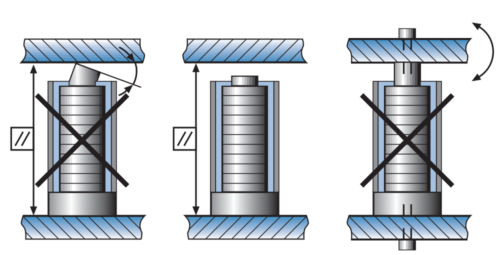
No lateral force or torque



Ball tips or flexures to decouple lateral forces or bending forces



Ball tips or flexures to decouple bending forces



Bolting between plates is not recommended

Handling Precautions

Piezoelectric actuators must be handled with care because the internal ceramic materials as well as ceramic end-plates are fragile. Do not use metal tools for actuator handling. Do not scratch the coating on the side surfaces.

Besides these general instructions the following precautions have to be considered during handling of PI Ceramic piezoelectric actuators:

1. Piezoelectric stack actuators without axial preload are sensitive to pulling forces.

   A preload of half of the blocking force is generally recommended (see PI main catalog data tables p. 13 to p. 27). This recommendation is also valid for PICA™-Shear actuators in axial direction, perpendicular to the shear diplacement directions.

2. Piezoelectric stack actuators may be stressed in the axial direction only. The applied force must be centered very well. Tilting and shearing forces, which can also be induced by parallelism errors of the endplates, have to be avoided because they will damage the actuator. This can be ensured by the use of ball tips, flexible tips, adequate guiding mechanisms etc. An exception to this requirement is made for the PICA™-Shear actuators, because they operate in the shear direction. Do not exceed the maximum shear force specifications for these actuators.

3. Piezoelectric stack actuators have to be mounted by gluing them between even metal or ceramic surfaces by a cold or hot curing epoxy, respectively. Ground surfaces are preferred. Please,

do not exceed the specified working temperature range of the actuator during curing.

4. The environment of all actuators should be as dry as possible. While PICMA® actuators are guarded against humidity by their ceramic coating, other actuators must be protected by other measures (hermetic sealing, dry air flow, etc).

   The combination of long-term high electric DC fields and high relative humidity values should be avoided with all piezoelectric actuators. The electric field attracts the water molecules or hydroxy ions from the environment to the surface of the stack and leads to a permanent increase in its leakage current. This can finally result in damage to the actuator. There is no polymer coating which can avoid the forced penetration of these molecules.

5. It is important to short-circuit the piezoelectric stack actuators during any handling operation. The resulting loads will induce charges on the stack electrodes which might result in high electric fields if the leads are not shorted:

   a) changing temperatures, for example during curing or soldering processes, induces charges due to the pyroelectric effect

   b) changing mechanical loads, for example during preload application, induces charges due to the direct piezoelectric effect

   Should the stack become charged, rapid discharging—especially without a preload—might damage the stack. Therefore, it is appropriate to use a resistor for discharging after any mistreatment. PI Ceramic delivers PICA™-Stack piezoelectric actuators with a shorting clamp. We recommend the use of gloves and safety glasses during handling.

6. The lateral (side) surfaces of PICMA® and PICA™-Stack actuators are not, or not fully, electrically insulated to allow a more compact design and integration of the stack in the final assembly by the customer. Therefore, the customer is responsible for designing in the required separation or suitable insulating materials, like polyimide foil or PTFE tape, to insulate the stack from its surrounding.

7. Prevent any contamination of the stack surfaces with conductive or corrosive substances. Cleaning of the stacks should be done with isopropanol only. Do not use acetone. Avoid excessive ultrasonic cleaning at higher temperatures.

Other PI Product Lines

Piezo Nanopositioning Stages

PI designs and manufactures the fastest and highest precision piezo nanopositioning and scanning systems in the world. PI Piezo Flexure Nano-Positioners are are available in 1 to 6 DOF versions.

Packaged / Preloaded Piezo Actuators

Packaged piezo actuators come in a variety of configurations, from the ultra-flat disk actuators to water-protected high-load designs for machining applications.

Micropositioning Stages & Actuators

PI offers a large range of high-precision MicroPositioning devices and systems for OEM and research. Our expertise spans from manual actuators to the unique PI IntelliStage™ translation stage with integrated controller, and the Hexapod 6D positioning systems.

High-Speed Piezoelectric Motors

PILine® Linear Piezo Motors are based on a novel solid-state ultrasonic piezoceramic drive. They are lightweight, low-profile and provide a number of features and advantages not available with conventional motors.

For more information on piezoceramic materials and components see the PI Ceramic material catalog and website (www.piceramic.de).

For more information on these and other PI product lines see the Physik Instrumente (PI) NanoPositioning catalog and website (www.pi.ws).

CAT Actuators · MNP/E · 10/06.2,5

Subject to change without notice.

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"Long-term business relationships, reliability, open and friendly communication with customers and suppliers are of the essence for PI and all members of the worldwide PI group and far more important than short-term gain."

Dr. Karl Spanner, President