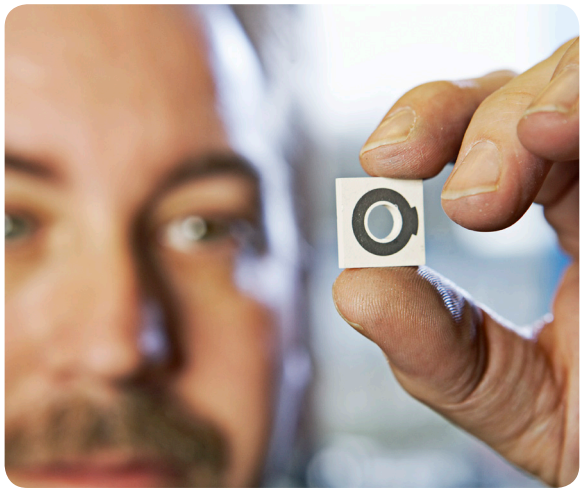
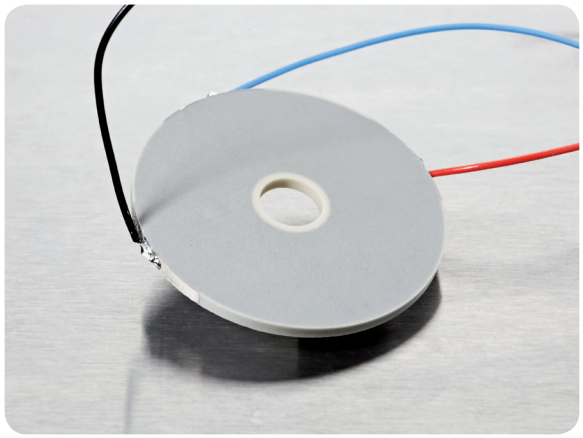
PIEZO ACTUATORS

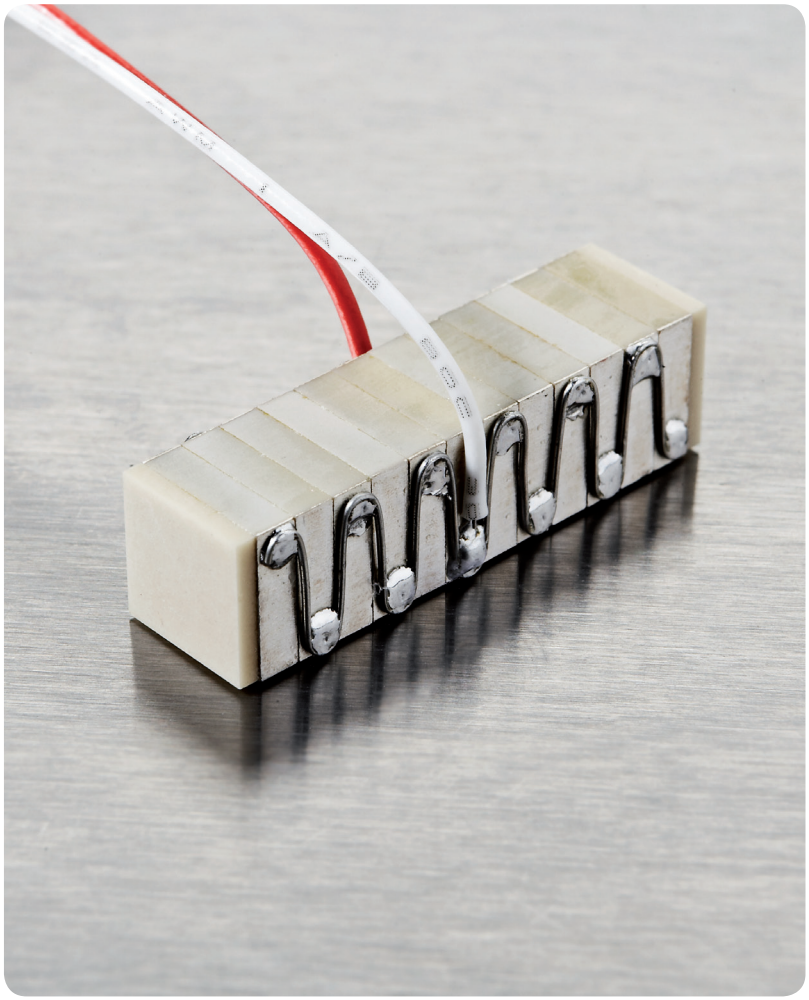
Noliac Group develops and manufactures piezoceramic actuators of high quality and tailored for custom specifications. The actuators are offered in a wide range of sizes and geometries.

Advantages of piezoelectric actuators:

- Very precise movement
- Compact
- High force
- Low energy consumption
- Quick response time (µs range)
- No EMI (ElectroMagnetic Interference)







noliac

PIEZO ACTUATORS

Piezo actuator applications

Optics

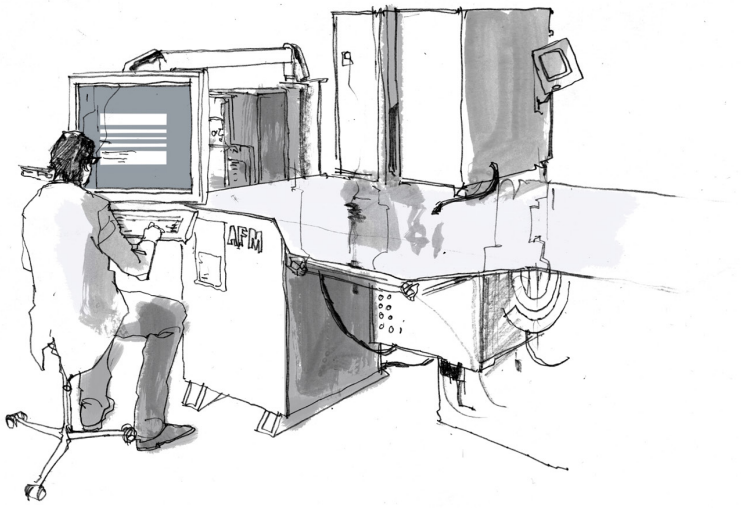
Fiber positioning applications
Add/Drop Multiplexer (ADM)
Fiber filters (BGF)
Optical switches
Adaptive optics
Tunable lasers

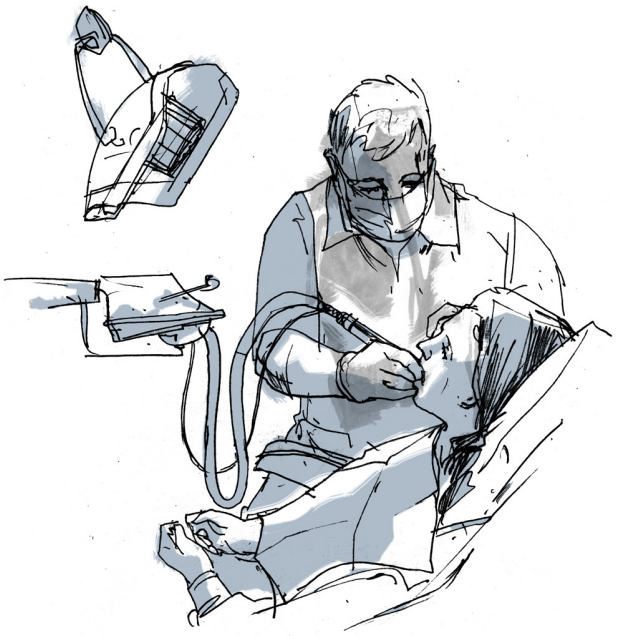
Aerospace/space

Vibration control and cancellation
Thrusters (valve and pumps)
Structual health monitoring
Active trailing edge
Fuel injection
Valves

Life science/medical

Piezo valves for drug dispensers
Medical transducers
Droplet generation
Scalers (dental)
Micro-pumps





Instrumentation

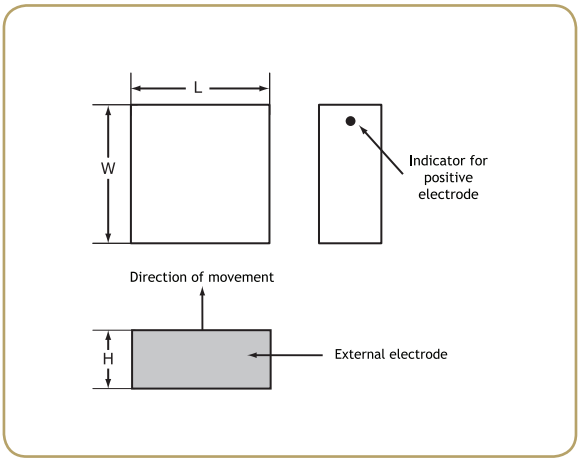
XYZ tables
Interferometers
Micropositionering
AFM microscopy
Piezoelectric positioning stage
Stepper piezoelectric integrated nanomotion
Wafer and mask positioning/alignment
Translation stage
Active damping

PIEZO ACTUATORS

Linear and stacked actuators

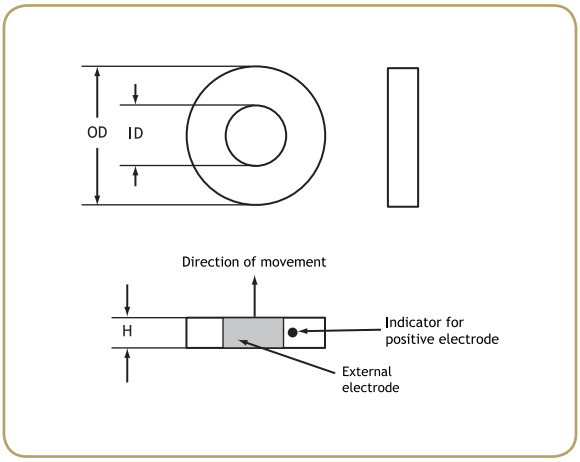
LINEAR MULTILAYER ACTUATORS

Typical outline of linear plate actuators



Symbol	Parameter	Unit
L	Length excluding external connections	mm
W	Width	mm
H	Height	mm

Typical outline of linear ring actuators



Symbol	Parameter	Unit
OD	Outer diameter excluding external connections	mm
ID	Inner diameter	mm
H	Height	mm

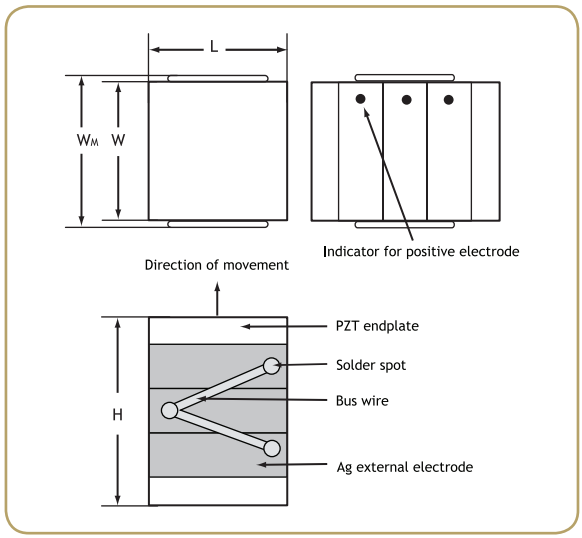
Linear multilayer piezoelectric actuators are constructed by up to 100 ceramic layers, co-fired to a monolithic ceramic, typically with a height up to 2-3 mm. Linear multilayer piezoelectric actuators can be made very small, e.g. 1 mm × 1 mm × 0.2 mm, or very large, e.g. 70 mm × 35 mm × 3 mm. Further, they can be custom designed in regards to ceramic material, layer thickness, oprating voltage, geometries (squares, rings, rectangles, chamfered, etc.), electrode materials and electrode design.

PIEZO ACTUATORS

Linear and stacked actuators

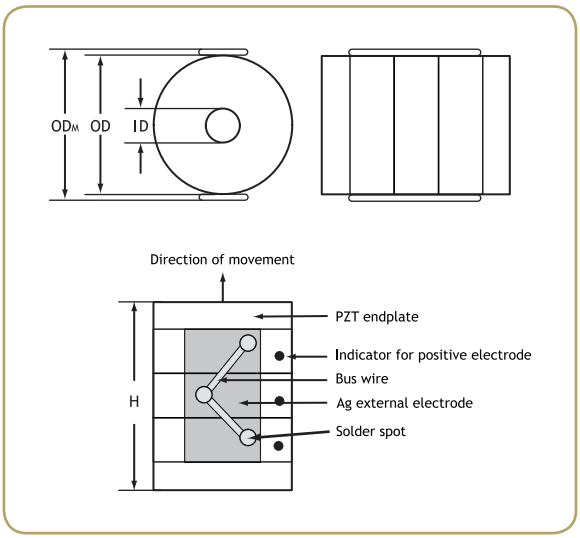
STACKED MULTILAYER ACTUATORS

Typical outline of stacked plates



Symbol	Parameter	Unit
L	Length excluding external connections	mm
W	Width	mm
H	Height	mm

Typical outline of stacked rings



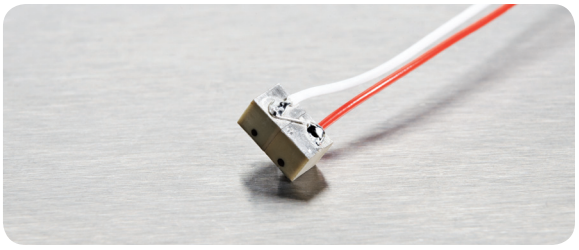
Symbol	Parameter	Unit
OD	Outer diameter excluding external connections	mm
ID	Inner diameter	mm
H	Height	mm

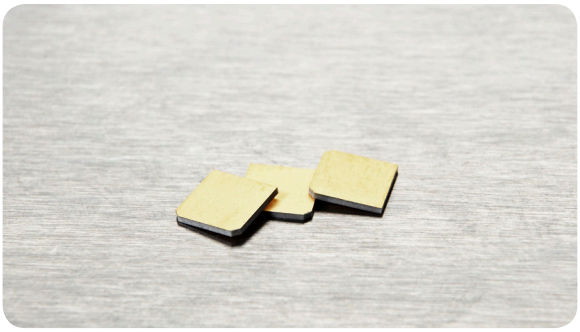
Stacked multilayer piezoelectric actuators are made of two or several linear actuators glued together. The purpose of the stacking is to obtain more displacement than can be achieved by a single linear actuator. Noliac offers a high degree of flexibility as a wide range of actuator dimensions can be made from a defined number of linear actuator plates or rings.

PIEZO ACTUATORS

Wire options for linear and stacked actuators

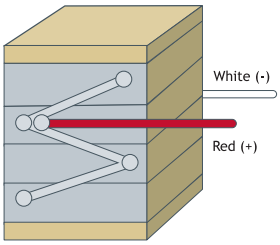
	Option A	Option B	Option C
Type	28 AWG Teflon	28 AWG Teflon	Custom
Length	200 +/- 10 mm	200 +/- 10 mm	To be defined
Position	Middle of the actuator	Middle of the actuator	To be defined
Direction	Perpendicular to the height	Toward top	To be defined





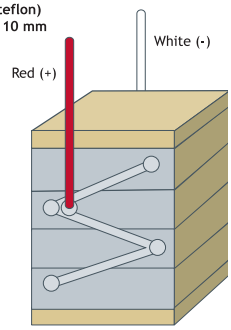
Type A

28 AWG (teflon)
× 200 +/- 10 mm



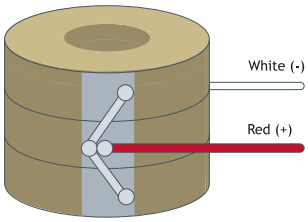
Type B

28 AWG (teflon)
× 200 +/- 10 mm



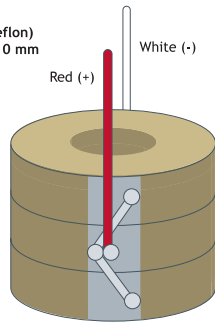
Type A

28 AWG (teflon)
× 200 +/- 10 mm



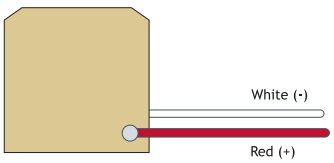
Type B

28 AWG (teflon)
× 200 +/- 10 mm



Type A

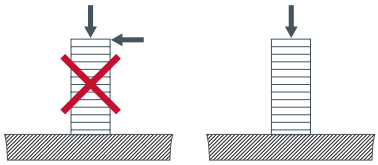
28 AWG (teflon)
× 200 +/- 10 mm



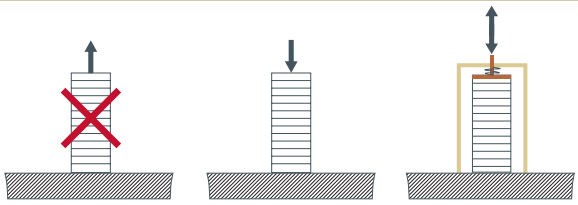
PIEZO ACTUATORS

Mount and connect linear and stacked actuators

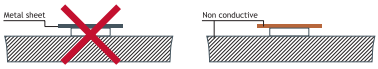
The actuators are usually grinded on top and bottom surfaces (perpendicular to the direction of expansion) in order to obtain flat and parallel surfaces for mounting. The actuators may be mounted either by mechanical clamping or gluing.



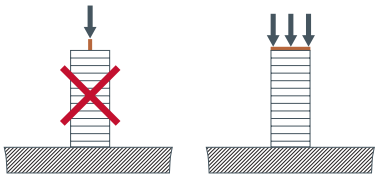
The actuators must only be stressed axially. Tilting and shearing forces must be avoided.



The actuators without preload are sensitive to pulling forces. It is recommended to apply a pre-load in order to optimize the performances of the actuators.



For linear actuators it is recommended not to use a metal plate on top and bottom in order to avoid short circuit.



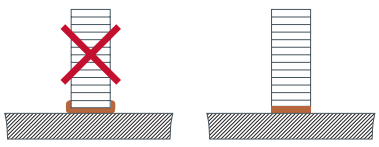
The force must be applied on the full surface of the actuator in order to assure a good load distribution.

Avoiding short circuit can either be achieved by:

- Adding Kapton foil on the metallic surfaces.
- Having inactive ceramic plates between the actuator and the metal plate.

Stacked actuators are manufactured with top and bottom insulating ceramic end plates.

If glued it is important to ensure a very thin glue line between the actuator and the substrate.
It is recommended that a pressure, e.g. 2 - 5 MPa, is applied during the curing process.



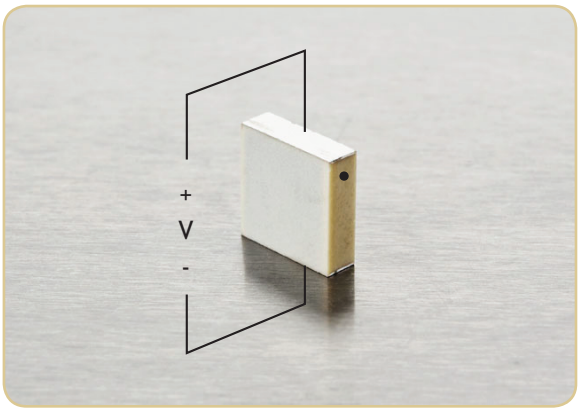
Epoxy glues are well suited for gluing piezoceramics.

To avoid significant loss of performance, the mounting of the actuators should avoid mechanical clamping and/or gluing on the sides of the actuator.

During manufacturing or handling, minor chips on the end-plates can appear. Minor chips cannot be avoided, but such chips do not affect performance.

PIEZO ACTUATORS

Mount and connect linear and stacked actuators



ELECTRICAL CONNECTION

External electrodes

The external electrodes are screen printed silver as standard. Other materials, e.g. gold or silver/palladium are available on request. The positive electrode is indicated by a black spot.

Electrical connection to the external electrodes can be achieved by mechanical contacts, soldering, gluing with electrically conductive glues or wire bonding.

Mechanical connections

Mechanical connections can be arranged by e.g. copper springs contacted to the external electrodes. It is recommended to use external electrodes of gold in order to eliminate oxidation of the electrodes.

Soldering

Soldering electrical wires to the screen-printed silver electrode makes an excellent and time-stable connection. In order to avoid challenges with wetting the solder on the silver surface, always clean the external electrodes with a glass brush or steel wool.

Soldering material must contain Ag.

Gluing wire contacts

Electrical connection can also be arranged by gluing wires to the external silver electrodes. Noliac recommends a two component soft epoxy glue with minimum 75% silver content and a curing temperature below 150ºC to avoid depolarization of the PZT. Gluing is recommended as alternative to soldering the wires when the PZT is working at high frequency or the PZT is subjected to high thermal variations from the environment. It is recommended to use external electrodes of silver in order to archive good electrical contact between glue and electrode.

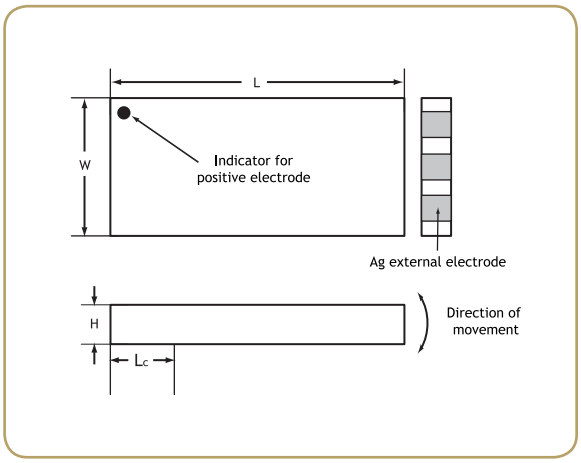
Wire bonding contacts

Electrical connection can be done by wire bonding to the external gold electrodes. Noliac recommends external gold electrodes as gold generates only a thin oxide layer, which has to be penetrated in the wire bonding friction process and thereby ensures a better mechanical and electrical contact.

Bending actuators

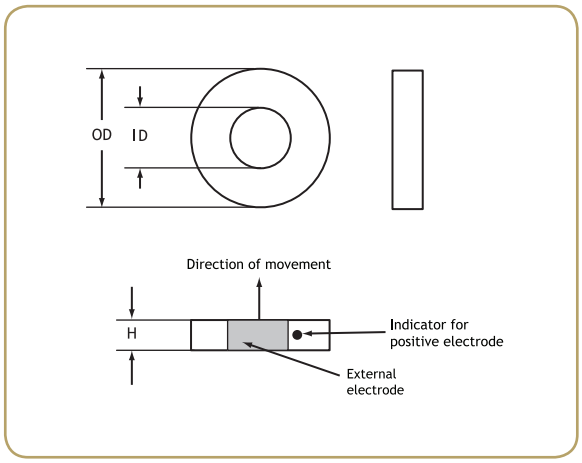
BENDING MULTILAYER ACTUATORS

Typical outline of bending plate



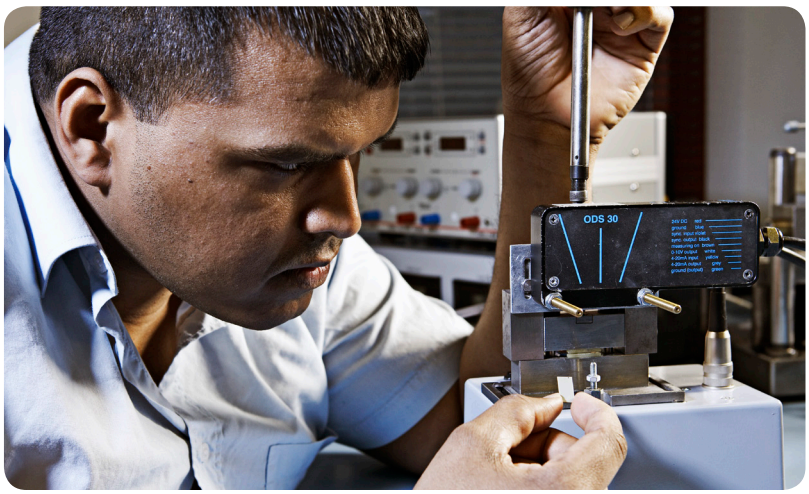
Symbol	Parameter	Unit
L	Length excluding external connections	mm
L_c	Clamping length	mm
W	Width	mm
H	Height	mm

Typical outline of bending ring



Symbol	Parameter	Unit
OD	Outer diameter excluding external connections	mm
ID	Inner diameter	mm
H	Height	mm

Bending multilayer piezoelectric actuators are co-fired ceramic actuators with ceramic layers and internal electrodes configured as to generate a bending mode. Bending multilayer piezoelectric actuators can be custom designed in regards to layer thickness, oprating voltage, geometries and electrode design. Bending multilayer actuators may be stacked in order to multiply force or stroke.

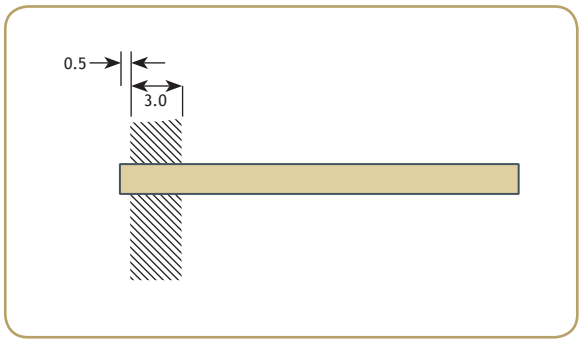


PIEZO ACTUATORS

Mount and connect bending plate actuators

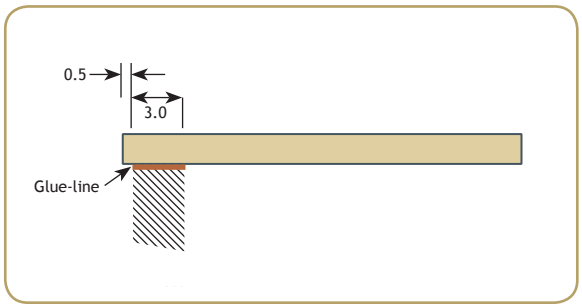
MOUNTING

Bending plate actuators may be mounted either by mechanical clamping or gluing. Bending plate actuators are not machined on top and bottom surfaces and as such may have small variations in the surface. For this reason a mechanical clamping should be done with moderate force, approximately 5 times the specified blocking force.



If mounted with glue it should be emphasized that the gluing contact surface is restricted to cover only the inactive part of the bender in order not to reduce the stroke of the bender.

Epoxy glues are well suited for gluing piezoceramics and several alternatives exists.



CONTROL INSTRUCTIONS

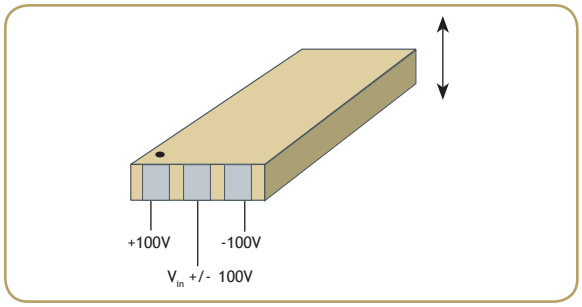
Bending actuator plates can be controlled by:

Differential voltage control

In this mode the bending can be controlled both upwards and downwards. Apply +100V to the positive electrode (indicated by the black dot), -100V to the negative electrode and a voltage V_{in} to the middle electrode such as $-100V < V_{in} < 100V$.

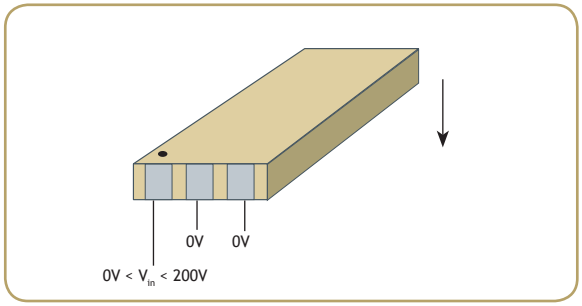
If $0V < V_{in} < 100V$, the plate will bend down with the black spot facing up.

If $-100V < V_{in} < 0V$, the plate will bend up with the black spot facing up.



Single side voltage control

In this mode, the bending can be controlled for one side only, i.e. bending up with the black dot facing up. Apply 0V to the negative and middle electrode, and up to 200V to the positive electrode.



PIEZO ACTUATORS

Mount and connect bending ring actuators

MOUNTING

Bending ring actuators may be mounted either by mechanical clamping or gluing.

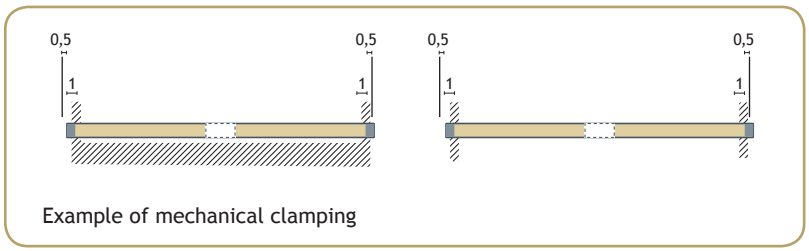
Mechanical clamping

A mechanical clamping should be done with moderate force, as low as possible to avoid unwanted clamping and thus reduce the maximum stroke.

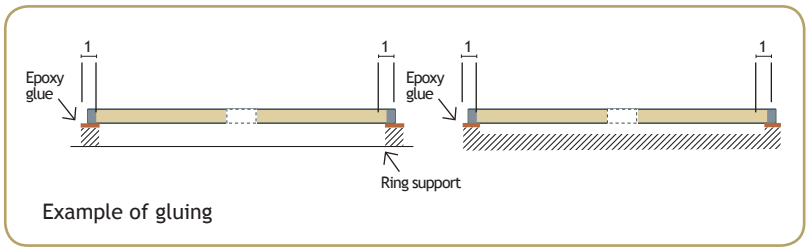
Gluing

Epoxy glues are well suited for gluing piezo ceramics and several alternatives exists. Please contact us if you need support on selection of appropriate glue for your application.

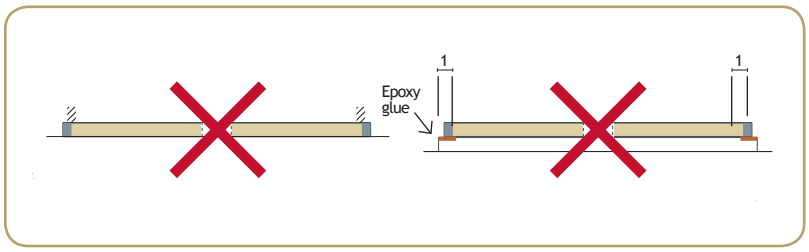
Important remark:
Mounting of bending ring actuators at their outer diameters needs some flexibility at the contact line to avoid unwanted clamping that will reduce the bender's efficiency. Therefore mechanical clamping should be done with moderate forces and if the ring is glued, a flexible epoxy should be used.



Example of mechanical clamping



Example of gluing



CONTROL INSTRUCTIONS

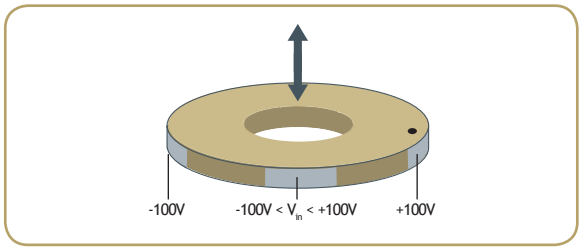
Bending ring actuators can be controlled by:

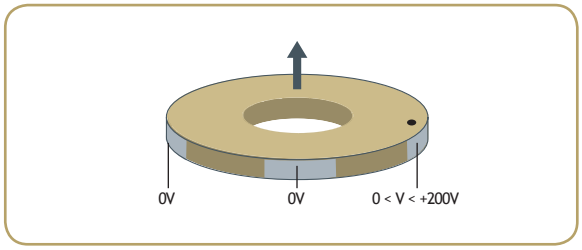
Differential voltage control

In this mode the bending can be controlled both upwards and downwards. Apply +100V to the positive electrode (indicated by the black dot), -100V to the negative electrode and a voltage V_{in} to the middle electrode such as $-100V < V_{in} < 100V$.

If $0V < V_{in} < 100V$, the ring will bend down with the black spot facing up.

If $-100V < V_{in} < 0V$, the ring will bend up with the black spot facing up.





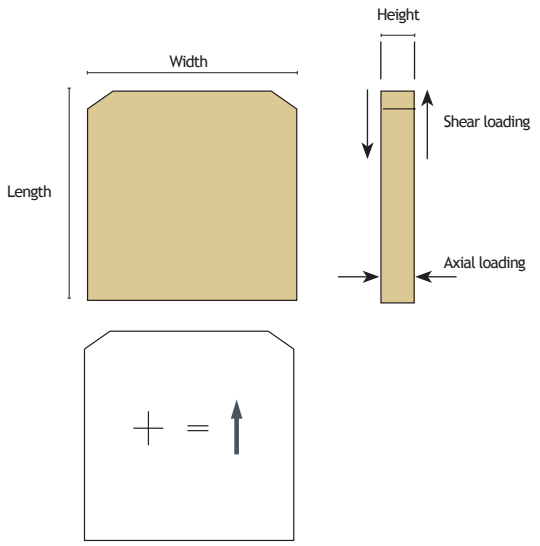
Single side voltage control

In this mode, the bending can be controlled for one side only, i.e. bending up with the black dot facing up. Apply 0V to the negative and middle electrode, and up to 200V to the positive electrode.

Shear actuators

SHEAR MONOLAYER ACTUATORS

Typical outline of shear plate



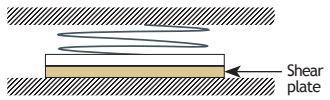
Sign convention:
A positive voltage on one electrode leads to a relative displacement of this electrode towards the chamfered edge. This displacement is recorded as positive.

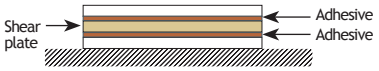
In comparison with single linear actuators, shear actuators are adapted for small transverse displacements where space is a constraint. They offer short response times (high resonance frequency) for a minimum cost.

Mount and connect shear actuators

MOUNTING

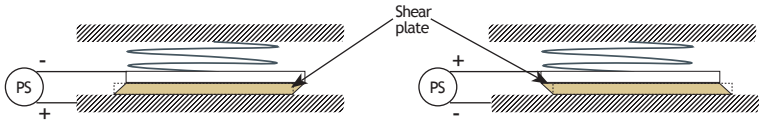
Shear plate actuators present electrodes on top and bottom surfaces. They may be mounted either by mechanical clamping or gluing.





Clamping and gluing options

In case of clamping, axial stress on shear plate actuators must be controlled. Too low pressure can lead to slippage whereas too high pressure can damage the ceramic. With the appropriate contact surface and in the case of low shear force, a pressure of 1 to 3 MPa can be recommended.



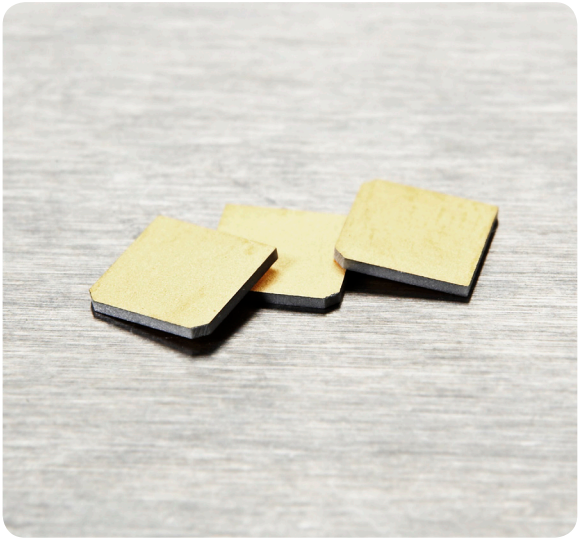
Activation in the case of clamping

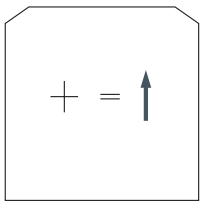
If clamping is used, the stiffness of the loading mechanism in the actuation direction shall be as low as possible in order not to hinder the movement of the actuator.

Uneven and even loading

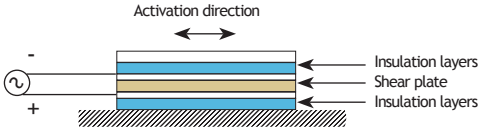
The force must be applied on the full surface of the actuator in order to ensure a good load distribution. In particular when applying the pressure, the contact surfaces have to be sufficiently flat or compliant.

Mount and connect shear actuators





Sign convention



Method for complete electrical insulation

It can be necessary to insulate the contact surfaces from the rest of the structure. This can be achieved by adding inactive ceramic plates in the structure, or polyimide film insulator.

Preferred gluing layout

If glued it is important to ensure a very thin glue line between the shear plate actuators and the substrate. This is generally ensured by using low viscosity glue. A pressure, e.g. 2 - 3 MPa, should be applied during the curing process.

Epoxy glues are well suited for gluing piezoceramics however several alternatives exist.

ELECTRICAL CONNECTION

External electrodes
Since shear plate actuators can be used with bipolar symmetrical electrical supply, both electrodes are identical. The direction of operation is indicated by the chamfers.

Sign convention: A positive voltage on one electrode leads to a relative displacement of this electrode towards the chamfered edge.

Electrical connection to the external electrodes can be achieved by mechanical contacts, soldering, gluing with electrically conductive glues or wire bonding.

Mechanical connections
Mechanical connections can be arranged by e.g. copper springs contacted to the external electrodes. Shear plate actuators are provided with gold plated electrodes for optimal electrical contact and to avoid oxidation of the electrodes. For demanding applications, it might be necessary to have both contacts gold plated.

Names	Plate	Ring	Linear	Stacked	Bending	Shear	Length (L)/ Outer diameter (OD)	Tol.	Width (W)/ Inner diameter (ID)	Tol.	Width max Wm) max	Height (H) mm	Tol.	Nominal operating V	Free stroke @ nominal Tol.: +/- 15% µm	Blocking force @nominal Tol.: +/- 20% N	Capacitance Tol.:+/- 15% nF	Maximum operating temperature °C	Material NCE	Unloaded resonance frequency Hz	Chamfers mm
NAC2001	x		x				2	+/-0.10	2	+/-0.10		2	+/-0.05	60	2.6	168	150	200	NCE51	>486k	
NAC2002	x		x				3	+/-0.10	3	+/-0.10		2	+/-0.05	60	2.6	378	390	200	NCE51	>486k	
NAC2003	x		x				5	+/-0.10	5	+/-0.10		2	+/-0.05	60	2.6	1050	1150	200	NCE51	>486k	
NAC2011	x		x				2	+/-0.10	2	+/-0.10		2	+/-0.05	150	3.0	168	25	200	NCE51F	>486k	
NAC2012	x		x				3	+/-0.10	3	+/-0.10		2	+/-0.05	150	3.0	378	65	200	NCE51F	>486k	
NAC2013	x		x				5	+/-0.10	5	+/-0.10		2	+/-0.05	150	3.0	1050	190	200	NCE51F	>486k	
NAC2014	x		x				7	+/-0.15	7	+/-0.15		2	+/-0.05	150	3.0	2060	380	200	NCE51F	>486k	
NAC2015	x		x				10	+/-0.20	10	+/-0.20		2	+/-0.05	150	3.0	4200	760	200	NCE51F	>486k	
NAC2021	x		x				7	+/-0.15	7	+/-0.15		2	+/-0.05	200	3.1	2060	220	200	NCE51F	>486k	
NAC2022	x		x				10	+/-0.20	10	+/-0.20		2	+/-0.05	200	3.1	4200	440	200	NCE51F	>486k	
NAC2023	x		x				15	+/-0.30	15	+/-0.30		2	+/-0.05	200	3.1	9450	970	200	NCE51F	>486k	
NAC2024	x		x				3	+/-0.10	3	+/-0.10		2	+/-0.05	200	1.8	290	25	200	NCE46	>500k	
NAC2025	x		x				5	+/-0.10	5	+/-0.10		2	+/-0.05	200	2.0	800	75	200	NCE46	>500k	
NAC2001-Hxx	x			x			2	+0.30/-0.10	2	+0.30/-0.10	3.8	4-20**	+/-0.20 or 1%*	60	2.5-22.2	168	140-1300	150	NCE51	>248k->52k	
NAC2002-Hxx	x			x			3	+0.30/-0.10	3	+0.30/-0.10	4.8	4-30	+/-0.20 or 1%*	60	2.5-34.6	378	370-5200	150	NCE51	>248k->35k	
NAC2003-Hxx	x			x			5	+0.30/-0.10	5	+0.30/-0.10	6.8	4-50	+/-0.20 or 1%*	60	2.5-59.3	1050	1100-26200	150	NCE51	>248k->22k	
NAC2011-Hxx	x			x			2	+0.30/-0.10	2	+0.30/-0.10	3.8	4-20**	+/-0.20 or 1%*	150	2.8-25.7	168	24-210	150	NCE51F	>248k->52k	
NAC2012-Hxx	x			x			3	+0.30/-0.10	3	+0.30/-0.10	4.8	4-30	+/-0.20 or 1%*	150	2.8-39.9	378	62-860	150	NCE51F	>248k->35k	
NAC2013-Hxx	x			x			5	+0.30/-0.10	5	+0.30/-0.10	6.8	4-50	+/-0.20 or 1%*	150	2.8-68.4	1050	180-4350	150	NCE51F	>248k->22k	
NAC2014-Hxx	x			x			7	+0.35/-0.15	7	+0.35/-0.15	8.8	4-70	+/-0.20 or 1%*	150	2.8-96.9	2060	360-12250	150	NCE51F	>248k->16k	
NAC2015-Hxx	x			x			10	+0.40/-0.20	10	+0.40/-0.20	11.8	4-100	+/-0.20 or 1%*	150	2.8-139.6	4200	720-35400	150	NCE51F	>248k->11k	
NAC2021-Hxx	x			x			7	+0.35/-0.15	7	+0.35/-0.15	8.8	4-70	+/-0.20 or 1%*	200	2.9-100.1	2060	210-7100	150	NCE51F	>248k->16k	
NAC2022-Hxx	x			x			10	+0.40/-0.20	10	+0.40/-0.20	11.8	4-100	+/-0.20 or 1%*	200	2.9-144.3	4200	420-20500	150	NCE51F	>248k->11k	
NAC2023-Hxx	x			x			15	+0.50/-0.30	15	+0.50/-0.30	16.8	4-150	+/-0.20 or 1%*	200	2.9-217.9	9450	920-68200	150	NCE51F	>248k->7k	
NAC2024-Hxx	x			x			3	+0.30/-0.10	3	+0.30/-0.10	4.8	4-30	+/-0.20 or 1%*	200	1.7-24	290	24-350	150	NCE46	>250k->35k	
NAC2025-Hxx	x			x			5	+0.30/-0.10	5	+0.30/-0.10	6.8	4-50	+/-0.20 or 1%*	200	1.9-46	800	71-1700	150	NCE46	>250k->22k	
NAC2121		x	x				6	+/- 0.20	2	+/-0.10		2	+/-0.05	200	2.8	1060	90	200	NCE51F	>486k	
NAC2122		x	x				8	+/- 0.25	3	+/-0.10		2	+/-0.05	200	2.8	1810	180	200	NCE51F	>486k	
NAC2123		x	x				12	+/- 0.40	6	+/-0.20		2	+/-0.05	200	2.8	3560	350	200	NCE51F	>486k	
NAC2124		x	x				15	+/- 0.45	9	+/-0.30		2	+/-0.05	200	2.8	4750	470	200	NCE51F	>486k	
NAC2125		x	x				20	+/- 0.60	12	+/-0.40		2	+/-0.05	200	2.8	8450	860	200	NCE51F	>486k	

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* Whichever is largest

** For stacks higher than 10 mm, Noliac recommends to add a support within the application in order to avoid bending and buckling during mounting and operation

Plate	Ring	Linear	Stacked	Bending	Shear	Names	Length (L)/ Outer diameter (OD)		Width (W)/ Inner diameter (ID)		Width max Wm)	Height (H)		Nominal operating	Free stroke @ nominal Tol.: +/− 15%	Blocking force @nominal Tol.: +/− 20%	Capacitance Tol.:+/− 15%	Maximum operating temperature	Material	Unloaded resonance frequency	Chamfers
								Tol.		Tol.	max	mm	Tol.	V	µm	N	nF	°C	NCE	Hz	mm
	x		x			NAC2121–Hxx	6	+0.40/−0.20	2	+0.10/−0.30	7.8	4–60	+/−0.20 or 1%*	200	2.7–77.1	1060	86–2500	150	NCE51F	>248k–>18k	
	x		x			NAC2122–Hxx	8	+0.45/−0.25	3	+0.10/−0.30	9.8	4–80	+/−0.20 or 1%*	200	2.7–103.7	1810	170–6650	150	NCE51F	>248k –>14k	
	x		x			NAC2123–Hxx	12	+0.60/−0.40	6	+0.20/−0.40	13.8	4–120	+/−0.20 or 1%*	200	2.7–156.9	3560	330–19600	150	NCE51F	>248k–>9k	
	x		x			NAC2124–Hxx	15	+0.65/−0.45	9	+0.30/−0.50	16.8	4–150	+/−0.20 or 1%*	200	2.7–196.8	4750	450–33050	150	NCE51F	>248k–>7k	
	x		x			NAC2125–Hxx	20	+0.80/−0.60	12	+0.40/−0.60	21.8	4–200	+/−0.20 or 1%*	200	2.7–263.3	8450	870–86550	150	NCE51F	>248k–>6k	
x				x		CMBP01	21	+/−0.45	7.8	+/−0.15		0.7	+/−0.10	200	+/−195.0	1.2	2 × 110	150	NCE57	>730	
x				x		CMBP02	21	+/−0.45	7.8	+/−0.15		1.3	+/−0.10	200	+/−120.0	3.7	2 × 220	150	NCE57	>1300	
x				x		CMBP03	21	+/−0.45	7.8	+/−0.15		1.8	+/−0.10	200	+/−85.0	5.5	2 × 330	150	NCE57	>1880	
x				x		CMBP04	32	+/−0.65	7.8	+/−0.15		0.7	+/−0.10	200	+/−475.0	0.75	2 × 160	150	NCE57	>275	
x				x		CMBP05	32	+/−0.65	7.8	+/−0.15		1.3	+/−0.10	200	+/−345.0	2.25	2 × 320	150	NCE57	>490	
x				x		CMBP06	32	+/−0.65	7.8	+/−0.15		1.8	+/−0.10	200	+/−210.0	4.3	2 × 480	150	NCE57	>705	
x				x		CMBP07	50	+/−1.00	7.8	+/−0.15		0.7	+/−0.10	200	+/−1270.0	0.4	2 × 250	150	NCE57	>100	
x				x		CMBP08	50	+/−1.00	7.8	+/−0.15		1.3	+/−0.10	200	+/−850.0	1.6	2 × 500	150	NCE57	>180	
x				x		CMBP09	50	+/−1.00	7.8	+/−0.15		1.8	+/−0.10	200	+/−635.0	2.9	2 × 750	150	NCE57	>265	
	x			x		CMBR02	20	+/−0.60	4	+/−0.15		1.3	+/−0.10	200	+/−28.0	16.0	2 × 400	150	NCE57	>12.8k	
	x			x		CMBR03	20	+/−0.60	4	+/−0.15		1.8	+/−0.10	200	+/−20.0	22.0	2 × 670	150	NCE57	>18.4k	
	x			x		CMBR04	30	+/−0.90	6	+/−0.20		0.7	+/−0.10	200	+/−108.0	11.0	2 × 470	150	NCE57	>3.7k	
	x			x		CMBR05	30	+/−0.90	6	+/−0.20		1.3	+/−0.10	200	+/−7.00	29.0	2 × 940	150	NCE57	>6.0k	
	x			x		CMBR07	40	+/−1.20	8	+/−0.25		0.7	+/−0.10	200	+/−185.0	13.0	2 × 800	150	NCE57	>1.8k	
	x			x		CMBR08	40	+/−1.20	8	+/−0.25		1.3	+/−0.10	200	+/−115.0	39.0	2 × 1740	150	NCE57	>3.4k	
x					x	CSAP01	2	+/−0.10	2	+/−0.10		0.5	+/−0.05		1.5****		0.133	200	NCE51	1.750	0.2 × 45°
x					x	CSAP02	5	+/−0.10	5	+/−0.10		0.5	+/−0.05		1.5****		0.83	200	NCE51	1.750	0.5 × 45°
x					x	CSAP03	10	+/−0.20	10	+/−0.20		0.5	+/−0.05		1.5****		3.32	200	NCE51	1.750	1.0 × 45°

Electrodes and wires

Plate	Ring	Linear	Stacked	Bending	Shear	Type	Description
x		x				External electrodes	Screen–printed Ag or Au
	x	x				External electrodes	Fired on Ag or Au
			x			External electrodes	Screen–printed Ag and soldered bus wire (option: glued connections)
					x	External electrodes	Au on Ni, plated
x	x	x	x			Wires	None as standard
x	x		x	x		Wires	28 AWG x 200 mm (+/−20 mm) teflon if height ≥1.2mm
x	x			x		Wires	30 AWG x 200 mm (+/−20 mm) teflon if height <1.2mm.

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*** At ambient temperature

**** From −Vmax to +Vmax. Stroke measured under up to 3.5 MPa axial load without loss of performance.