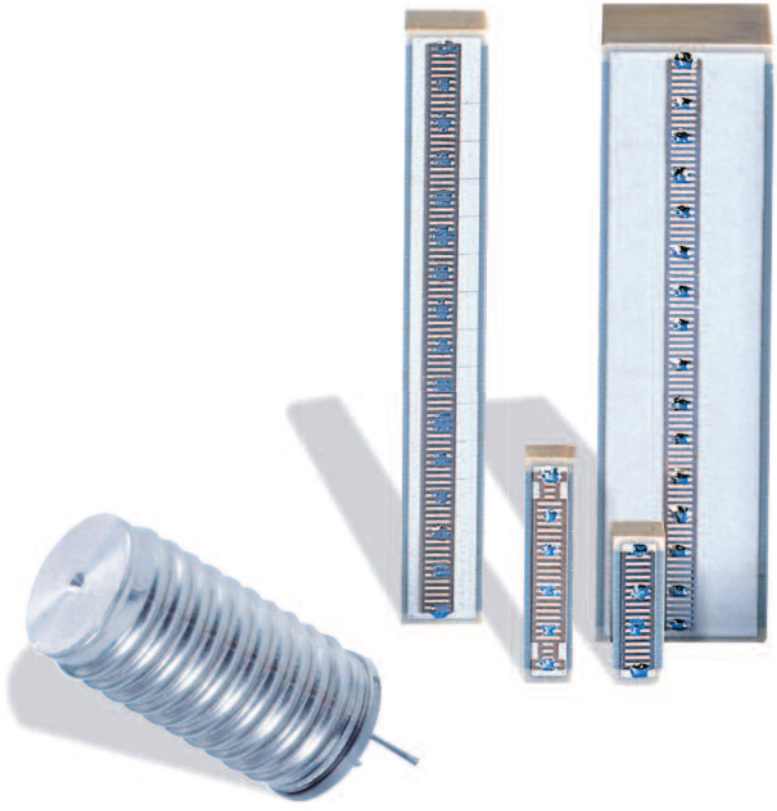
PICMA® Multilayer Piezo Actuators

Reliability, Durability, Efficiency



Piezoelectric Actuators from PI Ceramic

Leaders in Piezoelectric Technology

PI Ceramic is one of the world's market leaders for piezoelectric actuators and sensors. They currently employ over 150 staff, including no less than 30 engineers, in piezo research, development and ceramics manufacturing. A broad range of expertise in the complex development and manufacturing process of functional ceramic components combined with state of the art equipment ensures the high quality, flexibility and adherence to supply deadlines.


PI Ceramic in Lederhose, Thuringia/Germany

Core Competences of PI Ceramic

- Standard piezo components for actuator, ultrasonic and high-power ultrasonic applications, system solutions
- Manufacturing of components of up to several 100,000 units per year
- Development of custom-engineered solutions
- High degree of flexibility in the engineering process, short lead times
- All key technologies and state-of-the-art equipment for ceramic production available in-house
- ISO 9001-2000, ISO 14001 and OHSAS 18001 certified

PI Ceramic supplies piezo-ceramic solutions to all important high-tech markets:

- Industrial automation
- Semiconductor industry
- Medical engineering
- Mechanical and precision engineering
- Aviation and aerospace
- Automotive industry

Award-Winning PICMA® Technology: A Revolution in Durability

PICMA® piezoelectric actuators from PI Ceramic are the only monolithic, multilayer, piezoelectric actuators in the world which have a ceramic insulation layer. The patented PICMA® technology makes it possible to manufacture components with a particularly long lifetime. Decades of experience with PICMA® series in various applications show that the lifetime has been increased by at least a factor of 10 compared to previously used, conventional, polymer-coated, multilayer piezoelectric actuators.

Flexibility with a Complete Ceramic Seal

PI Ceramic can manufacture almost any shape of PICMA® multilayer piezoelectric actuator using the latest production technology. All surfaces are hereby covered with a ceramic insulation layer. Not only are variable basic shapes possible, such as round or triangular cross-sections, but also insulated internal bores on benders, chips or stack actuators, therefore making their integration in an application easier.

Hermetic Encapsulation for Even Greater Safety

PICMA® actuators are also available in an encapsulated version. Hermetically sealed in a compact stainless steel case, these actuators resist extreme environmental conditions such as splash water or very high humidity.

Some PICMA® Applications

- Precision mechanics / precision machining
- High-speed switches
- Active and adaptive optics
- Active vibration damping
- Adaptronics, smart materials
- Pneumatic and hydraulic valves
- Metrology / interferometry
- Life science, biotechnology
- Nanotechnology


Patented technology for maximum operational safety and durability: PICMA®

PICMA®: Reliability and Continuous Further Development

Ceramic-Insulated, Piezoelectric Actuators Offer Superior Lifetime

PICMA® multilayer piezo actuators are based on a special PZT (lead zirconate – lead titanate) ceramic, which ideally combines the desired characteristics of the components such as high stiffness, low electrical capacity, high specific displacement, low load and temperature dependence of the specifications and long lifetime.

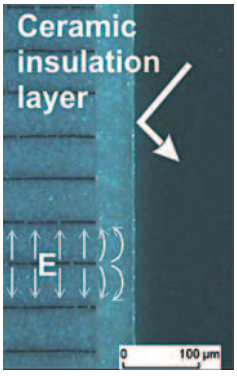


Fig. 1: The ceramic insulating layer prevents the penetration of water molecules and reliably protects the sensitive internal electrodes from mechanical damage and dirt

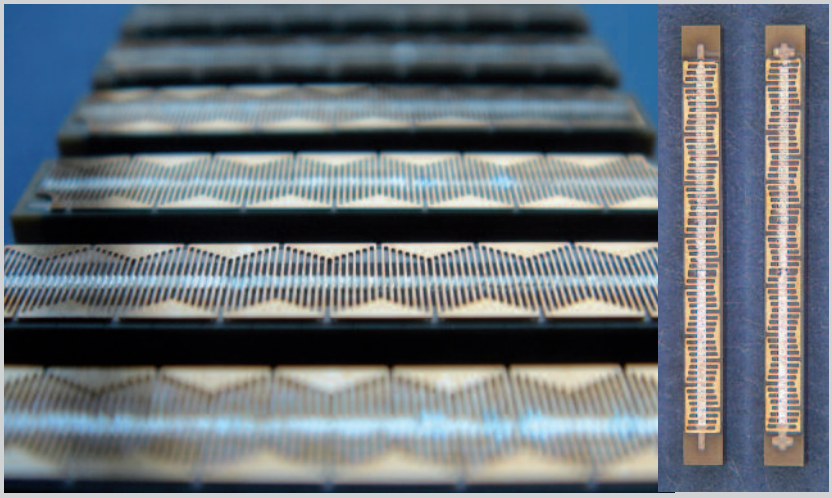


Fig. 2: Patented, meander-shaped external electrodes

Contacts for Large Electric Currents

Research on the termination electrodes led to a further improved design. The patented, meandering form of the external electrodes supplies the electric current evenly to the internal electrodes (Fig. 2). The contact here is chosen so that it remains electrically stable and mechanically flexible even at high currents up to 20 A and more, thus providing particularly dynamic control. This improves the lifetime of the actuator in applications with rapidly changing fields.

Influences on the Lifetime of a Piezo-Ceramic Actuator

Three essential factors affect the lifetime of piezo ceramics in positioning applications: Humidity, operating voltage and temperature.

Penetrating moisture and the electric field applied can cause electrochemical transport processes in the component, which are accelerated by higher temperatures. The result is a short circuit between the electrodes, which can cause irreparable damage to the actuator.

The actual application determines the extent to which the individual factors have an impact.

The internal electrodes and the ceramic are jointly sintered (co-fired technology) to create a monolithic piezo-ceramic block (Fig. 1). This block is protected against humidity and damage from increased leak current by a ceramic insulation layer. Therefore, PICMA® actuators are far superior in terms of reliability and lifetime to conventional, polymer-coated, multilayer, piezoelectric actuators. The construction with the ceramic insulation layer results also in a high resonance frequency, making the actuators ideally suited for high-dynamics operation.

Large Temperature Range – Optimum UHV Compatibility – Minimal Outgassing – Neutral in Magnetic Fields

The particularly high Curie temperature of 320 °C allows for a usable temperature range of up to 150 °C, far beyond the 80 °C limit of conventional multilayer actuators. This and the exclusive use of inorganic materials provide the optimum conditions for use in ultra-high vacuums: No outgassing and high bake-out temperatures. PICMA® piezoelectric actuators work at a reduced travel even in the cryogenic temperature range.

Thanks to their construction that is based solely on non-ferromagnetic materials, the actuators have an extremely low residual magnetism in the order of a few nanotesla.

Low Operating Voltage

In contrast to most commercially available multilayer piezo actuators, PICMA® actuators achieve their nominal displacement at operating voltages significantly below 150 V. This is achieved by using a particularly fine-grained ceramic material which allows a lower depth of the internal layers.

The products described in this document are at least partially protected by the following patents:
German patent no. 10021919
German patent no. 10234787
German patent no. 10348836
German patent no. 102005015405
German patent no. 102007011652
US patent no. 7,449,077

Safety with PICMA®

Long-Term Tests Prove the Superior Reliability

In positioning applications, the piezoelectric actuator is typically operated at constant voltage to maintain one position over an extended period of time. Here, the lifetime of piezoelectric actuators is affected especially by the voltage and the humidity.

Protective Ceramic Layer

The most important feature which protects PICMA® actuators against ingressing moisture is the monolithic construction with the ceramic insulation layer. The penetration of water molecules is effectively suppressed, which is impressively documented by measurements of the leak current (Fig. 3). Increased values are a sign of deteriorating insulation resistance and thus of a decrease in lifetime, as can be seen with polymer-coated actuators.

Realistic Study

Voltage	Failure Rate of PICMA® Actuators with Ceramic Insulation	Failure Rate of Conventional, Polymer-Coated Actuators
100 V DC	0 % (calculated MTTF: 1.3 · 10E6 h)	75 %
120 V DC	0 % (calculated MTTF: 178,000 h)	100 %
135 V DC	0 % (calculated MTTF: 49,000 h)	100 %
150 V DC	25 % (calculated MTTF: 15,500 h)	100 %

Tests under realistic conditions clearly confirm the high reliability of the ceramic-insulated PICMA® piezo actuators. Multilayer actuators were operated under conventional environmental conditions with different DC voltages. In this case, as well, PICMA® actuators with ceramic insulation convince by quite a margin: First failures occur only at 150 V, i.e. far above their specified nominal voltage, while after an 18-month test period only a small number of conventional polymer-insulated piezoelectric actuators are still functional. Test conditions: 22 °C, 55 % RH, testing period 18 months (13,400 h)

Tests Under Realistic and Extreme Conditions

The high reliability makes it virtually impossible to experimentally measure the lifetime of PICMA® actuators under realistic operating conditions. To estimate the lifetime, tests under extreme conditions are used.
These tests are then confirmed in a long-term series of tests that are carried out under realistic conditions (see "Realistic study").

Accelerated Life Test

An increased relative humidity combined with high ambient temperatures and control voltages sometimes above the nominal voltage range leads here to an accelerated degradation of the piezo ceramics. The boundary conditions are subsequently corrected using a mathematical model and this results in a specification for the average lifetime (Mean Time To Failure, MTTF) in a realistic application. Conventional, polymer-coated piezoelectric actuators typically survive continuous use at increased humidity for about 30 days (Fig. 4), whereas PICMA® multilayer piezoelectric actuators are still working reliably after more than four years!
The results were obtained from a representative random sample of PICMA® 5 x 5 x 18 (P-885.50) and are typical for the complete PICMA® product range.

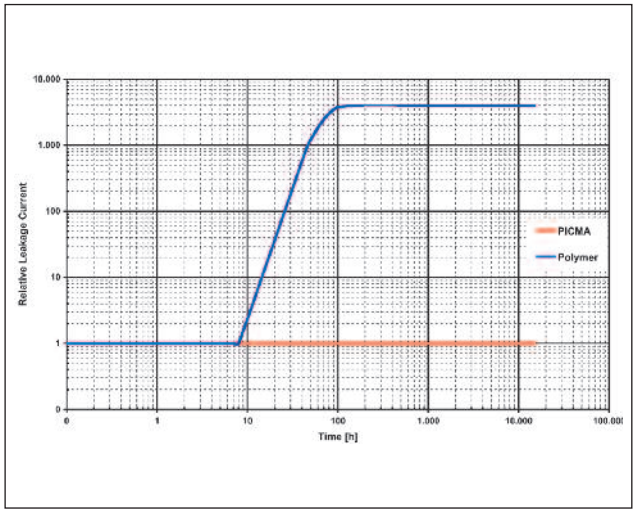


Fig. 3. PICMA® piezoelectric actuators (bottom curve, red) compared to polymer-coated multilayer piezoelectric actuators. The high insulation resistance of the PICMA® actuators remains stable over several time decades, whereas conventional, polymer-coated actuators exhibit a significantly increased leak current after a few hours. (Test conditions: 100 V DC, 25 °C, 70 % relative humidity [RH])

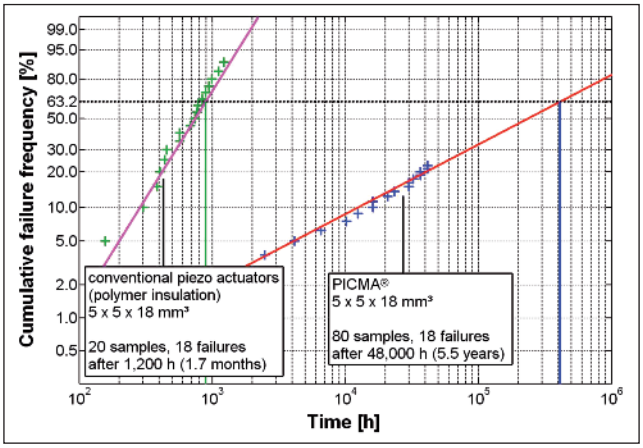


Fig. 4. Comparison of PICMA® and conventional piezo actuators insulated with a polymer coating.
Results of an accelerated life test with increased humidity for accelerated aging (Test conditions: 100 V DC, 22 °C, 90 % RH). Statistical methods can be used to derive values under normal climatic operating conditions from this. The extrapolated average lifetime (MTTF) for PICMA® actuators is more than 400,000 h (approx. 45 years). All polymer-coated comparison samples fail, at the most, after only 1,600 hours (MTTF = 890 hours, about 1 month)

Calculation of the Lifetime

Simple and Reliable

The results of the tests done with PICMA® actuators in continuous use at a constant voltage also help in determining the lifetime to be expected under predefined application conditions.
The individual factors which can have an impact here must be taken into consideration: Temperature, relative humidity and applied voltage. An extensive series of tests, which is still in progress, have provided thorough knowledge of the dependencies. They are shown in the adjacent diagrams (Fig. 5).

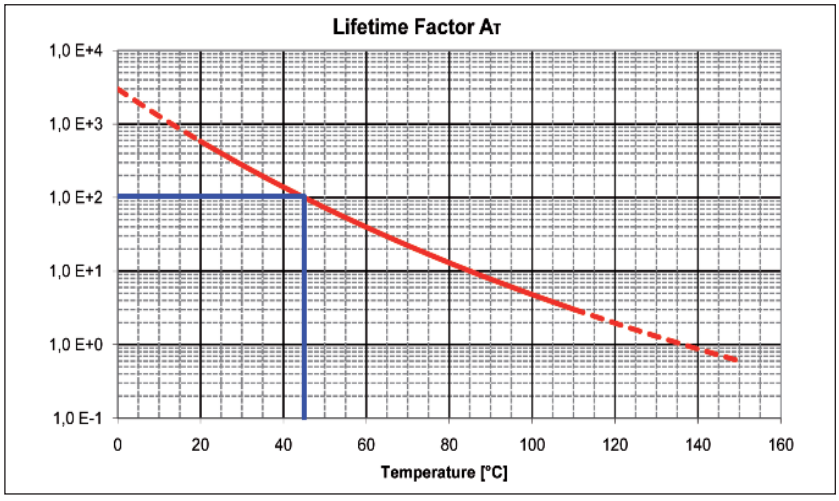
Calculating the Lifetime in the Application

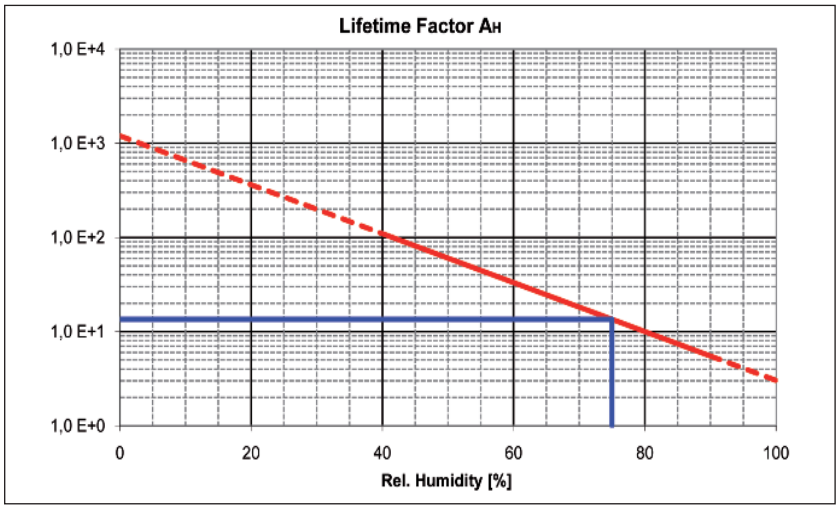
In the selected simplified presentation, the average lifetime of a PICMA® multilayer actuator can be directly derived for the intended operating conditions. The effect of each individual factor on the lifetime can be read off the diagrams. The lifetime calculated in hours simply results as the product of all three values read off the diagrams.

This calculation can also be used to optimize a new application in terms of its lifetime as early as in the design phase. A decrease in the control voltage or the control of temperature and humidity with flushing air or additional encapsulation can be very important here.
The impact that the applied voltage has, is particularly important. The lifetime to be expected at 80 V DC, for example, is 10 times higher than that to be expected at 100 V DC.

Example

The simple formula MTTF = A_U * A_T * A_F provides a quick estimate of the reliability in hours.
In concrete terms: The values for 75 % RH (A_F=14), 100 V DC (A_U=75) and 45 °C (A_T=100) result in an approximate MTTF of 105,000 h, i.e. more than 11 years (see markings on the diagrams).





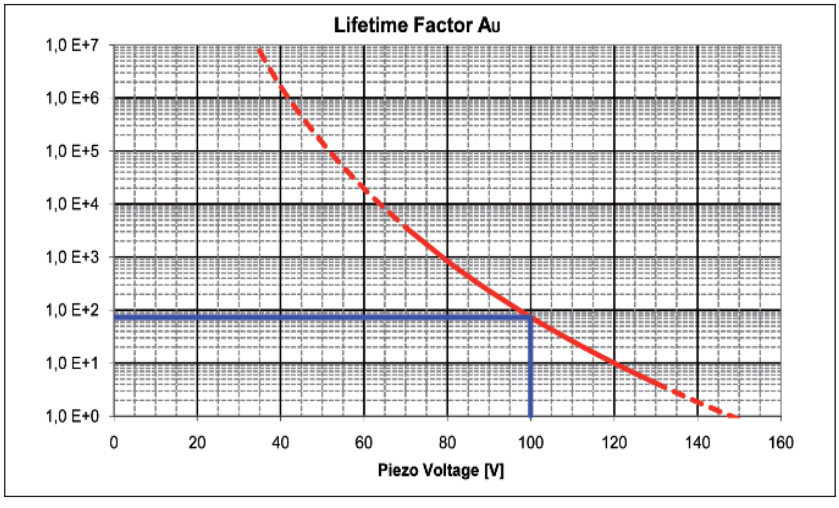


Fig. 5: The diagrams show the interdependency between the mean MTTF of a PICMA® actuator and the value of the voltage applied, the ambient temperature and the relative humidity. Important: With decreasing voltage the lifetime increases exponentially. This must always be taken into consideration in an application.

PICMA® Piezo Actuators under Permanent Cyclic Load

Dynamic Application: AC Voltage / AC Operation

Dynamic Continuous Operation

Cyclic demands with a rapidly alternating electrical field and high control voltages (typically > 50 Hz; > 50 V) are common conditions for multilayer piezoelectric actuators, for example when used in valves, pumps or ultrasonic transducers.
The lifetime of the piezo element is in this case dominated by different factors to those affecting DC operation:
The impact of the dynamic forces and the changing state of the mechanical stress increases. Therefore, this can lead to the formation of cracks in the stack construction and hence to electrical discharges. The impact of the humidity, on the other hand, is negligible because it is reduced locally by the warming-up of the piezoceramic.

The most important factors affecting the lifetime are therefore the voltage and the type of the signal. In AC operation, the lifetime itself is not expressed as a time period but more sensibly as a number of cycles.

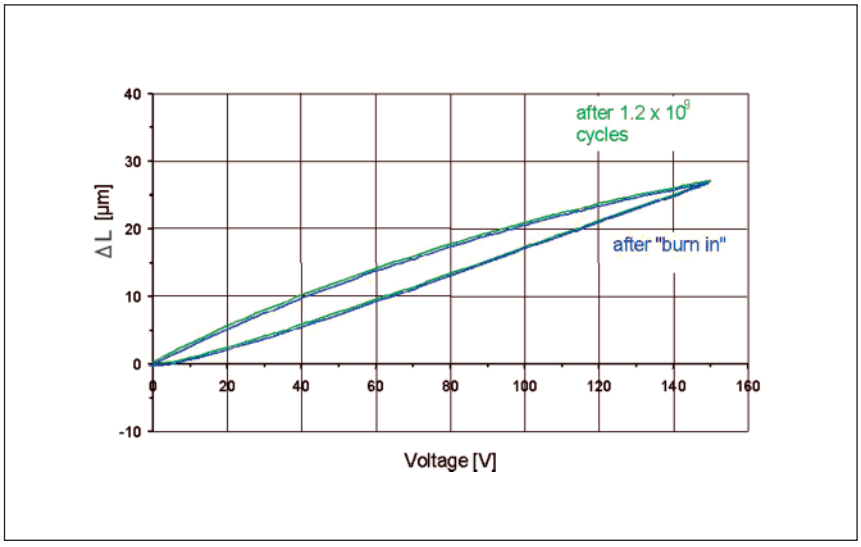


Fig. 6: Dynamic test series with eight PICMA® actuators 5 x 5 x 18 mm: Total number of cycles 4.0 x 10^9 cycles; 116 Hz sinusoidal control (1.0 x 10^7 cycles per day), 100 V unipolar operating voltage, 15 MPa preloading. Control measurements after each series of 10^9 cycles. Only insignificant decrease in the displacement.

Extraordinarily Robust: 10^{10} Working Cycles

Due to the stability of the material behavior and their mechanical construction, PICMA® actuators exhibit no signs of wear even after many billions of load cycles (Fig. 6).
The target of 10^{10} working cycles is especially important for industrial use. The proof for the reliability of the PICMA® technology is obtained by means of a test with particularly high control frequency.
Preloaded PICMA® actuators with dimensions of 5 x 5 x 36 mm were loaded at room temperature and average humidity with a sinusoidal signal of 120 V unipolar voltage at 1,157 Hz. This amounts to 10^8 cycles per day! Even at this high voltage and frequency there was not a single failure and the actuators showed no significant changes in displacement.

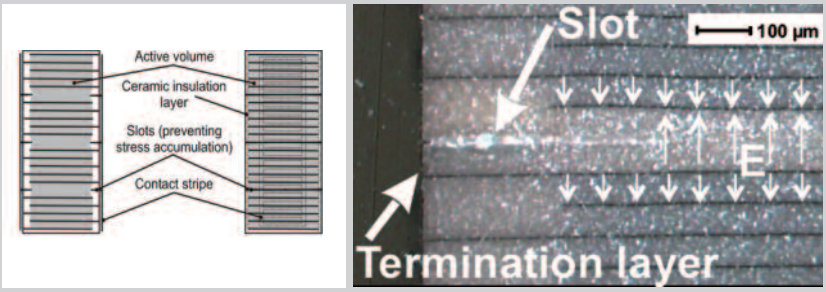


Fig. 7: Patented PICMA® design with lateral slots to avoid uncontrolled expansion cracks during dynamic control

Also Stable in the AC Field

PI reduces the probability of crack formation by using a particular patented design with lateral slots. These reliably prevent the mechanical tensile stresses in the stack from becoming too high and the formation of uncontrolled additional cracks (Fig. 7). Furthermore, the patented meander-shaped construction of the termination electrodes (see Fig. 2) ensures all internal electrodes have a stable electrical contact even at extreme dynamic loads.

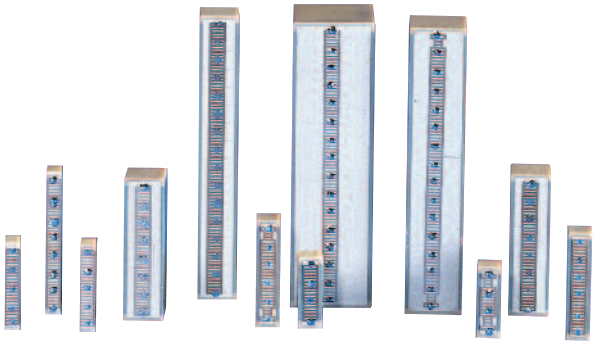
Longer Operating Periods and Higher Control Frequencies

The dynamic operation of PICMA® piezo elements benefits significantly from the large range of operating temperatures of up to 150 °C.
The intrinsic warming of the elements when dynamically controlled is proportional to the operating frequency. A higher operating temperature thus also allows higher control frequencies and longer periods of operation. Additionally, the displacement of the PICMA® piezoceramics exhibits only a low dependence on temperature.

P-882 · P-888 PICMA® Multilayer Piezo Stack Actuators

Ceramic-Insulated High-Power Actuators

- **Superior Lifetime Even Under Extreme Conditions**
- **Very Large Operating Temperature Range**
- **High Humidity Resistance**
- **Excellent Temperature Stability**
- **High Stiffness**
- **Peak Current up to 20 A**
- **UHV Compatible to 10^{-9} hPa**
- **Sub-Millisecond Response / Sub-Nanometer Resolution**
- **Ideal for Dynamic Operation**



Ideal for Closed-Loop Operation

PICMA® actuators achieve positioning resolutions in the sub-nanometer range and response times in the microsecond range. The ceramic surface of the actuators is excellently suitable for mounting sensors, such as strain gauges. In contrast to polymer-coated actuators, the sensor can be applied directly to the ceramic of the PICMA® actuator, allowing for higher stability, linearity and measuring accuracy.

Improved reliability even for permanently high humidity or splash water by hermetic encapsulation with inert gas filling. Available on request.

Technical Data / Product Order Numbers

Order numbers*	Dimensions A x B x L [mm]	Nominal displacement [µm] (0 – 100 V)	Max. displacement [µm] (0 – 120 V)	Blocking force [N] (0 – 120 V)	Stiffness [N/µm]	Electrical capacitance [µF] ±20 %	Resonant frequency [kHz] ±20 %
P-882.11	2 x 3 x 9	6.5 ±20 %	8 ±20 %	190	24	0.15	135
P-882.31	2 x 3 x 13.5	11 ±20 %	13 ±20 %	210	16	0.22	90
P-882.51	2 x 3 x 18	15 ±10 %	18 ±10 %	210	12	0.31	70
P-883.11	3 x 3 x 9	6.5 ±20 %	8 ±20 %	290	36	0.21	135
P-883.31	3 x 3 x 13.5	11 ±20 %	13 ±20 %	310	24	0.35	90
P-883.51	3 x 3 x 18	15 ±10 %	18 ±10 %	310	18	0.48	70
P-885.11	5 x 5 x 9	6.5 ±20 %	8 ±20 %	800	100	0.6	135
P-885.31	5 x 5 x 13.5	11 ±20 %	13 ±20 %	870	67	1.1	90
P-885.51	5 x 5 x 18	15 ±10 %	18 ±10 %	900	50	1.5	70
P-885.91	5 x 5 x 36	32 ±10 %	38 ±10 %	950	25	3.1	40
P-887.31	7 x 7 x 13.5	11 ±20 %	13 ±20 %	1700	130	2.2	90
P-887.51	7 x 7 x 18	15 ±10 %	18 ±10 %	1750	100	3.1	70
P-887.91	7 x 7 x 36	32 ±10 %	38 ±10 %	1850	50	6.4	40
P-888.31	10 x 10 x 13.5	11 ±20 %	13 ±20 %	3500	267	4.3	90
P-888.51	10 x 10 x 18	15 ±10 %	18 ±10 %	3600	200	6.0	70
P-888.91	10 x 10 x 36	32 ±10 %	38 ±10 %	3800	100	13.0	40

Standard piezo ceramic type: 252
Standard connection types: 100 mm pigtail
* For optional solderable contacts, change order number extension to .x0 (e.g. P-882.10)
Recommended preload for dynamic operation: 15 MPa
Maximum preload for constant force: 30 MPa
Resonant frequency at 1 V_{pp}, unloaded, free at both sides. The value is halved for unilateral clamping
Capacitance at 1 V_{pp}, 1 kHz
Operating voltage: -30 to +130 V; the lifetime depends on the voltage applied.
Operating temperature range: -40 to +150 °C
Standard mechanical interfaces: Ceramics
Available options: strain gauge sensors, special mechanical interfaces, etc.
Other specifications on request.

For more information on piezo-ceramic materials and elements, see the PI Ceramic catalog or visit their website (www.piceramic.de)

The current edition of the main PI catalog "Piezo – Nano – Positioning: Inspirations 2009" demonstrates the broad PI product range and new technical solutions in the areas of:

Nanopositioning systems/scanning systems
Fast scanning stages for microscopy
Piezo actuators
Piezo motors
Piezo controllers
Motorized micro-translation stages and linear actuators
Motor controllers
Six-axis adjustment systems, hexapods

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