PZ 138E User Manual

PICA™-Stack / PICA™-Power / PICA™-Thru

Piezoceramic Actuators

Release 1.0.0.

Product Description and Operating Notes

This document describes the following products:

P-007.xx to P-056.xx	PICA™-Stack, max. displacement 300 µm
P-007.xxP to P-056.xxP	PICA™-Power, max. displacement 180 µm
P-010.xxH to P-025.xxH	PICA™-Thru, max. displacement 80 µm, with clear aperture

Release: *1.0.0.*
Release Date: *2004-02-19*

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0 Manufacturer Declarations

0.1 Quality and Warranty Clauses

Certification

Physik Instrumente (PI) and PI Ceramic (PIC) certify that the product met its published specifications at the time of shipment. The device was measured and tested.

Warranty

This Physik Instrumente / PI Ceramic product is warranted against defects in materials and workmanship for a period of one year from date of shipment. Duration and conditions of warranty for this product may be superseded when the product is integrated into (becomes a part of) other Physik Instrumente / PI Ceramic products. During the warranty period, Physik Instrumente / PI Ceramic will, at its option, either repair or replace products which prove to be defective.

Limitation of Warranty

The foregoing warranty shall not apply to defects resulting from improper or inadequate maintenance by the Buyer, Buyer supplied products or interfacing, unauthorised modification or misuse, operation outside of the environmental specifications for the product, or improper site preparation or maintenance.

The design and connection of any circuitry to this product is the sole responsibility of the Buyer. PI/PIC does not warrant the Buyer's circuitry or malfunctions of PI/PIC products that result from the Buyer's circuitry. In addition, PI/PIC does not warrant any damage that occurs as a result of the Buyer's circuit or any defects that result from Buyer-supplied products.

No other warranty is expressed or implied. Physik Instrumente / PI Ceramic specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

0.2 Safety Precautions

Danger! High Voltage

PICA™ piezoelectric actuators require high voltages of up to 1000 volts. Follow General Accident Prevention Rules!

Working with these devices requires adequate educated and trained operating personnel.

To avoid electric shock, never touch a non-encapsulated stack actuator before it was discharged, and keep leads shorted.

Use of gloves and safety glasses is recommended during handling.

Warning: Avoid Damage

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.

Rapid discharging could damage the stack.

Pulling forces could damage the ceramic. A preload is strictly recommended.

Dynamic operation: Switch off power to the actuator immediately if you hear or see resonant behavior.

1 Introduction

PICA™ series stacked piezoceramic actuators are compact, high-reliable and cost effective micropositioning components. They are especially designed for high-duty-cycle applications.

A piezoelectric actuator produces extremely fine positioning changes by conversion of smallest changes in operating voltage. Force generation upto 100000 N, response times in the microsecond range and acceleration rates of more than 10000 g's can be obtained.

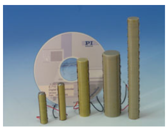
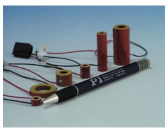
Fields of application are NanoPositioning, High-Load Positioning, Active Vibration Cancellation, Precision Engineering, Chip Manufacturing, Optics, etc.

1.1 General Features

- Unlimited Resolution
- Large Force Generation
- Rapid Response
- No Wear and Tear
- Low Power Consumption
- No Magnetic Fields
- Vacuum and Clean-Room Compatible
- Operating at Cryogenic Temperatures
- Variety of Shapes / Large Cross Sections available
- Extreme Reliability
- Operating Voltage Range 0 to 1000 V
- Closed-loop Versions available

1.2 Model Survey

This manual comprises the following actuators:

Model	Displace-ment	Notes
PICA™-Stack P-007.xx – P-056.xx 	5 to 300 µm	PICA™-Stack actuators are specially designed for high-duty-cycle applications. They are made of the PIC 151 material (properties see p. 15; for further information see the Tutorial section of the PI Ceramic catalog). PICA™-Stack actuators are delivered with metal endcaps for improved robustness and reliability.
PICA™-Power P-007.xxP – P-056.xxP 	5 to 180 µm	PICA™-Power actuators are optimized for high-temperature working conditions and high-duty-cycle dynamic applications. They are made of the PIC 255 material (properties see p. 15; for further information see the Tutorial section of the PI Ceramic catalog). As PICA™-Stack's they are delivered with metal endcaps.
PICA™-Thru P-010.xxH – P-025.xxH 	5 to 80 µm	PICA™-Thru actuators are hollow piezo stack actuators. These tubular devices are high-resolution linear actuators for static and dynamic applications. They are made of the PIC 151 material (properties see p. 15; for further information see the Tutorial section of the PI Ceramic catalog). PICA™-Thru actuators made of PIC 255 are available on request.

1.3 Working Principle

PICA™ actuators consist of piezoceramic disks (0.2 to 1.0 mm thick), separated by thin metallic electrodes. Each individual layer is stacked and glued together with alternating poling directions respectively.

The displacement of a piezo stack can be estimated by

$\Delta L \approx d_{33}\, U\, n$

where d_{33} *= deformation coefficient (electrical field dependency; see PI Ceramic catalog)*

U = operating voltage

n = number of ceramic layers

The maximum electrical field which can be recommended for (reliable) operation is on the order of 1 to 2 kV/mm (or 1000 V max. operating voltage).

The PICA™ actuators can be used for static and dynamic operation. Stack elements can withstand high pressure and exhibit the highest stiffness of all piezo actuator designs.

Warning

Pulling forces could damage the ceramic. A preload is strictly recommended.

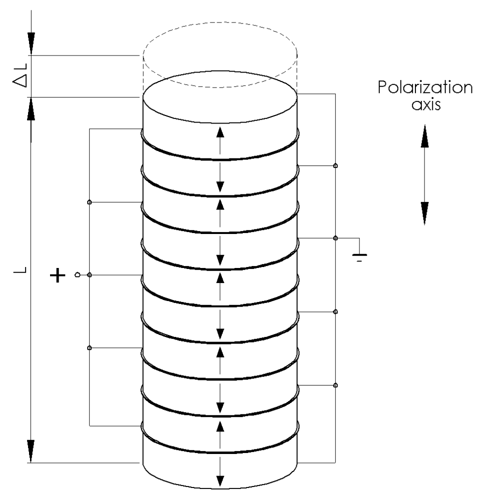


Fig. 1: Design of a PICA Stack Actuator

For further information (e.g. mechanical considerations, dynamic behavior and lifetime) see the “Tutorial” Section of the PIC catalog (see www.piceramic.com).

2 General Handling Precautions

Danger! High Voltage

PICA™ piezoelectric actuators require high voltages of up to 1000 volts. Follow General Accident Prevention Rules!

Working with these devices requires adequate educated and trained operating personnel.

Warning: Avoid Damage

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.

Beside these general instructions the following precautions have to be considered during handling of PI Ceramic PICA™ actuators.

2.1 Discharging stack actuators

Danger! High Voltage

To avoid electric shock, never touch a non-encapsulated stack actuator before it was discharged, and keep leads shorted.

Use of gloves and safety glasses is recommended during handling.

Warning: Avoid Damage

Rapid discharging could damage the stack.

Note that rapid discharging—especially without a preload—might damage the stack. Use a 10 kOhm current limiting resistor for discharging after any mistreatment. PI Ceramic delivers PICA™ actuators with a shorting clamp.

Generally it is important to short-circuit piezoelectric stack actuators during any handling operations since they could induce charges on the stack electrodes. These charges might result in high electric fields if the leads are not shorted.

In particular charges can be induced by

a) changing temperatures, for example during curing or soldering processes (pyroelectric effect).

b) changing mechanical loads, for example during preload application (direct piezoelectric effect).

2.2 Maximum Load, Preload

Warning: Avoid Damage

Pulling forces could damage the ceramic. A preload is strictly recommended.

Piezoelectric stack actuators without axial preload are sensitive to pulling forces. A preload of half of the blocking force is generally recommended (see specification tables p. 11 to p. 13).

Do not exceed the maximum load, which is in the range of 30 MPa (conservative value). Stacked actuators are made as a combination of several materials (ceramic, metal electrode sheets, epoxies, etc.) and therefore different from mechanical strength values of the piezoceramics. Parameters like aspect ratio, buckling, interaction at the mechanical interfaces, etc. must be considered too.

If the specified maximum load is significantly exceeded mechanical and electrical damage may occur. The probability of defects increases with rising preload too, because additional pulling forces could be generated in parts of the stack.

2.3 Applied Forces

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 (see “Mechanical Mounting”, p. 7).

2.4 Environmental Conditions

The environment of all actuators should be as dry as possible. The actuators must be protected against humidity by measures like 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 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.

2.5 Stack Insulation

The lateral (side) surfaces of PICA™ 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.

2.6 Cleaning

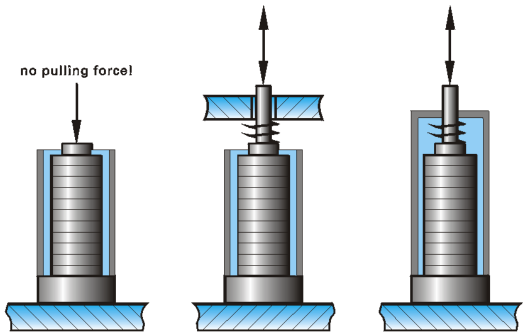
Prevent any contamination of the stack surfaces with conductive or corrosive substances. Cleaning of the stacks should be done with isopropanol only. Do not use acetone. Avoid excessive ultrasonic cleaning at higher temperatures.

3 Mounting

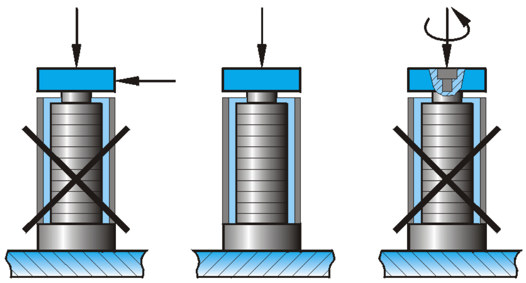
When mounting PICA™ actuators always respect the general handling precautions listed in section 2.

3.1 Mechanical Mounting

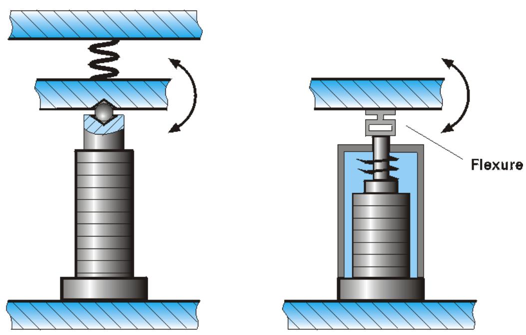
No pulling force without preload (see p. 5)



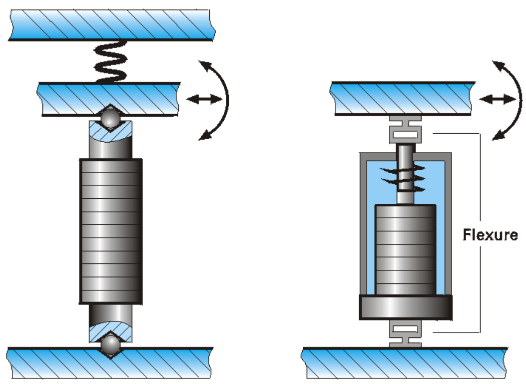
No lateral force or torque



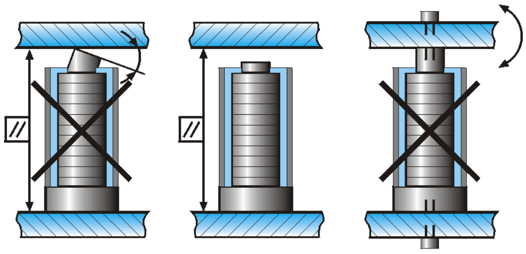
Ball tips or flexures to decouple bending forces



Ball tips or flexures to decouple lateral forces or bending forces



Bolting between plates is not recommended



The installation of the actuator should be done in a way that the center axis of displacement and load are aligned. The axis of displacement should be exactly perpendicular to the mounting surface.

Piezoelectric stack actuators have to be mounted by gluing them between even metal or ceramic surfaces by a cold or hot curing epoxy, respectively. Smooth surfaces are preferred. The bonding surfaces should be degreased and not touched by unprotected fingers. Keep the bonding layer as thin as possible. Do not exceed the specified working temperature range of the actuator during curing and keep the electrical leads shorted.

Never disassemble the PICA™ actuator, since this could cause an electric shock and will lead to an irreparable damage.

3.2 Electrical Connections

Connect the red wire to the positive (+) terminal of the power supply.

The red wire has to be driven with a positive voltage with respect to the other lead. A cross-check with the electronics manual is strongly recommended.

Any mounting of additional connectors has to be done according to the manual of the specific amplifier / controller.

4 Operating

When operating PICA™ actuators always respect the general handling precautions listed in section 2.

Warning: Avoid Injury

All PICA™ series actuators require high voltages of up to 1000 volts. Follow General Accident Prevention Rules!

Working with these devices requires adequate educated and trained operating personnel.

4.1 Recommended Electronics

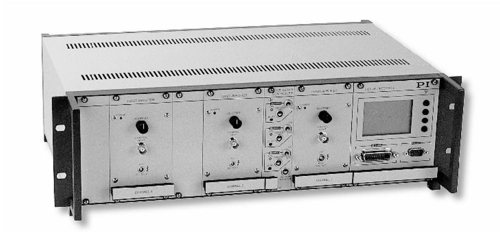
All PICA™ actuators are operated with an operating voltage in the range of 0 to 1000 V. Please make sure, that the electronics used provides this feature.

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. With all electronics listed below except for the E-461, the output polarity can be set either to negative or positive. Also, bipolar output can be selected for special applications.

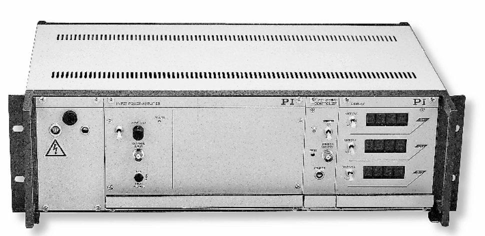
For closed-loop positioning applications, a variety of analog and digital controllers is also available. The modular E-500 system can be upgraded from an amplifier to a servo-controller and offers a variety of computer interfaces.

Of course, PI also designs custom amplifiers and controllers.

E-500 Modular Piezo Control System. Depending on the application, amplifiers, sensor circuitry, position servo-control module and computer interface combined with a graphical display are assembled in one 19" rackmount chassis.

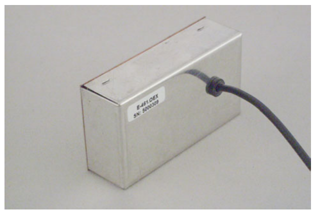


E-480.00 High-Power Amplifier with Energy Recovery (2000 W, 1100 V). The E-480 is available with servo-control and/or computer interface and display modules as upgrades, which come installed directly in the E-480 case.



E-461 Amplifier Module (0.3 W, 1000 V). The E-461 is a low-cost amplifier for high-voltage piezo actuators.. The figure at right shows the OEM version.

Note that the output polarity is negative (-10 to -1000 V output voltage).



E-420 Power Amplifier Module (500 W peak power, 1100 V). These amplifiers are designed as plug-in modules to be used with a special chassis having an appropriate mother board for additional modules like servo position controllers or digital interfaces.

4.2 Driving the Actuators

Attention

The red lead always has to be driven with a positive voltage with respect to the other lead.

First check if the piezo control electronics is switched to the right output polarity.

Do not operate actuators at higher voltages or different polarity than stated in the specification tables (p. 11 to p. 13).

Dynamic operation is limited by the resonant frequency of the actuator (see p. 11 to p. 13) and/or the positioning system as a whole. The piezo actuator can reach its nominal displacement in about ⅓ of the period of the resonant frequency. Additionally the output current of the used amplifier and rise time determine the maximum operating frequency. Acting dynamic forces (see “Fundamentals” at www.pi.ws), phase and amplitude response of the system are limiting the maximum operating frequency respectively.

For high dynamic operation cooling measures may be necessary to avoid any overheating, caused by the conversion of electrical power to heat, expressed by the dielectric loss factor. In large-signal conditions up to 12% of the electrical power pumped into the actuator is converted to heat.

Please contact our specialists for any specific questions!

Warning: Avoid Damage

Dynamic operation: Switch off power to the actuator immediately if you hear or see any resonant behavior.

For closed-loop operation (actuator with integrated position sensor) see either separate Technical Note or PI catalog.

5 Technical Data

5.1 Specifications

5.1.1 PICA™-Stack Actuators

Ordering Number	Displacement [µm -10/+20%]	Diameter D [mm]	Length L [mm ±0.5]	Blocking force [N]	Stiffness [N/µm]	Capacitance [nF ±20%]	Unloaded 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	125
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-018,20	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	830	51
P-035.20	30	35	32	24000	810	1700	33
P-035.40	60	35	57	28000	460	3400	19
P-035.80	120	35	104	30000	250	6900	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

Resonant frequency measured at 1 V_{pp} , unclamped. Capacitance measured at 1 V_{pp} , 1 kHz. Blocking force at 1000 V.

Standard ceramic type: PIC 151 (see page 15)
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. Specifications subject to change without notice.

5.1.2 PICA™-Power Actuators

Ordering Number	Displacement [µm -10/+20%]	Diameter D [mm]	Length L [mm ±0.5]	Blocking Force [N]	Stiffness [N/µm]	Capacitance [nF ±20%]	Unloaded 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	610	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	7900	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

Resonant frequency measured at 1 V_{pp}, unclamped. Capacitance measured at 1 V_{pp}, 1 kHz. Blocking force at 1000 V.

Standard ceramic type: PIC 255 (see page 15) 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.
Specifications subject to change without notice.

5.1.3 PICA™-Thru Actuators

Ordering 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%]	Unloaded Resonant Frequency [kHz]
P-010.00H	5	10	5	7	1200	230	15	144
P-010.05H	10	10	5	12	1400	140	30	80
P-010.10H	15	10	5	15	1700	110	40	67
P-010.15H	20	10	5	21	1700	80	65	45
P-010.20H	30	10	5	27	1800	59	82	39
P-010.30H	40	10	5	40	1800	40	110	30
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	3600	360	90	80
P-016.10H	15	16	8	15	4000	270	120	67
P-016.15H	20	16	8	21	4200	210	180	45
P-016.20H	30	16	8	27	4500	150	230	39
P-016.30H	40	16	8	40	4600	110	340	30
P-016.40H	60	16	8	52	4800	78	490	21
P-025.10H	15	25	16	16	7400	490	220	63
P-025.20H	30	25	16	27	8700	290	460	39
P-025.40H	60	25	16	51	9000	150	920	22
P-025.50H	80	25	16	66	9600	120	1200	17

Resonant frequency measured at 1 V_{pp}, unclamped. Capacitance measured at 1 V_{pp}, 1 kHz. Blocking force measured at 1000 V.

Standard ceramic type: PIC 151 (see page 15)
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.
Specifications subject to change without notice.

5.2 Dimensions

5.2.1 PICA™-Stack Actuators and PICA™-Power Actuators

Dimensions in mm

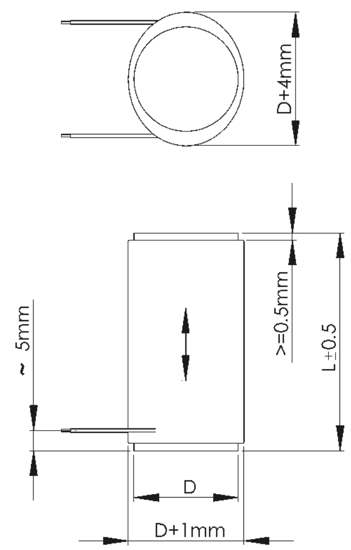


Fig. 2: PICA™-Stack / PICA™-Power dimensions, see specification tables on p. 11 and p. 12 for further information

5.2.2 PICA™-Thru Actuators

Dimensions in mm

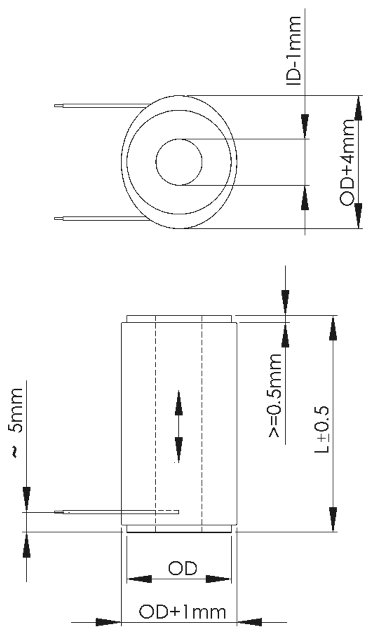


Fig. 3: PICA™-Thru dimensions, see specification table on p. 13 for further information

5.3 PI Ceramic Standard PZT Materials

Parameter	Unit		PIC 151	PIC 255
Density	ρ	g/cm^3	7.8	7.8
Curie Temperature	T_C	°C	250	350
Relative Dielectric Permittivity	$\varepsilon_{33}^T / \varepsilon_0$		2400	1750
	$\varepsilon_{11}^T / \varepsilon_0$		1980	1650
Dielectric Dissipation Factor	$\tan\delta$	10^{-3}	20	20
Electromechanical Coupling Factor	k_p		0.62	0.62
	k_t		0.53	
	k_{31}		0.38	0.35
	k_{33}		0.69	0.69
Mechanical Quality Factor	Q_m		100	80
Frequency Constant	N_p	Hzm	1950	2000
	N_1	Hzm	1500	1420
	N_3	Hzm	1750	
	N_t	Hzm	1950	2000
Piezoelectric Deformation (Charge) Coefficient	d_{31}	pm/V	-210	-180
	d_{33}	pm/V	500	400
	d_{15}	pm/V		500
Piezoelectric Voltage Coefficient	g_{31}	10^{-3} Vm/N	-11.5	-11.3
	g_{33}	10^{-3} Vm/N	22	25
Elastic Compliance Coefficient	s_{11}^E	10^{-12} m^2/N	15.0	16.1
	s_{33}^E	10^{-12} m^2/N	19.0	20.7
Elastic Stiffness Coefficient	c_{33}^D	10^{10} N/m^2	10.0	13.4
Temperature Coefficient	$TC\varepsilon_{33}$	$10^{-3}/K$	6	4

This data was measured according to EN50324 I/II.