CATALOG

EQUIPMENT FOR NANOPOSITIONING

piezosystem jena
incredibly precise

This Catalog Does Not Show All Of Our Products!
The Full Product Range Can Be Found At:

www.piezosystem.com

piezosystemjena
incredibly precise

Your Partner From Germany For Incredibly Precise Positioning Solutions!

This catalog provides an overview of our product range. Due to variety of customer specific solutions, this catalog does not include all of ***piezosystem jena****'s products. The full listing of our product portfolio with complete information, technical data and technical drawings can be found at:* ***www.piezosystem.com***

Our Product Range Includes:

Piezostages: Linear Stages, Multiaxis-Positioners, Mirror Tip- / Tilting Platforms, …

Piezocomposite Actuators – size comparisson with camera lens

Piezocomposite Actuators for high dynamic applications and shockwave excitation

Long Travel / Motion Control: Linear Stages, Rotary Stages, Goniometers

Electronic Controllers: analog or digital, High Power Controller and

Fiberswitches, Multiplexer
For more information:
www.optojena.com

piezosystem jena develops and manufactures high quality, ultra precise and extreme reliable products for micro and nano positioning applications. Our products have served a wide range of customers in different industries for more than 24 years.

Applications

- Microscopy
- Semiconductor Industry
- Laser Technology
- Automation
- Life and Material Science

Application:
Wafer Inspection

Our products are also the first choice for industrial and research applications and have been used by leading international research institutions

Key Features

- High precision down to 1 Nanometer accuracy
- High speed and long-lasting reliability
- Motion without drift and hysteresis by integrating superb sensor technology
- Long-term stability by using only high quality components
- High generated forces
- Vacuum and cryogenic versions
- Elements prepared to work in magnetic fields (on request)
- Optimal measurement and calibration conditions
- Customized solutions

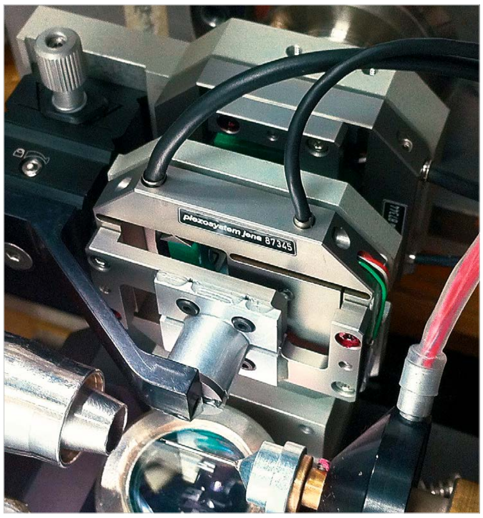
The product development, production and worldwide sales are united under the same roof in the headquarters of ***piezosystem jena*** in Germany. Therefore we are able to react quickly to the demands of our customers.
We set highest priority in a direct user contact and in the development of long-term customer relationships. Our experienced team sales engineers are happy to advice you on the integration of our products over the whole process **from the individual consultation to the technical support and aftercare**. Together with our customers, **we develop a solution that fits your needs**.
piezosystem jena works together with a network of **highly qualified representatives** in Japan, France, China, Israel, Korea, Italy, Great Britain, Taiwan and many other countries. In our **worldwide network**, you will find the partner for your country that helps you to select the most suitable product for your needs. We are present in the United States for more than 15 years at our location in Massachusetts. From here we serve all of the 50 US-states, as well as Canada with fast and efficient customer service and technical consultancy.

On the next pages we invite you to a journey through a **selection of our products**. **Selected application notes** will demonstrate you how our products are used in different set-ups. This may be an inspiration to the vast fields of possibilities in the wide **world of nanopositioning**.

Beam Adjustment - Synchrotrons

Beam Shuttering – Pure Edge 240 Collimator

The Pure Edge 240 collimator is a system for adjusting the size of an output beam.
Worldwide, users of synchrotrons have different requirements regarding the output beam. One very important aspect is **adjusting the size of the beam-square**. ALS at Lawrence Berkeley National Laboratory used to change the aperture size by swapping different size pinhole apertures. The pinholes are used in low temperature environments. Thus, the replacement of pinholes used to be very time consuming. The manual system had to be heated up; reconfigured and then cooled back to operating temperatures.
***piezosystem jena* developed in cooperation with LBNL a new system which provides different size beam-squares very precisely within a few milliseconds**. The device is called the Pure Edge 240 collimator. It is based on 2 orthogonally oriented piezo slits "PZS 4SG". It enables the customer to **adjust the area of the beam within 240 µm range** with a repeatability of just a few nanometers. Two NV 40/3 CLE controllers are used to adjust the Pure Edge 240 collimator. Settings can also be controlled using a PC.



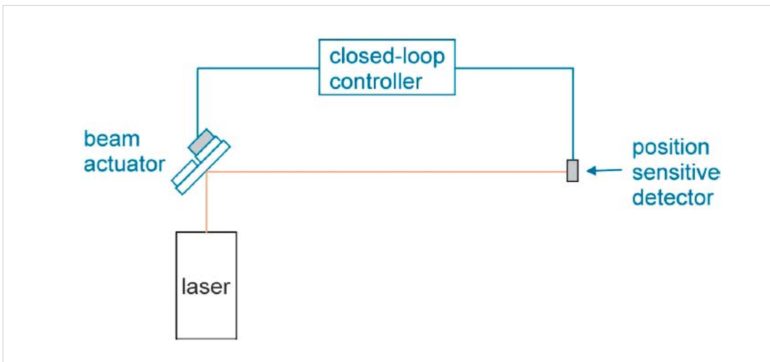
PureEdge 240 in Lawrence Berkeley Laboratory setup

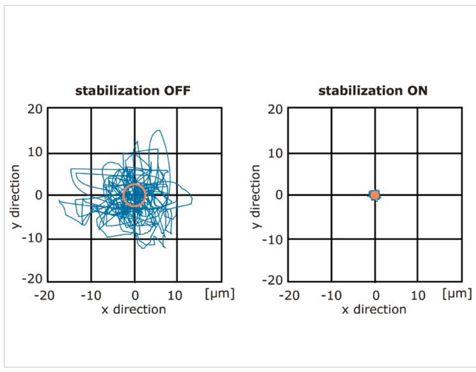
Beam Tracking

Self-Learning Laser Beam Positioning to Track Moving Objects

In biology applications a laser beam is used for cell stimulation. First the laser beam is redirected onto 2 mirrors then directed to the cells. An important requirement, to hold the laser beam onto the cell is very difficult to achieve due to thermal effects or external vibration. The position of the laser beam needs to be controlled in real-time to track the motion of the cell. For this task a system with two piezo-driven mirrors and two position-sensitive 4-quadrant diodes is used. The mirrors adjust a laser beam in any direction defined by the 4-quadrant-diodes. The signals are used to operate the PKS1 piezostage for stabilizing the position of the laser beam on the cell.
The regulation of the controller uses frequencies up to 100 Hz. The piezo stage needs to be 3 to 5 times faster than the frequency. piezosystem jena uses the mirror tip- and tilting piezostage PKS1. This piezo stage adjusts the direction of the mirror in milliseconds with a frequency between 300 and 1000 Hz. For a coarse adjustment the tilting platform can be moved up to ±2 degree manually.

PKS1





Laser beam adjustment, pictures by MRC

Micromanipulation

Micromanipulator Based on Piezosystem Jena's Actuator

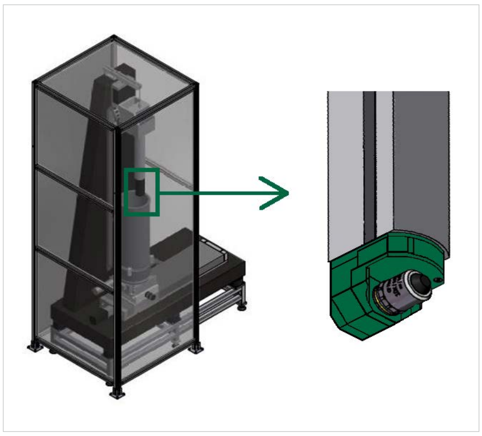
The Aureka® Micromanipulator from Jena based Aura Optik GmbH; is a platform for microsampling, designed as a combination microscope and micromanipulator.
In combination with the Zeiss Axio.ZoomV16 microscope; tasks in the fields of life science and chemistry are completed easily. N series piezo actuators from piezosystem jena working in this system offer a total travel of up to 500 µm. The micro manipulators are operated simply by using 3D joysticks.

Setup of a ZEISS Axio. ZoomV16 with micromanipulators from Aura Optik. Pictures Carl Zeiss Microscopy GmbH / Aura Optik GmbH

Metrology

3D-Surface Inspection of Hone-Structures of Engines Using nanoX 240 SG

Honing of cylinder surfaces is a common way to extend the life of combustion engines, reduce pollution and save resources. Honing processes are becoming more complex. The need of detailed analysis of these structures has increased dramatically. White light interferometry is used to produce high resolution pictures for inspection. Precise motion of the objective is essential. piezosystem jena modified the nanoX 240 SG for inspection of cylinders The **cylinder scanner nanoX 240 SG** is designed to complete this task. It moves high loads in any direction very precisely with its temperature compensated design. The scanner is used to move objectives which are mounted to it. It has a focusing range of 200 micrometers with a resolution down to 5 nm. The feedback of the internal strain gage sensors are the base for creating 3D-images. The nanoX 240 SG can be used in combination with the controller 30DV50 for step scanning or for continuous scanning. The small diameter of the cylinder scanner (CylScan from Breitmeier) is used for all size cylinders of cars and utility vehicles. It is used for quality control and numerous measuring tasks.



Credit by Breitmeier Messtechnik GmbH

Cylinder scanner nanoX 240 SG

Metrology – Microscopy

Structured Illumination Microscope Using PZ 250 SG

Surface topography has become crucial to quality inspection. Advanced technologies, such as structured illumination microscopy have accurately improved results. They have overcome the limits of conventional light microscopy by increasing resolution down to a few nm, with very precise and repeatable motion. ***piezosystem jena*** has developed a new series of nanopositioners, the PZ 250 SG capable of moving a few kg's up to 350 µm approaching repeatability of a few nanometers. The design has been engineered to provide very compact, robust and reliable stages. They are uniquely protected to sideway force making them ideal for use in an industrial environment.
Made available with different bottom plates, e. g. fitting to NIKON LV 150 3x2 Stage or Märzhäuser Scan 100.

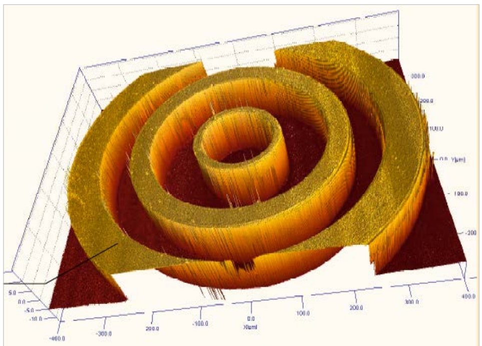
Extract of features:
motion open/closed loop: 350/250 µm
strain gage feedback sensor
repeatability: ± 2 nm
load: 1 kg

Piezo Stack PZ Series with an accuracy below 10 nm

Microscopy

Contactless 3D Inspection of Surfaces with a White Light Interferometer

Surface inspection is important for many manufacturing processes in countless industrial and research fields. Today optical measuring methods provide resolutions down to single-digit nanometers. Such depths of field require the use of high resolution nanopositioners.
piezosystem jena's MIPOS 500 SG is one of the main components of the smartWLI-microscope.
The MIPOS 500 SG provides a motion range of up to 500 µm and is capable of moving objectives up to 500 grams at a high frequency.
The smart**WLI**-microscope is an upgrade for optical microscopes. This system is developed and manufactured by GBS mbH, Ilmenau and can fit on major microscope manufacturers, e. g. ZEISS, LEICA, NIKON, OLYMPUS, MT RATHENOW. By using the smart**WLI**-microscope, the user can upgrade a common 2D optical microscope to a 3D surface measurement system. The surface scanning is based on white light interferometry. With the smartWLI-microscope from GBS-Ilmenau mbH it is possible to reduce the measurement time drastically.


3d estimation of a measured ring structure

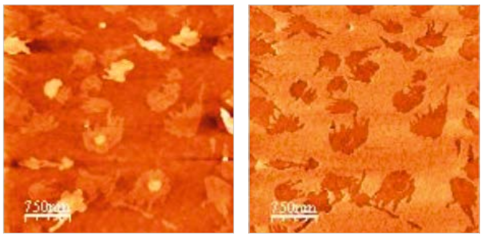
3d surface measurement system smartWLI-microscope

Metrology - AFM Microscopy

Nanolife AFM System Based on Piezosystem Scanners

Nanotec Eléctronica S.L. from Spain has developed an innovative concept for AFM microscopy. By using this platform, conventional optical microscopes (fluorescence microscopes, up-side down) or Raman microscopes can produce simultaneous AFM and optical images.
These generated images can now be viewed at the same time. To meet the high speed resolution requirements, of the SPM system **„Nanolife"** uses the piezoelectric elements (PXY 80 D12) from ***piezosystem jena***. Their task is to move a probe within a range of 80 µm. With very high resolution in the subnanometer range combined with the ultrafast reaction times of piezoelectric elements, the images can be generated quickly and precisely. These advantages make the PXY D12 series reliable and a recommended element for AFM applications.

The pictures were generated by Dr. Elena López-Elvira by using the innovative AFM platform in the ICMM-CSIC (Madrid, Spain). AFM Images of P3OT polymer in air (non-contact Mode) Topography AFM (left) and Frequency Shift (right) images of 3.75 x 3.75 µm and Z scale 32 nm



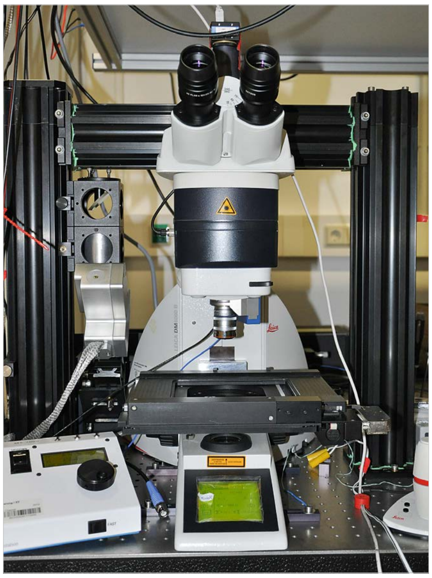
AFM Images of P3OT polymer in air

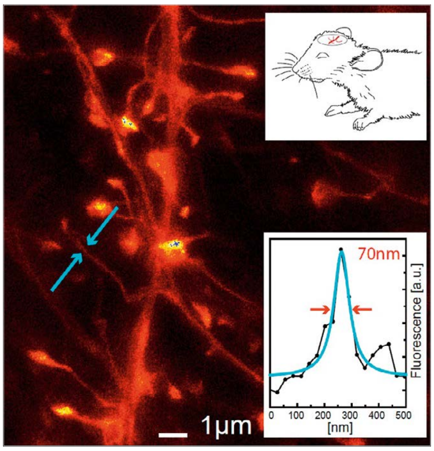
PXY 80 D12

Microscopy - Biology

Super-Resolution STED Microscopy (Chemistry Nobel Prize 2014)

In conventional microscopy the limit of the resolution is half of the wavelength of light. For blue light this is 200 nm. This resolution limit was postulated by Ernst Abbe and for decades it was considered that this limit could not be overcome. The reason for this is based on the diffraction, which occurs at two clearly differentiated objects and makes both objects appear blurred together as one. Using the Stimulate Emission Depletion (STED) Method developed by Prof. Dr. Hell, MPI Göttingen, a higher resolution could be achieved which was far below the previously mentioned limit. The microscope becomes a nanoscope and alters long-standing conceptions about the resolving power in light microscopy.
In this method a cell is excited by a diffraction-limited laser source. Immediately this cell is then overlaid by another laser source. This second laser has a special feature of having a hole in the middle, a so-called "doughnut-shaped" beam. The result is a prevention of the effective excitation of the cell, except in the focal spot that happens to be in the central area of the doughnut-shaped beam. The remaining spot circumference can be reduced to achieve a higher resolution.





piezosystem jena *elements used in the super-resolution imaging of a neuronal cell in a living mouse brain.* ***piezosystem jena*** *products in the above set up: Microscope Positioner MIPOS 100 CAP and piezo amplifier NV 120 CLE.*
Images courtesy of Dr. Katrin Willig, Center for Nanoscale Microscopy and Molecular Physiology of the Brain, Göttingen; As well as Prof. Dr. Stefan W. Hell, Max Planck Institute for Biophysical Chemistry, Göttingen, Germany

Spectroscopy

PAHL 120 from Piezosystem Jena Guaranteed High Resolution in Four Bounce Crystal Monochromator

The I20 XAS beamline at Diamond Light Source has had very challenging requirements. Among these, the parallelism of the first and second crystal had to be solved in steps greater than 90 nrad, resulting in resolution of better than 1 nm for 120 µm travel range.
Extreme high stiffness was also required due to the high mass of the crystals and their high thermal load.
The PAHL 120 was chosen because of their high stiffness, long travel range and high resolution without friction. They were modified for vacuum application of 10^{-8} mbar and to be used at a cryogenic temperature of 77 K.
Additionally the customer asked for a sophisticated control with remotely configured PID loops, filtering and other parameters. ***piezosystem jena`s*** controller d-Drive offers these specifications.
Long term stability is achieved by using closed loop control by d-Drive and capacitive sensors.

Controller d-Drive (4 channel amplifier)

Piezo Actuator PAHL

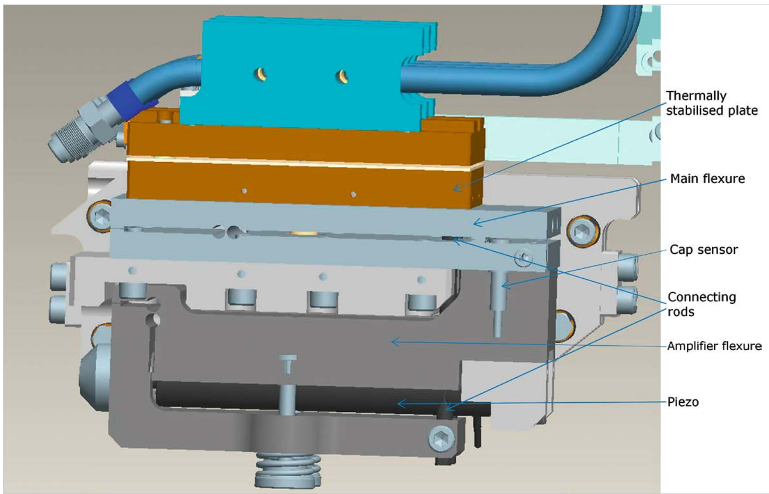


Image: Diamond Light Source

Semiconductor

Large Wafer Inspection for the Semiconductor Industry by Piezosystem Jena, PZ 250 CAP WL

Highly precise positioning of inspection systems for wafers with a diameter up to 12"
The manufacturing process of substrates for electronic components requires very specific controlled environmental conditions. The standard in quality control is extremely high and an efficient automated process requires very precise repeatability. To support this process, ***piezosystem jena*** has developed a highly precise **positioning system for wafers up to 12":** PZ 250 CAP WL. A 12 inch frame as well as 12 inch needle EE wafer storage can be carried. This system can be integrated into an inline-control as a stand-alone-system or can be integrated into an automatic inspection system. Exact positioning processes are guaranteed to shorten cycle times. The wafer is positioned within milliseconds precisely from a few micrometers up to 250 µm and reaches a repeatability of a few nanometers. The design allows for easy integration into the NIKON microscope ECLIPSE with L3-S12-stage. Other interfaces are also available upon request.

Wafer Positioner PZ 250 CAP

Advantages:
- resolution: 3 nm
- repeatability: ±3 nm
- long term stability: less than 10 nm

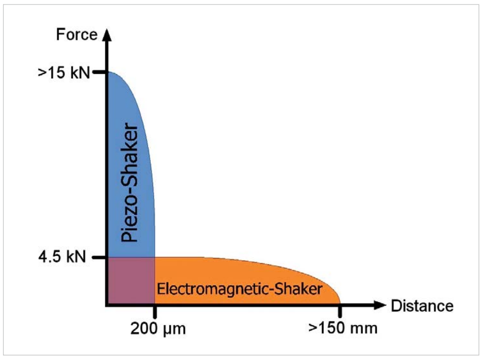
(The measuring system ConfoDisc CL200/CL300 from the company confovis GmbH is based on the NIKON microscope L200 or L300. It is particularly suitable for the detailed measurement of wafers in the semiconductor industry.)

Measuring system ConfoDisc CL200/CL300 from Confovis

Shaker – Vibration Excitation

Shaker Applications for Piezocomposite Actuators

Piezo electric shakers based on piezocomposite actuators from ***piezosystem jena*** are used in a wide range of applications. Due to their char-acteristics Piezo-shakers are able to generate frequencies to over 100 kHz and accelerations up to 10’000 g. Force modulation in the tens of kN’s used in the smallest of installation spaces, is the benefit of piezo-composite actuators. Actuator sizes vary from a few millimeters to tens of centimeters. In comparison to other shaker types e. g. electro-magnetic shakers; piezo electric shakers have smaller size but much greater force generation. These characteristics make piezo electric shakers well suited for applications in material testing, active vibration damping and vibration excitation.



Comparison of electromagnetic and piezo electric shakers

Frequency Comparison of Piezoelectric and Electromagnetic Shakers:

manufacturer	shaker type	product	stroke	force	frequency
piezosystem jena	piezo electric	micro PiSha	to 5 µm	1 kN	100 kHz
	piezo electric	PiSha 1000/35/150	75 µm	± 15 kN	200 Hz*
other manufacturers	electromagnetic shaker		25.4 mm	< 350 N	30 Hz
	electromagnetic shaker		50 mm	4.5 kN	2,5 kHz
	electromagnetic shaker		-	50 N	2 kHz
	electromagnetic shaker		150 mm	900 N	200 Hz
	pneumatic shaker		-	< 1680 N	< 130 Hz

* with seismic mass of 80 kg (176 lbs)

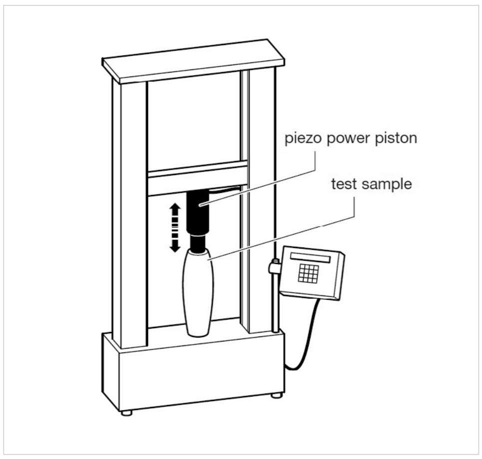
Material Testing

High Accelerations with Piezocomposite Pulse Generators

Piezo electric pulse generators (PIA) from ***piezosystem jena*** provide fast **accelerations up to 10’000 g** for testing objects, structures and materi-als. Using a special piezo electric ceramic material; they generate pulses with **energies up to nearly 4 Joule** twice as high as comparable ceram-ics from common actuators. The impact parameters, such as energy, ac-celeration, stroke etc. are **adjustable “on the fly”**. The impact partners (actuator and sample) are in contact before the shock, therefore high repeti-tion rates and precise triggering are possible. PIA impulse generators are used in material testing for instance; impact-echo-technique, sensor testing and calibration.
In a material testing set-up the impulse generator can impose a sample with an enormous high fre-quency fine modulation.


Pulse Generator

Technical Data:
Accelerations: > 10’000 g
Amplitude: 100 µm
Energy: < 4 J

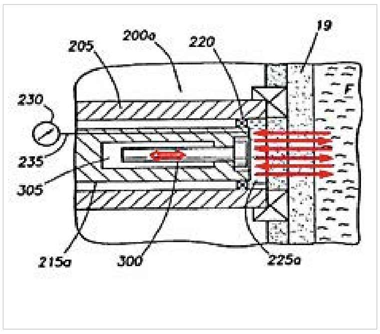


High-load, long stroke piezo-actuator for material testing in a set-up for test-engi-neering

Geology

Pore Pressure Measurement in the Oil Well

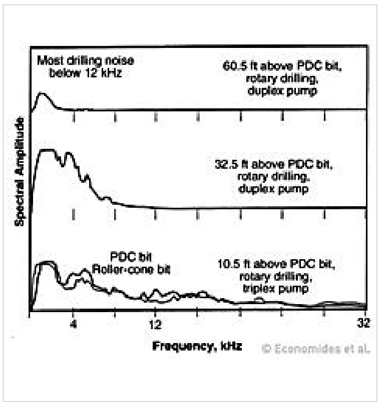
U.S. patent US 7331223 B2 describes a procedure for fast pore pressure measurement in the well. A piston oscillates between extended and retracted positions and creates a fluid movement of the resource (e. g. oil). This fluid movement jets through the pores of the formation and provides a fast and precise pore pressure measurement.
Components used in the Bottom Hole Assembly (BHA) must withstand severe conditions e. g. high temperatures and high pressures (HT/HP). Piezocomposite actuators from ***piezosystem jena*** are well suited to generate the necessary oscillation even under the extreme conditions in the well. Piezocomposite actuators generate oscillations with frequencies up to 100 kHz and withstand temperatures over 200 °C/392 °F and high pressures without significant performance loss.



Extract of the patent US 7331223 B2 for fast pore pressure measurement in the oil well.

Measurement/Logging While Drilling (M/LWD)

As one single part of the Bottom Hole Assembly (BHA) piezocomposite actuators takes place in the field Measurement/Logging While Drilling (M/LWD). In the BHA piezocomposite actuators are used to generate sonic signals. These signals are reflected at the formation interface and/or at the bore hole coating. They deliver information about the coating and the surrounding formation. It is necessary to drown out the noise of the drill bit. Piezocomposite actuators generate frequencies of above 10 kHz. Thus it is possible to drown out the drill bits noise in a distance of 10 m/32 ft. So it is possible to generate analyzable signals during the drilling process. That's why piezocomposite actuators from ***piezosystem jena*** save production time.
Frequencies as a result of the drilling process according to the distance to the drill bit. (PetroWiki®, From Economides, Watters, and Dunn-Norman, Petroleum Well Construction, © 1998; reproduced by permission of John Wiley & Sons Ltd.)



Space applications

Applications of piezo electric actuators are not limited to the earth's surface. Piezo actuators are used in many satellite missions and for experiments in the ISS. The well known comet lander Philae has two piezo based sensors on board. One sensor is used to analyze the structural and mechanical characteristics of the comets surface. The other one is a sensor for the detection of dust particles in the comets coma. Other uses are telescopic adjustments or active vibration damping on satellites or experiments on the ISS such as the Miller-Urey experiment.
This shows the wide range of applications of piezo electric actuators. ***piezosystem jena*** has over 24 years experience in this field and will help you to find the best solution for your application, both on earth or in space!

Information: http://www.kfki.hu/~aekihp/reports2001/dim.htm

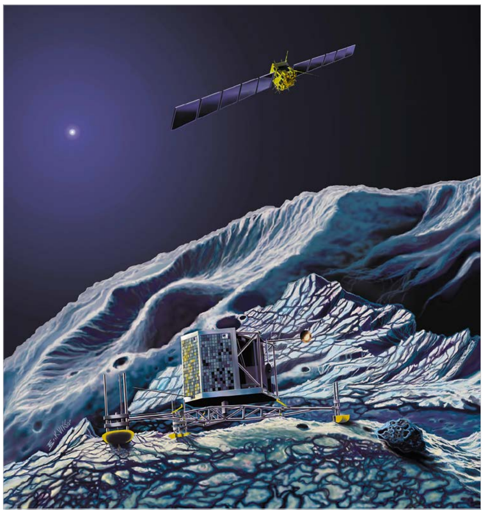


Image: ESA

General Remarks

ASI / ASC

ASI and ASC are advanced functionalities of piezoelectric systems offered by ***piezosystem jena*** for automatic sensor identification, and the ability to exchange single parts of a system. Actuators and electronics can be exchanged, without new calibration procedure. These systems can remain on location or in the field without any time or money being spent for additional shipping.

ASI Function:

Automatic Sensor Identification

The ASI function allows you to exchange the same type of actuator and use it with the same amplifier. Actuators for an ASI compatible amplifier are equipped with an external preamplifier.
New calibration is no longer necessary (valid only for standard calibration).

ASC Function:

Automatic System Calibration

In addition to the ASI function ASC provides even more functionality for our customers. The integrated circuit built into a closed loop actuator contains also the parameters for its calibration and other information such as:

- motion
- name
- axis
- serial number
- PID-control and filter setting

Thus the electronics can identify not only the actuator, but also its calibration data. The actuator can be used with a different type of electronic, without needing to be recalibrated. The new system works immediately and at its peak performance.
Another significant advantage is the full function generator setup. The full function generator setup contains standard values for amplitude, offset, frequency, and so on. All of this information is stored inside an ID-chip that is located on the actuator's connector. The setup is immediately active again after switching on the electronic.

Blocking Forces

Mechanically, a piezo actuator can be treated as a mechanical spring with a spring constant (stiffness). If the actuator is operated with the maximum voltage but it is fixed between walls with an infinitely high stiffness the actuator cannot move. It generates its maximum forces called blocking forces.

Cables

piezosystem jena uses cable with high voltage signal insulation and shielding protection. For vacuum applications, the standard cable comes with Teflon, Polyimide or Kapton insulation material for no out-gassing. Other cables in various lengths are also available upon request.

Cable Length

open loop actuators	1 m
with sensor preamplifier	2 m
with SG-sensor without sensor preamplifier	1.2 m
with CAP-sensor without sensor preamplifier	1.6 m
prepared for vacuum/outside vacuum	0.6 m / 2.0 m

Calibration Procedure

Each closed loop system will be calibrated to provide the highest possible accuracy and to achieve the fastest possible response. The calibration is done with a high resolution interferometer set up. Unless otherwise noted, all calibrations are done at 22°C ±1K with a pressure and humidity compensated laser interferometer. A calibration protocol is provided with each calibrated system.

Standard Calibration:

If not otherwise specified, all closed loop systems are calibrated related to our "standard calibration conditions" (external load, dynamic behavior, position of installation).

Customized Calibration:

If the piezo system has to work under different conditions a special calibration might be necessary. Please ask our team for assistance in advance.

Closed Loop Operation

To overcome creep (drift) and hysteresis and to compensate for changing environmental conditions (e.g. forces from outside), a piezo system can be equipped with a measurement system. The closed loop electronics uses the feedback from the position sensor to control the motion of the piezo system. ***piezosystem jena*** uses mainly strain gauge sensors or capacitive sensors.
Elements equipped with a strain gauge sensor are named with the suffix SG. Elements with integrated capacitive sensors are named with the suffix CAP.

Connectors Voltage

controller	connector type
analog amplifiers (not nanoX)	LEMO 0S.302
for nanoX	ODU L-series 3pin
digital amplifiers	D-Sub 15
high power amplifiers	D-Sub 15 5W1

Sensor

controller	sensor
SG non-external preamplifier	LEMO 0S.304
CAP non-external preamplifier	LEMO 0S.650
external preamplifier SG or CAP	ODU L-series 4pin
digital amplifiers	D-Sub 15

Cryogenic Application

piezosystem jena can modify most of the elements to be usable at cryogenic temperatures. Please note that the original motion of the system is reduced when used at low temperature.

Drift / Creep

Creep (drift) describes a movement of the position of a piezo actuator after the input change (voltage change) has stopped. The creep of piezoceramics is based on a change of the remanent polarization of the ceramics even if the applied voltage does not change anymore.

To overcome the effect of creep, the piezo system has to be equipped with a sensor and feedback control electronics (see also ***chapter 3.8*** of the piezoline).

External Sensor Pre-Amplifier

The preamplifier makes the sensor signal insensitive to external disturbances.
It is often located in a small box installed along the cable of the actuator.

Hysteresis

Piezo actuators show hysteresis in their large signal behavior. Hysteresis is also based on the remanent polarization of the piezo ceramic material. The motion caused by this polarization shows a time delay related to the motion caused by the applied voltage.

To overcome the effect of hysteresis, the system has to be equipped with a measurement system and closed loop control electronics. (see also ***chapter 3.2*** of the piezoline)

Linearity

The linearity describes the difference of the position measured by the integrated measurement system of the actuator compared to the exactly measured position using a laser beam interferometer.
Each calibrated system (closed loop system) made by ***piezosystem jena*** comes with a calibration protocol indicating the linearity and repeatability.
Data for linearity given in the catalog are typical values measured for many elements of the same type of actuator (stage). Values for linearity for a particular system may differ from catalog values. Data given in the calibration protocol are related to well-defined environmental conditions. If the measurements conditions vary compared to the conditions stated in the calibration protocol, linearity data may change. (see also ***chapter 9.5*** of the piezoline).

Noise

Position noise is the variation of the position in the element (or measurement signal) even if the system is not moving. Noise values in this catalog are peak to peak values. Other publications often use other values for noise. RMS values are 2-3 times smaller compared to peak to peak values. However, the piezo element with its unlimited mechanical resolution reproduces all electric signals which are within its frequency response capability. Mechanical resolution calculated from RMS values result in better data than they are in reality.

Open Loop Operation

The actuator is operated without a measurement system. Displacement is approximately correlated to the drive voltage. Non-linearity, hysteresis and creep are not compensated.

Push and Pull Force

Piezoceramic stacks can withstand high pressure push forces (push forces are opposite to the direction of motion). However due to their construction as a multilayer element they can only withstand low pull forces (tensile forces in the direction of motion). Piezo stages consist of multilayer piezoceramic stacks integrated into a special construction for the magnification of motion. This construction can include different kinds of preloading mechanisms allowing for higher compressive and tensile forces to the piezo stages.

Push and pull forces specified in this catalog indicate maximum forces to be applied to the piezo stages, or piezo actuators without mechanically damaging the elements.
If the applied forces are higher than the specified values the elements can be damaged and might not work properly.

Repeatability

The repeatability designates the error which arises if the same position from the same direction is permanently approached.
The repeatability for each calibrated system (closed loop system) is shown in the calibration protocol supplied with the calibrated system.
Data for repeatability given in the catalog are typical values measured for many elements of the same type of actuator (stage). Values for repeatability for a particular system may differ from catalog values.
Data given in the calibration protocol are related to well defined environmental conditions. If the measurement conditions vary compared to the conditions stated in the calibration protocol, repeatability data may change. (see also ***chapter 9.5*** of the piezoline).

Resolution

The resolution specifies the smallest motion of a piezo actuator which can be resolved (measured).

The piezo effect is a real solid state effect (in theory) without any limitations to the resolution. An infinitely small change in the electrical field (voltage) gives rise to an infinitely small mechanical displacement. In reality, the resolution is limited by the environmental conditions (e.g. acoustic and thermal noise) as well as by the voltage noise of the electronic amplifier.

High resolution piezo amplifiers from ***piezosystem jena*** come with a typical signal noise of 0.3 mV @ 500 Hz (noise related to a bandwidth of 0 to 500 Hz). All values for the resolution given in the catalog are based on a calculation related to the noise of the amplifier being used.

Resonant Frequency

Piezo actuators are oscillating mechanical systems characterized by the resonant frequency. The resonant frequency is determined by the stiffness and the mass distribution (effective moved mass) within the actuator. Actuators from ***piezosystem jena*** reach resonant frequencies of up to 100 kHz. All values given in the table of the catalog are based on the average measurement values for each part of the given series.

ROHS Regulation

All products offered by ***piezosystem jena***
fulfill the requirements of the ROHS.

Stiffness

Mechanically, a piezo actuator can be treated as a mechanical spring with a spring constant (stiffness) of the actuator. The stiffness is an important parameter describing frequency behavior as well as generated forces. For piezo actuators without motion magnification, the stiffness is proportional to the cross section of the ceramics and it decreases with an increasing length of the actuator.
(see also ***chapter 3.5*** of the piezoline).

Temperature Range for Using Piezoelectric Actuators

piezosystem jena's piezoelectric ceramics have a Curie temperature of approximately 150°C. The piezoelectric effect can be used down to nearly 4 Kelvin. But the effect drops down to nearly 10% of the effect at room temperature.
If not specified otherwise our actuators work well in the temperature range between -20 to +80°C.
As an option, most of the actuators can be modified to work at lower temperatures (down to 4 K) or higher temperatures (up to the Curie's temperature).
However: data and parameters given in the catalog are measured at room temperatures and they change when applied to lower or higher temperatures. This deviation depends on the ceramic actuator used and on the special construction as well.
Temperature changes also affect the accuracy of the system. Please ask us if you need to use the system in a lower or higher temperature range prior to the calibration procedure. Please note that the temperature effect can be more important for the material around the ceramic stack type actuators, such as the stainless steel casing, than for the ceramic itself.

Vacuum – Using under Vacuum Condition

piezosystem jena can offer most of the
elements with vacuum options. Piezoelectic actuators for vacuum applications are produced from materials (for example adhesives) with low out-gassing characteristics. Piezo elements from ***piezosystem jena*** can be baked out up to 80°C (175°F) without any problems. Elements with special preparation can be baked out up to 150°C (300°F).

Vacuum Feed Through

piezosystem jena provides a range of vacuum feed through for all kinds of systems. They are mainly divided in 2 series usable up to 10^{-7} hPa and usable up to 10^{-10} hPa. Please note that the feed through has to be part of a calibrated system. If the customer wants to use his own feed through, please contact us in advance.

Do You Know About Our NEW Product Line For Motion Control?

See page 43:

MOTION CONTROL 43

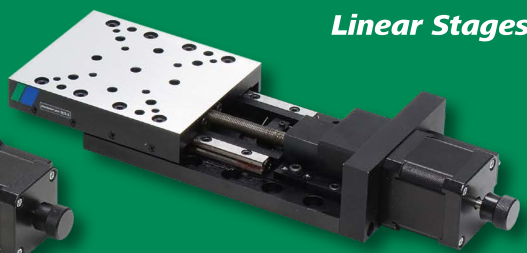
Motion Control

- Longer travel than piezoelectric drives (up to 50 mm)
- Long travel positioning in translation, rotation or goniometry
- Can be easily combined with other drives

Rotary Stages

Goniometer

Linear Stages



Do You Know About Piezocomposite Actuators For Highest Dynamic, Acceleration And Forces?

See page 57:

HIGH POWER PIEZO ACTUATORS 57

Piezocomposite Actuators:

- Dynamic: up to > 100 kHz
- Acceleration: up to 10’000 g
- Forces: up to 70’000 N

Geo-Shaker

Piezocomposite Actuators up to 1 meter length
(dog excluded)

Unhoused Ring Actuators

Stack Type Actuators Series P and PA

Different P-Actuators

Product Features P (without preload)

- motion up to 82 µm (larger motions on request)
- without preload

Applications

- micro positioning
- laser tuning
- semiconductors

Recommended Controller

- 12V40

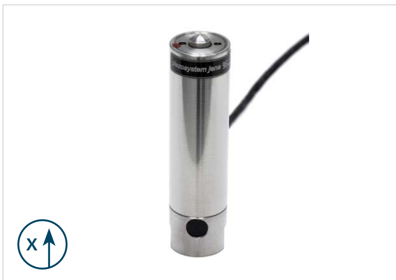
The series P actuators are based on stack type actuators covered with stainless steel housing. **The top and bottom plates are epoxied** and **eliminate technical play.** The P series actuators are not preloaded. Therefore they can't withstand tensile force and should not be driven dynamically. But they are able to **withstand pressure forces**.

Technical Data

series P	motion ol (-10/+20)%	resolution	capacitance (±20%)	blocking force	stiffness	dimensions Ød x l
	µm	*nm*	*µF*	*N*	*N/µm*	*mm*
P 8/8	9	0.02	0.18	200	22	Ø8 x 17
P 80/10	82	0.16	7.2	850	10	Ø10 x 91

series P

More P-elements?
www.piezosystem.com/p



PA 36/14

Product Features PA (preloaded)

- excellent dynamic properties due to high resonant frequencies
- integrated mechanical preload

Applications

- optics adjustment
- nano positioning

Recommended Controller

- 30V300 for high dynamic applications

The PA series actuators are based on stack type actuators using multilayer technology. They are particularly **useful for machine tools and dynamic scanning systems** because of their ability to **generate large forces**. Also they can be subjected to **high mass loading**.

Technical Data

series PA	motion ol (-10/+20)%	resolution ol / cl	resonant frequency	blocking force	preload	dimensions Ød x l
	µm	*nm*	*kHz*	*N*	*N*	*mm*
PA 8/14	4,5	0.02/0.1	65	850	150	Ø14 x 28
PA 140/14	145	0.29	3	850	150	Ø14 x 163

series PA

More PA-elements?
www.piezosystem.com/pa

ol – open loop, cl – closed loop
Also available with integrated measurement system, as vacuum or cryogenic version. longer versions available on request

Stack Type Actuators Series PHL and PAHL

PHL 60/20

Product Features PHL (without preload)

- high-load actuator without preload
- motion up to 103 µm
- use under static conditions

Applications

- micro-positioning of heavy loads
- laser and mirror movement

Recommended Controller

- 30V300
- NV 120/1
- ENV-series

Due to their high **blocking forces** (up to 3500 N), the stack type actuators series PHL are ideally suited for **applications in machine industry**. The actuators provide response times in the millisecond range with sub-nm resolution.

Technical Data

series PHL	motion (-10/+20)%	resolution	capacitance (±20%)	blocking force	stiffness	dimensions Ød x l
	µm	*nm*	*µF*	*N*	*N/µm*	*mm*
PHL 18/20	20	0.04	7	3500	175	Ø20 x 36
PHL 100/20	103	0.21	34	3500	35	Ø20 x 108

series PHL

More PHL-elements?
www.piezosystem.com/phl

PAHL 40/20

Product Features PAHL (preloaded)

- high load stack type actuator using multilayer technique
- integrated preload for dynamic use

Applications

- wafer alignment
- micro-positioning

Recommended Controller

- 30V300 for dynamic applications
- ENV800

These high load stack type actuators from the series PAHL are **internally preloaded** by the use of a mechanical spring. This makes them **ideal for dynamic applications**. These actuators **generate large forces** and can be subjected to high mass loads. So they are particularly useful for machine tools and dynamic scanning systems.

Technical Data

series PAHL	motion (-10/+20)%	resolution open loop	resonant frequency	blocking force	stiffness	dimensions Ød x l
	µm	*nm*	*kHz*	*N*	*N/µm*	*mm*
PAHL 18/20	21	0.04	22	3500	165	Ø20 x 36
PAHL 200/20	200	0.4	2	3500	17	Ø20 x 198

series PAHL

More PAHL-elements?
www.piezosystem.com/pahl

available with integrated measurement system (strain gauge), as vacuum and cryogenic version

Stack Type Actuators Series N

Stack type multilayer actuators ***without housing*** *for high accuracy under* ***high load environmental conditions***

different sizes of N stacks

Product Features (without preload)

- PZT multilayer stack type actuators without housing
- without preload
- motion up to 123 µm
- high stiffness up to 250 N/µm
- unlimited resolution

Applications

- fiber stretching and modulation
- micro-manipulation
- mirror tilt & tip

Recommended Controller

- 30V300
- 12V40

The stack type actuators series N consists of many connected ceramic layers. A **flexible coating** provides a **protection against mechanical stress**. These guarantee a **high reliability for dynamic and long endurance applications**. These actuators have been successfully worked for more than **20 years** in a vast number of applications in the fields of nano metrology, semiconductor, material sciences, scanning applications and much more. Their **high precise performance** makes them an excellent drive element for **system integration**.

Technical Data

Series N	motion (-10/+20)%	resolution	capacitance (±20%)	blocking force	stiffness	dimensions Ød x l or l x w x h
	µm	*nm*	*µF*	*N*	*N/µm*	*mm*
N 2/5 (round form)	2	0.004	0.1	500	250	Ø5 x 5
N 120/S10 (square form)	123	0.25	36.4	3500	28	108 x 12 x 14

Vacuum and cryogenic versions are also available.

Ring Actuators Series R/RA

*The **free inside diameter** makes bare and housed ring actuators suitable for all kind of optical applications*

RA 12/24

Product Features

- **R actuators: without preload**
- **RA actuators with preload**
- motion up to 50 µm
- free inside diameter (9 mm up to 14 mm)
- sub nm-resolution
- **blocking force up to 4000 N**
- µs response time
- flexible epoxy insulation

Applications

- micro positioning
- laser beam steering
- scanning systems for atomic force microscopes
- piezo electrical pumps
- fiber positioning
- laser tuning

Recommended Controller

- 30V300
- NV40/1
- 12V40

Piezoelectric ring actuators series R and RA consist of a large number of contacted ceramic rings. Their **free inside dia-meter** makes them especially suitable for all **optical applications**. Compared to small tube actuators, they reach a doubled extension and a **higher stiffness (up to 330 N/µm)**. The ring actuators of the series RA are available with housing. Series R comes without housing.

Technical Data

Series R/RA	motion ol (-10/+20)%	resolution open loop	resonant frequency	blocking force	stiffness	dimensions Ød2 x Ød1 x l
	µm	*nm*	*kHz*	*N*	*N/µm*	*mm*
R 12/14	12	0.03	-	2000	160	Ø14 x Ø9 x 13.5
RA 50/35	50	0.1	7	4000	80	Ø35 x Ø14 x 77

ol – open loop
Also available with integrated measurement system or as cryogenic version.

Stack Type Actuators Series PA/T and P/S

PA 50/T14

Product Features PA/T (preloaded)
- preloaded stack type actuator with outside threading for easy system integration
- vacuum and cryogenic temperature versions available

Applications
- mirror adjustment
- automation

Recommended Controller
- 30V300
- 12V40

The series PA/T, based on stack type actuators in multilayer design, is **mechanically preloaded** what makes it perfectly suited for **dynamic applications**. These actuators have a **M14 outside threading** that can be used to mount the actuator and lock in its position precisely.

Technical Data

series PA/T	motion (-10/+20)%	resolution	resonant frequency	blocking force	stiffness	preload	dimensions Ød x l
	µm	nm	kHz	N	N/µm	N	mm
PA 35/T14	42	0.08	12	850	20	150	Ø14 x 53
PA 100/T14	105	0.21	4	850	8	150	Ø14 x 107

series PA/T

More PA/T-elements?
www.piezosystem.com/pa-t

P 18/S13

Product Features P/S (preloaded)
- **hermetically sealed** for applications in aggressive and humid environments (up to IP68)
- integrated mechanical preload

Applications
- valve technology
- automation

Recommended Controller
- NV40/1
- 12V40

The actuators of the P/S series are based on multilayer stack type actuators without lever transmission. The construction of the housing is completely **hermetically sealed** and tightly encloses the stack, thereby **avoiding any mechanical play.**

Technical Data

series P/S	motion (±10%)	resolution	resonant frequency	capacitance (±20%)	blocking force	stiffness	dimensions Ød x spanner flats x l
	µm	nm	kHz	µF	N	N/µm	mm
P 18/S08	18	0.03	18	0.5	200	11	Ø8 x Ø7 x 30
P 70/S22	70	0.14	6	21.6	3400	49	Ø22 x Ø20 x 90.5

series P/S

More P/S-elements?
www.piezosystem.com/p-s

Hermetically sealed available according to IP68.

Compact 1-Axis Translation Stages Series PU and PX

PU 65 HR

Product Features PU

- high mechanical stability due to high stiffness
- accurate parallel motion from parallelogram design

Applications

- universal applications for 1D, 2D and 3D systems
- automation

Recommended Controller

- 12V40

The series PU is constructed from a **single metallic part** which includes the flexure guiding system. **Actuators can be used in combination to build a 2D or 3D stage**. These systems are able to generate single axis motion of 40 to 100 micrometers and the internal preload enables them to be **used for dynamic applications**.

Technical Data

series PU	motion (±10%)	resolution	resonant frequency	max. push/pull force	stiffness	dimensions l x w x h
	µm	*nm*	*Hz*	*N*	*N/µm*	*mm*
PU 40	40	0.08	1300	32/3	1	28.5 x 14 x 14
series PX/PU — More PX/PU-elements? ***www.piezosystem.com/px-pu***						
PU 100	100	0.2	340	135/13	1.54	50 x 25 x 25

Also available with integrated measurement system.

PX 400 CAP Vacuum

Product Features PX

- highly compact stages with superior performance
- integrated preload

Applications

- scanning systems
- precision engineering

Recommended Controller

- NV 40/1 CLE

The systems of the series PX are single-axis positioning stages with a **motion range up to 400 micrometers** without mechanical play. The PX Series is **available in OEM, vacuum, and cryogenic configurations**.

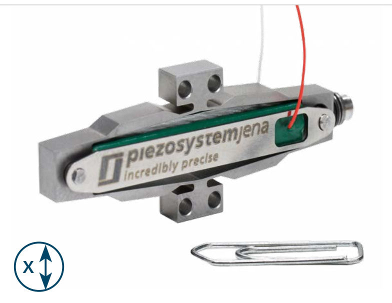
Technical Data

series PX	motion (±10%)	resolution	resonant frequency	max. push/pull force	stiffness	dimensions l x w x h
	µm	*nm*	*Hz*	*N*	*N/µm*	*mm*
PX 38	38	0.07	760	30/3	1	25 x 25 x 18
More PX/PU-elements? ***www.piezosystem.com/px-pu***						
PX 400	400	0.8	200	300/30	1	52 x 48 x 20

CAP – capacitive measuring system
Also available with integrated measurement system.

Products shown in this catalog are only a small part of our full product range. Please check out our web page: *www.piezosystem.com* for the complete series and for detailed information.

Long Distance Linear Actuators PX



PX 500

Product Features PX 500

- travel range: 500 micrometers
- integrated preload for dynamic use
- OEM module with small dimensions

Applications

- scanning systems
- precision engineering
- automation

Recommended Controller

- 12V40

The linear actuator PX 500 **moves precisely and incredibly fast. High frequencies and long travel** can also be reached. Due to its compact design it can easily be integrated for **OEM applications**. The positioners are ideally suited for **micro positioning** of optical components such as mirrors and laser diodes or for opening and closing micro fluid valves.

Technical Data

series PX	motion (±10%)	resolution	resonant frequency unloaded/loaded (12g)	max. push/ pull force	capacitance	dimensions l x w x h
	µm	*nm*	*Hz*	*N*	*µF*	*mm*
PX 500	500	1.2	450/200	35/3	3.6	52 x 20 x 8

Available with integrated measurement system, as vacuum and cryogenic version.

PX 500

More information about the PX 500:
www.piezosystem.com/px500

PX 1500

Product Features PX 1500

- linear motion range 1500 µm
- integrated preload for dynamic use
- small dimensions for easy system integration

Applications

- scanning systems
- precision engineering
- automation

Recommended Controller

- 12V40

The PX 1500 produces a maximum **displacement of 1500 µm**. This actuator is superior in both **dynamic speed and single step resolution** when compared to motorized stages. With its compact dimensions it is also well suited for **OEM applications**.

Technical Data

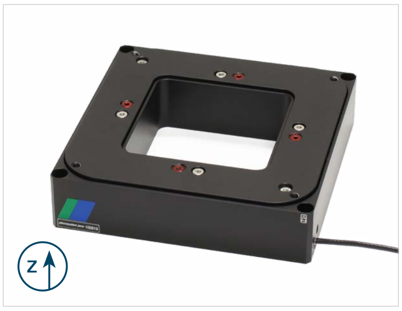
series PX	motion (±10%)	resolution	resonant frequency unloaded/loaded (12g)	max. push/ pull force	capacitance	dimensions l x w x h
	µm	*nm*	*Hz*	*N*	*µF*	*mm*
PX 1500	1500	3	180/150	50/5	7.2	87 x 34 x 13

Available with integrated measurement system, as vacuum and cryogenic version.

PX 1500

More information about the PX 1500:
www.piezosystem.com/px1500

Compact 1-Axis Translation Stages Series PZ and PZ OEM



PZ 700

Product Features PZ

- motion up to 700 µm
- PZ 700 with inside aperture of up to 66 x 66 mm

Applications

- fiber positioning
- laser optics
- scanning systems

Recommended Controller

- 12V40

The series PZ stages are ideally suited for **nm-precise positioning of optic components**; such as mirrors and laser diodes or adjustment in semiconductor technologies. They are also **available in vacuum or cryogenic temperature configurations**.

Technical Data

series PZ	axis	motion (±10%)	resolution open loop	resonant frequency	max. push/ pull force	stiffness	capacitance (±20%)	dimensions l x w x h
		µm	*nm*	*Hz*	*N*	*N/µm*	*µF*	*mm*
PZ 10	z	9	0.02	5000	3150/315	350	3.6	36.5 x 36.5 x 15
series PZ — More PZ-elements? *www.piezosystem.com/pz*								
PZ 700	z	700	1.4	230/185/135*	450/45	0.4	34.8	120 x 120 x 28

*unloaded, 100g load, 300g load
Also available with integrated measurement system (except PZ 10).

PZ 200 OEM

Product Features series PZ OEM

- accurate parallel motion (up to 400 µm)
- motion free of mechanical play with the use of solid state hinges

Applications

- fiber positioning
- laser optics
- automation

Recommended Controller

- 30V300

The series PZ OEM was developed as a special version to the PZ stages. These elements have a **simplistic design** without bottom or top plate and are **easily adapted to other systems**. They have a low mass and can therefore reach **high resonant frequencies**.

Technical Data

series PZ OEM	axis	motion (±10%)	resolution open loop	resonant frequency	max. push/ pull force	stiffness	capacitance (±20%)	dimensions l x w x h
		µm	*nm*	*Hz*	*N*	*N/µm*	*µF*	*mm*
PZ 8 D12	z	8	0.02	3000	38/4	5	0.7	21 x 26 x 15
More PZ-elements? *www.piezosystem.com/pz*								
PZ 400 OEM	z	400	0.8	295	148/15	0.4	13.6	66 x 20 x 24

Also available with integrated measurement system.

High Speed Piezo Translation Stages nanoX

nanoX 200

Product Features nanoX

- linear stroke up to 480 micrometers
- excellent guidance accuracy
- up to 5 N stiffness in z-axis
- high mass loads

Applications

- machine tools
- life science

Recommended Controller

- 30DV50
- 30V300 nanoX

The nanoX series offers fast and **high dynamic performance** due to the exceptional **bidirectional lever transmission design**. For optical laser applications the systems offer a **free aperture of 3mm**.

Technical Data

series nanoX	axis	motion open loop (±10%)	resolution open loop	capacitance (±10%)	max. load	dimensions l x w x h
		µm	nm	µF	N	mm
nanoX 200	x	240	0.4	2 x 2.6	100	52 x 52 x 22
nanoX 400	x	480	0.8	2 x 5.1	50	52 x 52 x 32

Also available with integrated capacitive sensors, as vacuum and cryogenic version

series nanoX

Complete information about nanoX elements:
www.piezosystem.com/nanox

nanoX 240 SG 45°

Product Features nanoX 240 SG

- up to 240 µm range of motion
- integrated position encoder

Applications

- cylinder head inspection system

Recommended Controller

- 30V300nanoX

The one-axis linear positioning stage nanoX 240 SG is a positioning stage **for beam deflecting applications** based on the **ultra fast and precise nanoX technology**. Due to FEA-optimization the stage offers a high dynamic performance and excellent guiding accuracy even under **high loads**.

Technical Data

nanoX 240 SG	axis	motion open (±10%)/ closed loop	resolution open/closed loop	typ. repeatability	stiffness	typ. non-linearity
		µm	nm	nm	N/µm	%
nanoX 240 SG	x	240/200	0.4/4	10	0.3	0.2

SG – strain gauge measuring system
The nanoX is also available in different sizes and with different deflection angles.

nanoX240

Complete information about the nanoX 240 SG:
www.piezosystem.com/nanox240

High-Speed Translation Stage nanoSX and nanoSXY

nanoSX 800 and nanoSX 400

Product Features nanoSX

- travel range up to 900 micrometers
- excellent guidance accuracy
- high speed motion
- temperature compensated

Applications

- scanning systems
- machine tools

Recommended Controller

- 30DV50
- 30V300 nanoX

The nanoSX series provides a **large positioning and scanning range**. With a height of only 10 mm and 20 mm respectively these low voltage linear stages are **exceptionally compact**. Additionally, the nanoSX elements feature a **central aperture of 12.5 mm**.

Technical Data

series nanoSX	axis	motion open loop (±10%)	resolution open loop	capacitance (±10%)	max. load	stiffness (x/y/z)	dimensions l x w x h
		µm	*nm*	*µF*	*N*	*N/µm*	*mm*
nanoSX 400	x	450	0.6	2 x 3.5	100	0.5/5/5	60 x 60 x 10
nanoSX 800	x	900	1.2	2 x 7	50	0.5/3/3	60 x 60 x 20

Also available with integrated measurement system, as vacuum and cryogenic version

series nanoX

For complete information about series nanoX:
www.piezosystem.com/nanox

nanoSXY 400 CAP

Product Features nanoSXY

- up to 450 µm travel range
- higher stiffness and resonance frequency than traditional stage designs

Applications

- high precision positioning
- scanning microscopy

Recommended Controller

- d-Drive
- d-Drive pro

The nanoSXY series provides long travel with **a central aperture of 12.5 mm**. The bidirectional stage offers an excellent **guidance accuracy** which leads to an improved frequency spectrum. Furthermore pressure power and restoring forces depend only on the ceramic force generation.

Technical Data

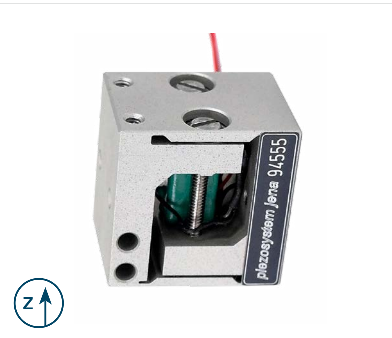
series nanoSXY	axes	motion ol/cl	resolution ol/cl	typ. repeatability	stiffness (x/y/z)	max. load	dimensions l x w x h
		µm	*nm*	*nm*	*N/µm*	*N*	*mm*
nanoSXY 120 CAP	x,y	120/100	0.25/1	±3	0.6/0.6/2.5	50	60 x 82 x 30
nanoSXY 400 CAP	x,y	450/350	0.6/1	12	0.35/0.35/2.5	50	60 x 82 x 30

CAP – capacitive sensor system, ol – open loop, cl – closed loop
Vacuum and cryogenic versions are also available.

Compact 2-Axes Translation Stages Series PXY D12

2-axes nano positioner *series which can be expanded with a z-axis stage to serve* ***AFM applications***

PXY 80 D12



PZ8 D12

Product Features

- motion in x- and y-direction **up to 200 µm**
- **high resonant frequency**
- option: **optimization for minimum z-motion**
- versions with an integrated measurement system available
- position sensor for feedback control

Applications

- scanning systems
- STM and AFM microscopy
- wafer handling
- electronics and robotics

Recommended Controller

- NV 40/3 CLE for open loop / closed loop systems
- d-Drive for closed loop systems
- d-Drive^{pro} for closed loop systems

Options

- z-axis stage (PZ D12 – elements)
- integrated measurement system
- vacuum compatible version
- cryogenic compatible version

Elements of the series PXY D12 are **developed for STM and AFM applications**. These systems are **optimized for high resonant frequency and high stiffness in both axes.** For special applications, the elements can be customized for a minimum **z-motion of less than 30 nm** while moving in the x- and y-directions.

Additionally, the **one-axis piezo stage PZ D12 can be mounted onto this stage**. The PZ D12 provides a motion of 8 µm or 20 µm in the z-direction.

Technical Data

series PXY D12	axes	motion (±10%)	resolution	resonant frequency (x/y/z)	stiffness	dimensions l x w x h
		µm	*nm*	*Hz*	*N/µm*	*mm*
PXY 40 D12	x,y	40	0.08	1100/1300/-	1.5/1.8	54 x 53.5 x 20
PZ 20 D12	z	20	0.04	- /-/1800	3.3	20.5 x 26 x 15

series PXY D12

More PXY D12-elements?

www.piezosystem.com/pxy-d12

ol – open loop, cl – closed loop

Compact 2-Axes Translation Stages Series PXY with Centered Hole

piezo xy positioner constructed with a ***free center hole*** *for optical scanning applications*

PXY 16

Product Features

- 16 µm travel in x- and y-directions
- high resonant frequency
- high stiffness
- minimum z-motion
- central aperture

Applications

- scanning systems with highest z-stiffness and resonant frequency
- ray-/beam deflection

Recommended Controller

- ENV System
- NV 40/3 CLE

The elements in the series PXY OEM were specially developed for **optical scanning applications**. They provide a positioning and scanning range of up to 16 µm.
The design, in parallel kinematics order, results in superior dynamical behavior in x- and y-axis. It also guarantees higher stiffness in all three perpendicular axes with higher responsiveness than conventional systems. Due to FEA-optimization of the PXY OEM stages, they **offer an extremely high dynamical performance** and excellent guiding accuracy.

Technical Data

series PXY	axes	motion open loop (±10%)	resolution	resonant frequency (x/y)	central aperture	weight	dimensions l x w x h
		µm	*nm*	*Hz*	*mm*	*g*	*mm*
PXY 16 OEM	x,y	16	0.04	335/335	Ø 66	900	104 x 104 x 20

Available with integrated measurement system, as vacuum and cryogenic version.

series PXY

More PXY-elements?
www.piezosystem.com/pxy

Products shown in this catalog are only a small part of our full product range. Please check out our web page: *www.piezosystem.com* **for the complete series and for detailed information.**

Compact 2-Axes Translation Stages Series PXY Big Aperture

*XY-axis positioning stages for **industrial nano positioning** and **scanning applications***

PXY 200 SG (strain gauge)

Product Features

- motion range up to 250 µm in x- and y-axis
- central aperture
- high load flexure hinges in parallel design
- integrated feedback sensors
- rapid short settling time because of high stiffness

Applications

- microscopy stage (for light transmitting applications)
- wafer handling and semiconductor
- mask positioning and lithography
- near field scanning and AFM microscopy
- metrology and material sciences

Recommended Controller

- NV 40/3 CLE
- d-Drive
- d-Drive[pro]

Many applications like microscopy applications often require a nano positioning element with **a high level of positioning accuracy, high guidance accuracy** and a central aperture. The systems of series PXY combine these characteristics in a compact stage with a **large motion range up to 250 µm in the x and y directions**. The special design of the **FEA optimized** flexure hinges enables the stage to reach the **shortest settling time** and reduces the lateral runout in the z-axis down to a few nanometers. Its unique scanning performance can be reached even with **high loads** mounted on top of the stage (max. load: **up to 100 N**).

Technical Data

series PXY	axes	motion open loop (±10%)	resolution	capacitance per axis (±20%)	central aperture	weight	dimensions l x w x h
		µm	nm	µF	mm	g	mm
PXY 36	x,y	36	0.07	3.6	50 x 50	700	100 x 100 x 25
PXY 201	x,y	250	0.5	3.5	30 x 30	300	74 x 74 x 24

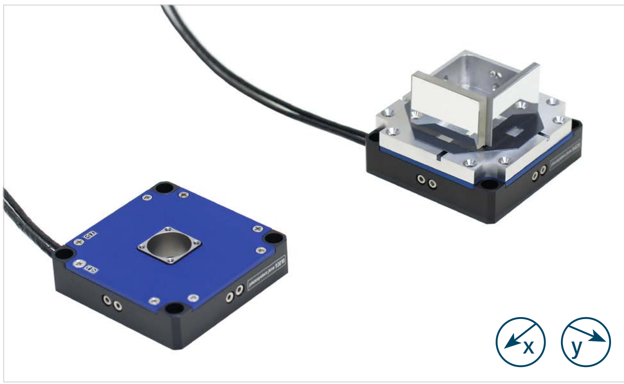
series PXY

More PXY-elements?
www.piezosystem.com/pxy

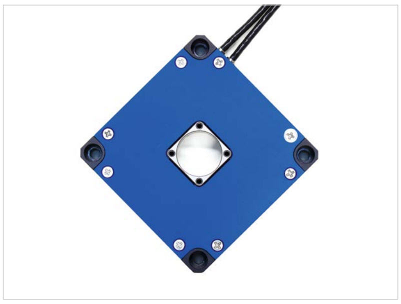
Available with integrated measurement system, as vacuum and cryogenic version.

Compact 2-Axes Translation Stage ScanXY 40

*2D scan and positioning stage providing **speed and low settling time** for nm-precise positioning tasks*



ScanXY 40 and ScanXY 40 with customized setup.



ScanXY 40 top view

Product Features

- 2D motion in XY
- **40 µm travel range per axis**
- motion without mechanical play
- 1.4 kHz unloaded resonant frequency
- lowest settling time
- large central opening

Applications

- mirror and lens positioning
- 2D-scanning systems
- beam alignment
- semiconductor
- micro manipulation

Recommended Controller

- ENV system
- d-Drive
- d-Drive^pro

The ScanXY 40 piezoelectric actuating stage is mainly designed to fulfill requirements for **2D scanning applications**. Exceptional characteristics are a **high resonant frequency and a low settling time** in compact design. These are important characteristics for semiconductor technologies, opto-electronics, measurement technologies and quality assurance as well as microbiology. The x- and y-axis of the 2D piezo scanner can be controlled separately. Both axes are positioned orthogonally to each other.

Technical Data

series ScanXY	axes	motion (±10%)	resolution	stiffness x/y	resonant frequency	dimensions l x w x h
		µm	*nm*	*N/µm*	*Hz*	*mm*
ScanXY 40	x,y	40	0.1	1.1	1430	58 x 58 x 15

series Scan XY

Complete Information about the Scan XY:
www.piezosystem.com/scan

3-Axes Positioner TRITOR Series

*Compact 3D nanopositioner with **motions of 9 µm up to 400 µm** in all 3 axes*

microTRITOR (size comparison with golf ball)

TRITOR 38 Vacuum

Product Features

- 3-axes positioner
- high resolution in nm and sub-nm range
- high repeatability due to positioning sensors
- motion up to 400 µm
- parallel motion without mechanical play

Applications

- optics, laser tuning, fiber positioning
- micro manipulation
- scanning systems
- semiconductor technology
- life science

Recommended Controller

- NV 40/3 CLE

The piezo elements of the TRITOR series are designed to **position in 3 dimensions on the smallest possible area** with simultaneously extreme resolutions, high resonant frequencies and blocking forces up to 100 N. As an option, **integrated positioning systems** are available to overcome creep and hysteresis.
TRITOR elements can be easily combined with other mechanical positioning systems.

Technical Data

series TRITOR	motion (x,y,z) ol (±10)%	resolution	resonant frequency x/y/z	blocking force x/y/z	stiffness x/y/z	dimensions l x w x h
	µm	nm	Hz	*N*	*N/µm*	*mm*
microTRITOR	9	0.02	2100/2230/2290	10/10/10	1/1/1	15 x 15 x 15
TRITOR 400	400	0.8	180/280/140	120/120/100	0.3/0.3/0.25	116 x 106 x 40

series TRITOR

More TRITOR-elements?
www.piezosystem.com/tritor

Available with integrated measurement system, as well as vacuum and cryogenic versions.

Please check out our web page: ***www.piezosystem.com*** for the complete series and for detailed information.

PENTOR 5-Axes Nanopositioning System

*5-axes piezo **positioner with 17 mm aperture** for optic and microscopy applications*

PENTOR

Product Features

- combination of a 3-axes translation system and 2-axes tilting system
- central aperture with 17 mm diameter
- integrated preload
- translation each axis: 100 µm
- tip/tilt each direction: ±2 mrad

Applications

- scanning
- micro positioning
- life science
- beam steering

Recommended Controller

- d-Drive
- d-Drive[pro]

The translation and tilting system PENTOR with **free central aperture** is developed especially for applications which require a central opening as in optical setups. It offers a **motion in XYZ of 100 µm and a tilt of ±2 mrad on any two orthogonal axes**. Flexure hinges for the three translation axes guarantee the highest degree of parallelism over the travel range of the stage. **Each axis has an integrated mechanical preload**, making the PENTOR system very well suited for precise high resolution movements. **The construction of the tilting part of the stage is temperature compensated**: therefore changes in the surrounding temperature do not affect the tilting angle.

Technical Data

series PENTOR			translation (x,y,z)		angular movement (Θx,Θy)	
	axes	capacitance per axis (±20%)	motion per axis ol (±10%)/ cl (±0.2%)	resolution ol/cl	motion per axis ol (±10%)/ cl (±0.2%)	typ. non-linearity
		µF	µm	nm	mrad	%
PENTOR	x,y,z,Θx,Θy	1.7	100/-	0.2/-	Θx,Θy ±2	-
PENTOR SG	x,y,z,Θx,Θy	1.7	100/80	0.2/2	Θx,Θy ±2/±1.6	Θx 0.18,Θy 0.13

SG – strain gauge measurement system
ol – open loop, cl – closed loop

PENTOR

Complete Information about the PENTOR:
www.piezosystem.com/pentor

1-Axis Mirror Tilting Platform Series PSH

PSH 4/1

PSH 35/1

1-dimension tilting system ideally suited for applications which require ***extremely high angular resolution***

Product Features

- **tilt angle up to ±20 mrad**
- **high dynamics** due to a high resonant frequency
- mirror mounting adapter for flexible use
- sub-µrad resolution
- compact size

Applications

- high frequency scanners
- laser alignment
- beam deflection

Recommended Controller

- ENV 300 nanoX amplifier
- ENV 300 for PSH 35

The piezo tilting systems of the series PSH have been developed for the **fast and precise positioning of mirrors, with settling times in the µs range**. The drive sections in the solid state flexure hinge design generate motion without mechanical play.

Special feature of the series PSH:

- PSH 4/1 **high resonant frequency of more than 6.5 kHz with very short settling time**
- PSH 15/1 developed for **1''** components
- PSH 35 ideally suitable for **dynamic motion of small mirrors**

Technical Data

series PSH	axis	tilt ol (±10%)/ cl (±0.2%)	resolution ol/cl	resonant frequency	typ. repeatability	weight	dimensions l x w x h
		mrad	*µrad*	*Hz*	*µrad*	*g*	*mm*
PSH 4/1	Θx	±2/-	0.008/-	6500	-	20	Ø12 x 20
PSH 35/1	Θx	35(2°)/26	0.07/0.7	1200	3	65	60 x 20 x 27

series PSH

More PSH-elements?
www.piezosystem.com/psh

ol = open loop, cl = closed loop
available with integrated measurement system (strain gauge)

Products shown in this catalog are only a small part of our full product range. Please check out our web page: *www.piezosystem.com* for the complete series and for detailed information.

2-Axes Mirror Tilting System Series PSH x/2

PSH 5/2

PSH 10/2 Vacuum

Product Features PSH x/2

- dynamic tilting systems
- tilting up to ±5 mrad
- temperature compensated

Applications

- beam steering
- scanning processes

Recommended Controller

- d-Drive
- d-Drive[pro]
- ENV 800 nanoX CLE

The PSH x/2 stages **tilt mirrors or optics up to 1" diameter up to ±4 mrad around the x- and y-axes**. The mirror mounts are preloaded. Due to the high resonant frequency these actuators are **very well suited for dynamic applications.**

Technical Data

series PSH x/2	axes	tilt ol (±10%)/ cl (±0.2%)	resolution open loop	resonant frequency (unloaded)	dimensions l x w x h
		mrad	*µrad*	*Hz*	*mm*
PSH 5/2	Θx, Θy	±2.5/±2	0.01	3600	22 x 22 x 29.5
PSH 10/2	Θx, Θy	±5/±4	0.02	3500	22 x 22 x 47.5

ol – open loop, cl – closed loop
Also available with integrated measurement system. (strain gauge)

series PSH-x2

Complete information about series PSH x/2:
www.piezosystem.com/psh-x2

PSH 25/2

Product Features PSH 25/2

- sub µrad resolution
- **tilting range of up to ±20 mrad**
- for dynamic applications

Applications

- laser scanning
- image processing and stabilization

Recommended Controller

- d-Drive
- d-Drive[pro]
- ENV 800 nanoX CLE

The PSH 25 SG OEM is characterized by the **positioning of optical components in two axes**. It has a tilting range of ±20 mrad in open loop. Optics and optical components with a diameter up to 25.4 mm (1") can be easily mounted to its platform.

Technical Data

series PSH 25/2	axes	tilt ol (±10%)/ cl (±0.2%)	resolution open loop	capacitance	resonant frequency (unloaded)	dimensions l x w x h
		mrad	*µrad*	*µF*	*Hz*	*mm*
PSH 25/2	Θx, Θy	±20/±16	0.1	1.6	1400	60 x 60 x 40.5

ol – open loop, cl – closed loop
Also available with integrated measurement system. (strain gauge)

PSH 25

Complete information about the PSH 25/2:
www.piezosystem.com/psh25

2-Axes Mirror Tilting System Series PKS 1

Mirror tilting system developed for
fast and fine mirror adjustment

front view of PKS 1

back view of PKS 1

Product Features

- orthogonal tilting axes
- high resonant frequency due to high stiffness
- applicable to vacuum conditions
- piezo driven fine adjusting range of 1 mrad
- coarse adjustment angle of ±2°
- compact design

Options

- diverse versions for 1/2'' and 1'' mirrors

Applications

- laser techniques
- beam alignment
- scanning systems

Recommended Controller

- 12V40

This system can perform corrections, and high precision adjustments to a laser within microseconds. A compact design based on two orthogonal tilting axes and a high stiffness offer a **resonant frequency of 450 Hz** in combination with a **fine resolution of 2 nrad**. The system combines the coarse manual adjusting angle of ±2° with the piezo drive for a **fine adjustment of 1 mrad**.
A mirror (Ø12.7 mm and Ø25.4 mm) can be mounted easily by using the set screw or can be fixed directly to the stage.

Technical Data

series PKS	axes	tilting angle open loop	resolution open loop	resonant frequency	weight	dimensions l x w x h
		mrad	*µrad*	*Hz*	*g*	*mm*
PKS 1	Θx, Θy	1	0.002	450	84	48 x 31 x 36

series PKS

Complete information about the PKS1:
www.piezosystem.com/pks

3-Axes Mirror Tilting Platform Series PSH 1(z) – 4(z)

*PSH 1(z)-4(z) allow for **the tilting of mirrors in 3 axes up to 4 mrad** and optionally platform motion in the z-axis of up to 33 µm*

PSH 1

PSH 2za vacuum

Product Features

- developed for fast scanning and moving of mirrors
- 2 active axes, z-version: 3 active axes

Applications

- laser beam steering
- laser scanning

Recommended Controller

- NV 40/3 (CLE) (open/closed loop)
- d-Drive
- d-Drive^{pro}

The PSH 1 to PSH 4 systems have three working PZT actuators to tip/tilt and move the top plate in 3 directions (tilting range up to 4 mrad and optionally lateral **motion up to 33 µm in z-axis**). With regard to tilting **their construction is temperature compensated** so that changes in environmental temperature do not affect the tilting angle.

Technical Data

series PSH	axes	tilting angle ol (±10%)/ cl (±0.2%)	typ. resolution	top plate size A	top plate size B	z-motion	dimensions l x w x h
		mrad	*µrad*	*mm*		*µm*	*mm*
PSH 1 (z)	Θx, Θy, z	1/0.8	0.002	25/25	38/38	8	25 x 25 x 24

series PSH

More PSH-elements?
www.piezosystem.com/psh1-4

PSH 4 (z)	Θx, Θy, z	4/3.2	0.008	25/25	38/38	33	25 x 25 x 51

ol – open loop, cl – closed loop
available with integrated measurement system (strain gauge)

Microscope Objective Systems nanoMIPOS & MIPOS

nanoMIPOS 200

Product Features nanoMIPOS

- up to 400 µm focusing range and sub-nm step width
- integrated capacitive feedback sensor available
- lens positioning system
- temperature compensated
- optimized for dynamic use

Applications

- scanning microscopy
- biotechnology

Recommended Controller

- 30DV50

The series nanoMIPOS is developed for **nanometer precise adjustment of microscope objectives**. Further advantages of these actuators are that they **can be driven dynamically** and they are **temperature compensated**. They offer **outstanding** guidance accuracy with almost no parasitic motion as well as a high resonant frequency.

Technical Data

series nanoMIPOS	axis	motion ol (±10%)/cl (±0.2%)	resolution	max. lens diameter	typ. tilt (at full motion)	dimensions l x w x h
		µm	*nm*	*mm*	*µrad*	*mm*
nanoMIPOS 200	z	250/200	0.5	60	20	93.5 x 70 x 65
nanoMIPOS 400	z	400/320	0.8	39	<5	65 x 45 x 40

ol – open loop, cl – closed loop
also available with measurement system (capacitive)

series MIPOS

More MIPOS-elements?
www.piezosystem.com/mipos

MIPOS 100 SG with mounted objective

Product Features MIPOS

- parallelogram design
- high resonant frequency
- easy to attach to any microscope

Applications

- surface scanning and analysis
- semiconductor test equipment

Recommended Controller

- NV 40/1 CLE

The piezo elements of the MIPOS series are designed to **precisely adjust microscope objectives**. The high position resolution makes the series MIPOS especially **well suited for "single photon" or "super resolution microscopy"**. MIPOS systems are being used for **STED microscopy** for which the **Nobel Prize was awarded in 2014**.

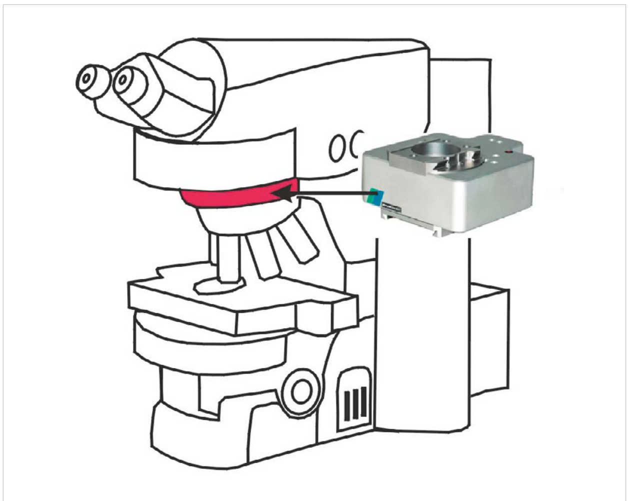
Technical Data

series MIPOS	motion (-10/+20%)	resolution open loop	resonant frequency 0 g/300 g	capacitance (±20%)	stiffness	dimensions l x w x h
	µm	*nm*	*Hz*	*µF*	*N/µm*	*mm*
MIPOS 20	20	0.04	950/240	0.7	4	54 x 32 x 32.5
MIPOS 500	500	0.9	230/110	21	0.27	60.5 x 50 x 40.1

available with integrated measurement system, vacuum and cryogenic versions are also available

Microscope Objective/Lens Positioning Systems

MIPOS R120



MIPOS R120 installed on a microscope

Piezoelectric positioning system for ***moving of the complete microscope revolver*** *compatible with all major brands*

Product Features MIPOS R120
- **precise movement of the lens revolver**
- 150 µm focusing range
- high resonant frequency
- precise motion without tilt
- **maximum load of up to 5 kg**

Options
- integrated positioning sensor for active tilt correction

Applications
- confocal and ultra high resolution microscopy
- semiconductor equipment
- surface analysis
- biotechnology (e.g. cell inspection)

Recommended Controller
- NV 120/1 CLE

The MIPOS R120 is designed to focus and position microscope objectives. As a highlight the operator can **switch between the lenses of the objective revolver without changing the set-up or losing the fixed point on the probe**. A highly parallel movement **is guaranteed** without influencing the optical axis due to the well proven parallelogram principle and integrated preload. With its very compact yet robust design, the MIPOS R120 is able to **carry an objective revolver with a load of up to 5 kg**.

Technical Data

MIPOS R120	axis	motion ol (±10%)/cl (±0.2%)	resolution ol/cl	resonant frequency @ 0 g/5000 g	max. load	dimensions l x w x h
		µm	*nm*	*Hz*	*N*	*mm*
MIPOS R 120 CAP	z	150/(120)*	0.3/(1)*	300/80	50	100 x 100 x 26

ol – open loop, cl – closed loop
CAP – capacitive measurement system
*available with integrated measurement system (capacitive or strain gauge)

MIPOS R120

Complete information about the MIPOS R120:
www.piezosystem.com/r120

Special System – Piezo Micrometer Screw Drive MICI

MICI 80 SG

MICI 180 with micrometer screw

***Hybrid element** that combines the advantages of a **long travel** of micrometer screws with the **fine positioning resolution** of a piezo stage*

Product Features

- **motion up to 250 µm**
- high resonant frequency
- high precision adjustment of linear positioner
- motion without mechanical play

Applications

- increased resolution of linear stages
- quality control
- automation
- fine adjustment of optical components

Recommended Controller

- 12V40

These elements were originally **developed for quality control applications** in the optics industry. They consist of a piezoelectric actuator in combination with a micrometer screw drive. The user can first adjust the coarse position of the actuator, and then do the fine tuning with the piezo stage. **Long travels and sub-nm resolution** can be reached. Due to a very **robust construction**, the element is capable of **moving high loads.**

Technical Data

OEM MICI systems	motion ol (±10%)/cl	resolution ol/cl	resonant frequency without micrometer drives	stiffness	max. push/pull force	dimensions l x w x h
	µm	*nm*	*Hz*	*N/µm*	*N*	*mm*
MICI 80 (SG)	80/(66)	0.1/(2)	990	1.8	170/17	64 x 27 x 33.5
MICI 200 (SG)	250/(200)	0.56/(6)	330	0.46	110/11	85 x 28 x 36.5

series MICI

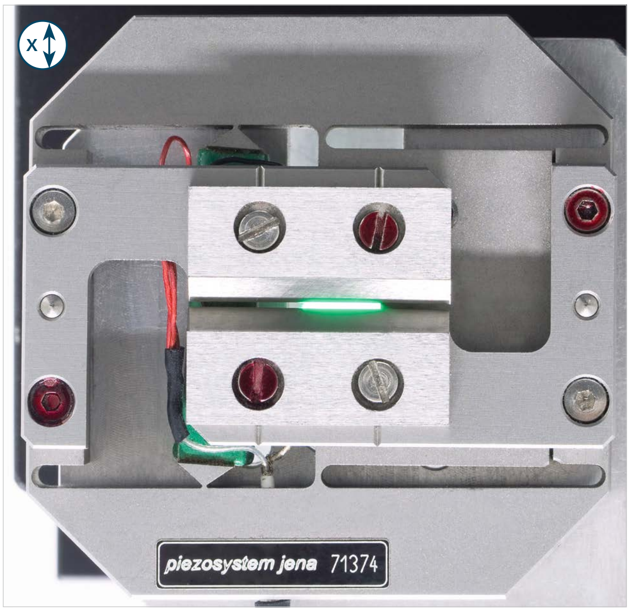
More MICI-elements?
www.piezosystem.com/mici

ol – open loop, cl – closed loop, (SG) - with strain gauge measuring system available as vacuum and cryogenic version

Products shown in this catalog are only a small part of our full product range. Please check out our web page: *www.piezosystem.com* for the complete series and for detailed information.

Special Systems – Shutter/Slit System PZS

PZS 3 – great gap- highly precise adjustable



PZS 4 slit system with synchronized edges

*Piezo slit system with an **opening from 60 µm up to 1500 µm** through 2 adjustable slit edges*

Product Features

- **symmetrical motion of 2 slit edges**
- driven by only one piezo actuator
- opening up to 1500 µm (PZS 3)
- **precise nm resolution**
- vacuum compatible version
- **optional measurement feedback system**

Applications

- spectroscopy
- optics
- shutters and scanners
- optical switches
- laser beam collimation

Recommended Controller

- NV 40/1 CLE

Options

- different body and slit edge materials (stainless steel, invar)
- UHV compatible version
- available as opening or closing versions

The **piezo-slit/shutter stages** use two slit edges driven by a single piezoelectric actuator. They are constructed with solid state flexure hinges, arranged within a parallelogram design. This principle ensures a **synchronized motion of the two slit edges** with respect to each other. To avoid the influence of hysteresis, creep and temperature effects, the piezo slit can be **equipped with a strain gauge measurement system**. This feedback system provides a **positioning accuracy of 0.2% or better.**

Technical Data

series PZS	opening ol (±10%)/ cl (±0.2%)	resolution ol/cl	resonant frequency	capacitance (±20%)	aperture	dimensions l x w x h	advantage
	µm	*nm*	*Hz*	*µF*	*mm*	*mm*	
PZS 1 (SG)	0 to 230/190	0.5/3	450	1.8	Ø8	42 x 42 x 14	dynamic
PZS 2 (SG)	0 to 60/50	0.01/0.8	1400	0.7	Ø4	22 x 22 x 9.5	ultra compact
PZS 3	0 to 1500/-	3/-	200	7.2	9 x 4	96 x 25 x 14	great gap – highly precise adjustment
PZS 4 (SG)	0 to 300/240	0.6/8	500	2.5	Ø10	50 x 50 x 14	dynamic

ol – open loop, cl – closed loop, (SG) - version with strain gauge measuring system
available as vacuum or cryogenic version

series PZS

For complete information about series PZS:
www.piezosystem.com/pzs

High Resolution Rotary Piezo Stage ROTOR 10

1-Axis Rotary Stage, nearly unlimited resolution with ***high planar guiding accuracy***

ROTOR 10 SG

Product Features

- **rotary motion up to ±5.5 mrad**
- high dynamic performance
- high planar motion
- **resolution: 0.02 µrad**
- **3 mm free aperture**
- integrated temperature compensation

Applications

- fiber alignment
- precision adjustment for biological instruments
- material science/crystallography
- laser beam steering
- sensor scanning

Recommended Controller

- 30DV50 OEM
- ENV system; NV 40/1

The piezoelectric based rotary stage ROTOR 10 is a one axis low voltage rotary stage. The piezo element provides a **scanning range of up to ±5.5 mrad**. A key feature for all piezo mechanically driven stages is the **nearly unlimited position resolution**. Another benefit is the well-defined axis of rotation which is centrically located. A free aperture also makes these stages **useful for axial beam applications**.

Technical Data

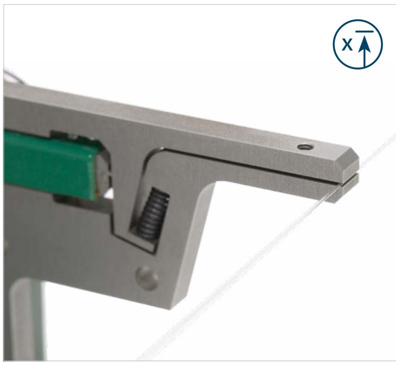
series ROTOR 10	active axis	motion ol (±10%)/cl (±0.2%)	resolution ol/cl	resonant frequency	rotation error Θx/Θy	dimensions l x w x h
		mrad	*µrad*	*Hz*	*µrad*	*mm*
ROTOR 10 (SG)	Θz	11/9	0.02/0.2	500	35/35	42 x 42 x 23

ol – open loop, cl – closed loop
also available with strain gauge (SG) measuring system, for vacuum and cryogenic applications.

piezo ROTOR

Complete information about the piezo ROTOR:
www.piezosystem.com/rotor10

Piezo Driven Gripper System



GRIPPY 3

Fiber Gripper

*Piezoelectric actuator based **gripper system** for **micro positioning and handling** applications comes in a **very compact design***

Product Features

- up to 300 µm gap motion
- adjustable grip force
- high speed
- compact dimensions
- own tools and instruments mountable
- variable gap shape design

Applications

- micro optics manipulation
- fiber optics assembly
- precision mounting and adjusting
- biological sample manipulation

Recommended Controller

- 12V40

The Piezo grippers are designed for **applications** such as the **handling of micro systems**. The accurate and high speed motion of a piezo actuator is achieved by the levered transmission of a **solid state hinge flexure** to a **300 µm opening** of the gripper. Because of its compact dimensions, it is well suited for **OEM applications**. The mechanical design dimensions and fixing points can be **adjusted upon customer's request. Handling and manipulating of small parts in research labs or industry** are excellent application fields for the piezo gripper.

Technical Data

piezo gripper	free gap	free gripper motion (±10%)	capacitance (±20%)	weight	dimensions l x w x h
	mm	*µm*	*µF*	*g*	*mm*
GRIPPY 3	0.3	275	0.8	25	54.5 x 38 x 7
Fiber Gripper	0.4, adjustable range*	300	1.7	23	58 x 12 x 15

*other diameters available upon request

Gripper

Full information about piezo gripper elements:
www.piezosystem.com/gripper

Motion Control - Rotary Stages - NEW

We offer systems with an excellent ratio between price and performance for long travel in rotation or translation.

ROTOR RA-55-40 with controller MC-101-01

ROTOR RA-100-30

Rotary stage for probe positioning and handling, working as stepper and/or continuous rotation

Product Features

- continuous rotation
- max. rotation speed up to 770°/s
- max. 32’768 steps per rotation ≙ 40 arcsec
- no backlash (RA-55-40)
- encoders for closed loop available

Applications

- probe handling
- probe positioning
- research and development
- laboratories
- industry

Recommended Controller

- MC-101-01 (only for RA-55-40)
- MC-201-01

The rotary stages RA-xx use a stepping motor for **long travel positioning**. The rotary stage is accompanied by a regulating electronic. This electronic can control all important parameters for the use of the stage such as current position, velocity, acceleration and torque. Optionally, the stage can be equipped with a **home reference** which enables the actuator to **reach the starting point from any position**, no matter how many movements it has performed.

Technical Data

Rotary Stages	axis	max. rotation speed	repeatability	max. load	dimensions Ø x h
		°/s	arcsec/µrad	kg	mm
RA-55-40	Θz	770	±36/±175	0.5	Ø50 x 40
RA-100-30	Θz	20	18/0.09	45	Ø100 / Ø30 x 45

available with integrated positioning encoder

Motion Control - Linear Stages - NEW

Linear stage LA-90-50

Linear stages for probe positioning and handling, working as stepper and/or continuous translation

Product Features
- translation up to 50 mm
- max. speed 40 mm/s
- encoder for closed loop available

Applications
- probe handling, probe positioning
- research and development
- laboratories
- industry

Recommended Controller
- MC-201-01

The linear stages LA-xx are one-axis positioners which can move masses up to 20 kg. They have a robust, flat design. Combined with the controller MC-201-01 this linear stage can be **controlled in position, velocity, acceleration and even more**. Furthermore it has an outstanding value for money ratio.

Technical Data

Linear Stages	axis	travel	max. speed	repeatability	max. load	dimensions l x w x h
		mm	*mm/s*	*µm*	*kg*	*mm*
LA-40-36	x	36,5	40	±5	6.1 (dyn.)/3.2 (stat.)	156 x 40 x 22
LA-90-50	x	50	10	±5	20 (hor.)/3 (vert.)	245 x 90 x 44

available with integrated positioning encoder

Linear Stages

More Linear Stages?
www.piezosystem.com/linear

Motion Control - Goniometer - NEW

Goniometer GA-65-30

Goniometer stages for probe positioning and handling, working as stepper and/or continuous translation

Product Features

- rotation radius 50 mm
- max. speed 7°/s
- max. tilt angle ±15°
- with included Encoder for closed loop available

Tilting range up to ±15°, combined with a precision of 0.03 mm. These are amazing specs of the goniometer. The stage is driven by a **stepper motor**, which is equipped with a worm gear. Furthermore the GA-65-30 **can be combined with other positioning systems** like piezoelectric stages or actuators.

Technical Data

Goniometer	axis	angle	max. speed	repeatability	max. load	dimensions l x w x h
		°	°/ s	arcsec	kg	mm
GA-65-30	Θy	±15	7	±4	5	169 x 76.5 x 44

available with integrated positioning encoder

Goniometer

More information about the Goniometer:
www.piezosystem.com/gonio

Products shown in this catalog are only a small part of our full product range. Please check out our web page: *www.piezosystem.com* for the complete series and for detailed information.

Electronic Digital System: d-Drive^{pro}

High performance** digital controller for piezo actuators providing **24 bit resolution and synchronized 3-axes regulation

d-Drive^{pro}

Applications

- Scanning applications
- Nano positioning

Product Features

- highest resolution: 24 bit
- integrated wave generator (arbitrary, vector)
- parallel processing of the converter data
- trigger output
- freely programmable frequency generator
- synchronous 3-channel-modulator with 120 mA continuous current
- single channel can be expand to 300 mA
- slew rate, notch and low pass filter
- **Automatic Sensor Identification (ASI)**
- **Automatic System Calibration (ASC)**
- supply for external sensors
- compatible instruction set to d-Drive®

Options

- trigger input
- detection of the specific resonant frequency
- real time curve tracking
- digital input/output
- charge controlled operation of the piezo actuators
- temperature monitoring at the actuator
- expandable interfaces (CAN, RS485, RS422)

With the d-Drive^{pro} ***piezosystem jena*** offers its customers an innovative, efficient digital controller. The **storage of user specific functions** makes it now possible to work in arbitrary or vector mode. **Step functions as well as precise defined functions** can be realized and enables the d-Drive^{pro} for a wide range of applications. The integrated Field Programmable Gate Array (FPGA) provides **parallel processing of converter data with a sampling rate up to 200 kHz** of all measurement inputs. Additionally the d-Drive^{pro} can be equipped with a trigger input and output.

Technical Data

d-Drive^{pro}	unit	19'' rack/ desktop casing
output voltage	*V*	-20 ... +130 (+130 … -20 for nanoX actuators)
output current (continuous)	*mA*	3 x 120, (6 x 60 for nanoX actuators)
voltage noise (RMS @ 500 Hz)	*mV*	**< 0.15**
modulation input	*V*	0 … +10 (disconnectable)
input impedance	*kΩ*	100
monitor output	*V*	0 … +10 (programmable signal source)
monitor output, typ. impedance	*Ω*	50
resolution (oversampling)	*bit*	24
safety functions	-	over temperature protection, short circuit proved
features	-	slew rate, notch filter, low pass filter, integrated function generator (sine, triangular, square, arbitrary, vector function), different trigger functions, automatic sensor identification, automatic system calibration

d-Drive^{pro}

Specific and detailed information about the d-Drive pro: ***www.piezosystem.com/d-drive-pro***

Electronic Digital System: d-Drive

Series d-Drive digital piezo controller designed for up to 6 channels featuring ***ASI - Automatic Sensor Identification function***

d-Drive

Product Features

- controlled by PC or via front panel
- 20 bit resolution
- system includes 19'' casing with 2 power classes, USB-Interface module EDS and Piezo amplifier, series EVD
- modular for up to 6 channels
- **Automatic Sensor Identification (ASI)**
- **Automatic System Calibration (ASC)**
- several drivers available

Applications

- nano positioning and scanning applications
- scanning and microscopy

The d-Drive system combines highest positioning accuracy with unique handling comfort. All features can be **controlled via PC** and main functions can be regulated directly on the front panel.
The modular setup allows custom configurations according to the needs of individual applications.

Typically a controller consists of
- Casing with an integrated wide range power supply (100-240 V/50-60 Hz)
- Amplifier module for each axis (dependent on the required power)
- Interface module EDS 2 (optional without display: EDS 1)

Technical Data

d-Drive	unit	EVD 50	EVD 125	EVD 300
output voltage	*V*	-20 … +130 V (+130 … -20 V for nanoX actuators)		
output current (continuous)	*mA*	50 (2 x 50 for nanoX actuators)	125 (2 x 125 for nanoX actuators)	300 (2 x 300 for nanoX actuators)
output voltage noise (RMS @ 500 Hz)	*mV*	**< 0.3**	**< 0.5**	**< 0.5**
modulation input	*V*	0 … +10 (disconnectable)		
input impedance	*kΩ*	25		
monitor output	*V*	0 … +10 (programmable signal source)		
monitor output impedance typ.	*Ω*	50		
resolution (oversampling)	*bit*	20		
safety functions	-	over temperature protection, short circuit proved		
features	-	slew rate, notch filter, low pass filter, integrated function generator (sine, triangular, square function), different trigger functions, automatic sensor identification, automatic system calibration		

d-Drive

Specific and detailed information about the d-Drive: ***www.piezosystem.com/d-drive***

for EVD series:
www.piezosystem.com/evd

1 Channel Digital OEM Piezo Controller

Fully programmable 1 channel digital controller ***for use as single unit in industrial applications***

30DV50 OEM

Product Features

- 1 channel digital piezo controller
- output voltage from -20…+130 V DC
- **output current up to 300 mA (30DV300)**
- 64 MHz processor
- 20 µs sampling in closed loop mode
- **Automatic Sensor Identification (ASI)**
- **Automatic System Calibration (ASC)**
- for strain gage and capacitve sensor systems
- built in function generator
- programmable slew rate

Applications

- digital control of piezo actuating systems in Industrial and laboratory settings for automatic control of high resolution nano-positioning applications

Our digital amplifiers 30DV50 and 30DV300 **automatically read data for the actuator system**. Namely; motion, capacitance, strain gauge measurement feedback, and resonant frequency. The 30DV300 has been specifically designed for use with currents up to 300 mA. **A unique feature** of these controllers is that they can be used in combination with strain gauges, LVDT or capacitive feedback sensors.

Technical Data

	unit	30DV50	30DV300
output voltage	*V*	-20 … +130	
output current	*mA*	50	300
output voltage noise (RMS @ 500 Hz)	*mV*	**< 0.3**	
modulation input	*V*	0 … +10	
input impedance	*kΩ*	25	
monitor output	*V*	0 … +10	
monitor output impedance	*Ω*	1	
resolution	*bit*	20	
interfaces	-	RS232	
safety functions	-	over temperature protection, short circuit proved	
features		integrated function generator, Automatic Sensor Identification (ASI)	

30DV50

30DV300

Specific and detailed information about the 30DV50 Controller: ***www.piezosystem.com/30dv50***

For 30DV300: ***www.piezosystem.com/30dv300***

Low Noise Analog System ENV – 0.3 mV!

***Plug-in-system** with **one or more** amplifier modules*

ENV modular system

Versions

- ENV 40 motion with highest resolution
- ENV 300 flexible system for higher dynamic work
- ENV 800 high dynamic work for high load actuators

Product Features

- modular multi channel amplifier system
- fast and high power analog piezo amplifier
- table top casing or 19’’-rack mount system
- separate input and output for each channel
- inside space 42 to 84 HP

Applications

- multi-axes actuator
- high frequency applications (ENV 300 and above)
- automated processes in engineering
- precision alignment in optical applications

The system ENV can be easily customized with **different casings**, the main **supply module ENT**, the **piezo amplifier module ENV** and the **PC interface EDA**.
A display shows the output voltage and, if used with a measurement system and closed loop module, **it presents the calibrated motion**. Different **modules for open loop/closed loop** are available, as well as the common types of PC interfaces.
The system can realize high resolutions in nm and sub-nm range due to its very low noise characteristics.

Technical Data

series ENV	unit	ENV 40	ENV 300	ENV 800 nanoX CLE
output voltage	*V*	-10 … +150	-20 … +130	-20 … +130
output current (continuous)	*mA*	40 (2 x 40 with nanoX)	300 (2 x 150 with nanoX)	800 (2 x 400 with nanoX)
output voltage noise (RMS @500 Hz)	*mV*	**< 0.3**	**< 0.3**	**< 0.3**
modulation input (BNC connector)	*V*	0 … +10	0 … +10	0 … +10
modulation input impedance	*kΩ*	10	10	10
monitor output (BNC connector)	*V*	-1 … +15 (ol) 0 … 10 (cl)	-2 … +13 (ol) 0 … +10 (cl)	-2 … +13 (ol) 0 … +10 (cl)
monitor output impedance	*kΩ*	100 (ol) < 35 (cl)	100 (ol) < 1 (cl)	100 (ol) < 1 (cl)
DC voltage offset	-	adjustable via potentiometer	adjustable via potentiometer	adjustable via potentiometer

ol – open loop, cl – closed loop

series ENV

More ENV-systems?
www.piezosystem.com/env

Electronic Interface Board Series EDA

EDA 4

Interface board with micro-controller
*for **automation of positioning processes**, data acquisition and control of analog modular system ENV*

Product Features

- AD/DA interface boards
- 4 channel DAC
- 4 channel ADC
- 128k Flash on-board programmable
- comes with demo program for Windows
- easy access via terminal program

Applications

- PC control of analog amplifiers
- automatic process control
- PC independent system control

The EDA interface module universal I/O board is designed as a **19'' slot card** which **records measurement signals for operating additional electronics**. Scan functions can be programmed easily. The main advantages of these modules are the **built-in micro-controller** and free programmable memory capacity. The micro-controller is **capable of input and output procedures or voltage values programmed in the memory**. The EDA modules can also work as a normal PC-line operated system.

Technical Data

	unit	EDA 4	EDA 5
type of interface	-	RS 232	RS 232, IEEE 488.2
resolution	*bit*	16	
sample rate	*ksamples/s*	32	
analog inputs / outputs	-	4 / 4	
output voltage range	*V*	0 … +10	
digital inputs / outputs	-	8 (programmable, analog) / 8 TTL	
modul width	*HP*	6	10

series EDA

Specific and detailed information about the EDA-modules: ***www.piezosystem.com/eda***

1-Channel Piezo Controller

NV 40/1 CLE with MIPOS 100

Product Features NV 40/1 CLE

- open and closed loop operations
- strain gauge or capacitive sensor controller
- RS232 interface (9-pol. D-Sub)
- 5 digit display
- memory function

The **stand alone amplifier NV 40/1 CLE**, equipped **with a sensor positioning control**, is well suited for low voltage elements. Piezo actuators can be controlled by an analog modulation input signal, a computer interface or manually through a potentiometer. Due to a **very low voltage noise** this amplifier is **ideal for sub-nm positioning**.

NV 40/1

Complete details and information about the NV 40/1: ***www.piezosystem.com/nv40-1***

NV 120/1 CLE

Product Features NV 120/1 and NV 120/1 CLE

- 120 mA permanent output current
- USB 2.0 and RS232 interface
- dimmable TFT display
- analog input/output
- CLE-version for closed loop actuating systems (equipped with feedback sensors: strain gauge or capacitive)
- combinable with actuators with part number suffix "D"

The NV 120 series is designed to control piezo actuators **with (NV 120/1 CLE) and without (NV 120/1) an integrated measurement system**. They achieve **position resolution in the sub-nm range** in addition to a **setting time in the microsecond range**. The NV 120 series is designed to be a compact table top system in a rugged metal housing.

	unit	NV 40/1 CLE	NV 120/1 (CLE)
output voltage	*V*	-10 … +150	-20 … +130
output current (continuous)	*mA*	40	120
voltage noise (RMS @ 500 Hz)	*mV*	**< 0.3**	
modulation input	*V*	0 … +10	
modulation output	*V*	0 … +10	
resolution	*bit*	16	
safety functions	-	overvoltage protection, short circuit proof	
features	-	signal values are shown either in volts or micrometers, memory function	**ASI-function**, soft start function, temperature monitoring / TFTdisplay

nv120-1

Complete details and information about the NV120/1: ***www.piezosystem.com/nv120-1***

3-Channel Piezo Controller

low noise < 0.3 mV_{RMS} @ 500 Hz

NV 40/3 and NV 40/3 CLE designed for ***easy controlling of 3 axes nano-positioning piezo stages*** *with sub-nanometer accuracy*

NV 40/3

Product Features

- 3-channel piezo controller
- **ASI function (Automatic Sensor Identification)**
- permanent output current 40 mA per channel
- **signal noise < 0.3 mV_{RMS} @ 500 Hz**
- piezo control up to kHz frequency (depends on driven amplitude and electrical capacitance)
- manual control, analog input 0 … 10 V, USB interface
- TFT-display dimmable for lab use
- wide range power supply 100 V … 240 V
- table top version

Applications

- laboratory applications
- industrial applications
- drift compensated controlling of piezo actuators with measurement systems

The NV 40/3 amplifier is designed for **controlling low voltage piezo elements without feedback sensors**. Due to the very low voltage noise of only 0.3 mV_{RMS} this system is ideal for **positioning applications with sub-nm resolution**.

The NV 40/3 CLE is equipped with a sensor servo module for **controlling actuators with external measurement systems**. The soft start ensures actuator-safe activation of the system. The electronic **PID controller eliminates any drift and hysteresis**.

Technical Data

	unit	NV 40/3	NV 40/3 CLE
sensor controller	-	-	strain gauge / capacitive
output voltage	*V*	-20 ... +130	
output current (continuous)	*mA*	40 per channel	
voltage noise (RMS @ 500 Hz)	*mV*	**< 0.3**	
modulation input	*V*	0 … +10	
monitor output	*V*	0 … +10	
resolution (oversampling)	*bit*	16	
interface	-	USB, RS232	
connector output voltage	-	Sub-D 15 pin	
safety functions	-	overvoltage protection, short circuit proof	
features	-	**ASI-function**, soft start function, temperature monitoring	

NV 40/3

Specific and detailed information about the NV 40/3:
www.piezosystem.com/nv40-3

OEM Electronics – Analog – 12V40 and 24V40

*Piezo controller designed with a very low **voltage noise of only 0.3 mV$_{RMS}$ @ 500 Hz** are ideal for sub nanometer positioning tasks*

12V40 SG

Product Features

- 1-channel OEM piezo controller
- compact size
- screw slot casing and 19''-rack mount module available
- manual and external controlling
- all connections also available at the backplane
- robust and high reliability
- 12 or 24 V DC main supply
- signal noise < 0.3 mV$_{RMS}$
- optional SG or CAP sensor module
- power on delay
- overvoltage protection

Applications

- pick & place automation
- OEM integration
- valve and gripper technology
- switching technology

The 12V40 and the 24V40 piezo controllers from piezosystem jena are specifically made for piezo electric actuators used for **nano positioning tasks in industrial applications**. The 12V40 requires a main supply voltage of 12 V DC while the 24V40 requires a 24 V DC main voltage supply. The use of these piezo controllers offers piezoelectric actuator control with **extreme resolution and without any time delay**. The piezo controller offers the user the choice to **control** a piezoelectric element **manually or via analog modulation input** with a signal of 0 to 10 V DC with a nearly unlimited step resolution. For industrial use, connection to the controller is available from both the front and rear of the casing.

Technical Data

	unit	12V40 / 24V40	12V40CLE / 24V40CLE
sensor controller	-	-	strain gauge, capacitive
output voltage	*V*	-10 ... +150	
output current (continuous)	*mA*	40	
voltage noise (RMS @ 500 Hz)	*mV*	**< 0.3**	
modulation input	*V*	0 ... +10 (front and rear panel)	
monitor output	*V*	-1 ... +15 front panel/0 ... +10 rear panel	
safety functions	-	overvoltage protection	
features	-	power on delay	

12V40 / 24V40

For complete information about these Controllers: **www.piezosystem.com/12v40**

OEM Electronics – Analog – 30V300

Piezo controller series designed for the control of high precision, flexure guided piezo actuator stages ***used in high dynamic nano positioning tasks***

30V300 nanoX CL

Product Features

- one channel low noise piezo controller
- **300 mA permanent output current**
- OEM design, robust casing
- small dimensions
- closed loop version available
- 19’’ screw-slot and stand-alone version available
- soft start function
- overdrive protection
- short circuit proof

Applications

- high speed and precision control of piezo actuating systems in industrial and laboratory environments
- automatic control for high resolution
- nano positioning applications

The 30V300 OEM series stands out due to the **300 mA permanent output current** which allows **driving piezo actuator elements with high frequencies**. The driven piezo stages can reach **shortest settling times** and can complete high **positioning tasks in the millisecond range**. The 30V300 is available in a table top version (robust metal casing), industrial rack mount 19’’-version and in a screw slot mounting version.

Nearly unlimited positioning resolution of piezoelectric actuators are guaranteed due to a low voltage noise of 0.3 mV_{RMS}.
The DC Offset can be displaced statically via potentiometer. The 30V300 CLE includes an **integrated sensor controller for high dynamic control of piezo electric elements**.

Technical Data

	unit	30V300	30V300 CLE
output voltage	V	-20 ... +130	
output current (continuous)	mA	300	
voltage noise (RMS @ 500 Hz)	mV	**< 0.3**	
modulation input	V	0 ... +10	
monitor output	V	-2 ... +13	0 ... +10
safety functions	-	overdrive protection, short circuit proof	
features	-	power on delay	

Additional versions: 30V300 nanoX and 30V300 nanoXCLE

30V300

Specific and detailed information about the 30V300:
www.piezosystem.com/30v300

OEM Electronics – Analog – Nano Box

***1 channel piezo amplifier** to control piezoelectric actuators in static and low dynamic applications*

nano box

Product Features

- 1 channel piezo amplifier
- built in function generator
- 10 mA permanent output current
- modulation input
- small size
- short circuit proof

Applications

- laboratory applications
- automation
- prototyping
- low cost applications

The nano box is designed as a **stand alone analog piezo amplifier** for **low cost and OEM applications**. Small dimensions and a robust metallic housing enable the nano box for easy integration into existing systems. An internal function generator is **manually adjustable** in a small range. The voltage offset can be adjusted by an analog modulation signal or manual by using the potentiometer knob on the front panel.

Technical Data

	unit	nano box
output voltage	*V*	0 … +150
output current (permanent)	*mA*	10
voltage noise (RMS @ 500 Hz)	-	**< 3**
connector output voltage	-	LEMO 0S.302
modulation input	*V*	0 … +5 (BNC)
input resistance	*kΩ*	5
built in wave form generator	*Hz*	2 … 35 (triangular wave)
main supply	-	9 V DC ±10 % 0.25 A
dimensions l x w x h	*mm*	130 x 55 x 24

nano box

Complete information about the nano Box:
www.piezosystem.com/nano-box

OEM Electronics – Digital – Nano Box USB

Digital amplifier with 16 bit D/A resolution and USB 2.0 interface ***simplifies system integration via PC***

nano box USB

Product Features

- 1 channel piezo controller
- **USB 2.0 interface**
- **16 bit resolution**
- strain gauge sensor controller
- 10 mA permanent output current
- small size
- short circuit proof

Applications

- laboratory applications
- nano positioning
- wafer handling
- PC controlled positioning

The nano box USB is designed as a s**tand alone piezo amplifier** to control piezo electrical actuators in static and low dynamic applications. The low level output signal allows precise control of high resolution actuators over the entire range of motion. The **integrated sensor controller** allows reading out the positioning information to **compensate for drift behavior**.

Technical Data

	unit	nano box USB
output voltage	*V*	0 … +130
output current (permanent)	*mA*	10
voltage noise (RMS @ 500 Hz)	*mV*	**< 0.3**
connector output voltage	-	D-Sub 15 pin
command parameter resolution	*bit*	16
software	-	LabView, Software example
main supply	*V DC*	24
dimensions l x w x h	*mm*	108 x 68 x 24

nano box usb

Complete information about the nano Box USB:
www.piezosystem.com/nano-box-usb

Piezocomposite Stack Actuators Series PSt and PSt VS

High power actuator for applications, requiring high loads and extreme dynamics

PSt 1000/10/7

PSt 1000/35/7 VS45 and PSt 1000/35/40 VS45 (size comparison with pen)

Product Features

- **max. load up to 70’000 N**
- max. force generation 50’000 N
- **resonance frequency up to 60 kHz**
- **resolution in the nm and sub-nm range**
- travel range up to 260 µm (higher motion range on request)

Applications

- high force generation
- material testing
- stabilization
- sensor testing
- test and acceleration damping
- active vibration cancelation
- fuel injection
- active engine mounting
- positioning tasks

Options

- high power piezo material for power applications
- vacuum version
- integrated strain gauge measurement system for highest accuracy
- low temperature modification

Additionally available for PSt VS:

- thermostable modification
- increased preload

Recommended Controller

- SVR-series: high voltage amplifier for quasistatic operation (e. g. positioning tasks)
- PosiCon-Series: closed loop system for precise positioning
- RCV-series: high power switching amplifier for extreme dynamics

Elements of series PSt or PSt VS are recommended for **use under high loads**. PSt VS versions include casing and preload, PSt have no casing and are not preloaded. Their **high stiffness and resonant frequency** make these actuators an excellent choice for applications that require an **outstanding dynamic**.
Extreme **temperatures from -60 °C to +200 °C** do not affect the reliability of elements series PSt and PSt VS.

Example Technical Data

	unit		PSt 1000/10/7		PSt 1000/35/200 VS45
max. stroke	*µm*	from	12	to	260
length	*mm*	from	9	to	194
capacitance	*nF*	from	20	to	6500
stiffness	*N/µm*	from	300	to	150
resonant frequency	*kHz*	from	60	to	4

series PSt

More PSt-elements?
www.piezo.eu/pst

Piezocomposite Ring Actuators Series HPSt and HPSt VS

Ring actuators with free aperture
for static and dynamic applications

HPSt 1000/25-15/20 VS35

HPSt in different sizes

Product Features
- **max. load: 35’000 N**
- max. force generation: 20’000 N
- **resonant frequency up to 50 kHz**
- travel range: up to 130 µm (more on request)

Applications
- adjustment of optical components
- sensor testing
- test and acceleration damping
- active vibration cancelation
- fuel injection
- active engine mounting
- positioning tasks

Options
- high power piezo material for power applications
- vacuum design
- integrated strain gauge measurement system for highest accuracy
- low temperature modification

Additionally available for HPSt VS:
- low temperature modification
- thermostable modification
- optics adaptor

Recommended Controller
- SVR-series: high voltage amplifier for quasistatic operation (e. g. positioning tasks)
- PosiCon-Series: closed loop system for precise positioning
- RCV-series: high power switching amplifier for extreme dynamics

Elements of series HPSt or HPSt VS are recommended for use under high loads. HPSt VS versions include **housing and preload**, HPSt are unhoused and without preload. Because of a **free central opening** the ring actuators are applicable for laser applications. The opening can be used for a more effective cooling for high dynamical applications.

Example Technical Data

	unit		HPSt 1000/10-5/7		HPSt 1000/35-25/100 VS45
max. stroke	*µm*	from	12	to	130
length	*mm*	from	9	to	107
capacitance	*nF*	from	15	to	1800
stiffness	*N/µm*	from	210	to	160
resonant frequency	*kHz*	from	50	to	10

series HPSt

More HPSt-elements?
www.piezo.eu/hpst

Piezoelectric PIA Shock Generators

Piezoelectric shock generators producing
exactly triggered mechanic pulses

PIA 300/10/3

Shock wave generator

Product Features

- adjustable impact parameters such as energy, acceleration and stroke **E < 4 Joule; a > 10'000 g, ΔL > 100 µm**
- high repeatability of the impact parameters, precise time behavior
- pulse energies up to Joule values
- variable collision- and repetition rates
- lowest rise times in the µs's
- pulse width at about 10 µs
- µs precise triggering

Applications

- shock wave generation
- material testing
- short pulse excitation
- sensor testing and calibration
- modal analysis

Recommended Controller

- High Voltage Pulser HVP

PIA shock generators are able to produce **mechanic pulses with highest accelerations and shortest pulse widths**. Furthermore these shocks can be precisely triggered and show a remarkable repeatability. With these properties PIA shock generators **are perfect for** material testing, sensor testing, modal analysis or acceleration tests.

Example Technical Data

series PIA	operating voltage	amplitude @ max. voltage	capacitance	max. acceleration
	V	*µm*	*nF*	*m · s^{-2}*
PIA 300/10/3	0 … +300	7	140	up to <100'000
PIA 1000/10/7	0 … +1000	7	80	up to <100'000
PIA 800/35/80	-200 … +800	80	6.6	up to <100'000

series PIA

More PIA-elements?
www.piezo.eu/pia

Products shown in this catalog are only a small part of our full product range. Please check out our web page: *www.piezosystem.com* for the complete series and for detailed information.

Piezoelectric Shaker - PiSha

*Piezo-Shaker for **vibration excitation** with **high frequencies** and **large forces***

Geo-Shaker with a glass of water to show the vibration

Product Features

- **frequency range over 100 kHz**, depending on the configuration of the shaker
- **high accelerations up to 10'000 g**
- amplitudes from micrometers to multi hundred micrometers
- **force modulation of multi tens of kN** (measured under blocking conditions – depending on shaker dimensioning, frequency of operation and installation conditions)
- compact dimensions of the piezoelectric structures down to the millimeter range
- high forces
- thermal management

Applications

- material characterization with respect to frequency/velocity/acceleration
- modal analysis
- investigation on structure borne noise/sound of machine parts
- fatigue testing of mechanical components
- fretting arrangements
- flaw detection in composite materials

Recommended Controller

- LE 150/100 EBW for high frequency operation
- RCV switching amplifier for high power applications

In comparison to conventional shaker systems piezoshakers exhibit a **high stiffness** and **high force generation** combined with rather small sizes. This results from the high energy density of the piezo material leading to a very wide frequency range. The tunability makes them perfect for applications like **modal analysis, material characterization or acceleration tests**.

Example Technical Data

series PiSha	operating voltage	oscillation amplitude	force modulation (blocking limit)	1st resonant frequency
	V	*µm*	*N*	*Hz*
PiSha 150/16/3	0 … +150	1.5	1200	35'000
PiSha 1000/35/150	0 … +1000	75	±15'000 with 80 kg seismic mass	200
Micro PiSha	0 … +150	< 5	1000	100'000

series PiSha

More PiSha-elements?
www.piezo.eu/pisha

High Voltage Piezo Amplifiers

SVR 1000/1 (1 channel)
SVR 1000/3 (3 channels)

Low voltage noise guarantees excellent positioning accuracy

Product Features Analog Amplifier SVR

- **1 or 3 channel** amplifier
- manual setting of DC-Offsets
- LCD + BNC-Monitor output (1:1000)

Technical Data

series SVR	voltage range	max. current	noise
	V	mA	mV_{PP}
SVR 350 bip	-350 … +350	12	1 (≥100 nF load)
SVR 500	-100 … +500	15	1 (for 1 µF load)
SVR 1000	-200 … +1000	8	1 (for 0.47 µF load)

series SVR

Complete and detailed information about SVR controllers: **www.piezo.eu/svr**

RCV 1000/7

High Power Switching amplifier developed for dynamic control of high volume piezo actuators.

Product Features Switching Amplifier RCV

- 1 channel switching amplifier
- manual setting of DC-Offset
- LCD + BNC-Monitor output (1:1000)

Technical Data

series RCV	voltage range	max. current	noise
	V	A	V_{PP}
RCV 1000/3	0 … +1000	3	≤ 1 (depends on the load)
RCV 1000/7	0 … +1000	7	≤ 2 (depends on the load)

series RCV

Complete and detailed information about RCV controllers: **www.piezo.eu/rcv**

HVP 300/20

High voltage pulser with high peak currents for driving of piezoelectric shock generators

Product Features High Voltage Pulser HVP

- 1 channel voltage pulser
- max. charging voltage: 1000 V
- **peak currents: up to 200 A**
- manual setting of charging voltage
- LCD + BNC-Monitor output (1:1000)

series HVP

Complete and detailed information about the HVP controller: **www.piezo.eu/hvp**

Piezoline

Contents

Introduction – Instruction for Using

Piezoelectric actuators are established to the field of micropositioning. They provide performance levels that cannot be achieved by conventional drive mechanisms.

However, the field of piezoelectrics is complex and requires clarification.

These pages should give an introduction into the working principles, and advantages of piezoelectric actuators. By using the index we hope you may be able to refer to the relevant information quickly and efficiently. The examples given should present a feeling of the performance of the actuators.

The parameters and dimensions used in the piezoline are described on ***page 99***.

Conversion tables for frequently used physical values such as temperature, pressure, angle and more you will see ***on page 100***.

Basic Remark

For designing new products containing piezoelements it is helpful to know about the theory and principle relations between many parameters. However, the formulas given here can give only a rough estimation depending on many environmental conditions. Before starting with the theoretical aspects we give you some basic remarks – the results of working long years with piezoelectric elements.
Often you will find these remarks also at the end of each chapter in red boxes.

Sealings

Epoxy Versus Ceramic Sealing

It is a well known fact that the most critical parameter for piezoelectric elements is high humidity in direct contact with the ceramic material. Most of our elements and stages are double sealed. A special epoxy sealing is followed by a special rubber material for additional protection from humidity and electrical break through.

The elastic epoxy expands as the piezoceramic expands, keeping the piezo element properly sealed.

We do not recommend using hard sealing materials e.g. ceramic sealings. Since ceramic sealing is a hard material, it may have advantages for vacuum (low outgassing), but it may get cracks over the time as the piezoelement expands. Please see also ***chapter 3.9*** working under vacuum conditions. If you consider different sealing materials as offered from ***piezosystem jena***, please ask about long term tests. For best reliability we recommend using only piezoelements proven over many years in many applications such as those used by ***piezosystem jena***.

Our goal is to provide our customers with innovative but proven systems. Only when our customers are successful on the market over many years will they be satisfied with ***piezosystem jena***. Customers of piezosystem jena have been using piezo elements for over 24 years.

OEM Applications

Chapter 11 will tell you basics about the reliability of piezoelectric elements. When considering piezoelements for industrial applications, it is useful to work with a lower voltage than specified. Working with 100 - 130 V instead of the maximum voltage extends lifetime and allows for more motion if needed in the future.

Atmosphere Conditions
Working Under Normal Conditions

Piezoelements from ***piezosystem jena*** are sealed against humidity and normal environmental conditions.

For higher humidity conditions we offer special sealings. If necessary, ***piezosystem jena*** can provide actuators hermetically sealed for work under extreme environmental conditions.

Vacuum Operation

Piezoelements will work under different pressure conditions, even at ultra high vacuum conditions. Piezoelements from ***piezosystem jena*** use isolated electrodes with an excellent outgassing behavior even for ultra-high vacuum conditions.

For more detailed information please check our piezoline, ***chapter 3.9***.

Piezoelectric Actuators

In the last few years, piezoelectric actuators have found a niche in the field of micro-positioning. The main advantages of these actuators are their high resolution (to sub-nanometers) and their high dynamics.

Other advantages of these actuators are the generation of large forces (up to 50 kN) and a large dynamic range of motion (up to mm range). Piezoelectric actuators can also operate in vacuum, have no mechanical play and have no wear.

Piezoelectric elements are very efficient requiring low energy to work under quasi-static conditions as well as under high external loads.

Piezoelectric elements from ***piezosystem jena*** are extremely well suited for applications in:

- optics, laser applications
- high resolution positioning such as active and adaptive optics, integrated optics, photonics
- communication techniques, fiber optics
- life science
- automation
- machining, tool adjustment, valves, piezomotors.

The advantageous properties of piezoelectric actuators may only be utilized when they are operated under the correct conditions.

It is important to understand how the different properties are related to one another. An improvement in one property may be at the sacrifice of another, for example.

Example number 1

A piezoelectric actuator has to move a high external mass. In principle, it is not a problem to do this, but as the external mass increases, the resonant frequency will rapidly decrease.

Piezoelectric elements have a very high inner resistance, so no current is needed for static or quasi-static work. But by their nature, piezoelements are capacitors. If they work dynamically, a high current is necessary for charging and discharging. So, often in a dynamic application, the maximum current of the power supply determines the shortest rise times of the actuators.

Our team from ***piezosystem jena*** is experienced in working with piezoelements and we can give advice in solving your positioning problems.

We can advise you of the parameters you should induce to reach an optimal result when working with piezoelectric elements.

1 Piezoelectric Effect – Inverse Piezoelectric Effect

The result of external forces to a piezoelectric material are positive and negative electrical charges at the surface of the material. If electrodes are connected to opposite surfaces, the charges will generate a voltage U. By generating forces F to the piezoelectric material, the volume (bulk) of the material will be approximately constant.

$$U = \frac{d_{ij} \cdot F}{C} \quad (1.1)$$

d_{ij} - piezoelectric module; parameter of the material (depending on the direction)
C - electrical capacitance

The Curie brothers first discovered piezoelectricity in 1880. It was found by examination o f the crystal TOURMALINE.
Modern applications of the piezoelectric effect can be found in sensors for force and acceleration, microphones, and also in lighters.
An applied voltage to a piezoelectric material can cause a change of the dimensions of the material, thereby generating a motion. Lippmann predicted this inverse piezoelectric effect and the Curie brothers were the first to experimentally demonstrate it.

The first applications were in ultra sonic systems for underwater test and also underwater communications.

For actuators, the inverse piezoelectric effect was applied with the development of special ceramic materials.
Materials for piezoelectric actuators are PZT (lead-zirconium-titanate). For the electrostrictive effect the materials used are PMN (lead-magnesium-niobate).

There is a large number of different PZT materials for use as piezocomposite actuators. They differ in their characteristics and fields of application. The characteristics reach from different Curie temperatures over different charge constants to different elastic compliances. These characteristics open a wide field of applications from dynamic applications like modal analyses over high force generation in material testing to positioning tasks.

When speaking about actuators, the phrase "piezoelectric effect" is often used – strictly speaking, it should be called "inverse piezoelectric effect".

2 Design of Piezoactuators

2.1 Piezo Stacks – Stacked Design

There are two different design principles for piezo stacks. In one case the piezo stack consist of a large number of ceramic discs contacted by intermediate electrodes. These stacks are a composite material. In the other case the ceramic material is sintered with the electrodes. Such stacks are called monolithic. In both cases the electrodes are connected in a parallel line on both sides of the stack as shown in figure 2.1.1. The difference between the two designs is the thickness of the ceramic layer d_s and the applied voltage U to generate the electrical field strength E.

$$E = \frac{U}{d_i} \quad (2.1.1)$$

Piezo stacks are also called actuators, piezoelectric actuators or piezoelectric translators.

The maximum motion caused by the inverse piezoelectric effect depends on the electrical field strength and saturation effects of the ceramic material. The breakdown voltage of the ceramic limits the maximum field strength. Normally, piezo stacks work with maximum field strength of 2 kV/mm. This strength can be reached with different voltage values if used with different thickness of the single ceramic plates. As a result of the different thickness the piezocomposites can be driven with voltages up to 1000 V, the voltage range of monolithic stacks is up to 150 V.

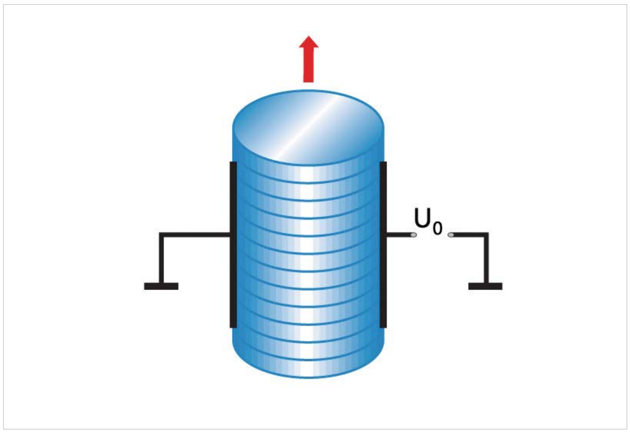


Figure 2.1.1 *Construction principle of a piezo stack*

Example number 2
An actuator consists of 20 ceramic plates. The thickness of one plate is 0.5 mm. The total length of the actuator is 10 mm. The actuator will reach a maximum expansion of approximately 10 µm for a voltage of 1000 V.
For plates with a smaller thickness the maximum voltage will be less. Modern multi-layer actuators consist of ceramic laminates with a thickness of typically 100 µm.

Example number 3
A multi-layer actuator with a total length of 10 mm consists of 100 disks with a thickness of 100 µm. The stack will reach nearly the same expansion of 10 µm with a voltage of 150 V. However, it should be mentioned that the capacitance of this multi-layer actuator is much higher than the capacitance of high voltage devices. This can be important for dynamical applications (see also section 3.7: Capacitance, section 5: Dynamic properties and chapter 10: Electronics).

It is more complicated to produce multi-layer piezoelectric actuators. Because of the advantage of the lower voltage, some companies are developing so called monolithic actuators. This means, the green sheet ceramic will be laminated with the electrode material. In this way, the full actuator will be made as one system. So the actuator will have the equivalent parameters (for example a high stiffness) of a solid ceramic material.

Piezo Stacks with and without Mechanical Preload

Piezocomposite and monolithic actuators are susceptible to tensile forces. On the contrary the compressive strength of piezo stacks is more than one order of magnitude larger than its tensile strength.

When actuators are used for dynamic applications, compressive and tensile forces occur simultaneously due to the acceleration of the ceramic material. To avoid damage to the actuators, the tensile strength can be raised by a mechanical preloading of the actuator. A second advantage of the preload is better stability of the actuators with a large

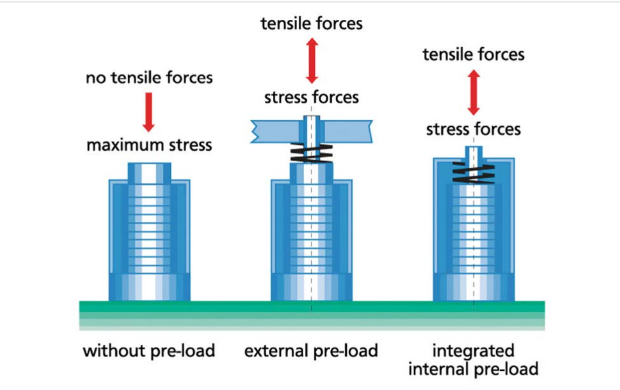


Figure 2.1.2 *Stacks without, with external and with internal preload.*

ratio between the length and the diameter. Normally the mechanical preload will be chosen within 1/10 of the maximum possible loads. You can find more information in sections 4 and 5 of the piezoline.

We recommend to use a preloaded actuator from ***piezosystem jena*** when:
- tensile forces can affect the actuator
- they are used in dynamical applications
- shear forces (shear strain) affect the actuator (external forces perpendicular to the direction of motion)

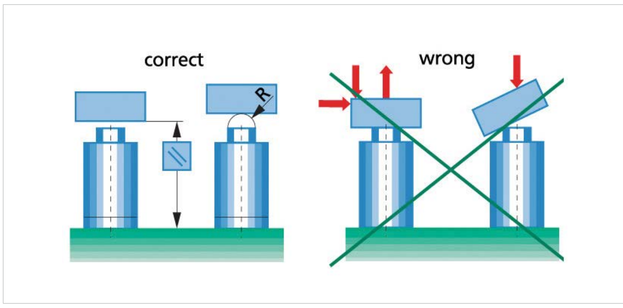


Figure 2.1.3 *Tilting forces*

Actuators without preload should be mounted on their bottom side. This can be done using adhesive or threads in the bottom of the housing. You should not apply shear, cross-bending or torsional forces to the actuator. Clamping around the circumference is not allowed. External forces on the top of the actuator should mainly be in the direction of expansion central to the end faces.

If you wish a detailed discussion, please contact our team or your local representative!

2.2 Tube Design

For this actuator the transversal piezoelectric effect is used. The tubes are made from a monolithic ceramic; they are metalized on the inner and outer surface. Normally, the inner surface is contacted to the positive voltage. If an electric

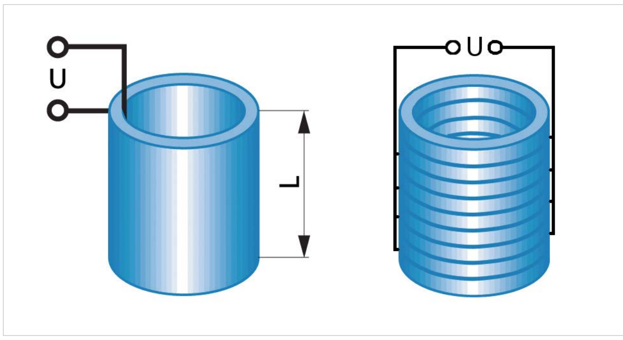


Figure 2.2.1: Left: *Piezotube with electrodes on the inner and outer surface.* ***Right:*** *Piezocomposite ring type actuator with intermediate electrodes.*

field is applied to the tube actuator, a contraction in the direction of the cylinder's axis, as well as a contraction in the cylinder's diameter, results in a downward motion. If the outer electrodes are divided, the tube can work as a bimorph element. In this way, it is possible to reach a larger sideways motion. Piezotubes are used for mirror mounts, inchworm motors, AFM (atomic force microscopes) STM microscopy, and in laser resonators.

Example number 4
Consider a tube actuator with a diameter of 10 mm, a wall thickness of 1 mm and a length of 20 mm. The maximum operating voltage is 1000 V. So, the applied field strength is 1 kV/mm. The transversal piezoelectric effect shows a relative contraction of approximately 0.05%. For the length of 20 mm, one will get an axial contraction of 10 µm.

Simultaneously the circumference of 31.42 mm will be shorter by 15 µm. This is related to a radial contraction of 4.7 µm.

Ring Type Actuators
Another form of ring-type actuators are piezocomposite ring-type actuators. Ring type actuators are piezostacks with a central hole (Fig. 2.2.1). They consist of ceramic layers and related electrodes with an inside aperture. Unlike to monolithic tube actuators the longitudinal piezoelectric effect is used. Because of the inside aperture the capacitance of the ring-type actuator is smaller than the capacitance of a solid cylinder, ***see section 3.7*** for further explanation.

2.3 Bimorph Elements

These elements are made from two thin piezoelectric ceramic plates mounted on both sides with a thin substrate. The principle is similar to thermo bimetal circuits.
Applying opposite field strength to the ceramic plates, one plate shows a contraction, the other will expand. The result is bending in the order of sub-mm up to several mm. Bimorph elements use the transversal piezoelectric effect (see also section 4). The working piezoelectric module is the d_{31} coefficient. Piezoelectric bimorph elements have a resonant frequency of several hundred Hz. Because they show a large drift (creep) while doing static work (because of shear stress in the layers) they are often used in dynamic applications. Due to their construction, they have a low stiffness and they cannot make a parallel motion (almost circular).

In the following figure, two kinds of piezoelectric bimorph elements are represented.

Serial bimorph
Both piezoelectric plates are polarized in opposite directions. If a voltage is applied as shown in figure 2.3.1 one plate shows a contraction, the other one will show an expansion.

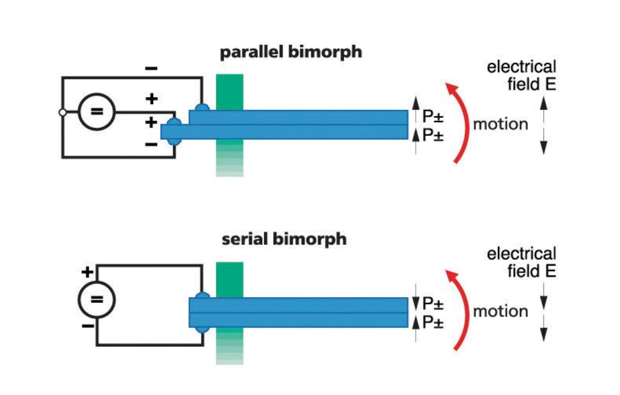


Figure 2.3.1: Parallel and serial bimorph piezo benders.

Parallel Bimorph
A metal plate middle electrode is between the two ceramic plates. The polarization of both ceramic plates is in the same direction. The bending of this bimorph will be reached by applying opposite voltages to the electrodes. Because of the metal plate in the middle, these bimorph elements have a higher stiffness.

2.4 Hybrid Design

For many applications it is necessary to have a motion on the order of 50 µm – 300 µm (for example fiber coupling tasks). To use stacked actuators for a motion of 300 µm, one needs a translator with a length of 300 mm, independent of whether you are using piezocomposite or monolithic stacks. The high capacitance is another disadvantage of such large stacks. Because of the inhomogeneous expansions of the ceramic plates, the top plate of the stack will always show a slight tilting motion.

piezosystem jena has developed a hybrid piezoelectric element for parallel motion with high accuracy. A lever design of the construction gives very compact dimensions. We have developed the hybrid elements for three dimensional motions. Since we use solid state hinges, mechanical play does not occur.

The working principal is shown in the figure below.

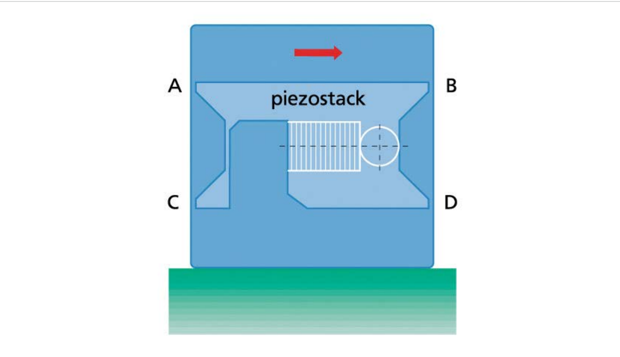


Figure 2.4.1: Parallelogram design

The flex mount points A, B, C and D are solid state hinges. ***piezosystem jena*** uses a monolithic design; the motion is achieved by bending these flex mounts.

Because of the rectangular design and the thread holes, it is very simple to combine these elements with normal mechanical stages. The advantage is a much higher accuracy and an excellent resolution of the motion. Because most of these elements have an integrated preload, they are suited for dynamical motions (see also ***section 6: lever transmission***!).

Example number 5
The piezoelements MiniTRITOR 38 from ***piezosystem jena*** generates a rectangular motion of 38 µm in x, y and z direction. Integrated solid state hinges with parallelogram design provide parallel motion without any mechanical play. The dimensions are 19 mm x 19 mm x 16 mm. Another element is the piezoelement PX 400. This element gives a motion of 400 µm; the dimensions are 52 mm x 48 mm x 20 mm. This element is also suited for dynamical motion. For more details please see our data sheets and ***section 6***.

For comparison, a piezo stack with 400 µm motion would need approximately a length of 400 mm!

3 Properties of Piezomechanical Actuators

3.1 Expansion

The relative expansion $\varepsilon = \Delta l / L_0$ (without external forces) of a piezoelement is proportional to the applied electric field strength.
Typical values of the ceramic materials are $\varepsilon \approx 0.1$ - 0.13% of the origin length at a field strength E = 2 kV/mm.

$$\frac{\Delta l}{L_0} = \epsilon = d_{ij} \cdot E \qquad (3.1.1)$$

ε = relative stretch (without dimension)
d = d_{ij} - piezo module (parameter of the material)
E = U/d_s electrical field strength
U = applied voltage
d_s = thickness of a single disk

The maximum expansion will rise by increasing the voltage. The relation is not perfectly linear as predicted by equation (3.1.1). The characteristic curve reflects the inherent hysteresis (see also section 3.2). The maximum expansion that can be achieved by using piezo stacks is up to 1.3 ‰ of the origin stack length. The expansion of a 300 mm stack amounts approximately 300 µm.

Typical piezo stacks have motion of 20 – 100 µm. For larger expansion, actuators with a lever transmission are superior.

It is possible to combine piezoelectric elements with mechanical or electromechanically driven systems. So, the motion will be several cm, although the motion will show mechanical play.

3.2 Hysteresis

Because of their ferroelectric nature, PZT ceramics show a typical hysteresis behavior. If voltage is applied in a positive direction and then in a negative direction (bipolar voltage), one can obtain the following curve.

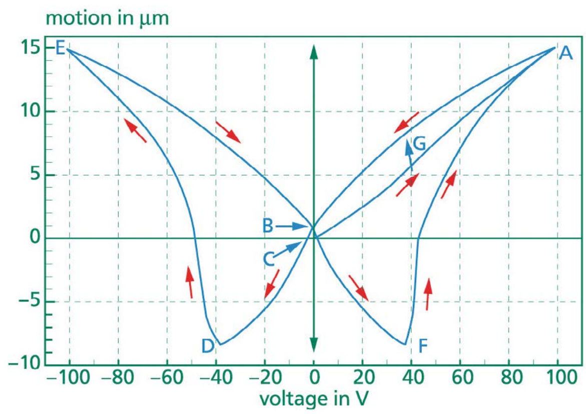


Figure 3.2.1: *Via the applied voltage, the motion of the element will follow the points ABCDEF.*

If the voltage is increased, the elongation increases. The maximum elongation (point A) will be limited by saturation and by the voltage stability (voltage break down) of the ceramic material. If the voltage is reversed, the piezoelement shows a contraction. After removing the voltage, a permanent polarization will remain. Therefore the position of the piezoelement is not zero (point B). If a definite negative voltage is applied (so-called coercive field strength; point C) the position will be zero.

The piezoelement will contract when the negative voltage is increased. At the same time the polarization in the ceramic begins to change. At point D the polarization of most of the dipoles is changed, so that the element will expand again for increasing negative voltage up to point E. If the negative voltage is reversed, the piezoelement will contract according to the behavior from point A to point B, so point B is again the point which refers to the remaining polarization. By further increasing the voltage (now positive) the element contracts (up to point F) with polarization changes. By further increasing the voltage, the element expands to point A.

The butterfly curve shows that by applying bipolar voltage it is not possible to accurately determine the position of the piezoelement. For example, for the same voltage, the element can be in position G or in position F.
Thus, normally one works with unipolar voltage outside the region of saturation and breakdown and outside the region of polarization changes. So piezoelements show the well-known expansion characteristics.

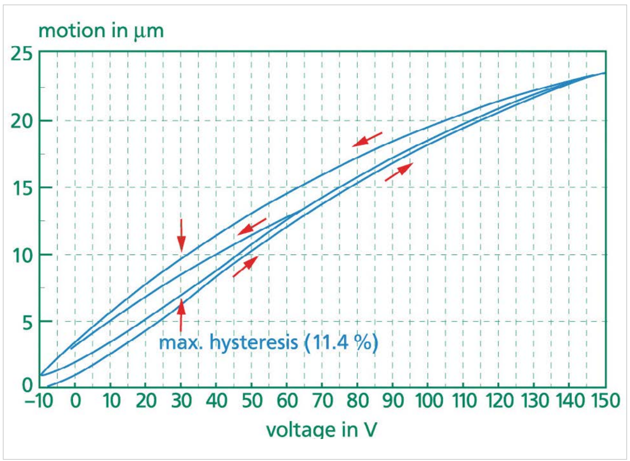


Figure 3.2.2: *Typical hysteresis curve of a multilayer piezo stack.*

To get larger motion, it is possible to work with a negative voltage in the order of 10 V to 20 V (for multi-layer elements). Therefore we drive our elements with voltages from –20 to +130 V.

Working in that range, you find the typical expansion curve of piezoelements. The typical width of the hysteresis is 10 – 15% of the complete motion.
Working in a small voltage range, the hysteresis is also smaller. This is also shown in the figure 3.2.2 above.

Each piezoelement provided by ***piezosystem jena*** comes with the measured curve of its hysteresis.

Hysteresis closed loop
In closed loop systems the closed loop control electronics compares a given or wanted position (e.g. through modulation input signal) with the actual position measured by the sensor system. Any deviation in both signals will be corrected. Thus closed loop systems do not show hysteresis within the accuracy of the closed loop system. For more details see ***chapter 8*** and ***9***.

OEM elements for industrial applications
For piezoelements working under industrial conditions, we recommend working with voltages up to a maximum of 100 V for monolithic actuators in order to achieve the best long term reliability. This is especially important if the piezoelement must work constantly with maximum expansion (under maximum voltage) over a long time period.
Piezocomposite actuators will be adapted for the specific application in most cases. This includes a recommended voltage range. Please see also ***chapter 11: reliability***!

3.3 Resolution

Independent of the hysteresis, piezoelectric devices have a very high resolution, due to the solid state effect. A piezoelement PX 38 from ***piezosystem jena*** was tested in an interferometer and a motion of $\frac{1}{100}$ nm was detected.
Therefore the resolution is limited by the noise characteristic of the power supply. Our power supplies are optimized to solve this problem (please see also ***section 9.1*** and ***10.1***).
The resolution of piezocomposite actuators is secondary because these elements are mainly used in high dynamic applications or to generate high power pulses. Therefore an accurate positioning is not necessary often.

Example number 6
Our NV40/1 CLE has a voltage noise of < 0.3 mV at the output. Relative to 150 V maximum voltage this is a value of $2 \cdot 10^{-6}$. Operating a piezoelement with a maximum expansion of 20 µm, the mechanical noise of this system will generate oscillations in the order of 0.04 nm.

You are invited to speak with our team about the specifications of our various power supplies!

We have several different voltage amplifiers (power supplies). Our products range from compact 1 and 3 channel supplies to power supplies in 19 inch euro-system.

3.4 Polarity

In general our piezoelements work with a positive polarity. A minimum reversal voltage on the order of 20 % of the maximum voltage (for example -20 to 130 V multilayer elements) will increase the total expansion. A higher reversal voltage is not recommended because of depolarization effects. On request, it is possible to construct the elements with positive or negative polarity.

3.5 Stiffness

A piezoelectric actuator can be described by a mechanical spring with constant stiffness c_T^E. The stiffness is an important parameter for characterization of the resonant frequency and generated forces.

$$C_T^E = \frac{A}{S_{33}^E \cdot L_0} \qquad (3.5.1)$$

The stiffness is proportional to the cross section A of the actuator. The stiffness decreases with an increasing actuator length L_0. In reality the dependence is more complicated. The stiffness is also related to other parameters, e.g. how the electrodes are connected.

When the electrodes are not connected, there is no way for the energy to be dissipated; therefore in this case the stiffness has its largest value.

Stiffness
However, formula 3.5.1 does not describe the exact reality. Depending on the kind of operation (static, dynamic operation) and environmental influences (load, electrical parameters of the electronic supply, small or large signal operation) the stiffness can vary up to a factor of 2 or more. Thus using formula 3.5.1 can give only a rough estimation of the expected properties of the piezoelements. Please consider, the electrical capacitance measured for piezoelements with small signals can increase up to 2 times when operated with large signals (under full motion).

Example number 7
An actuator with a cross section of 5 x 5 mm and an active length of 9 mm has a stiffness of C_{T1}^E = 120 N/µm. If we double the active length (18mm) while keeping the same cross section, then the stiffness will be reduced in half to 60 N/µm. If an actuator with a cross section 4 times larger (for example 10 x 10 mm, length 18 mm) is used, the stiffness will be 240 N/µm.

3.6 Thermal Effects

Temperature variation is an important factor in the accuracy of a micro positioning system. The thermal expansion coefficient of stainless steel for example, is about $12 \cdot 10^{-6}$ K^{-1}. Imagine a cube of 10 · 10 · 10 mm. A temperature change of only 1K leads to an expansion of more than 0.1 µm in each direction. With these relationships in mind, it is easy to understand that the calibration of piezoelements with integrated measurement systems depends on the temperature. If the operating temperature is different from the temperature during calibration, errors will occur.

When speaking about temperature coefficients of piezoelements, we must consider three effects:

a) The temperature behavior of the piezo ceramic material depends on the type of ceramic material. Monolithic stacks show a negative temperature coefficient of $\alpha_{LV} \approx -6 \cdot 10^{-6}$ K^{-1} in the range up to 120 °C. The sintered electrode material is too thin to have a visible effect. Piezocomposite stacks show nearly no temperature dependency. This depends on the higher thickness of the intermediate electrodes. The positive of the electrodes balance the negative α of the ceramic material. The thermal change in length of a whole short circuit actuator (e.g. series P, PA, PAHL) is the sum of the thermal expansions of the piezo ceramic and metal components of the actuator.

$$\Delta l_{th} = \Delta T \cdot (L_p \cdot \alpha_p + L_m \cdot \alpha_m) \qquad (3.6.1)$$

Δl_{th} = thermal expansion of the whole actuator
L_p = length of the piezo stack
L_m = length of the metal housing
α_p = temperature coefficient of the piezo ceramic
α_m = temperature coefficient of the metal housing
ΔT = temperature differential

Example number 8
If the temperature around a PA 16 actuator changes from 20°C to 30°C the length difference at a voltage of 150 V (full stroke) is

$$\Delta l_{actuator} = \Delta l_{steel} + \Delta l_{stack} + \Delta l_{piezoeffect}$$

The length of the steel parts is 16 mm:

$$\Delta l_{steel} = 16 \cdot 10^{-3}\ \mathrm{m} \cdot \frac{12 \cdot 10^{-6}}{\mathrm{K}} \cdot 10\ \mathrm{K} = 1.92\ \mu\mathrm{m}$$

The length of the piezo is 19 mm:

$$\Delta l_{stack} = 19 \cdot 10^{-3}\ \mathrm{m} \cdot \frac{-6 \cdot 10^{-6}}{K} \cdot 10\ \mathrm{K} = -1.14\ \mu\mathrm{m}$$

So the total difference is $\Delta l_{actuator} = 0.78\ \mu$m.

b) The piezo effect itself also depends on the temperature. In the range < 260 K, the effect decreases with falling temperature with a factor of approximately 0.4% per Kelvin.

$$\alpha_{piezoeffect} = 4 \cdot 10^{-3} \cdot K^{-1} \qquad (3.6.2)$$

In the region of liquid nitrogen (T_1; ca. 77 K), the expansion due to the piezoeffect will be around 10 - 30% of the expansion at room temperature (T_0). Assuming the relation between the change of the piezo electrical expansion with temperature is lineal, it can be expressed as:

$\Delta l_{T_1} = \Delta l_{T_0} (1 - \alpha_{piezoeffect} \Delta T)$
Δl_{T_1} = expansion at T_1
Δl_{T_0} = expansion at room temperature
$\Delta T = T_0 - T_1$
$\alpha_{piezoeffect}$ = temperature coefficient of the piezo effect

In the range of 260 K to 390 K the change of the piezoeffect can be neglected.

Example number 9
To estimate what maximum stroke by a PX 100 at −195 °C (liquid nitrogen) can be expected, the temperature difference to −10 °C should be calculated. So it is ΔT = 185 K. The estimated stroke is around 25 µm.

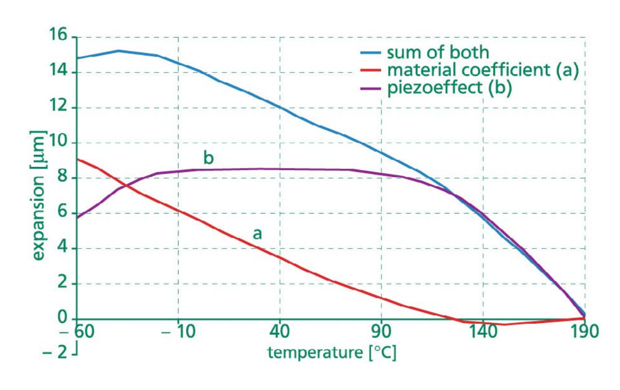


Figure 3.6.1: *Example of temperature dependence of multilayer ceramic L_{piezo} = 18 mm at room temperature.*

c) The ferroelectric hysteresis decreases with falling temperature. The hysteresis of piezoelectric actuators is a result of the ferroelectric polarization (see also ***chapter 3.2***). At very low temperatures of four Kelvin for example, there are almost no changes of the electrical dipoles (domain switching) and so there is very little hysteresis.
In the region of room temperature, the influence of temperature variations to the hysteresis can be neglected.

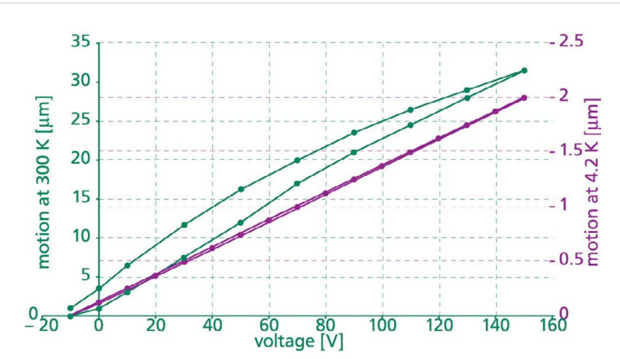


Figure 3.6.2 *Hysteresis curve of a PA 25 element at room temperature and at 4 K.*

But please take into account:

Although the piezo effect decreases with falling temperature, piezoelectric actuators principally can work at very low temperatures - down to the temperature of liquid He (4 K).
If you want to work in a low temperature environment, please tell us about this fact, so we can prepare the actuator for this temperature region.

Stages
The temperature behavior for elements integrated into a lever design depends on both the temperature effect for the piezoelement and the behavior of the stage. It may differ from the behavior described above for the piezoelement itself. Because of the different constructions used for different stages a general rule cannot be given.

Closed loop stages
Please take care to use closed loop stages at near the temperature at which they were calibrated. Only at the temperature of calibration, piezoelements show the best accuracy.

3.7 Capacitance

As mentioned a stack actuator consists of thin ceramic plates as dielectric and electrodes. This is a system of parallel capacitors.

$$C = n \cdot \epsilon_{33} \cdot \frac{A}{d_s} \qquad (3.7.1)$$

n - number of ceramic plates
ε_{33} - dielectric constant
A - cross section of the actuator or the ceramic plates
d_s - thickness of a ceramic plate

Example number 10
A monolithic stack with an (active) length of 16 mm, a cross section of 25 mm² and a thickness of the ceramic plates of 110 µm consists of approximately 144 plates. With a relative dielectricity of ε_r = 5400 one yields a capacitance of the actuator of approximately 1.6 µF (see formula 3.7.1).

Capacitance of multi-layer actuators – capacitance of high voltage actuators

Let us consider the following comparison:

Example number 11
A monolithic actuator (index 1; parameter see example number 10) should be replaced by a piezocomposite actuator with the same length (index 2). For simplicity, both stacks consist of the same material. Refer to formula 3.7.1. The thickness of the ceramic plates of the piezocomposite actuator is 5 times larger ($d_{s2} = 5 \cdot d_{s1}$) so the number of plates is 5 times lower ($n_2 = 1/5 \cdot n_1$).
Thus the capacitance of the high voltage actuator is much lower than the capacitance of the multi-layer actuator C2 = C1/25.

The operating voltage for the same expansion is lower for monolithic stacks. But the capacitance is increasing quadratically.

Please note:
Because of the higher capacitance of low voltage monolithic stacks, these actuators need much more current in dynamic applications. The current can be neglected for static and quasi-static motions.

Please note:
The piezoelectric properties of actuators are not constant as assumed in simple descriptions. Most of the parameters depend on the strength of the internal field. Most of the values given in the literature are for low electric fields. These values can differ for high electric fields. As an example, the capacitance for high voltage operation is nearly twice that given for low voltages.

3.8 Drift – Creep (Open Loop Systems)

Another characteristic of piezoelectric actuators is a short dimensional stabilization known as creep. A step change in the applied voltage will produce an initial motion followed by a smaller change in a much longer time scale as shown in the figure 3.8.1.
As one can see, the creep will be within 1 % to 2 %, in a decade of time. The creep depends on the expansion Δl, of the ceramic material (parameter γ), on the external loads, and on time. The dependence of the creep can be shown also as a logarithmic dependence of time.

$$\Delta l(t) = \Delta l_{0.1} \cdot \left(1 + \gamma \cdot \lg \frac{t}{0.1s}\right) \qquad (3.8.1)$$

$\Delta l_{0.1}$ - motion length after 0.1 s after ending of rise time of the voltage.

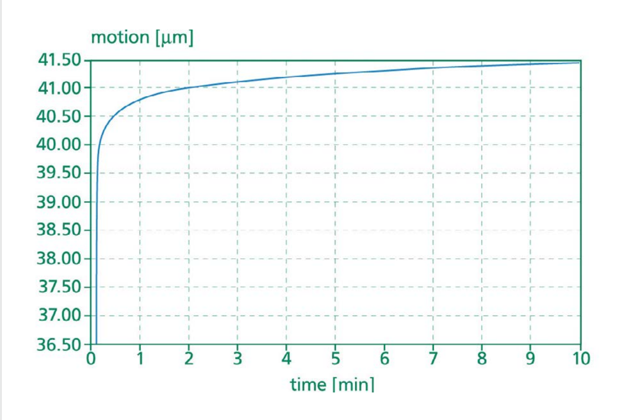


Figure 3.8.1 *Creep of the PU 40 translation stage.*

In this case we reach a value for $\gamma \approx 0.015$. The value of γ depends on the material, the construction and the environmental conditions (e.g. forces).
When the motion (voltage) is stopped, after a few seconds, the creep practically stops.

Repeatability for periodical signals
When working with periodic signals, the repeatability of a position will not be deteriorated with creep. Because of the strong time dependence of the motion, creep occurs in all oscillations in the same order.

In figure 3.8.2 we have shown a periodic oscillation of a mirror mount PSH. The power supply is a normal power supply controlled by a function generator. The full tilting angle is approximately 380 arcseconds. In the picture there is a section of only 10 arcseconds (from 302" up to 312"). It can be seen that the repeatability is better than 0.1" which is better than 0.03 %.

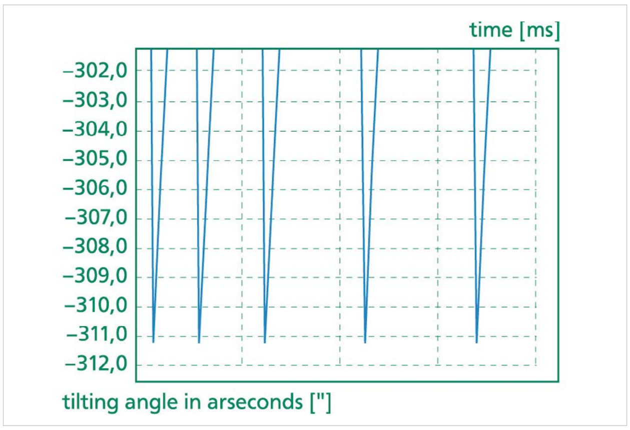


Figure 3.8.2: *Repeatability of a position with periodic motion of a mirror mount.*

As a result of this experiment, we have reached a high repeatability within the system without a closed loop control. For such experiments the repeatability is only determined by the quality of the power supply.

3.9 Working Under Vacuum Conditions

Physics – Low electric breakdown voltage at low pressure conditions

In the pressure range from 0.001 bar to 1 bar (or 100 Pa to 10^5 Pa) the electric breakdown of voltage in the air has a minimum value (down to 1 kV/mm).
If a high voltage is applied in air between electrodes in this pressure range, then an electric breakdown can occur.
This is why piezoelectric stacks without insulation should not be used in the pressure range of 0.001 bar to 1 bar (or 100 Pa to 10^5 Pa).
The reason for this low electric breakdown voltage in air is completely natural and not related to any specific ceramic material.

The operation of piezoelectric multilayer stacks from ***piezosystem jena*** is not limited by this effect.
In almost all cases ***piezosystem jena*** uses only stacks with isolated electrodes.

Piezoelectric multilayer elements in vacuum

The piezoelectric effect, in general works very well under vacuum conditions.
The only problem may arise from outgassing of the materials used.

piezosystem jena uses multilayer stacks with new insulation materials with a very low outgassing behavior.
These stacks are well suited for vacuum and ultra-high vacuum applications.
The electrodes of piezo stacks available from ***piezosystem jena*** are not in contact with air and can be operated through the whole pressure range from ultra-high vacuum to normal pressure conditions without any problems.

Piezostacks from ***piezosystem jena*** have been continuously used in many different applications and pressure regions for many years without any problems!

Rare exceptions:

For a few optic applications contaminations on optic elements are not acceptable (e.g. for EUV Lithography).
These applications take place under ultra-high vacuum conditions For these applications ***piezosystem jena*** can make special modifications and will avoid using insulation materials.
These stacks should not be used in the pressure range from 100 Pa to 10^5 Pa (risk of damage).
For safety reasons piezoelements without insulation should not be used in environments where someone can touch the contacts.

Please contact ***piezosystem jena*** if you have applications with very low outgassing requirements.

Example number 12
The piezoelectric driven optical slit from piezosystem jena was especially prepared for vacuum applications. Up to a pressure of $5 \cdot 10^{-9}$ hPa, no influence of outgassing of the piezoelement was detected.

Heating, baking out of piezoelements.

Piezoelements from ***piezosystem jena*** can be baked out up to 80 °C (175 °F) without problems. Elements with special preparation can be baked out up to 150 °C (300 °F).

3.10 Curie's Temperature

The ferroelectric nature, and also the piezoelectric properties, will be lost if the material is heated over the Curie point. So it is important to work below the Curie temperature T_C.

The Curie temperature is dependent on the used ceramic material. Normally, monolithic actuators have a Curie temperature of 150 °C (300 °F). Piezocomposite actuators have different Curie temperatures of up to 350 °C (660 °F).

Please note that the variety of Curie temperatures leads to changes of other characteristics of the ceramic material. It is not possible to increase the Curie temperature and let the other characteristic (like d_{33}) unchanged.

If a piezoelectric ceramic is heated (for example under dynamic conditions) up to the Curie temperature, thermal depolarization will occur. If temperature parameters are not given we recommend working in temperatures up to $T_c/2$ (normally up to 80 °C for monolithic actuators).

If materials become depolarized, the piezoeffect is lost. However, applying a high electrical field to the actuator can restore it. Thus, special piezoelectric materials can be annealed in the vacuum chambers.

The self heating of piezoactuators can be ignored when working under static and quasi-static conditions. It should be taken into account for dynamical applications (see ***section 5***).

If there is a particular problem, please contact us for more information!

4 Static Behavior of Piezoelectric Actuators

To generate an expansion in a piezoelectric actuator, the ceramic material must be pre-polarized. The majority of the dipoles must be oriented in one direction. If an electrical field is now applied in the direction of the dipoles, (here the z direction) the actuator will show an expansion in the direction of the field (longitudinal effect) and will show a contraction perpendicular to the field (transversal effect).

The motion is expressed by the equation:

longitudinal effect
$$\epsilon_z = \frac{\Delta l_z}{l_z} = S_{33}^E \cdot T_z + d_{33} \cdot E \qquad (4.0.1)$$

transversal effect
$$\epsilon_y = \frac{\Delta l_y}{l_y} = S_{11}^E \cdot T_y + d_{31} \cdot E \qquad (4.0.2)$$

ε - relative strain
T = F/A - mechanical tension pressure (e.g. caused by external forces)
S_{ii} - coefficient of elasticity (reciprocal value of the young modulus)
Δl_z - expansion of the actuator in z dimension
l_z, $l_{x,y}$ - length of piezoelectric active part of the actuator
E = U/d_s electrical field strength, U-applied Voltage

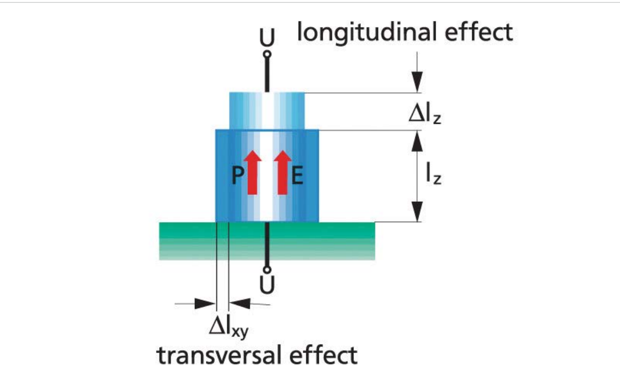


***Figure 4.1** stacked actuators with longitudinal expansion and transversal compression*

Piezoceramics are pre-polarized ferroelectric materials; their parameters are anisotropic and depend on the direction. The first subscript in the d_{ij} constant indicates the direction of the applied electric field and the second is the direction of the induced strain. For, around the z-axis, rotation-symmetric actuators the elongation in x and y direction is the same. Therefore the piezoelectric transversal effect for both directions is combined into d_{31}.

Typical coefficients are:

coefficient	dimension	PZT
d_{33}	m/V	$700 \cdot 10^{-12}$
d_{31}	m/V	$-275 \cdot 10^{-12}$
S_{33}^E	m²/N	$20 \cdot 10^{-12}$
S_{11}^E	m²/N	$15 \cdot 10^{-12}$
tanδ	--	3-5 %
k	--	0,65

The negative sign represents the contraction perpendicular to the field. Typically, piezocomposite actuators are made from harder PZT ceramics than monolithic actuators.

For the sake of simplicity, if not otherwise mentioned, from now on we will refer to the longitudinal piezoelectric effect d_{33}, $\Delta l_z = \Delta l$, $l_z = l$. However all relations can be written in the same manner for the transversal effect.

$$\epsilon = \frac{\Delta l}{l} = S_{33}^E \cdot T + d_{33} \cdot E = \frac{F}{c_T \cdot L_0} + d_{33} \cdot E \qquad (4.0.3)$$

The first term of the equation (4.0.3) describes the mechanical quality of an actuator as a spring with a stiffness C_T, L_0 = total length of the actuator. The second term describes the expansion in an electrical field E.

4.1 No Voltage is Applied to the Actuator, E = 0

The actuator is short-circuited. Formula (4.0.3) becomes $\varepsilon = \Delta l/L_0 = S_{33} \cdot T$. The deformation of the actuator Δl is determined by the stiffness of the actuator c_T^E because of the action of an external load with the pressure T, so it becomes "shorter".

$$\frac{\Delta l}{L_0} = \frac{F}{L_0 \cdot c_T^E} \cdots \text{or} \cdots \Delta l = \frac{F}{c_T^E} \qquad (4.1.1)$$

The stiffness c_T^E of an actuator can be calculated by taking into account the stiffness of the ceramic plates. This approximation assumes that the adhesive between plates is infinitely thin.
Monolithic multi-layer actuators perform well in this respect, giving stiffness on the order of 85% - 90% of the stiffness of the pure ceramic material. Especially for piezocomposite actuators, the stiffness of the metallic electrodes and the adhesive have a large influence on the stiffness of the stack.

Example number 13
On a stack operates an external force of F = 70 N. This force leads to a change in length of 1 µm. Using formula (4.1.1) it is easy to calculate the stiffness of the stack to 70 N/µm.

4.2 No External Forces, F = 0

The motion of a stack without any preload and without external forces can be expressed by:

The maximum expansion depends on the length of the stack, on the ceramic material and on the applied field strength.

$$\Delta l_0 = \frac{F}{c_T} + d_{33} \cdot E \cdot L_0 = (F = 0) = L_0 \cdot E \cdot d_{33} \quad (4.2.1)$$

Example number 14
Let us consider a multi-layer stack with the following parameters:

Piezoelectric constant	$d_{33} = 635 \cdot 10^{-12}$ m/V
Active length	L_0 = 16 mm

The thickness of a single plate is 100 µm. The operating voltage is 150 V. The field strength is E = 1.5 kV/mm.

The expansion will be Δl_0 = 15 µm without external forces (see formula 4.2.1).

4.3 Constant External Loads, F = Constant

Operating with constant force F or weight, the actuators will be compressed (see Figure 4.3.1).

$$\Delta l_n = \frac{F}{c_T} = \frac{m \cdot g}{c_T} \quad (4.3.1)$$

However, the expansion Δl_0 due to the applied voltage will be the same as when an external force is not applied (see formula 4.2.1).

In cases where excessively high external forces are applied, depolarization may occur if there is no applied electrical field. This effect depends on the type of ceramic materials used.

This polarization may be reversed if an electrical field is applied.

However the depolarization can be irreversible if the external forces have exceeded the threshold limit for that material. Damage to the internal ceramic plates may also occur. Therefore it is important to respect the given data for the relevant materials.

Standard actuators from ***piezosystem jena*** with an edge length 5 x 5 mm show depolarization effects for external loads >1 kN. Please see the given parameters in our data sheets!

If your problem needs additional clarification, do not hesitate to contact our team from piezosystem jena.

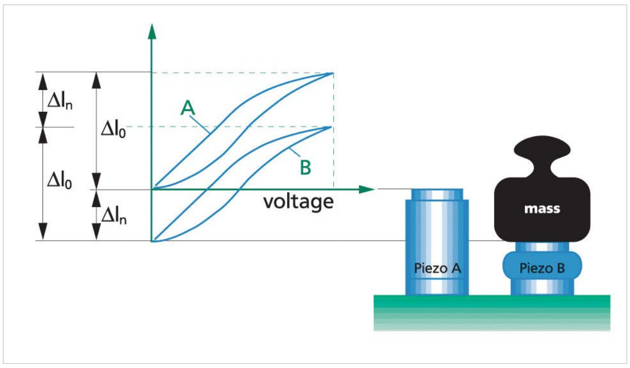


Figure 4.3.1: *Motion under an external, constant force.*

4.4 Changing External Loads and Forces, F = f (Δl)

As an example of changing external forces, consider attaching an external spring. Because of the spring's nature, the force F, operating to the actuator, rises with the increasing elongation of the actuator. If the external forces can be expressed as F = $-c_F \cdot \Delta l$ (c_F stiffness of the spring) we get the following expansion of the actuator:

$$\Delta l = E \cdot d_{33} \cdot L_0 - \frac{c_F}{c_T} \cdot \Delta l \quad (4.4.1)$$

respectively the motion given in relation to the motion without external forces:

$$\Delta l = \Delta l_0 \cdot \frac{c_T}{c_T + c_F} \quad (4.4.2)$$

Part of the motion will be needed to compensate the external forces, therefore the final motion becomes smaller (see also figure 4.4.1).

If the stiffness of the actuator and the stiffness of the external spring are equal, the actuator will reach only half of its normal motion.

Example number 15
The actuator PA 16/12 has a stiffness of c_T = 65 N/µm. The motion Δl_0 without external forces is 16 µm. This actuator is assembled in a housing with a preload stiffness c_F = 1/10 c_T. In comparison with formula (4.4.2) the motion will decrease to 14.5 µm. If the stiffness of the preload is increased to 70 % of the stiffness of the actuator c_F = 0.7 c_T = 46 N/µm, the motion will reach only Δl = 9.4 µm.

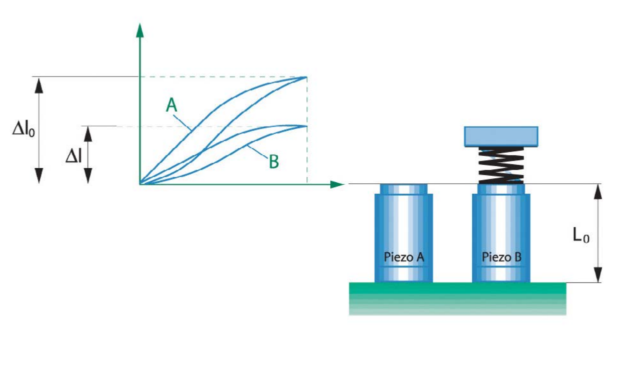


Figure 4.4.1 *motion dependence of external spring forces*

4.5 Force Generation

Using equation (4.4.2) we can calculate the effective forces, which can be reached with an actuator operating against an external spring.

$$F_{eff} = c_T \cdot \Delta l \cdot \left(1 - \frac{c_T}{c_T + c_F}\right) = c_T \cdot (\Delta l_0 - \Delta l) \qquad (4.5.1)$$

Δl_0- motion without external loads (µm)
Δl - motion under external loads (µm)

Example number 16
Again, we will use the actuator PA 16/12. For motion without external load Δl_0, the stiffness is C_T = 65 N/µm. This actuator is working against a spring with a stiffness C_F = 64 N/µm. In this assembly the actuator will reach an effective force of 516 N. When it operates with an external spring with a stiffness of 500 N/µm, it will reach an effective force of F = 920 N.

An external variable force operating with an actuator will decrease the full motion.

Integrated preloads of piezoelectric actuators are external forces. The value of the integrated preload often reaches 1/10 of the maximum possible load of the actuator.

But preloaded actuators can work under tensile forces. They are well suited for dynamic applications.

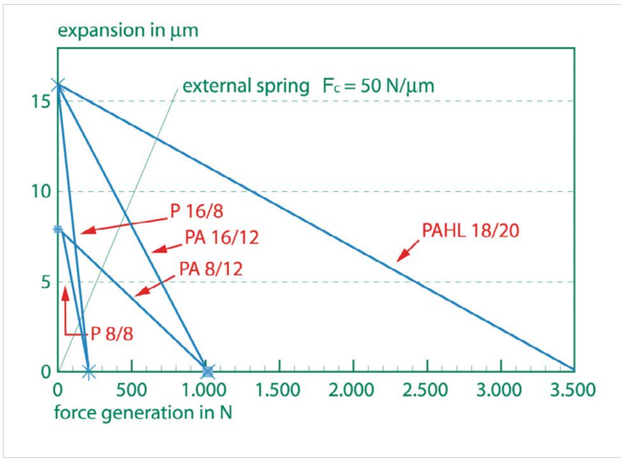


Figure 4.5.1: *Stress strain diagram of piezoelectric actuators.*

Operating against external spring forces, actuators show the following behavior of the generated forces in dependence on the expansion. This stress diagram (Fig. 4.5.1) is valid for monolithic and piezocomposite actuators used by ***piezosystem jena***.

The cross over with the x-axis indicates the blocking force. The cross over with the y-axis shows maximum expansion without external forces. Also shown is the curve of an external spring. The crossover of this spring load line with the curve of the actuator gives the actual parameters, which can be reached with this actuator operating against a defined spring.

An actuator can generate the maximum mechanical energy if it is operating to an external spring with a stiffness of half the actuator stiffness ($C_F = C_T$). In this case the actuator reaches only 50 % of its normal (without external forces) expansion.

Example number 17
An actuator of the type PA 16/12 operates to an external spring, without loads the actuator reaches a motion of 16 µm. A generated force of 320 N is needed. What motion can be reached under such conditions?

Answers:
Look at the diagram, the vertical line beginning at the point of 320 N crosses over to the actuator´s PA 16/12 curve. The horizontal line, beginning at this point of the cross over will end in the value of the possible motion, approximately 11 µm. The same result can be calculated using (4.5.1). For the real expansion Δl under external spring forces we yield from (4.5.1) $\Delta l = \Delta l_0 - F_{eff} / c_T$. The stiffness of the actuator is c_T = 85 N/µm. The result will also Δl = 11 µm.

For further information about the generation of high energy pulses please see the booklet “Piezo composites” on **www.piezo.eu**.

4.6 Blocking Force, Δl = 0

The actuator is located between two walls (with an infinitively large stiffness). So it cannot expand (see formula 4.2.1.):

$$0 = -\frac{F}{c_T} + d_{33} \cdot E \cdot L_0 \qquad (4.6.1.)$$

In this situation the actuator can generate the highest force F_{max}.

$$F_{max} = c_T \cdot \Delta l_0 \qquad (4.6.2.)$$

This force is called blocking force of an actuator.

Please note:
In practice an infinitely stiff wall or clamping to the actuator cannot be realized. For this reason an actuator will not reach its maximum theoretical force in reality. Please note also that if the actuator should generate its blocking forces it will not show any motion!

4.7 Push and Pull Forces

Piezoceramic stacks can withstand high pressure push forces (push forces are opposite the direction of motion). However due to their construction as a multilayer element they can withstand only low pull forces (tensile forces in the direction of motion). Piezo stages consist of a combination of multilayer piezoceramic stacks, working within a special construction for the magnification of motion. This construction can include different kinds of preloading mechanisms allowing for higher pull and push forces to the piezo stages.

Push and pull forces specified in this catalog indicate maximum forces to be applied to the piezo stages, or piezo actuators without mechanically damaging the elements.
If the applied forces are higher than the specified values the elements can be damaged and might not work properly.

Please note:
Push and pull forces can change the offset of the motion as well as the total motion range. This change can vary with the type of load (static load, or operation opposite a spring type force). Please see also chapter 4.3; 4.4; 4.5 and ***chapter 6*** of the piezoline.
Specifically dynamic operation (acceleration, change of the speed) generates dynamic forces to the piezoelement! Please be sure they do not exceed specified push or pull forces.
If the application requires higher forces than those specified, please contact our engineers. Depending on the stage it might be possible to modify the element for higher forces.

Closed loop systems
As mentioned above, external forces, such as different environmental conditions can change the offset, and the motion of a piezoelement. These forces can affect the specifications and thus the calibration can be changed. If a closed loop system is to be operated under different conditions, than those of which it is calibrated for, please contact our engineers. Please see also chapter Calibration and Special Calibration.

5 Dynamic Properties

5.1 Resonant Frequency

Piezoactuators are oscillating mechanical systems, characterized by the resonant frequency f_{res}. The resonant frequency is determined by the stiffness and the mass distribution (effective moved mass) within the actuator. Monolithic actuators from ***piezosystem jena*** reach resonant frequencies of over 100 kHz.

$$f^0_{res} = \frac{1}{2\pi} \cdot \sqrt{\frac{c_T}{m_{eff}}} \qquad (5.1.1)$$

An additional mass M loaded to the actuator decreases the resonant frequency of this system.

$$f^1_{res} = \frac{1}{2\pi} \cdot \sqrt{\frac{c_T}{m_{eff} + M}} = f^0_{res} \cdot \sqrt{\frac{m_{eff}}{m_{eff} + M}} \qquad (5.1.2)$$

That is why the resonant frequency of a complete system can deviate considerably from the resonant frequency of the single actuator. This is an important fact for example when using the mirror for fast tilting. Actuators using a lever transmission for larger motions show resonant frequencies typically within the range of 300 Hz up to 1.5 kHz.

In our data sheets for some elements not only the resonant frequency is given, but also the effective mass. By knowing the effective mass it is possible to estimate the resonant frequency with an additional mass (using formula 5.1.2.).
You will find more information about the simulation of dynamic properties in ***chapter 7***.

Please note!
Because of the complexity of this field, such calculations give only approximate values. These values should be experimentally verified by tests.

Example number 18
The resonant frequency of the actuator PA 25/12 is f^0_{res} = 12 kHz. The effective mass can be estimated by m_{eff} = 10 g. This actuator has to tilt a mirror with a mass M = 150 g. Because of this mass, the resonant frequency changes to f^1_{res} = 3 kHz.

Moving with the resonant frequency, the amplitude of the actuator is much higher as in the non-resonant case. Actuators with a lever transmission show super-elevations up to 30 times and higher in comparison to the non-resonant case.

When working with frequencies near the resonant frequency, one needs a much lower voltage for the same result. But please be careful! This advantage can damage your actuator if the motion exceeds the motion for maximum voltage in the non-resonant case!

We strongly recommend:
Actuators, which are not specially prepared, should be used with frequencies of maximal 80 % of the resonant frequency.
Please also consider the heating of piezoelectric elements while in dynamic motion.

piezosystem jena provides piezocomposite shakers for working above the resonant frequency.

Please note
Actuators that work near or above the resonant frequency need to be preloaded. Please consider resonance magnification near the resonance frequency and decrease in amplitude for higher frequencies.

Do not hesitate to contact us to solve your special tasks!

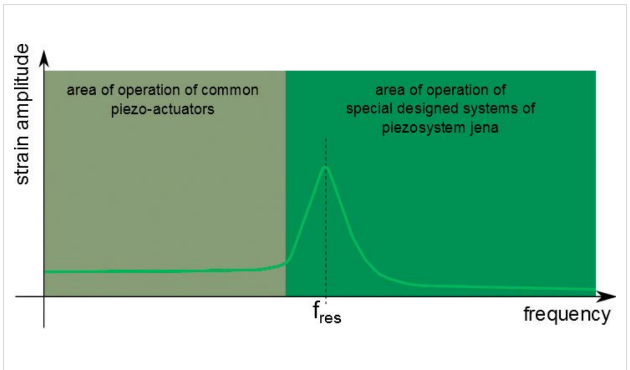


*Figure 5.1.1: Operating range of special designed piezocomposite shaker from **piezosystem jena**.*

5.2 Rise Time

Because of their high resonant frequency, piezoactuators are well suited for fast motions. Application examples are valve technology and for fast shutters. The shortest rise time t_{min} which an actuator needs for expansion, is determined by its resonant frequency.

$$t_{min} \approx \frac{1}{3 \cdot f_{res}} \qquad (5.2.1)$$

When an actuator is given a short electric pulse, the actuator expands within its rise time t_{min}. Simultaneously, the actuator´s resonant frequency will be excited. So it begins to oscillate with a damped oscillation relative to its position. A shorter electric pulse can result in a higher super-elevation but not in shorter rise times!

The figure shows a typical response to a short electric excitation of a piezoactuator nanoX 200 SG from ***piezosystem jena***. The approximately 31 oscillations in 60 ms agrees to a resonant frequency of almost 520 Hz and a rise time of 0.6 ms.

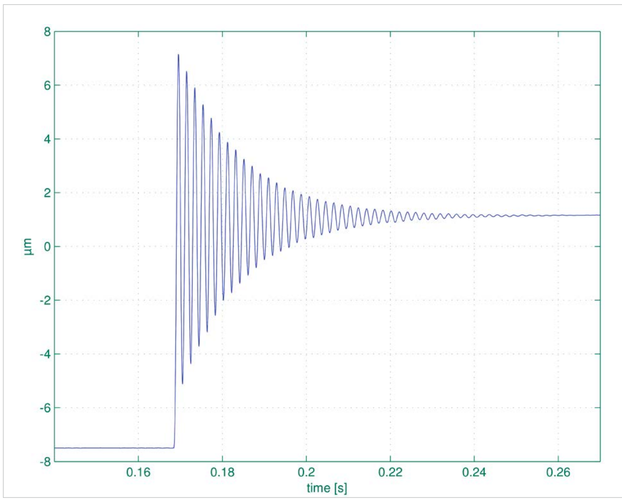


Figure 5.2.1 *Answer of a piezoelement nanoX 200 SG to an excitation voltage step of 10 V.*

5.3 Dynamic Forces

While working in a dynamic regime, compressive stress and tensile forces act on piezoelectric actuators. The compressive strength of piezoactuators is very high, but both types (monolithic and piezo composites) are very sensitive to tensile strength. But both forces F_{dyn} occur in the same order while moving dynamically (formula given for sinusoidal oscillation).

$$F_{dyn} = \pm (2\pi \cdot f)^2 \cdot m_{eff} \cdot \frac{\Delta l}{2} \qquad (5.3.1)$$

$\Delta l/2$ - magnitude of the oscillation (Δl full motion of the actuator).

A large acceleration operates on the ceramic and electrode material.

$$\alpha = \frac{\Delta l}{2} \cdot (2\pi \cdot f)^2 \cdot \sin(\phi) \qquad (5.3.2)$$

φ - angle of the phases of the oscillation.

Example number 19
An actuator with a motion of 20 µm and an operating frequency of 10 kHz has an acceleration of 39'500 m/s². This value exceeds the gravitational acceleration of the earth by 4000 times.

Please consider dynamic forces while in dynamic motion. They also appear without external loads!

That is why it is necessary to use preloaded actuators for dynamic applications. PA or PAHL types are preloaded monolithic actuators. Piezo-composite actuators from ***piezosystem jena*** also come as preloaded version. Piezocomposite actuators can also be specially designed for applications with high dynamics, e. g. frequencies up to 100 kHz and accelerations up to 10'000 g.

Actuators without preload can only be used for small frequencies in special cases!

Please note
When working under dynamic conditions, the current, which will be needed for the motion, can reach large and critical values. For calculation of the required current, see also ***section 10***, especially ***section 10.2*** and ***10.3***.

6 Actuators with Lever Transmission System

Most of our elements work with an integrated lever transmission (see ***figure 2.4.1***). This construction has some advantages:

- The motion can be much higher than the motion of the stack type actuator.
- Because of using a parallelogram design, the parallelism of the motion is much better than the parallelism of the motion of a simple stack.
- Because of solid state hinges, mechanical play does not occur. The fineness of the motion will be similar to that of actuators without lever transmission.
- Solid state hinges work without wear for a long time.
- Because of the lever transmission a short stack can be used to generate the same motion as a long stack can generate without a lever transmission system. Thus the capacitance of the whole system is much lower than the capacitance of an equivalent stack. This can be advantageous for dynamic applications due to the lower electric current requirements (see also ***section 10.2. Current)***.

As an approximation, piezoactuators with an integrated lever transmission can be seen as an actuator with a new stiffness and a new resonant frequency. In our data sheets these values are given for our elements.

Piezoelectric actuators with lever transmission have the electrical capacitance of a stack and they have a high inner resistance.

The essential changes to "normal" stack type actuators are:

The motion will be amplified by the transmission factor TF:

$$\Delta l_2 = TF \cdot \Delta l_1 \qquad (6.1)$$

The stiffness decreases quadratically with the transmission factor:

$$c_{ges} = c_F + \frac{c_T}{(TF)^2} \qquad (6.2)$$

c_T - stiffness to the stack
c_F - stiffness of the lever transmission construction.

Because of the lower stiffness the superelevation will be higher (up to 100 times and more in relation to the motion in the non-resonant frequency range).

The resonant frequency decreases linearly with the transmission factor TF.

$$f_{res}^2 = f_{res}^1 \cdot \frac{1}{TF} \qquad (6.3)$$

While the resonant frequency of a one-sided fixed piezoelectric stack reaches frequency values up to 50 kHz, the resonant frequency of systems with integrated lever transmission will reach values of 300 Hz up to 1.5 kHz.

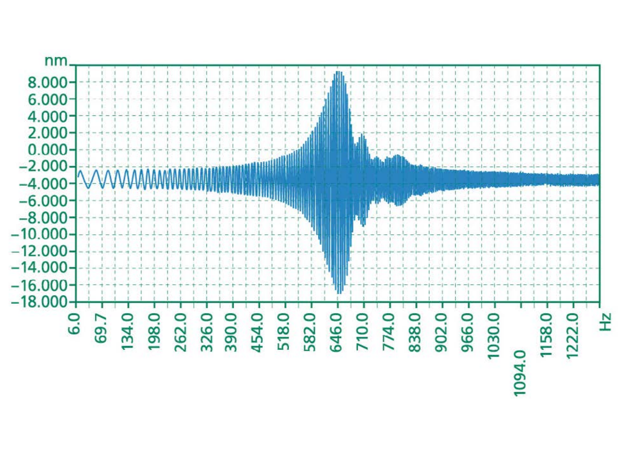


***Figure 6.1** resonant frequency of piezoelement with lever transmission series PU 100*

If the chosen experimental equipment is unfavorable, additional subordinate (cross) resonant frequencies may occur. The values of these frequencies can only be lower than the actuator´s main resonant frequency.

The blocking force (see also ***section 4.5.***) decreases linearly with the transmission factor.

$$F_{max_2} = F_{max_1} \cdot \frac{1}{TF} \qquad (6.4)$$

Please note

Usually piezocomposite actuators are used to generate high forces respectively high frequencies (in special cases above the resonant frequency). Because of that they are not used for lever transmission systems.

Cross motion

Because of the principle of a lever transmission with parallelogram design, the motion in one direction is followed by a small motion in the perpendicular direction (cross motion). Though the motion follows a parabolic curve, the end faces will make a parallel motion.
The order of this cross motion is approximately 0.125 % but depends on the specific construction parameters.
For example, a TRITOR element with 40 µm motion in the x-direction will make a simultaneous motion of about 50 nm in the y-direction. For most applications this will not disturb the positioning precision. But in other cases it should be taken into account.
The cross motion can be minimized by optimizing the construction of the piezoelement.
This was done for the piezoelement PU 100. By alignment the cross motion was minimized to less than 15 nm (see figure 6.2).

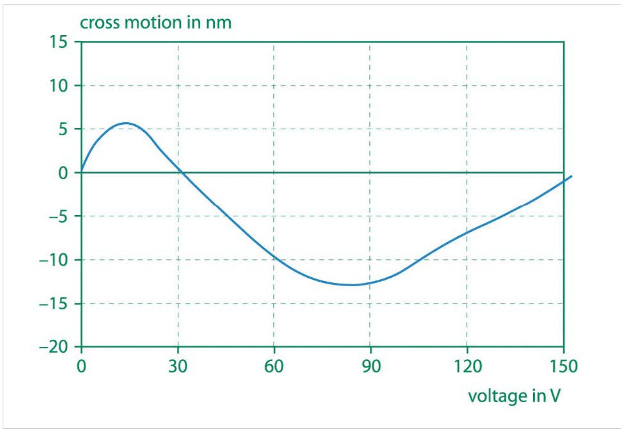


***Figure 6.2** Optimization of the cross motion of a piezoelement PU 100.*

7 Simulation of Dynamic Properties

7.1 Transformation of Electrical and Mechanical Properties

The piezoelectric effect describes the electromechanical coupling behavior of ferroelectric materials. A theoretical model of electromechanical transducers is given with an electromechanical network network (see Fig. 7.1.1). This network consists of electrical and mechanical components, which are connected via a specific four-pole circuit with the coupling factor y.

Using this model makes it possible to simulate the dynamic behavior of piezoelectric actuators.

The equivalent electrical circuit of piezoelectric actuators can be determined with the help of an electrical impedance analyzer. With the equivalent electrical circuit, it is possible to simulate the dynamic behavior of the corresponding actuator system. The electrical model can be implemented in standard simulation programs and, thus, whole systems, including the power supply and a closed loop control circuit, can be simulated.

In the case of piezoelectric transducers, the components of the theoretical networks are: the electrical free capacitance C_b, the mechanical elements compliance n (mechanical stiffness n^{-1}), effective mass m and the intrinsic mechanical losses h. Due to the reciprocal network characteristic with the coupling factor y, the following relation can be given:

Electric	↔	Mechanic
Voltage u		force F·y
Current i		velocity $v \cdot y^{-1}$
Inductivity L		mass $m \cdot y^2$
Capacitance C		compliance $n \cdot y^{-2}$
Resistance R		intrinsic losses $h^{-1} \cdot y^2$
Parallel circuit		serial connection
Serial connection		parallel circuit

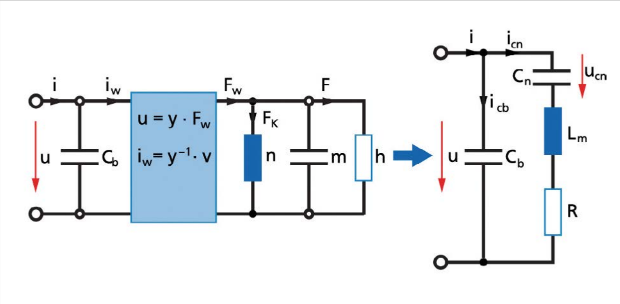


Figure 7.1.1: *Mechanical scheme and equivalent electric network of piezoelectric transducers.*

A transformation of the mechanical components to the electrical side of the four-pole network leads to the model of the equivalent electrical circuit of piezoelectric actuators (Figure 7.1.1).

with: $C_n = y^2 \cdot n \quad L_m = y^2 \cdot m \quad R = y^2 \cdot h^{-1}$

The representative electrical circuit gives a linear approximation of the electromechanical system. The characteristic equation of this network is similar to the characteristic equation of a simple spring-mass-oscillator. If a force F is applied to a mechanical spring with the stiffness n^{-1}, the displacement x is given with $x = F_k \cdot n$. With the given coupling relation, the equivalent equation for the electrical network is

$$x = \frac{u_{cn}}{y} \cdot y^2 \cdot C_n = y \cdot u_{cn} \cdot C_n \qquad (7.1)$$

The voltage u_{cn} is given with

$$u_{cn} = \frac{u}{(s+b)^2 + a^2} \qquad (7.2)$$

Therefore the characteristic equation for the mechanical displacement of piezoelectric transducers can be determined from the equivalent electrical circuit:

$$x = \frac{y \cdot u \cdot C_n}{(s+b)^2 + a^2} \quad \text{with} \quad a = \sqrt{\frac{1}{C_n \cdot L_m} - b^2} \qquad (7.3)$$

$$\text{and} \quad b = \frac{R}{2 \cdot L_m} \qquad s = 2 \cdot j \cdot \pi \cdot f$$

The resonant frequency is given by:

$$f_{res} = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{1}{L_m \cdot C_n}} \qquad (7.4)$$

As mentioned before, the model of the equivalent electrical circuit corresponds to a linear approximation of the real coupling behavior of electromechanical transducers. This model includes neither the piezoelectric hysteresis not the creep and saturation of polarization. Further restrictions of this model are given with the special characteristic of the piezoelectric material parameters. All specific material properties (e.g. compliance, capacitance, piezoelectric coefficient) are dependent on the applied electrical field. This dependence is not to be considered by the linear model.

Example number 20

We tried to find a simulation model for our actuator PU 90.

This model should be able to calculate the dynamic behavior of this element with different additional masses.

An additional mass leads to higher inductivity L_m in the model:

$L_m = y^2 \cdot (m_{eff} + m_{add})$.

m_{eff} is the effective moved mass of the actuator system without an additional load and m_{add} is the additional mass. To calculate L_m for any loads, it is necessary to find the values for y and m_{eff}.

This can be done with two measurements on an electrical impedance analyzer (with different loads). We made four measurements to reach a higher reliability in our model.

From these measurements, we obtained the following values for the model of the actuator system PU 90:

m_{eff} = 89.8 g; y = 2.12 m/As; R = 38.92 Ω ; C_n = 171 nF ; C_b = 1.56 µF

With this model we calculated the resonant frequency with respect to an additional load and we simulated the response of this actuator to a voltage step. We proved our model with some additional measurements which were done with the aid of an interferometer displacement sensor. The results are given in the diagrams. (7.1.2 – 7.1.4)

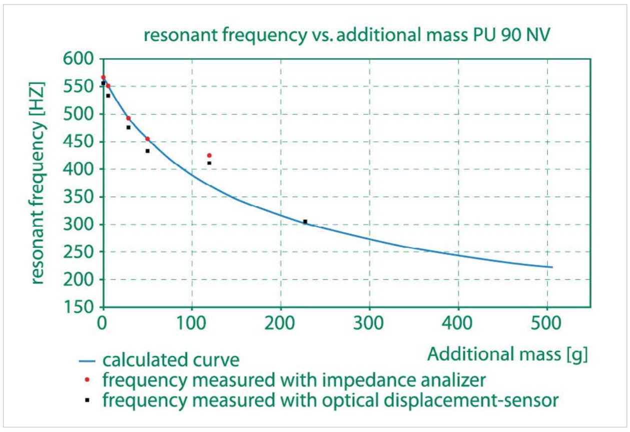


Figure 7.1.2: *Calculated resonant frequency of the actuator PU 90 with respect to an additional load.*

Simulation models of several of ***piezosystem jena***'s actuator systems were made. With these models it is possible to determine significant mechanical parameters for the dy-

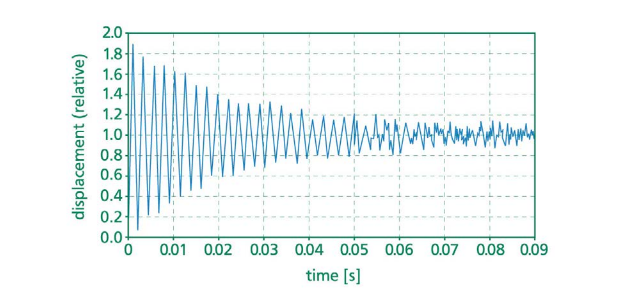


Figure 7.1.3: *PU 90 with additional load 51 g, measured response to a voltage step.*

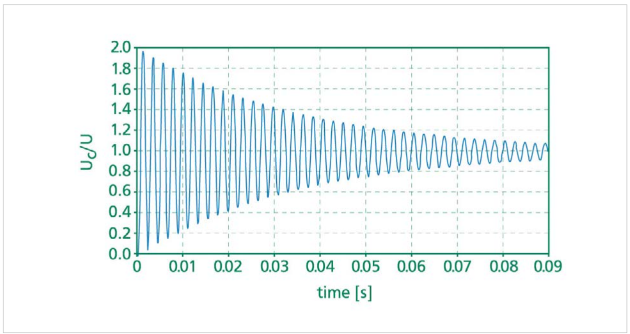


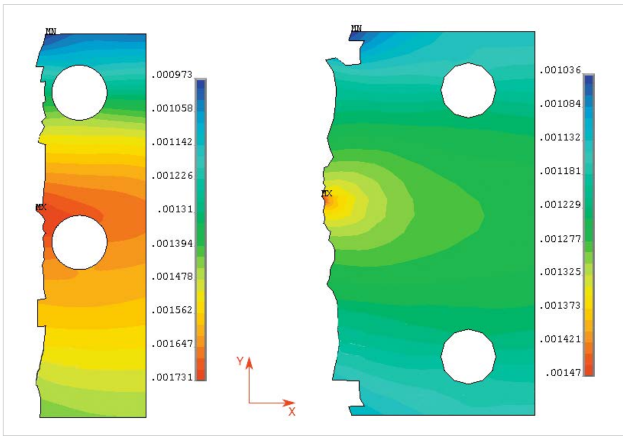
Figure 7.1.4: *PU 90 with additional load of 51 g, simulated response to a voltage step.*

namic use of piezoelectric actuators. In this way, custom-designed actuator systems can be realized much easier and more efficiently.

7.2. FEM Optimization

A lot of applications require special mechanical properties which have to be considered from the beginning of the development. Additional loads needs to be moved dynamically require a complex optimization process of the stage. Using only formula 3.5.1 or 6.2 does not allow one to develop optimized stages. The full construction should be designed using FEM calculations. With our extensive experience in FEM calculations we can optimize more accurate parameters as stiffness, minimum tilting properties and others.
The following 2 pictures show how to optimize a stage for minimum cross motion. Cross motion occurs if one axis is moved (here the y axis) but the other axis still shows a small motion.
This cross motion is a result of a non-optimized construction, material imperfections and other factors.
In figure 7.2.1 (left) the stress inside a stage is shown while the stage moves in y-axis. Tensile forces in x-axis occur leading to a tilt of 67 µrad (calculated by FEM analysis) because of the above-mentioned imperfections

In figure 7.2.1 (right) the holes for mounting the stage are replaced; optimized for a minimum x tilt. The result is a tilt of 6.6 µrad, which is 10 times smaller than for the non-optimized stage.
piezosystem jena uses its extensive experience in FEM calculations to develop special products optimized for the very special needs of your particular application.



7.2.1: Left: *non-optimized stage,* ***Right:*** *optimized stage*

8 Position Control – Closed Loop Systems

Because of the nearly unlimited resolution of the motion, piezoelectric actuators are ideally suited for high precision positioning in the µm range to the nm range.

However, because of the hysteresis the relation between the applied voltage and the actuator's motion is not unique.

There are some applications in practice where the high resolution of the motion is necessary, but the absolute positioning accuracy is not. The classic example is the problem of fiber positioning. The light of one fiber has to be coupled most efficiently into a second fiber, the knowledge of the absolute position of the fiber is not important.

Another example:
If it is possible to return after each positioning event (transaction) to the 0 voltage position, the hysteresis does not affect the action (see also ***chapter 3.8***).
Of course some applications demand a high positioning repeatability. This can be reached by combining piezoelectric actuators with a measurement system. Because of their high dynamics, piezoelectric actuators are well suited for a closed loop system with a measurement system.

piezosystem jena uses different measurement systems. With strain gauges it is possible to reach a position accuracy of 0.1 – 0.2 %. Better results can be reached with capacitive sensors.

You have to be careful working with a measurement system! Each measurement system always measures the motion at the place where the measurement system is located.

Variations between the measurement system and the point which should positioned (such as temperature effects), cannot be detected by the system.

piezosystem jena has developed piezoelements with a measurement system and we have also developed complete electronic controllers with integrated closed loop control. The closed loop is controlled by PID regulation circuit; the actual position measured is shown on the display.

Please note:
Often it is not possible to upgrade an existing piezoelectric element with a measurement system. Therefore it is important to investigate carefully depending on your application, if an integrated measurement system is really needed.
If a measurement system is used in a closed loop system, the full range of the motion will be smaller by about 10 - 20% to preserve the dynamic of the closed loop regulation.

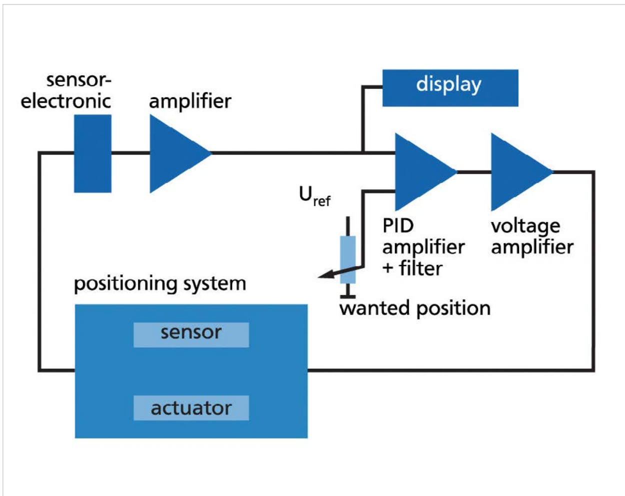


Figure 8.1. *principle of the closed loop control*

9 Characterization of Measurement Systems

The influence of the ferroelectric hysteresis and the effect of the time dependent creep limit the best mechanical parameters of piezoelectric actuators. In a large number of applications these effects do not play an important role. For other applications it is advantageous to implement a closed loop system. In a closed loop system the motion of the actuator will be measured and any unwanted changes from the given position will be corrected by the closed loop electronics.
piezosystem jena uses different types of measurement sensors:

- strain gauge measurement systems,
- capacitive sensors.

Strain gauges are very compact. They can be easily integrated into almost all piezoelectric translation stages from ***piezosystem jena***.

Capacitive sensors can be used for systems needing the highest accuracy and/or dynamics. In some cases it is necessary to measure the displacement from outside of the actuator. In order to provide the best performance for special requirements it is necessary to know the fundamental properties of the different sensor systems. In cases where µm and sub-µm accuracy is needed, the full system has to be optimized (actuator, sensor, electronics, environmental conditions, etc.).

After optimizing the actuator, a calibration procedure with an exact laser beam interferometer has to be made.

9.1. Resolution

The piezoelectric effect is a real solid state effect. In theory there is no limitation to the resolution; an infinitely small change in the electrical field gives rise to an infinitely small mechanical displacement. The real world offers some limits in resolution, which are caused by electrical, mechanical, acoustic and thermal noise.

mechanically:
The mechanical resolution is determined by the design of the drive. Piezo actuators from ***piezosystem jena*** are made with flexure hinges. Due to this construction principle no mechanical play arises, whereby the mechanical resolution is unlimited.

electrically:
During operation the resolution indicates how much the piezo actuator moves if no motion is indicated i.e. the output voltage of the amplifier is to remain constant. This resolution is determined by the noise of the output voltage. Here only the frequency range of the output voltage is taken into consideration, which the actuator is able to follow.

Usual piezo actuators with lever transmission of ***piezosystem jena*** have a resonant frequency between 200 Hz and 750 Hz, so the output voltage is measured only up to this frequency. Frequencies above this range cannot be converted into a motion by an actuator. A voltage noise of 0.3 mV means that the piezo actuator has a resolution of 0.2 nm, related to a total travel of e.g. 100 µm @ 150 V (total voltage range: -20 … +130 V).

$$\text{resolution} = \frac{\text{total stroke} \cdot \text{voltage noise}}{\text{voltage range}} \tag{9.1}$$

For the resolution in the closed loop mode the noise of the measuring system must also be considered. Therefore the noise of the output voltage in the closed loop mode is measured.

To measure the resolution of a closed loop system we used a PX 100 with capacitive sensor and a power supply NV 40/ CLE. The investigations were done under state-of-the-art laboratory conditions.
The element was driven with a square function of approximately 40 mV amplitude.

In figure 9.1.1 and 9.1.2 we show the sensor voltage and the measurement signal of the laser beam interferometer. The measurements were done for two different filter frequencies of the sensor electronics -10 Hz and 1 KHz.

One can see that the sensor signal with the 10 Hz filter seems to be even better than the interferometer signal.
The reason is that higher frequencies do not pass the 10 Hz filter of the electronics and thus they are not measured. The sensor seems to be less noisy which can result in a higher accuracy of the full system.

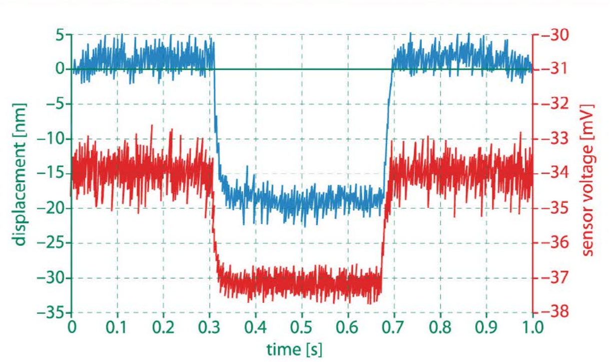


Figure 9.1.1: *Voltage signal from the capacitive sensor (red line) in comparison with the interferometer signal (blue line). The filter frequency of the sensor was set to 1 kHz.*

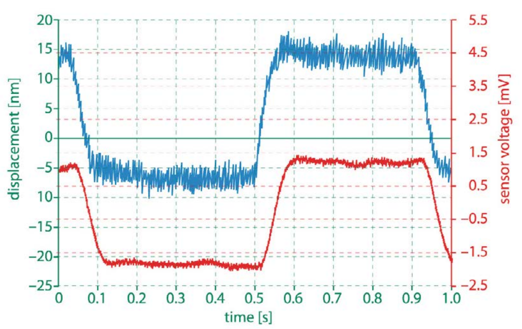


Figure 9.1.2: *Voltage signal from the capacitive sensor (red line) in comparison with the interferometer signal (blue line). The filter frequency of the sensor was set to 10 Hz.*

Please note:
The highest positioning resolution requires very stable measurement conditions. The best measurement conditions are:

- a well-grounded environment
- an area far from electromagnetic fields (use shielded cables)
- vibrationally isolated conditions (an actively damped table is recommended)
- stable temperature conditions

Otherwise the environmental conditions will determine the resolution of the experiment.

9.2 Linearity

In the ideal case, the relation between the input signal (signal defining the position of an actuator) and the output signal (realized motion) should be linear.
When speaking about systems with integrated sensors, the linearity of the sensor (plus sensor electronics) is an important quality parameter.

Absolute position calculated from sensitivity

The linearity describes the approximation of the relation between indicated and true position.

With the measured voltage (MON) the reached position can be calculated on the basis of the formula below.

$$\text{reached position} = \frac{\mathrm{V_{meas}} - \mathrm{V_{min}}}{\text{sensitivity}} \qquad (9.2.1)$$

The current values for the following calculations are taken from the calibration protocol (e.g. see ***9.5. calibration protocol for closed loop system***).

Example number 21
minimum voltage = – 0.007 V*
total stoke = 400 µm*
sensitivity = 0.0249 V/µm*

measured voltage = 3.864 V

$$\text{reached position} = \frac{\mathrm{V_{meas}} - \mathrm{V_{min}}}{\text{sensitivity}}$$

$$\text{reached position} = \frac{(3.864 - 0.007)\ \mathrm{V}}{0.0249\ \mathrm{V}/\mu\mathrm{m}} = 154.899\ \mu m$$

* values are given in the calibration protocol

Absolute position calculated from sensitivity with consideration of the non-linearity

As already mentioned, the monitor output voltage gives the best values for the current position of the system.
Taking into account the measured non-linearity of the positioning system (see calibration curve). The absolute position calculated from the sensitivity should be corrected by the non-linearity.

The deviation of the true actuators position from this linear relation is the non-linearity. This is described by a polynomial function of higher order. In order to calculate the true actuator position on the basis of the measured voltage, the non-linearity must be taken into account.

$$\text{reached position} = \frac{V_{\text{meas}} - V_{\text{min}}}{\text{sensitivity}} + \frac{\Delta l_{max} \cdot \text{nonliniarity}_{@\ \text{position}}\ [\%]}{100\ [\%]} \tag{9.2.2}$$

Example number 22
minimum voltage = -0.007 V*
total stroke = 400 µm*
sensitivity = 0.0249 V/µm*
non-linearity$_{@157\mu m}$ = 0.037%

measured voltage = 3.864V

$$\text{reached position} = \frac{V_{\text{meas}} - V_{\text{min}}}{\text{sensitivity}} + \frac{\Delta l_{max} \cdot \text{nonliniarity}_{@\ \text{position}}\ [\%]}{100\ [\%]}$$

= 154.899 µm + 148 nm
= 155.047 µm

*values are given in the measurement report

Taking into account the non-linearity of 148 nm at the position of the system of 154.899 µm (MON = 3.864 V) had to be corrected to 155.047 µm. We determine the linearity of a sensor system in the following way: We operate the piezoactuator with a triangular wave over the full range of motion. The motion of the system will be measured by the integrated sensor and by the laser beam interferometer.

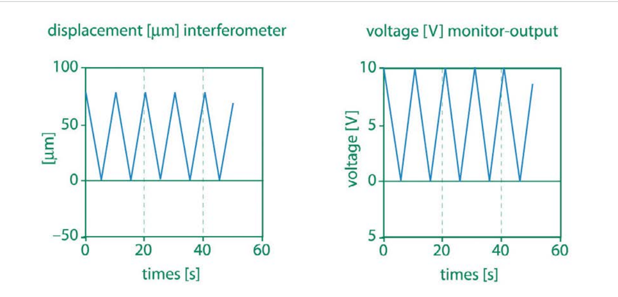


Figure 9.2.1: Signal from laser beam interferometer and Sensor output signal.

Figure 9.2.2 shows the non-linearity of a PX 100 system with a strain gauge measurement system.

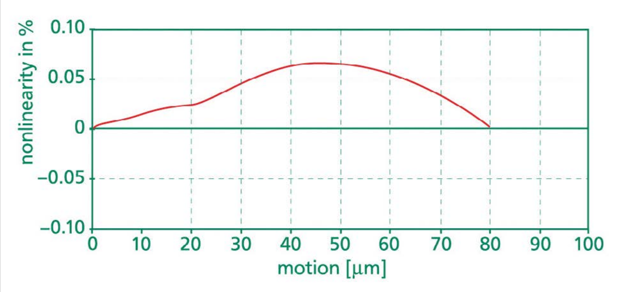


Figure 9.2.2: Non-linearity of a PX100 with strain gauge (SG).

The data for non-linearity related to the position, repeatability and lower and upper voltage limit are provided on the calibration report sent with every system from ***piezosystem jena***.

9.3 Repetition Accuracy (Repeatability) ISO 5725

The repetition accuracy designates the error which arises if the same position from the same direction is approached again and again. In order to achieve a certain position repeatedly the same modulation voltage must be applied. The difference between modulation voltage and monitor voltage is regulated to zero by the electronic controller. The deviation of the different reached positions is indicated by repeatability. In the provided calibration protocol the maximum value of this error is indicated.

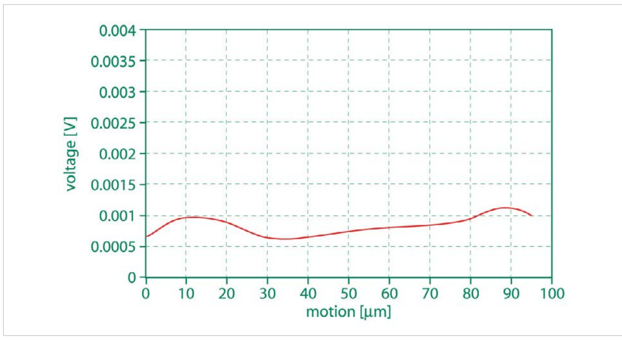


Figure 9.3.1: Typ. repeatability for a PX 100 with capacitive measurement system.

Note:
The exact position of piezoelements cannot be accurately represented by an amplifier display due to its resolution. For highly exact position-ing requirements it is recommended to supervise the position over the monitor voltage. For this an appropriate digital voltmeter can be used.

9.4 Dynamic Properties of a Closed Loop System

As stated, all single parts of a closed loop system influence the dynamic properties. This includes the properties of the actuator, of the sensor and the electronic system.

Please note:
When speaking about the properties of the actuator, it means the actuator as integrated into the real experiment. Additional masses or any forces from outside can influence the dynamic properties dramatically. You will find further details about dynamical properties in ***chapter 5***.

The closed loop electronics using control algorithms (P, PI, PID etc.) also affect the dynamic behavior. Each control system has to be calibrated with the special actuator. Do not change any modules or actuators of a control system, except those with the ASI/ASC function!

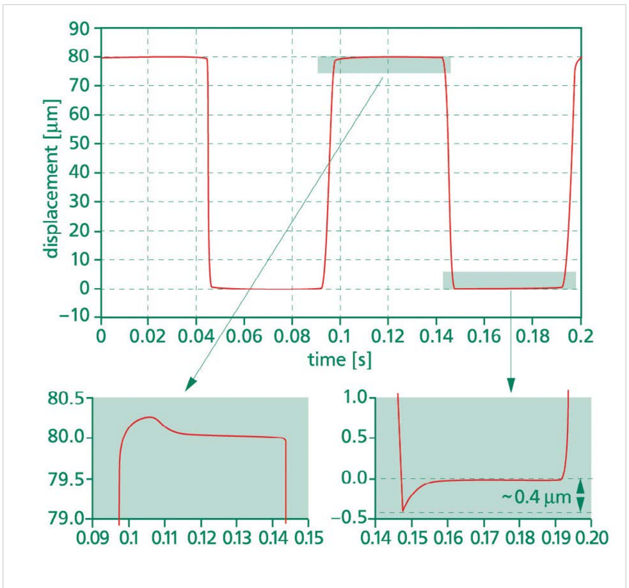


Figure 9.4.1 *Response time of a closed loop system PX100 with a strain gauge measurement system.*

Do not hesitate to ask us if you have any questions!

For a correct analysis of the dynamical properties, the damping curve and the phase shift over the frequency variation has to be measured. The dynamic function for operating the element should be investigated with respect to the containing frequency.
The driving frequency must be smaller than the maximum frequency of the full system. To ensure this, any curve differing from a sine wave form should be analyzed so as not to exceed the containing frequencies. Therefore, a Fourier transform might be helpful.
Of course this is not very practical.

An approximation in control theory says that the maximum system frequency of a feedback controlled system should be ten times less than the lowest characteristic frequency of the open loop system. From this rule of thumb you can see it is very difficult to realize dynamic closed loop systems.
To give a simple impression of what we achieve in closed loop, we did some pure tests with the elements PX 100 with strain gauge sensor. The element was driven with a rectangular function of 10 Hz with an amplitude of approximately 50% of the full motion. We determined the time in which the controlled system reached an accuracy of 99% and 99.9% of the final position.

9.5 Calibration Protocol for Closed Loop System

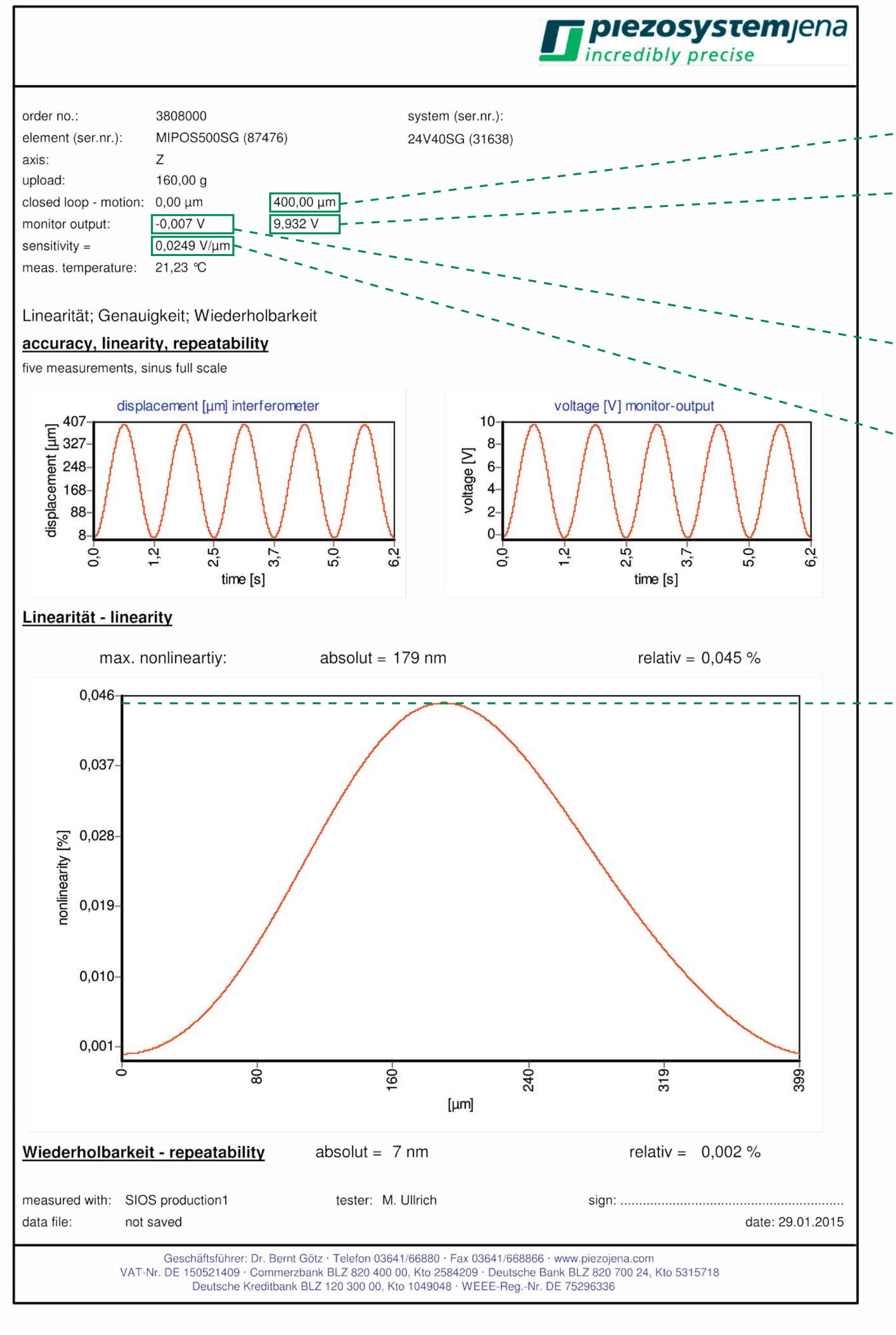
Each closed loop system to be delivered to our customers is calibrated to reach the optimum values in linearity and repeatability.
These data are shown in calibration protocol coming with the system.

How to calculate the nonlinearity in nm from the data of the calibration protocol:

$$\text{Nonlinearity} = \frac{\text{max. motion} \cdot \text{nonlinearity}_{@400\ \mu\text{m}}\ [\%]}{100\ [\%]}$$

$$\text{Nonlinearity} = \frac{400\ \mu\text{m} \cdot 0.0447\ [\%]}{100\ [\%]}$$

$$\text{Nonlinearity} = 179\ \text{nm}$$


piezosystemjena
incredibly precise

order no.: 3808000
element (ser.nr.): MIPOS500SG (87476)
axis: Z
upload: 160,00 g
closed loop - motion: 0,00 µm 400,00 µm
monitor output: -0,007 V 9,932 V
sensitivity = 0,0249 V/µm
meas. temperature: 21,23 °C

system (ser.nr.): 24V40SG (31638)

Linearität; Genauigkeit; Wiederholbarkeit
accuracy, linearity, repeatability
five measurements, sinus full scale

Linearität - linearity

max. nonlineartiy: absolut = 179 nm relativ = 0,045 %

Wiederholbarkeit - repeatability absolut = 7 nm relativ = 0,002 %

measured with: SIOS production1 tester: M. Ullrich sign: ....
data file: not saved date: 29.01.2015

Geschäftsführer: Dr. Bernt Götz · Telefon 03641/66880 · Fax 03641/668866 · www.piezojena.com
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meaning of parameters

a) total range of motion

b) maximum corresponding voltage (voltage at the monitor output, system switched into closed loop operation)

c) minimum voltage (closed loop) at monitor output

d) sensitivity (range of voltage related to the full range of motion, formula 9.2.1)

e) nonlinearity @ 400 µm = 0.045 % = 179 nm

10 Electronics Supplied for Piezoactuators

10.1 Noise

In chapter 3.3 we mentioned that the resolution of piezoelectric actuators is only limited by the voltage noise of the piezo amplifier. If the amplifier has a noise given by ΔU, the mechanical motion ΔX, determined by this noise will be:

$$\Delta x = \Delta l \cdot \frac{\Delta U}{U} = \left[\begin{array}{c} \Delta l = \Delta l_0 \\ \Delta U = U_0 \end{array} \right] = \Delta l_0 \cdot \frac{\Delta U}{U_0} \quad (10.1.1)$$

Where U is the current voltage to the piezoelement, Δl is the expansion for the voltage U.

Amplifiers from ***piezosystem jena*** are developed and optimized especially for piezoelectric actuators. So they have excellent noise characteristics, which allow positioning in the nm range.

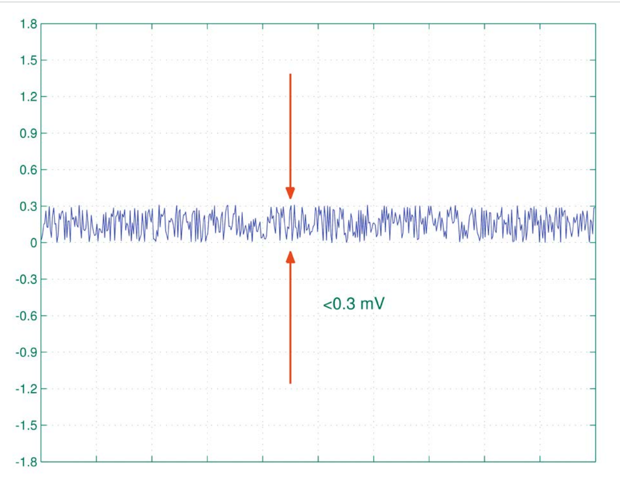


Figure 10.1.1: *Noise of the power supply NV 40/3.*

Example Number 23
The amplifier NV 40/3 is suited for 3 channels. This device has a voltage noise of < 0.3 mV. For a maximum output voltage of 150 V this is a dynamic range of $< 2 \cdot 10^{-6}$. For a piezoelement with a motion of 50 µm we yield a mechanical noise of 0.1 nm.

10.2 Current

For dynamical motions, all power supplies from ***piezosystem jena*** have a modulation input for each channel. So it is possible to generate oscillations given by a function generator via the modulation input. The electrical properties of piezoelectric actuators are such that they act as capacitors with a high inner resistance of typically $10^9\,\Omega$.

For static and quasi-static applications the current needed does not play a role. Because of their high resistance piezoelectric actuators do not need current to hold a position. They can also hold a position after separation from the power supply (please consider the safety instructions! We strongly recommend not to do this, the actuator keeps the stored voltage and this is extremely dangerous). For dynamic applications we should consider the problem of loading and unloading the large capacitances D. The maximum current i_{max} that would be needed for the actuator is:

$$I_{max} = C \cdot \frac{\mathrm{d}U}{\mathrm{d}t} \quad (10.2.1)$$

dU/dt - slope of the voltage.

The amount of the current needed can be very high for dynamic operations, so the slope of the voltage is often determined by the maximum current of the amplifier.
For a dynamic operation with a sinusoidal function, the maximum current i_{max} is determined by:

$$i_{max} = \pi \cdot f \cdot C \cdot U_{pp} \quad (10.2.2)$$

i_{max} – peak current required for sinusoidal operation (in A)
U_{pp} – peak-peak drive voltage (in V)
f – frequency (in Hz)
C – capacitance of the actuator (in F)

The average current for this operation is

$$i_{av} = \frac{i_{max}}{\pi} \quad (10.2.3)$$

10.3. Electrical Power

Because of the high current that is needed for dynamical applications, the electrical power needed can also be high. The power P_{max} for sinusoidal oscillation (with frequency f) of a piezoelement with capacitance C will be:

$$P_{max} = \pi \cdot C \cdot U^2 \cdot f \quad (10.3.1)$$

P_{max} – peak power (in W)
U – voltage (in V)
f – operating frequency (in Hz)

The average current for this operation is

$$P_{av} = \frac{P_{max}}{\pi} \quad (10.3.2)$$

Example Number 24
The piezoelement PAHL 18/20 is suited for high loads and it has a capacitance of 7 μF (for small field strength). This value can rise up to 14 μF for large operating electrical fields. For an oscillation of 1 kHz an actuator with 7 μF capacitance requires a current of 3.3 A. For a capacitance of 14 μF one needs a current of nearly 7 A. The output power will also increase 2 times and it will reach 1000 W. For such electrical power, heating of the actuator should be considered (see also ***section 10.6 power loss***).

10.4 Switched Regime – Oscillations with Rectangular Form

With their properties piezoelements can work in a switched regime (e.g. for valve applications). For the voltage supply we use an electronic switch. If a short pulse is applied to an actuator, the output voltage (also the voltage at the actuator) $U_a(t)$ will rise depending on the time t, the capacitance of the actuator C and the inner resistance of the power supply R_i.

$$U_A(t) = U_0 \cdot \left(1 - e^{-\frac{t}{R_i \cdot C}}\right) \qquad (10.4.1)$$

U_0 - maximum output voltage of the supply.

If the inner resistance of the power supply R_i is small enough, the output voltage increases very quickly. This can be realized faster than the minimum rise time of the actuator, which is determined by the resonant frequency (see also ***section 5.2***). That´s why the actuator is not able to expand faster. In such case the actuator will expand corresponding to the given electrical charges and so the expansion will reach an intermediate state smaller than the maximum output voltage U_0 of the piezo controller.
In this way it is possible to generate a continuing signal form with an electrical switch by a series of charging and discharging pulses.

10.5 Coupling Factor

The mechanical energy W_{mech} stored in the piezoelectric material is created as a consequence of applied electrical energy. The electromechanical coupling factor k_{33} describes the efficiency of the conversion of the electrical energy W_{electr} into stored mechanical energy W_{mech}.

$$k_{33}^2 = \frac{d_{33}^2}{\epsilon_{33}^T \cdot S_{33}^E} = \frac{W_{mech}}{W_{ges}} \qquad (10.5.1)$$

It can also be seen that the coupling factor depends on the direction and the parameters of the material. The formula is given here for the longitudinal effect.

The above mentioned formula is valid only for static and quasi-static conditions. Power losses (e.g. by warming) are not included. The electrical power, which is not converted into mechanical energy (as expressed by the coupling factor), is given in form of electrical charges. These charges are returned to the power supply while discharging the actuator's capacitance.

The coupling factor k_{33} reaches values up to $k_{33} = 0.68$ for ceramics used in monolithic actuators and up to $k_{33} = 0.74$ for piezocomposite ceramics.

10.6 Power Losses – Dissipation Factor

In the static regime the actuator stores energy $W = ½ \cdot C \cdot U^2$. While discharging the piezoelements most of the electrical energy returns to the power supply. Only a small part will be converted into heating the actuator. These dissipation losses, expressed by the loss factor tan δ, are in the order of 1 - 2% for small signal conditions, increasing up to 10% for large signal conditions.

$$P = P_{out} \cdot \tan(\delta) \sim f \cdot C \cdot U^2 \cdot \tan(\delta) \qquad (10.6.1)$$

Example Number 25
Let us consider the data given in example 24 .For the modulation of the piezoelement PAHL 18/20, an electrical power of approximately 1000 W is necessary. The dissipated energy will be in the order of 50 W, concentrated to a volume of 2 ccm. After a short time, heating will bring the actuator in the region of the Curie temperature leading to a depolarization of the actuator. As a consequence, the piezoelement will stop working. In such cases effective cooling will be necessary!

Power optimization
In some cases the choice of power supplies and piezoelements can be optimized for minimum power requirements. It might be better to use a longer stack with a lower operating voltage.

11 Reliability

Piezoelectric stacks from piezosystem jena have been used in various high end applications in the
automotive, semiconductor, aviation and space industries for over 20 years. They have performed over several billions of cycles. Many tests and applications have shown that piezoelectric stacks from piezosystem jena are both reliable and keep their performance and properties year after year.

Why Should You Use Piezoelectric Stacks from Piezosystem Jena?

1. Our stacks have been on the market longer than any other competing products. Over the years we have gained tremendous experience and expertise with piezo technology. We have used this knowledge and successfully integrated into many applications for several different industries.

2. Our Stacks and their insulation material have been continuously optimized and tested.

3. For over 20 years our stacks have been continuously used in 24/7 industrial applications without any issue.

4. Not only do we have a highly trained team of experts with many years of experience in the development and handling of piezoelectric actuators and stages, but we also strive for the best customer service and customer specific solutions which are realized in a timely manner.

It is our mission to share our expertise with our valued customers. Please do not hesitate to contact our specialists, if you have any questions regarding piezotechnology.

To take full advantage of the strengths offered by piezotechnology, it is essential to understand the core characteristics and performance traits.

Damage of Piezoelectric Stacks

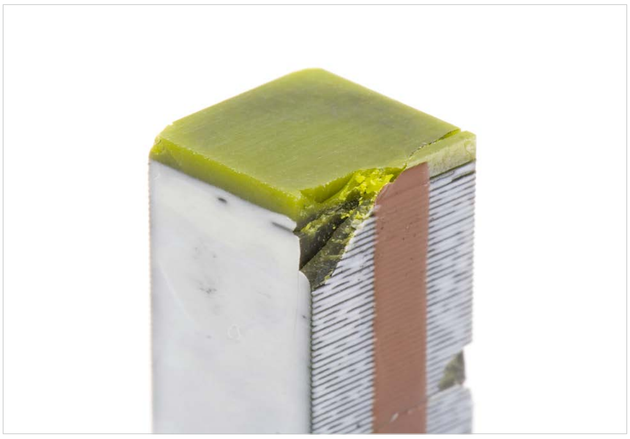
A piezoelectric stack scan failure is mainly caused by two reasons:

1. Mishandling

- Applying off-axis forces (please see chapter 2 and 13 ***"design of piezo actuators"*** and ***"guidelines for using")***

- Improper mounting of the stacks

- Incorrect voltage range and dynamic use exceeding the mechanical limitations (e.g. high electrical field strengths, forces, accelerations, torque …)



Defect of a piezostack due to non-symmetrical forces to the edge of the ceramic

2. Use under special environment conditions without preparation to the stacks for these conditions

- Low insulation between stacks and other conductive surfaces

- Contamination of the stack surface with conductive materials, electrolytes

Please do not touch piezoelectric stacks with bare hands!

Both reasons for malfunction of piezoelectric stacks can be avoided with proper handling!

Piezostacks with Different Types of Sealing and Insulation

Correct handling of the piezo is key in achieving the highest performance and reliability over many years. This includes protection against environment conditions which limit the lifecycle of the actuator. One of the biggest threats to the reliability of the piezo is an excessive humidity level.

High electrical field strength (between electrodes) yields to some migration of the electrodes into the ceramic. Thus the electrical breakdown voltage will decrease. If the piezostacks will be operated under higher humidity the effect of migration of the electrode material is accelerated.

This is one of the main reasons why it is so important to have a solid insulation of the ceramic and electrode material protecting against humidity.

Reliability for Static Operations

As stated above, for static operations migration of conductive material can lead to an increase of the applied field strength. The leak current increases which ultimately leads to an electrical break through.

If piezoelectric stacks are handled correctly, no conductive material will come in contact with the ceramics and the electrode material.

Piezostacks from piezosystem jena do not show any increase in the leak current over many cycles and many years – if handled correct.

Furthermore for applications that demand constantly applied high voltages on the stacks, we try to use lower voltage values on a longer stack. This tactic can dramatically increase the lifetime.

Reliability for Dynamic Operations

Electrically, piezoelectric stacks have a high capacitance with a high inner resistance. Working dynamically, the capacitance has to be charged and discharged. The current for charging and discharging mainly determines the operating frequency.

For dynamic work the electrical field applied on the electrodes changes with the operating frequency. For this reason no static electrical field is applied enforcing migration.

Therefore the accelerated migration of the electrode material into the piezoelectric ceramics is avoided.

Consequently the lifetime for dynamic operations is very high.

If piezoelements are operated under special environment conditions we recommend the following steps:

1. Ask our team for advice beforehand.

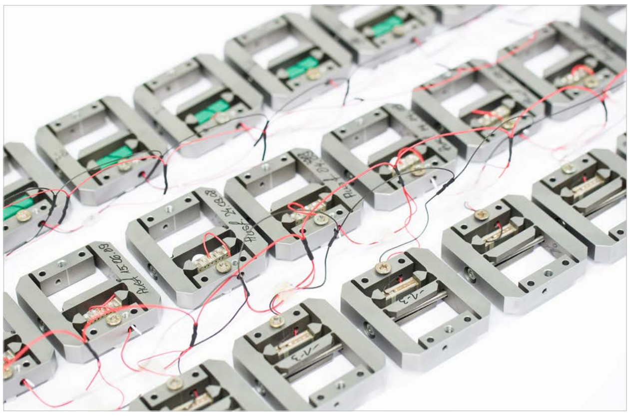
2. Use hermetically sealed piezo actuators for work under hard environment conditions

Piezostages – Piezo Stacks Integrated into Special Hinge Flexure System

For many applications piezoelectric stacks are integrated into a hinge flexure made by a wire erosion technique (EDM). This integration improves the guidance accuracy and extends the range of motion (lever transmission). These stages are found often in advanced manufacturing (e.g. machines for semiconductor production or laser technologies). For high-end industries like these reliability is critical. Any break or stop in production can lead to tremendous follow-up costs for the manufacturer and the supplier.

The correct use of piezostacks, the adequate integration into the application and the usage of a lever transmission system are all critical factors which ensure long and stable lifetime operations. This is why piezosystem jena has consistently tested and monitored its stages over many years.

The following picture shows a long term test of Piezostages



Flexure hinges can easily perform more than 10^{10} cycles of operations if they are designed properly and used in their elasticity range.

Note:
Piezostacks from piezosystem jena have been used for more than 20 years, 24 hours a day without any problem. Even altering effects were not obtained.

Year after year we deliver thousands of actuators working in a variety of applications. Proper handling during the construction of piezoelectric stages and working together with our customers ensures a long term reliability of our products without any significant failure rates.

Most failures of piezoelements occur because of improper mechanical handling and use of the elements. For proper handling and use please see also ***chapter 2***.

12 Piezoelectric, Electrostrictive and Magnetostrictive Actuators

When using a solid state effect for generating a motion piezoelectric actuators are the most commonly used actuators. But a motion can also be generated by using other effects such as electrostriction and magnetostriction.

We will give you an overview about these other principles.

	piezoelectric effect	electrostrictive effect	magnetostrictive effect
material	PZT	PMN	Terfenol
Curie temperature	150 – 350 °C	10 °C	ca. 380 °C
kind of material	ferroelectric	paraelectric	ferromagnetic
prepolarisation	synthetic by electric field	remanent	synthetic by magnetic field
expansion Δl	$\Delta l \sim E$	$\Delta l \sim E^2$	$\Delta l \sim H^2$
hysteresis	10 – 15 %	2 – 3 % (ΔT very small)	1 – 3 %
electrical equivalence	capacitance	capacitance (5 x higher)	inductivity
electr. control	voltage	voltage	current
coupling factor	up to 0.65	up to 0.65	up to 0.75
tanδ	0.05	< 0.05	-
temperature range	up to 200 °C	ΔT ~ 30 K	up to 70 % T_c
temperature dependence of the effect	small	large	small

Electrostriction

The electrostriction basically exists parallel to the piezoelectric effect.

The electrostrictive effect can be used above the Curie temperature. So electrostrictive materials are made from ceramics with a low Curie temperature. Electrostrictive actuators are also built as stack type actuators. The expansion of electrostrictive materials is nearly the same as for piezoelectric materials.

In a small temperature regime of a few degrees electrostrictive materials show a small hysteresis (2–3 %). But outside of this temperature range the hysteresis is larger than the hysteresis of piezoelectric materials. So electrostrictive materials can be used only in a small temperature region (ΔT ~ 10 K). That is why these actuators do not find such a wide range of applications like piezoelectric actuators.

Magnetostriction

A ferromagnetic material shows expansion under an applied external magnetic field. This effect is called the magnetostrictive effect and can be used for the construction of actuators. The material used is Terfenol ($Tb_{0,3}$, $Dy_{0,7}$, Fe_2).

Compared with the piezoelectric and electrostrictive effect, magnetostrictive actuators show similar properties. Magnetostrictive actuators have a higher Curie temperature and there is the possibility of thermal separation of the cooling system and the magnetostrictive material.

13 Guidelines for Using Piezoelectric Actuators

Piezoceramics are relatively brittle materials. This should be noted when handling piezoelectric actuators. All piezoelements (also elements with preload) are sensitive to shock forces.
Piezoelements without preload (e.g. series P, elements with lever transmission) should not be used under tensile forces (see also ***figure 2.1.2*** in section 2).
Applications in which tensile forces or shear forces occur, should be realized by preloaded elements. On request we can optimize the integrated or external preloads for special applications.
During dynamic use there can occur internal tensile forces due to the acceleration of the ceramic element itself (see also ***section 5 dynamic properties***).
Preloaded piezoelements have a top plate with threads. Please note the depth of the treads. Do not apply large forces for fixing screws at the piezoelements!
Actuators are capacitive loads. Do not discharge actuators by short circuiting the leads. Ensure dielectric strength of your power supplies, wiring and connectors to prevent accidental arcing.
Abrupt discharging may cause damage to the stacks.
Piezoelectric actuators such as stacks or various piezoelements with lever transmission work as capacitors. These elements are able to store electric energy over a long period of time. This stored energy may be dangerous.
Connect and disconnect the elements only when the power supply is switched off. Because of the piezoelectric and pyroelectric effects, piezoactuators can generate electric charges if there are changes in the external mechanical loads or the temperature of the actuator.

Before you begin to work with any piezoelectric actuating system note: Switch off the power supply and discharge the actuator properly by setting the supplies to zero. If the actuator is disconnected, use a resistor for discharging the actuator.

Do not switch on the power supply when the actuators are disconnected. Attention! Connect the actuator and the power supply only if the power supply is switched off!

Power supplies for piezoelements are developed especially for our products. Do not use these supplies for other products or applications.

Disclaimer

piezosystem jena cannot be held responsible and shall incur no liability for errors in this catalog.

Piezocomposite Actuators

Cofired Multilayer Actuators

For the past few decades "cofired" multilayer stacks has been the state of the art method used for constructing piezo actuators. However there are a variety of applications where multilayer stacks reach their natural limitations.

Multilayer stacks consist of many ceramic layers (each approx. 100 µm in thickness) with thin (1 µm) electrodes between them. After stacking these layers the compound is then sintered at high temperatures (cofiring).

Multilayer actuators are operated with low voltages up to 200 V.

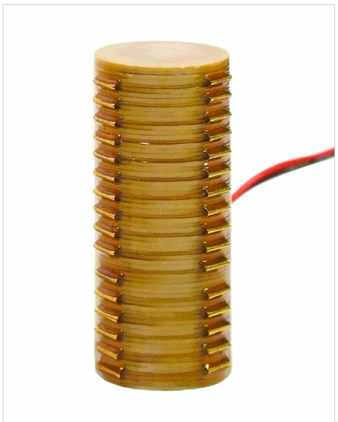


Figure 1: *Piezocomposite stack actuator made from single piezoceramic discs and intermediate metal electrodes*

Design of Piezocomposite Actuators

Piezocomposite actuators are made from completely sintered single PZT discs (thickness 0.3 to 0.5 mm) and separate intermediate metal foil electrodes which are held together by special high quality adhesives. Therefore these discretely stacked actuators are a composite material with some outstanding properties.

Piezocomposite actuators should be used to generate:

- High forces up to 50 kN
- High accelerations up to 100'000 m/s^2
- Short pulses
- To withstand loads up to 70 kN

Piezocomposite Ring Actuators are preferred for

- Optical applications
- Applications with high frequencies requiring effective cooling and special thermal behavior
- Applications with high bending stability

Stiffness

According to $C_T^E = \dfrac{A}{S_{33}^E \cdot L_0}$, the stiffness of Piezocomposite Actuators increases with the cross section and decreases with the length of the actuator. Piezocomposite Actuators with a preload show an elastic modulus nearly as high as that of multilayer stacks.

	Piezocomposite Actuators	Low Voltage Multilayer Stacks
preferred use	large cross sections generating high forces	small, medium cross sections for low volume elements
applications	high dynamic applications, shock generations, shakers, vibration generation short impulse excitation	positioning, scanning, integration into more dimensional positioning systems
operating voltage	500 V - 1000 V	up to 200 V
max. electrical field strength	approx. 2 kV/mm	
max. strain	0.1 to 0.15 % related to the stack length	
force generation	same order related to the same cross section	
positioning accuracy	same for both types: depending on the electrical supply and environmental conditions	
electrical capacitance / volume	approx. 10 nF/cm^3	approx. 2,5 µF/cm^3
production technology	stacking of sintered ceramic plates	stacking of non sintered ceramic layers and cofiring
material variety	large	small
operating temperature range	up to 200 °C	up to 100 °C
electrical current for dynamic applications / per volume	low current	high current
cross section of ceramics	diameters up to 35 mm	up to 14 x 14 mm^2

Dynamic Operation of Piezocomposite Actuators

In comparison to piezo actuators and piezo stages based on multilayer stacks, Piezocomposite Actuators are utilized more often in dynamic applications as opposed to positioning tasks.

The high stiffness of Piezocomposite Actuators directly leads to an increased resonance frequency making it possible to work at higher frequencies and driving larger external masses.

$$f_{res}^0 = \frac{1}{2\pi} \cdot \sqrt{\frac{c_T}{m_{eff}}}$$

$$f_{res}^1 = \frac{1}{2\pi} \cdot \sqrt{\frac{c_T}{m_{eff} + M}} = f_{res}^0 \cdot \sqrt{\frac{m_{eff}}{m_{eff} + M}}$$

Furthermore the relatively low capacitance results in reduced current consumption.

Piezocomposite Actuators can be used in high dynamic operation with frequencies up to several kHz, such as high frequency vibration excitation or material testing (fretting tests or super high cycle fatigue tests).

Specially designed piezo shakers or shock generators can work near or above the resonance frequency. Low voltage multilayer actuators are not suited for this kind of operation.

In dynamic operations 5% - 20% of the electric input power dissipates into heat. The resulting temperature change of the dynamic working actuator can exceed its Curie temperature easily and result in damage or the malfunction of the actuator.

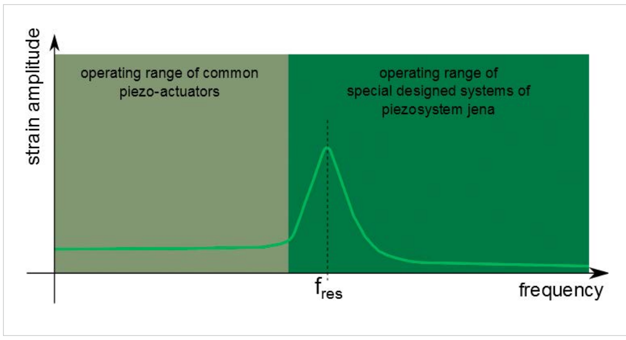


Figure 2: *frequency range of piezo shakers and standard piezo actuators*

Hence for long-term dynamic operation with Piezocomposite Actuators a heat management option is recommended to prevent overheating (compare ***chapter 3.10*** piezoline). ***piezosystem jena*** offers a "thermostable" option for Piezocomposite Actuators with casing and the use of high-temperature ceramic material for enhanced temperature ranges.

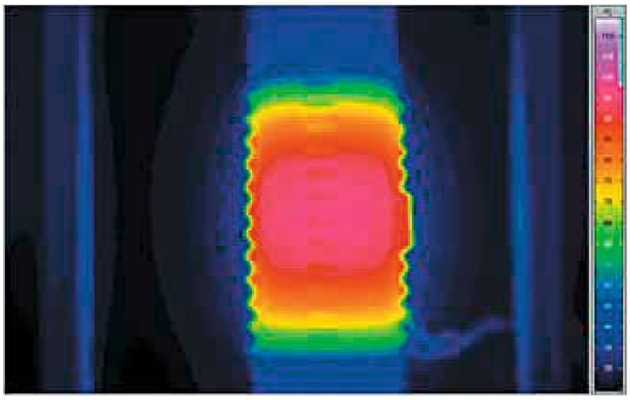


Figure 3: *Thermal image of a dynamically driven Piezocomposite Actuator, clamped at its end plates*

Piezo Shakers PiSha

In certain dynamic applications the requirements can easily exceed the capabilities of standard piezo actuators. Extreme accelerations in the range of several 1000 g and the resulting high power consumption require a specially adapted sophisticated design to withstand the high mechanical and thermal stresses. The solutions to these problems are special designed piezoelectric shakers (piezo shaker).

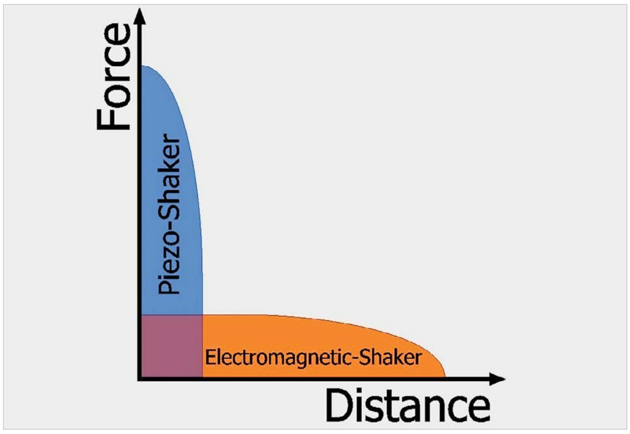


Figure 4: *Operating ranges of electromagnetic and piezoelectric shakers*

Key Features of Piezo Shakers

- High stiffness
- High forces, pressure forces up to several 10 kN
- Generation of kHz frequencies up to 100 kHz
- Amplitudes from sub-µm to several 100 µm
- High accelerations up to several 1000 g

*Please note, that these values cannot be achieved simultaneously

Piezo shakers show a higher stiffness and higher force potential than electromagnetic shakers. Therefore they usually cover different applications, especially those with higher frequencies. Due to the high power density of the piezoelectric material piezo shakers are ideally suited for miniaturized components.

Piezo Shakers versus Ultrasonic Transducers

There is a huge difference between piezo shakers and ultrasonic transducers. Ultrasonic generators use hard PZT materials with a high resonance magnification. Hence they operate at one specific frequency but consume a relatively small amount of electrical power.

Piezo shakers are tunable and work in a wide frequency range. In some cases they can also operate near or even above their natural frequency.

Piezo shakers are made from softer PZT material with a much smaller resonance magnification. In comparison to ultrasonic generators the power consumption is much higher.

Applications

With their high stiffness and high force potential piezo shakers are perfect for applications that require high frequencies up to 100 kHz tunable over a wide frequency range. Examples for such applications are:

- Acceleration tests
- Material characterization
- Defect detection
- Fatigue testing
- Modal analysis
- Non-destructive testing
- Vibration excitation

Functional Principle of Piezo Shakers

Piezo shakers are specially adapted piezo stack actuators. The driving voltage determines the amplitude of motion whereas the current determines the velocity. The internal design of the piezo shaker has to ensure that the shaker withstands the occurring high acceleration forces and thermal stress.

Operation Modes for Piezo Shakers

An efficient vibration excitation of an object strongly depends on the quality of coupling between shaker and the object. Depending on the application, different coupling arrangements can be achieved:

1. Bottom-Fixed Setup:

The bottom side of the piezo shaker is mounted to a heavy, non-moving base. The object is fixed at the shaker's moving end. In this case the motion is completely transferred to the object.

The maximum acceleration a is:

$$a = x \cdot (2\pi f)^2$$

x: amplitude,
f: frequency

Hence the resulting maximum force generation F is:

$$F = m \cdot a$$

m: mass of the object

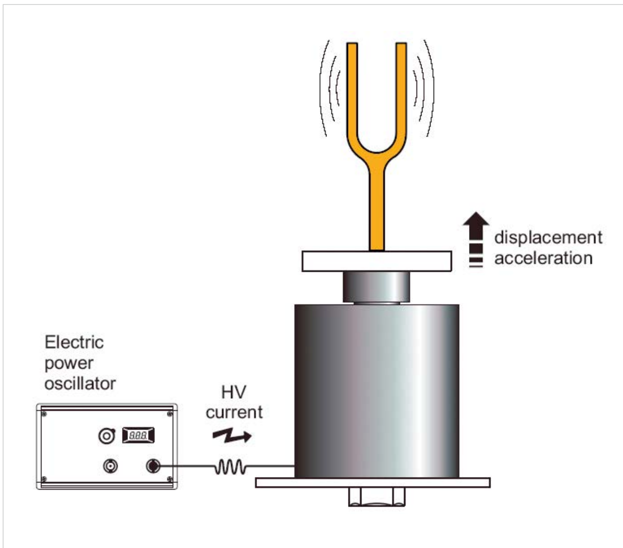


Figure 5: *Schematic of an inflexible setup of a piezo shaker*

2. Inertial Mass Setup

In this arrangement the shaker is freely mounted to the test object via its moving end. Operating the shaker generates an oscillation over the whole shaker body.

The achievable forces depend on the moving masses and the specimen's stiffness. Maximum forces and deformations

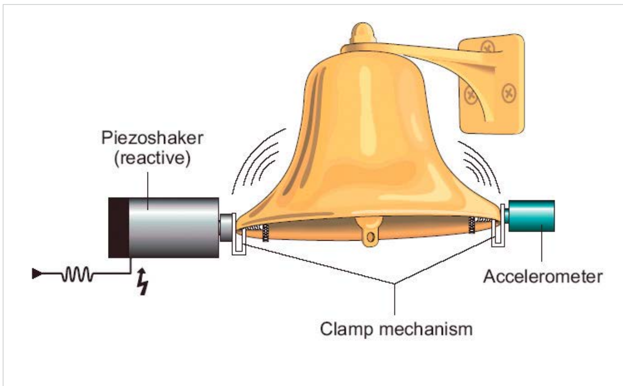


Figure 6: *Schematic of an inertial arrangement of a piezo shaker*

of the object will be generated, if the object is clamped tight (blocking condition). Adding seismic masses to the shaker allows a tuning of the system for frequency and forces. The vibration is detected via an accelerometer.

3. Clamped Setup:
The piezo shaker and the test object are mounted in a stiff clamping mechanism. The resulting amplitudes and forces depend on the shaker's and the test object's stiffness. The vibrations can be measured with a force sensor.

Depending on the setup the shaker can be integrated so that an additional clamping mechanism is not necessary.

Such kind of setup is often used for experiments for structure-borne sound investigations.

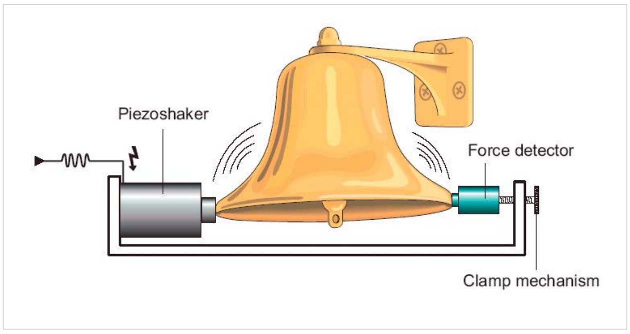


Figure 7: *Clamping arrangement of a piezo shaker*

Piezo Shock Generators PIA

Shock generators are used to transfer short pulses to objects, to investigate their properties.

Shock Generator versus Shaker

In comparison to shakers, shock generators are operated by short electrical pulses or rectangular signals to achieve single pulses with high acceleration rates. These accelerations are independent of the repetition rate which can reach values in the kHz range.

Shakers usually work with a steady sine wave form. The frequency and amplitude of this oscillation determines the accelerations and forces reached.
Both systems are used for material and structure research; however the type of excitation is different: Shakers generate an oscillation of the material; shock generators realize single pulses to the material.

Conventional Shock Generators

Classic shock generation is usually realized by accelerating a specific mass (for example a hammerhead) which then hits its collision partner. During that short contact phase energy and momentum are transferred (the so – called impulse). Time and shape of the impulse strongly depend on the acoustical and elastic properties of the involved bodies. Due to the uncertainties during acceleration and contact phase it is extremely difficult to achieve reproducible shocks. Furthermore, the achievable repetition rates of these ballistic methods are strongly limited. A precise triggering (timing in µs-range) of the shock event which is needed in metrology is not possible. All these restrictions can be overcome with the use of piezo shock generators.

Piezo Shock Generators

Piezo shock generators overcome disadvantages of conventional generators. They provide:

- Adjustable shock parameters:
  energy (< 4 Joule); acceleration (> 10'000 g); amplitude (> 100 µm)
- High repeatability of the pulse parameters
- Precise time behavior — triggering in the µsec range
- Variable repetition rates — up to several kHz (burst)
- Fast rise time: — down to µs values
- Adjustable pulse width — down to 10 µs

Synchronization of several pulse generators is possible!

Piezo shock generators have to be specially designed to survive the high mechanical stress occurring during shock generation. Extreme preloads are necessary to withstand the high accelerations and resulting forces. Standard actuators are not sufficiently preloaded and would be immediately damaged under these conditions.

Please contact our team for more Technical Advice!

Applications

- Acceleration tests Shock experiments
- Shockwave propagation
- Material characterization (for example in Split-Hopkinson-Bar arrangements)
- Hardness testing
- Modal analysis
- Impact based measurements (like solid-borne sound investigations)
- Impact-echo-measurements (for example in geological and structural investigations)
- Sonic logging

The Piezo Stack as Shock Generator

If a piezo stack is charged with a very short rise time, the mechanical axial pressure in the ceramic material immediately increases to a high value. This so-called blocking pressure is generated over the full length of the piezo stack and leads to an accelerated expansion of the piezo bar. In this way a propagating pressure front can be created in the coupled shock-partner. Hence, the piezo represents an "active-bar", which then produces mechanical shocks.

The Physical Shock

In metrology usually bars are used for shock wave propagation, due to the easier mathematical modeling. The compression can be measured using strain-gages whereas Laser-Doppler anemometers can be used to determine the particle velocity. Changes in the bar's cross section lead to a splitting of the shock wave into a transmitted and a reflected part. This behavior is used in the Split-Hopkinson-Bar experiment (Fig. 8) to determine material characteristics subjected to high strain-rates.

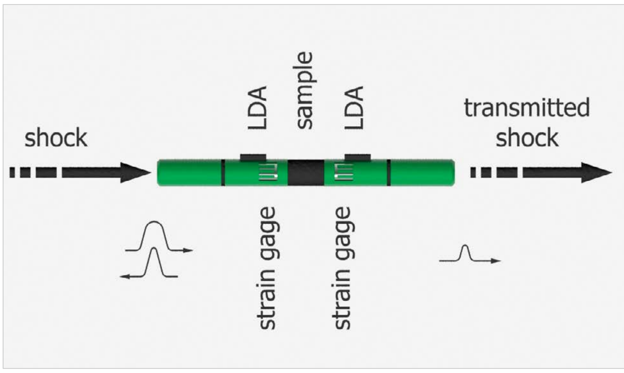


Figure 8: *Hopkinson-Bar for material testing. By strain gauge and laser-Doppler anemometer the triggered and the reflected shock can be compared.*

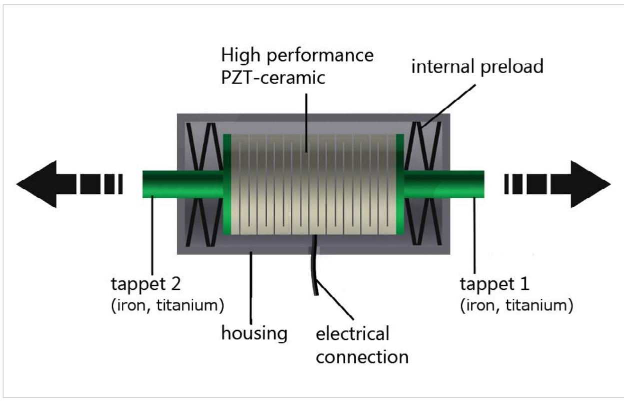


Figure 9: *Schematic representation of a symmetric piezo shock-wave generator.*

Layout of Piezo Shock Generators

Symmetric Shockwave Generators

Due to conservation of momentum, a piezo shock generator always creates two shocks propagating in opposite directions. This is used for the design of symmetric shockwave generators. (Fig. 9)

Single Sided Shockwave Generators

By applying a seismic mass on one side of the shock generator the backward running pulse can be reflected, resulting in a superposition of both pulses. The resulting pulse has nearly twice the energy and has an increased pulse duration showing a typical double-pulse profile. This concept is used for single-sided shock generators.

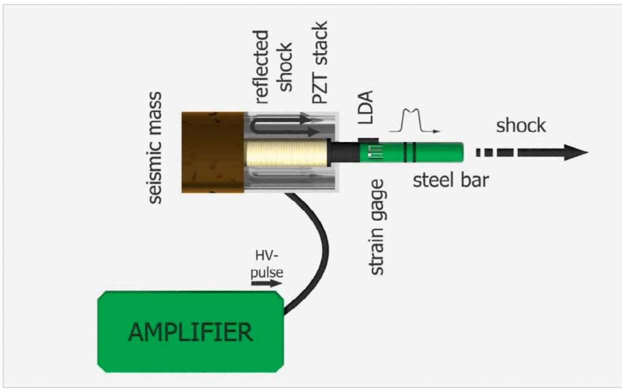


Figure 10: *Schematic representation of a single-sided shock generator with a seismic mass. The double pulse is build by the overlay of reflected and forward pulse*

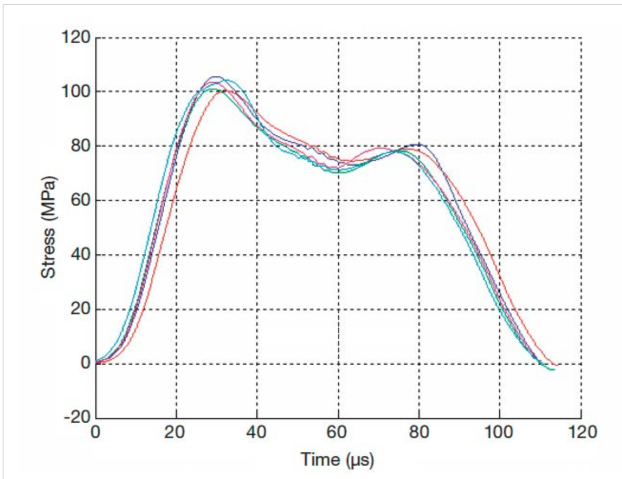


Figure 11: *Typical pulse shape of a shock-wave generator with a seismic mass.*

Electrical Operation of Piezo Shock Generators

For piezoelectric shock generation the piezo's capacitance has to be charged very fast. Considerations about position accuracy or voltage noise are irrelevant in such applications.

To reach electrical rise times in the microseconds range extremely high currents are necessary. These currents are provided using high power pulse switches as shown in Figure 12.

A capacitor bank (several 100 µF) is charged to the selected voltage (up to 1000 V). The piezo is then rapidly charged to the selected voltage via a small resistor leading to the actual mechanical shock. The piezo is then slowly discharged again. With the sufficient power of the amplifier pulse repetitions up to 100 Hz are possible. Due to the limited cooling of the actuators high repetition rates should be done in burst-mode.

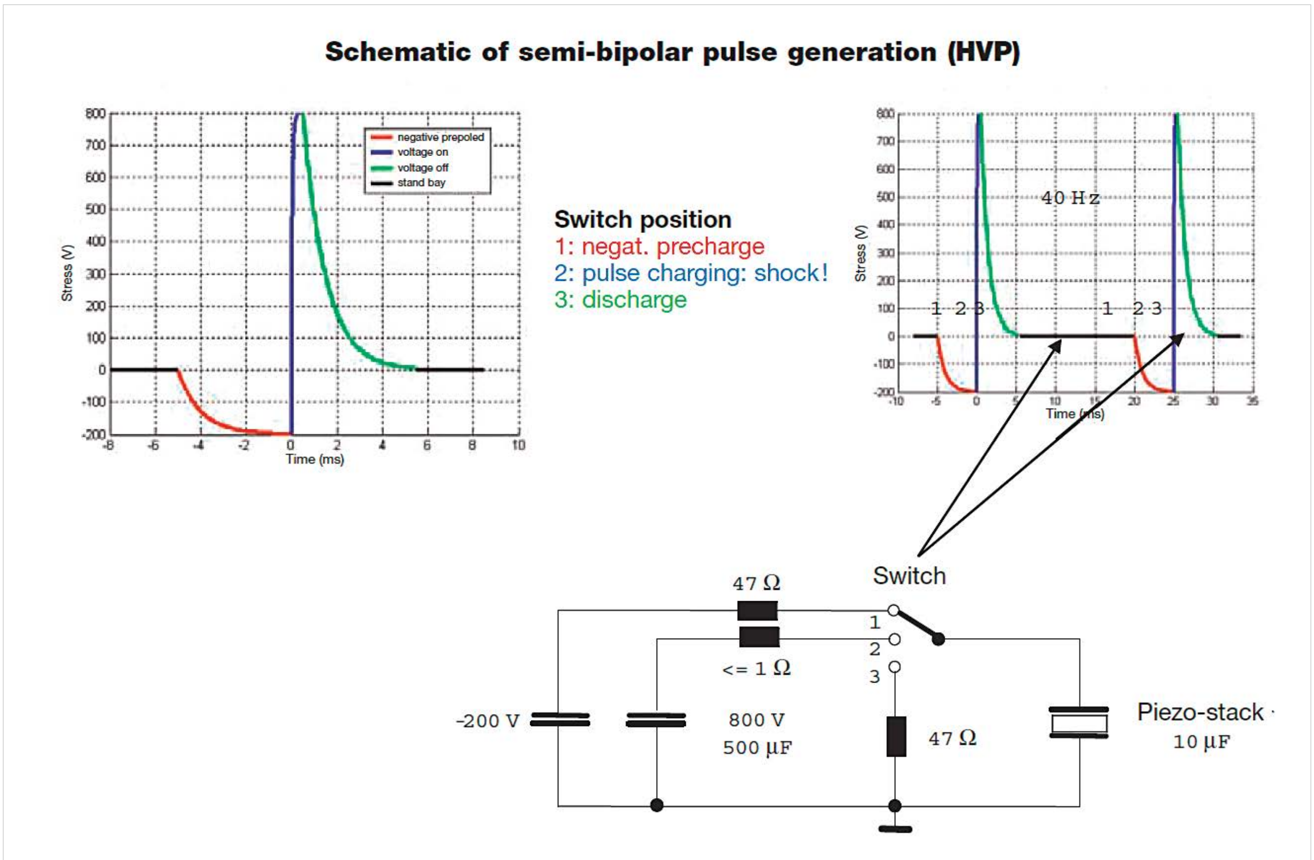


Figure 12: *Semi bipolar control with a high voltage pulser. The switch with three settings represents a combination of high power transistors, which are driven by a logic device.*
1. Negative charging to -200 V, 2. Shock like charging to +800 V, 3. Discharge to 0 V

Piezosystem Jena provides a wide range of Power Supplies for Piezo Shaker as well as for Shock Wave Generators:

amplifier	output voltage	peak output current	bandwith	description
for Piezo Shaker				
RCV 1000/7	1000 V	7 A	2 kHz	high power switching amplifier
LE 150/100 EBW	150 V	1 A	70 kHz	linear amplifier with enhanced bandwidth
for Shock Generator				
HVP 1000	1000 V	200 A	-	high voltage pulse switch amplifier
HVP 300/20	300 V	20 A	-	pulse switch amplifier

Used Units and Dimensions

a	acceleration [m/s²]
A	cross section of a stack or a single piezoceramic plate [mm²]
C	capacitance of the actuator [F]
c_F	stiffness, constant of an external spring (for example: preload) [N/µm]
$c_T = c_T^E$	stiffness of the actuator, translator (for E = constant) [N/µm]
$d = d_{ij}$	piezoelectric strain coefficient (tensor form); depending on the material and the direction [m/V = C/N]
d_{33}	piezoelectric strain coefficient for the longitudinal effect (typ. 300 – 500 · 10^{-12} C/N)
d_s	thickness of a single ceramic plate [mm]
$E = \frac{U}{L_0}$	external electric field strength [V/m]
F_{eff}	effective force, which can generated by an actuator for a given voltage [N]
F_{max}	blocking force of the actuator, maximum force which can be generated by the actuator at maximum operating voltage (if the actuator is mounted in a position where it can´t expand itself) [N]
F	force [N]
f	frequency [Hz]
f_{res}	resonant frequency [Hz]
I_{max}	maximum output current of the amplifier that is necessary for loading the actuators capacitance [A]
k	electromechanical coupling factor [without dimension]
L_0	length of the actuator (in a good approximation this length can be taken also for the length, which is piezoelectrically active $L_0 \approx 1_z$ [mm])
l_z	length of the piezoelectrically active part of the actuator [mm]
Δl_z	expansion of the actuator in z-direction [µm]
$\Delta l_{x,y}$	expansion in x or y direction [µm]
Δl_0	expansion of an actuator without any external loads or forces [µm]
Δl	expansion in general (also under external loads) [µm]
m_{eff}	effective mass (mass that will be moved), for an actuator that is clamped at one side, as a good approximation often it can be taken: $m_{eff} \approx m/2$ [g]
M	additional mass load to an actuator [g]
n	number of piezoelectric plates of an actuator [without dimension]
P	electrical power [W]
P_{out}	electrical power which is needed by the actuator [W]
R_i	inner resistance of the power supply; amplifier [Ω]
S_{ii}	elasticity or compliance tensor (reciprocal value of the “Young´s modulus”) [m²/N]
S_{33}	elasticity for the longitudinal effect [m²/N]
T_c	Curie temperature [C]
$T = \frac{F}{A}$	mechanical stress (e.g. because of an external force) [N/m²]
t	time [s]
U_0	maximum operating voltage [V]
U	actual voltage at the actuator [V]
$U_A(t)$	voltage at the actuator in dependence of the time [V]
TF	factor of a lever transmission [without dimension]
α	linear thermal coefficient of expansion [1/K]
$\tan \partial$	tangent of the loss angle; ∂-loss angle [without dimension]
Φ	phase angle of an oscillation [without dimension]
ε	relative strain [without dimension]
ε_{33}^T	absolute dielectricity constant (typ. $\varepsilon_{33}^T \approx 5400$; $\varepsilon_0 = 8{,}85 \times 10^{-12}$ F/N) for piezo ceramic materials

Conversion Metrical/English Units

Table 1 Conversion MKS / English Units

25.4 mm = 1 inch
1 mm = 0.03937 inch
1 m = 39.37 inch

mm	in
1…	0.039
5…	0.197
10…	0.394
15…	0.591
18…	0.709
20…	0.787
22…	0.866
25…	0.984
32…	1.260
40…	1.575
50…	1.969
69…	2.717

m	Inch
1…	39.4
8…	315.0
16…	629.9
25…	984.3
35…	1378.0
38…	1496.1
40…	1574.8
50…	1968.5
100…	3937.0
200…	7874.0
300…	11811.0
400…	15748.0

Table 2 Common MKS / English

length	
1 meter	39.37 inches
1 inch	2.54×10^{-2} meters
area	
1 meters²	1.55×10^{3} inches²
1 inches²	6.452×10^{-4} meters²
volume	
1 meters³	6.102×10^{4} inches³
1 inches³	1.639×10^{-5} meters³
force	
1 kilopound	9.807 newtons
1 newton	1.020×10^{-1} kilopounds
mass	
1 kilogram	2.205 pounds
1 pound	4.536×10^{-1} kilograms
pressure	
1 atm = 1.105 N/m² = 760 Torr = 1.01 bar	
capacitance	
1 picofarad	1×10^{-12} farad
1 nanofarad	1×10^{-9} farad

pressure	= 1 PA	1 Mpa	1 bar	1 mbar	1 mmHg	1 Torr	1 psi	1 kp/cm²
1PA = 1N/m²	= 1	10^{-6}	10^{-5}	10^{-2}	7.5×10^{-3}	7.5×10^{-3}	1.45×10^{-4}	1.02×10^{-5}
1 Mpa = 1MN/m²	= 10^{6}	1	10	10^{4}	7500	7500	145	10.2
1 bar	= 10^{5}	10^{-1}	1	10^{3}	750	750	14.5	1.02
1 mbar	= 10^{2}	10^{-4}	10^{-3}	1	7.5×10^{-1}	7.5×10^{-1}	1.45×10^{-2}	1.02×10^{-3}
1 mWS	= 9.81×10^{3}	9.81×10^{-3}	9.81×10^{-2}	9.81×10^{1}	7.36×10^{1}	7.36×10^{1}	1.42	10^{-1}
1 mmWS	= 9.81	9.81×10^{-6}	9.81×10^{-5}	9.81×10^{-2}	7.36×10^{-2}	7.36×10^{-2}	1.42×10^{-3}	10^{-4}
1 mmHg (Torr)	= 1.33×10^{2}	1.33×10^{-4}	1.33×10^{-3}	1.33	1	1	1.93×10^{-2}	1.36×10^{-3}
1 psi	= 6.89×10^{3}	6.89×10^{-3}	6.89×10^{-2}	6.89×10^{1}	5.17×10^{1}	5.17×10^{1}	1	7.03×10^{-2}
1 kp/cm² = 1 at	= 9.81×10^{4}	9.81×10^{-2}	9.81×10^{-1}	9.81×10^{2}	7.36×10^{2}	7.36×10^{2}	1.42×10^{1}	1

Example (last row):

1 at = 1 kp/cm²
= 9.81×10^{4} PA
= 981 mbar 9.81×10^{4} N/m²
= 736 Torr
= 14 psi (psi = pound per square inch)

angle	=	degree	arc sec	mrad	µrad
1 degree	=	1	3600	17.45	17.4×10^{3}
1 arc sec	=	2.77×10^{-4}	1	4.85×10^{-3}	4.85
1 mrad	=	0.057	206.3	1	10^{3}
1 microradian	=	57×10^{-6}	0.206	10^{-3}	1

Mechanical noise as a function of voltage noise

mech. noise in nm	motion in µm	noise in mV	max. voltage range in V
0.04	15	0.4	150
0.10	40	0.4	150
0.25	100	0.4	150
0.50	200	0.4	150
0.75	300	0.4	150
1.00	400	0.4	150

Temperature change of the length for different materials

$\Delta l = \alpha \times 10^{-6} \times \Delta T \times L$ (in mm) x 1000

expansion Δl in µm	length in mm	temperature ΔT T2-T1	temp. coefficient $\alpha \times 10^{-5}$ K^{-1}	material
- 6	50	20	-6	multilayer stack
- 1.2	20	10	-6	multilayer stack
+2.4	10	20	12	stainless steel
+0.15	10	10	1.5	invar
+2.38	10	10	23.8	aluminium
+0.94	10	10	9.4	titanium

+ expansion
- shrinkage

Contacts

Belgium
Laser 2000 Benelux C.V. → Netherlands

China/Hong Kong
Peiport Scientific Limited
20 Westlands Road, Rm. 1302, 13F.,
Westlands
Centre
TaiKoo Place, Quarry Bay
Hong Kong, China
phone: (+852) 2885 9525
fax: (+852) 2886 3241
e-mail: sales@peiport.com.hk
web: www.peiport.com

Denmark
Optonyx AB → Sweden

Finland
Optonyx AB → Sweden

France
TRIOPTICS France
66 Av. Niels Bohr BP 52132
69603 Villeurbanne Cedex
phone: (+33) 472 440 203
fax: (+33) 472 440 506
e-mail: info@trioptics.fr
web: www.trioptics.fr

Germany
Headquarters
piezosystem jena GmbH
Stockholmer Straße 12
D – 07747 Jena
phone: (+49) 3641 6688 0
fax: (+49) 3641 6688 66
e-mail: info@piezojena.com
web: www.piezosystem.com

India
SIMCO GLOBAL TECHNOLOGY & SYSTEMS Ltd.
14 Bhawani Kunj
Behind Sector D-II, Vasant Kunj
New Delhi-110 017
phone: (+91) 11 2689 9867
fax: (+91) 11 2612 4461
e-mail: simcogroup@sify.com
web: www.simco-groups.com

Israel
Prolog Optics
4 Ha`Horesh Road
P.O.B. 12193
IL - Yehud 56470
phone: (+972) 3536 40 11
fax: (+972) 3536 40 12
e-mail: mailto:shai@prologltd.com
web: www.prologoptics.com

Italy
Massimo Bonfante
Via Capecelatro 87
20148 Milano
phone: (+39) 02 36 52 46 30
fax: (+39) 02 99 98 12 25
e-mail: massimo@masbonfante.it
web: www.masbonfante.it

Japan
AUTEX Inc., Tokyo Office
Takasago Bldg.,16-5
Tomihisa-Cho, Shinjuku-Ku
Tokyo, 162-0067
phone: (+81) 332 266 321
fax: (+81) 332 266 290
e-mail: sales31@autex-inc.co.jp
web: www.autex-inc.co.jp

Japan Laser Corporation JLC
2-14-1 Nishi-Waseda
Shinjuku-Ku.
169-0051 Tokyo
phone: (+81) 3 5285 0861
fax: (+81) 3 5285 0860
e-mail: jlc@japanlaser.jp
web: http://www.japanlaser.co.jp/

Luxembourg
Laser 2000 Benelux C.V. → Netherlands

Malaysia/Singapore
ZUGO Photonics Sdn.Bhd
No.9, Jalan USJ 21/11, 47620 Subang
Jaya, Selangor Darul Ehsan
phone: (+603) 80 236 969
fax: (+603) 80 236 161
e-mail: enquiry@zugophotonics.com
web: www.zugophotonics.com

Inno-V Global Sdn Bhd
No. 44-2, Jln Puteri 1/4
47100 Puchong, Selangor
phone: (+603) 8063 9368
fax: (+603) 8063 9369
e-mail: sales@innov-global.com
web: www.innov-global.com

Netherlands/Belgium/Luxembourg
Laser 2000 Benelux C.V.
Voorbancken 13a
3645 GV Vinkeveen / Netherlands
phone: (+31) 297 266 191
fax: (+31) 297 266 134
e-mail: sales@laser2000.nl
web: www.laser2000.nl

Norway
Optonyx AB → Sweden

Poland
SPECTROPOL
ul.Miedzynarodowa 41/9
03-922 Warzaw
phone: (+48) 22 617 6717
fax: (+48) 22 617 6797
e-mail: biuro@spectropol.pl
web: www.spectropol.pl

Singapore → Malaysia

Sweden / Denmark / Norway / Finland
Optonyx AB
Enshagsslingan 23
18740 Täby / Sweden
phone: (+46) 855 111 410
fax: (+46) 855 111 415
e-mail: info@optonyx.com
web: www.optonyx.com

Taiwan
Nahshon Enterprise Co. Ltd.
3F. Room 6, 601 Chung Cheng Rd.
Shih Lin Dis., Taipei
phone: (+886) 228 126 213
fax: (+886) 228 126 183
e-mail: sales@nahshon.com.tw
web: www.nahshon.com.tw

United Kingdom
Qioptiq Photonics Ltd.
Mitchell Point, Ensign Way, Hamble
Hampshire SO31 4RF UK
phone: (+44) 1832 730 222
fax: (+44) 2380 744 501
e-mail: mailto:william.bailey@excelitas.com
web: www.excelitas.com

USA
piezosystem jena Inc.
2B Rosenfeld Drive
Hopedale, MA 01747
phone: (+1) 508 634 6688
fax: (+1) 508 634 6868
e-mail: usa@piezojena.com
web: www.piezo-usa.com

piezosystem jena GmbH
Stockholmer Str. 12
07747 Jena
GERMANY

phone: (+49) 36 41 66 88 0
fax: (+49) 36 41 66 88 66
e-mail: info@piezojena.com

piezosystem jena, Inc.
2B Rosenfeld Drive
Hopedale, MA, 01747
USA

phone: (+1) 508 634 66 88
fax: (+1) 508 634 68 68
e-mail: usa@piezojena.com

For more information please visit:
www.piezosystem.com

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