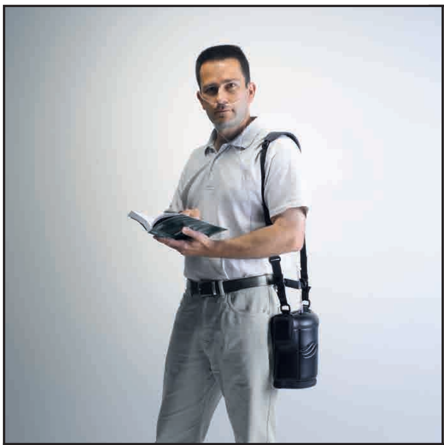
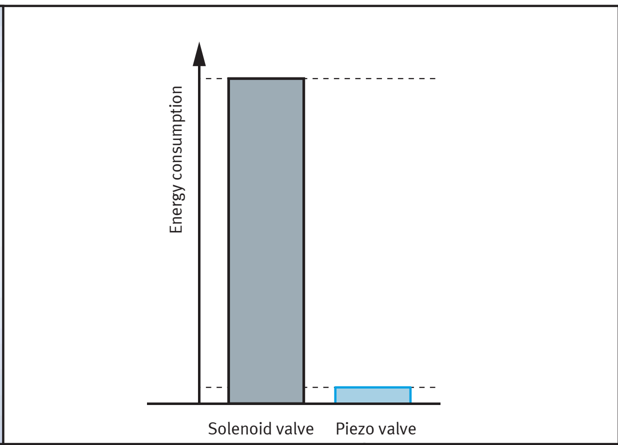
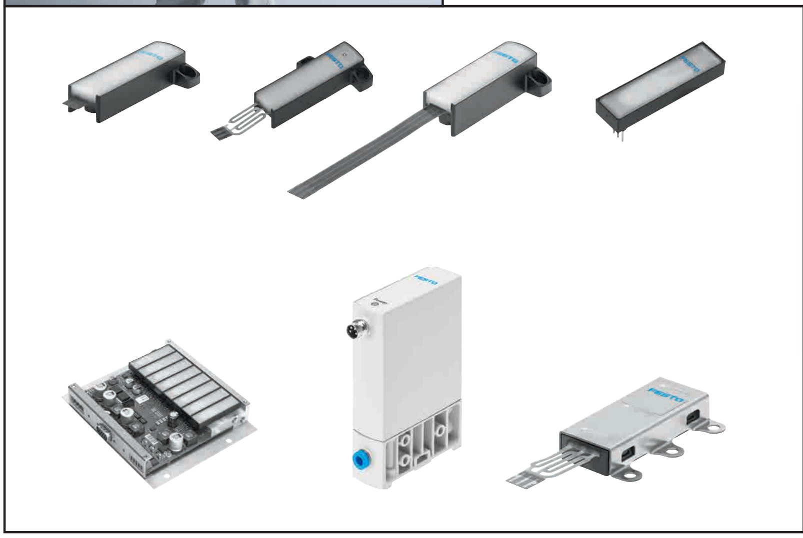
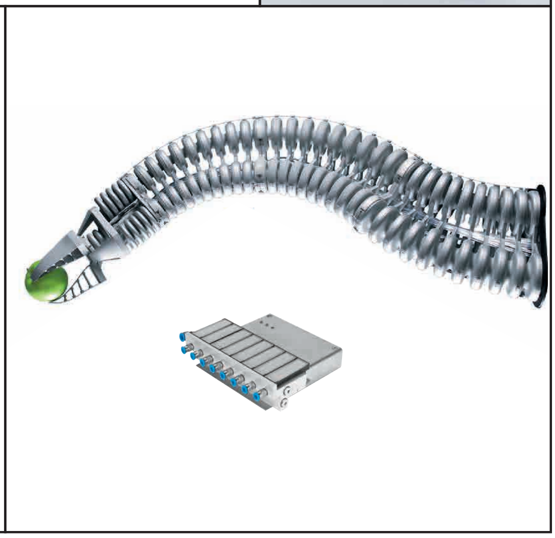
White paper
Piezo technology in pneumatic valves









Piezo valves are often a better alternative to conventional solenoid valves, especially in the areas of flow and pressure control and as directly controlled proportional valves. They are small, lightweight, extremely precise, very durable, incredibly fast and above all they save energy. For example, piezo valves do not need any energy to maintain a switching status. They therefore generate virtually no heat. In ATEX applications, many piezo valves are classified as intrinsically safe. What is more, piezo valves can potentially be operated without any noise. Another key advantage is that they always work proportionally – and are very wear-resistant too.

These properties make piezo valves ideal for use in, for example, the semiconductor industry. Here, their accuracy and ability to quickly reach preselected setpoints ensure precise metering of even the smallest amounts of air or gas, and precise regulation of the pressure and vacuum used to press silicon wafers onto a polishing table.
Other areas of use include adhesive applications with very accurate metering in small parts assembly or gentle and safe speed control for pneumatic cylinders. Applications in medical technology, laboratory automation and even motor vehicles also benefit from piezo valves.

This white paper provides you with answers to the following questions:
- How does piezo technology work, what is the principle behind it?
- What advantages does piezo technology offer?
- In which industry sectors and for which applications are piezo valves the technology of the future?
- Introduction to several versions of piezo valves

1. Piezo technology: history, mode of operation and applications

What is a piezo element?

Piezo elements are electromechanical transducers. With the so-called direct piezoelectric effect, a piezo element converts mechanical forces (pressure, tensile stress or acceleration) into a measurable voltage. The inverse piezoelectric effect is precisely the opposite: a piezo element is deformed when a voltage is applied to it, thus generating mechanical motion or oscillations.

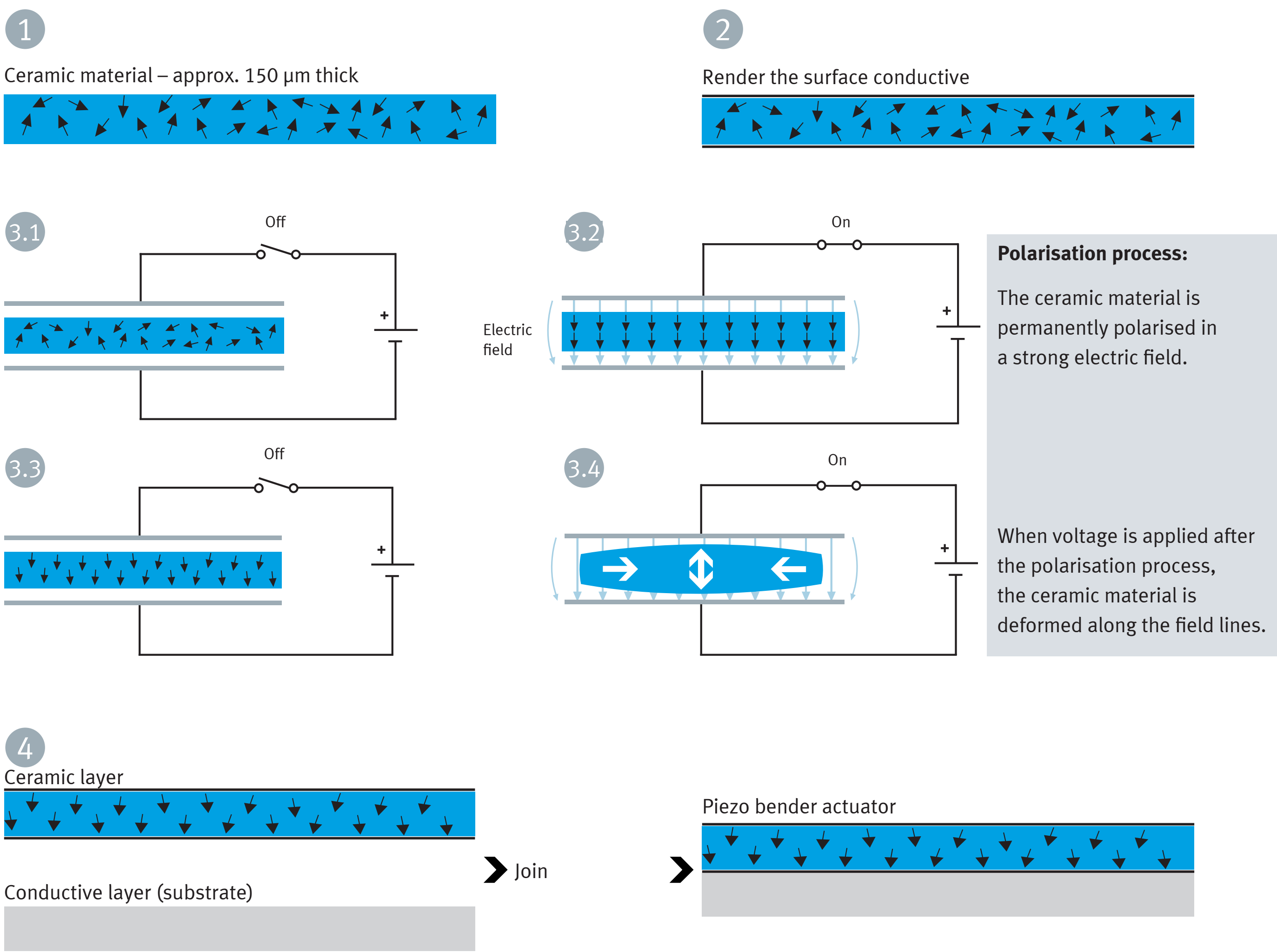
A brief history

The piezoelectric effect (from the Greek "Πιεζώ" (piezo) = pressing) was discovered in 1880 by the brothers Jacques and Pierre Curie, the latter being the husband of Marie Curie. They found that, when subjected to a mechanical load, certain non-conductive materials produce electrical charges on their surface, which has been rendered conductive.

The principle

Piezoelectric materials, usually special ceramic objects with surfaces which have been rendered conductive, convert electrical energy into mechanical energy and vice versa. The lattice structure of the molecules in these piezo-ceramics is asymmetrical below the Curie temperature Tc, and is thus a dipole. Under the influence of strong electric fields, it is possible to permanently polarise piezo-ceramics, or in other words give them a preferred direction. The ceramic material then has piezoelectric properties and changes shape when a voltage is applied. 3D deformation takes place along the field lines. Since the ceramic materials have a constant volume, shrinkage occurs in the material at right angles to the field lines. The advantage of piezo-based drives lies in the fact that they can be energised with almost zero power. In electrical terms, a piezo element is a capacitor consisting of two electrically conductive plates and the ceramic piezo material which functions as a dielectric. Current only flows while the capacitor is charging, and the flow drops to zero when charging is complete. Since electrical power is calculated as voltage x current, the power will be zero if no more current flows. In applications that need to be extremely energy-efficient it is even possible to recover the charging energy when the drive is reset. This can then be used again for the next charging operation.

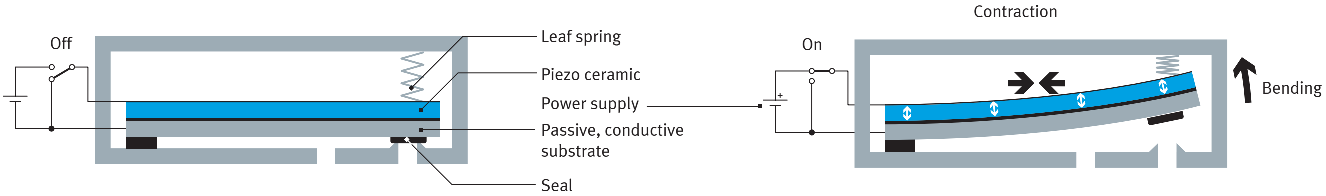
Design of the piezo element



Types and versions of piezo transducers and their applications

Depending on the needs of a particular application, the effect described earlier can be exploited using various types of transducers. Disc transducers, bender actuators and piezo stacks are the basic forms from which piezo elements with more or less complex structures can be derived.

The bender actuator has a rectangular shape. Its primary element is a piece of piezo ceramic material which has been rendered conductive on both surfaces. This ceramic material is entirely joined on one side to a substrate which is also conductive. The conductive surfaces of the ceramic layer and the substrate function as electrodes. If a voltage is now applied to these electrodes, the ceramic material expands in the direction of the electric field. Since in most applications bender actuators are fixed at the front end, this results in a bending motion at the free end. Bender actuators are available in multiple versions with different forces and actuator motion, and are highly suitable for use in pneumatic valves. Typical characteristic data include deflection amounting to several tenths of a millimetre and forces of up to 1 N. One special variant which is often used is the trimorph, which has a second ceramic layer on the reverse side of the substrate. This increases the performance of the transducer and it can be used in a wider temperature range thanks to its symmetry. Applications for bender actuators can be found in circular knitting machines, blind reading devices (Braille modules) and pneumatic valves – with the latter especially in proportional valves for pressure and flow control.

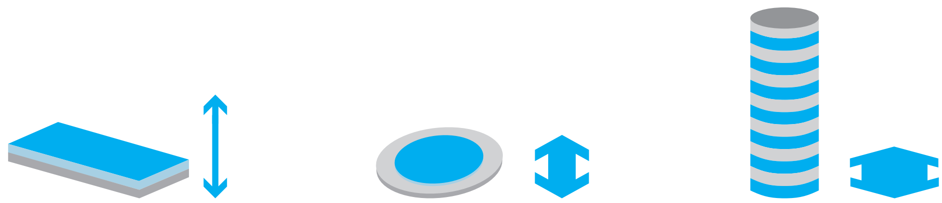


Function of the bender actuator in the piezo valve: when a voltage is applied, the piezo element bends due to a reduction in longitudinal direction.

A **disc transducer** is also a very simple piezo element. It takes the form of a thin ceramic disc which is bonded to a metal substrate. In order to generate an electric field, the circular area on the surface of the disc has to be metalized. If a voltage is now applied to this substrate and the electrode on the ceramic, the ceramic (as is also the case with the bender actuator) expands in the direction of the electric field and the disc becomes thicker, while at the same time its diameter becomes smaller. Together, the metallised area and the passive substrate act like a bimetallic strip and cause the overall system to bend in a spherical direction. This bending effect is used, among others, in high-frequency loudspeakers, sensors, micro-pumps, fans and ultrasound generators, such as are often used in automobile distance sensors.

Stack transducers (piezo stacks) are stacked piezo discs which are connected in series mechanically, and in parallel electrically. In contrast to disc transducers, operation is not triggered by the bending of a composite material but by direct expansion in the direction of the field. This configuration allows only short strokes – maximum 0.2% of the overall height – but with enormous actuating forces up to several kilonewtons. Applications can be found in the areas of liquid valves, such as diesel fuel-injection systems, and micro positioning.

Piezoelectric actuators with technical data for various transducers types



	Bender actuator	Disc translator	Stack transducer
Displacement	100 - 1,000 µm	10 - 100 µm	10 - 100 µm
Force	0.1 - 2 N	1 - 10 N	1,000 - 10,000 N

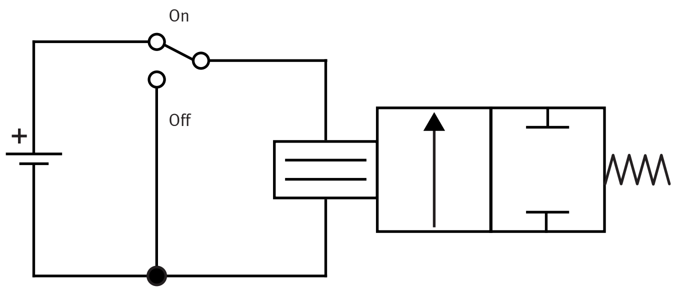
2. Operation of piezo valves

Piezo elements in the shape of bender actuators are primarily used in pneumatic valves. The performance of piezo valves depends on the strength of the electric field: the greater the field strength, the better the performance of the actuator and the valve. Compared to solenoid valves, piezo valves need no holding current to maintain a switching state. The higher supply voltage required by piezo valves in comparison with solenoid valves is of significance only during the switch-on phase. Even then, the switch-on energy consumed is well below the actuation power levels normal in pneumatics.

This switch-on energy "E" can be calculated as an approximation using the formula $E = CU^2/2$, where C is the capacitance of the transducer and U is the control voltage. Values usually lie between 0.5 and 5 mWs because the capacitance of the transducer is generally around 30 nF, while the control voltage can be up to 300 V DC.

Important to know: the switch-on energy of piezo valves is always specified in milliwatt seconds only. It is not possible, as it is with solenoid valves, to specify power ratings in watts.

When a piezo valve has been switched on and the connection to the power supply is then interrupted, the valve status is maintained because the charge carriers are no longer capable of flowing away due to the interruption. To reset the valve, the charge must be actively removed from the transducer. This can be achieved through buffer storage in another system (energy recovery) or by converting the energy to heat (short circuit). A changeover switch instead of an on-off switch is therefore required in order to operate the valve.

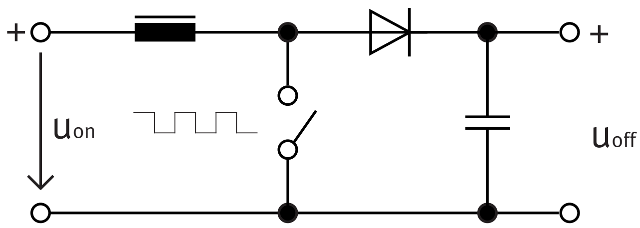


A piezo valve must be deliberately discharged in order to reset it.

High-voltage generation

High-performance valves need to be operated using high voltage. The principle of a boost converter has proved itself ideal for generating this high-voltage. A boost converter is extremely inexpensive and requires little space. With this device, the very high induction voltage generated during the cyclical switch-off of a coil (storage choke) is fed via a diode and stored in a capacitor – in the simplest case, the piezo transducer can also be used as a capacitor.

This circuit allows an output voltage of 300 V with an input voltage of as little as 1 V. The oscillator for the switch can often be realised by using the microprocessor already present in the system controller. However, there are also ready-made integrated circuits especially for this application. Modules of this kind also manage output voltage regulation and ensure maximum efficiency, which is well over 80%.



The high voltage required can be generated easily and cheaply with a boost converter using induction.

3. Advantages of piezo valves

In the world of electrically controlled pneumatic valves, solenoid valves are the absolute standard with a market share of almost 100%. Nevertheless, piezo valves offer many advantages over the prominent solenoid valves and open up entirely new areas of application.

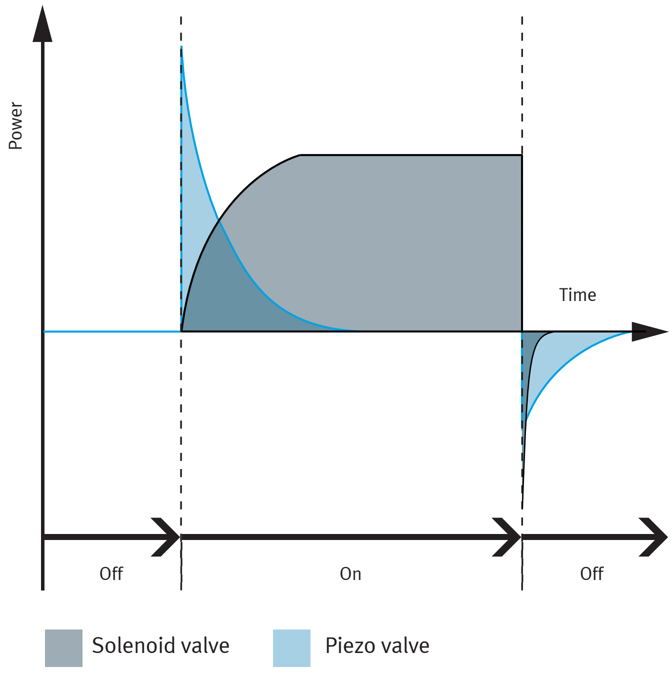
Low energy consumption – no heat generation
Thanks to their capacitive principle, piezo valves require virtually no energy to maintain an active state. The valves do not generate heat, provided that high-frequency control is not used due to the fact that switch-on energy is frequently required. The energy balance increases along with the required switching frequency.
Piezo technology is ideal for use in the “very low power” range of battery-powered devices. Compared to solenoid valves, it can increase the service life of a battery pack several times over in some cases.

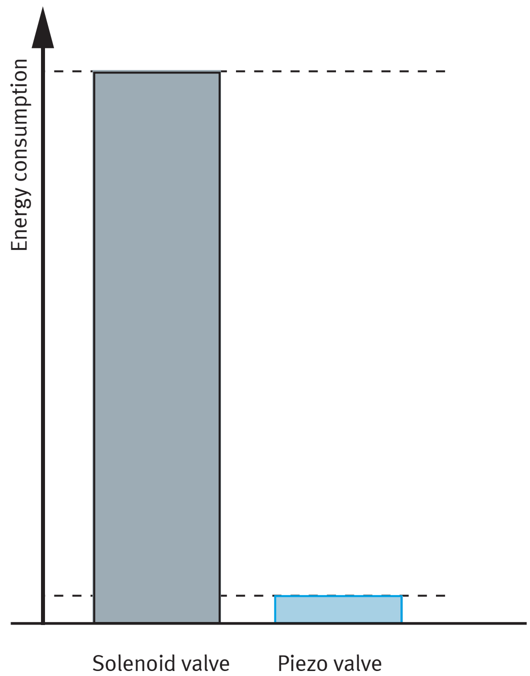
Intrinsic safety
“Intrinsic safety” " is increasingly specified as the required degree of protection for environments with potentially explosive atmospheres. An electrical system is intrinsically safe if the greatest amount of energy it can store is not enough to cause ignition of the atmosphere in the event of a fault. Piezo valves are an ideal way of meeting this requirement, thus resulting in a large number of potential applications.

Switching speed
Piezo valves can be incredibly fast, easily reaching the sub-microsecond range.

These valves are the ideal solution for applications where speed plays a decisive role. Applications include high-speed sorting systems and in particular closed-loop control circuits in general, as this type of circuit usually works better the faster the individual components react.

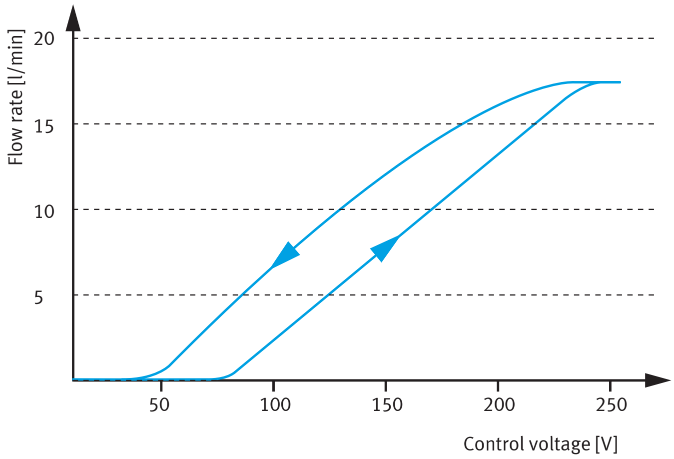
Energy-saving potential of piezo valves compared to solenoid valves





Proportionality

Proportionality is an intrinsic characteristic of piezo technology. Since ultimately all pneumatic processes in an application are analogue, this is an unbeatable advantage: there is no need for pulse-width modulation and the associated noise problems as a means of trying to achieve a certain proportionality when switching solenoid valves. This means that piezo valves are very resistant to wear and need only minimal energy input. Combined with their short response times, the proportionality of piezo valves make them ideal actuators for all higher-level control systems.



Proportionality of piezo valves: ideal actuators for higher-level control systems

Anti-magnetic

Piezo technology can also be used without any risk of failure in areas with a high magnetic field strength, for example magnetic resonance tomography (MRT).

Minimal weight

The fact that housings are usually plastic, and in particular the absence of iron and copper make them very portable.

Low costs

This technology can be mass-produced if large quantities are required, as for example for piezo-ignited lighters which are available for very little money.

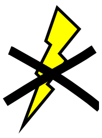
Long service life

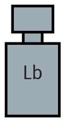
When a system is designed correctly, piezo drives can achieve an unusually high number of operating cycles. They consist of a single solid-state working component with no further wearing parts which might be subject to friction.

Restrictive "but":

These advantages cannot all be exploited at the same time in a single valve. Valves are generally designed for a particular application in which individual, specific benefits come to the fore.

Piezo valves offer many advantages:

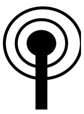

Very low power consumption

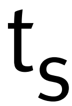


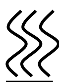
Minimal weight


Intrinsically safe

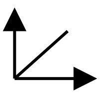

Anti-magnetic


Remote controllable

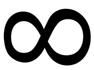

Short response times


No heat build-up


Potential savings


Proportionality


Silent switching


Long service life


Compact

4. Industry sectors and applications
Future Piezo applications

Flow control

In many applications with flow regulators a constant mass flow rate is required over long periods of time. A typical example is the production of artificial atmospheres, for example as required in the semiconductor industry at the front end for coating processes, and at the back end for bonding processes. This type of load is easy to manage for a piezo valve since it involves a steady state with virtually no consumption of energy. If, on the other hand, a pulse-width-modulated switching valve were used, this would represent an extremely heavy load for this valve – both in terms of energy and mechanically. The service life of systems of this kind is correspondingly low, which is why preference is given to piezo technology in this case.

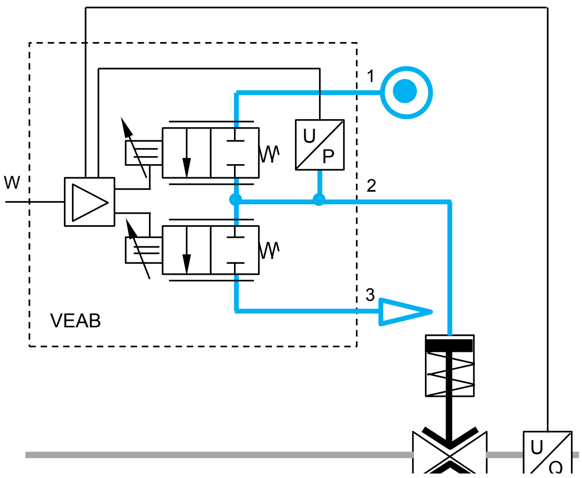
Non-destructive handling of fragile workpieces

A unique solution for handling sensitive workpieces is the so-called “speed controller” for double-acting pneumatic cylinders. This makes it possible to execute speed-controlled jerk-free motions with a pneumatic cylinder. For this purpose four piezo valves are combined with a controller unit to form a system which can be connected to a double-acting cylinder. Speed is controlled by maintaining a constant cylinder exhaust flow rate. This low-cost system works without an expensive displacement encoder. What is more, it allows smooth starting and braking.

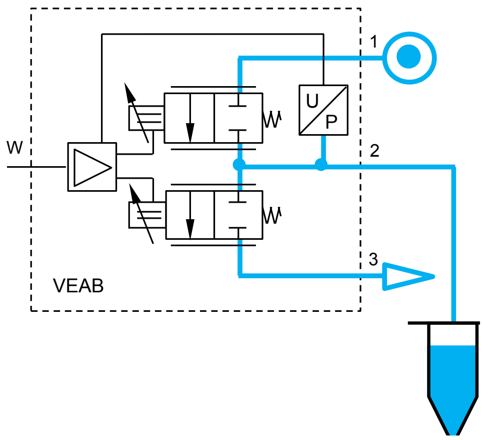
Industrial adhesive applications: fast and accurate metering

To prevent accidental dripping, a vacuum must be created in industrial adhesive applications after a predetermined amount of glue has been applied. Extremely precise metering is also required, especially in the case of small parts assembly. Conventional applications normally work with two valves, one for the vacuum and the second for positive pressure. Piezo valves are much more accurate and faster in these types of applications. Pressure and vacuum are controlled with the same valve – there is no need for a second valve.

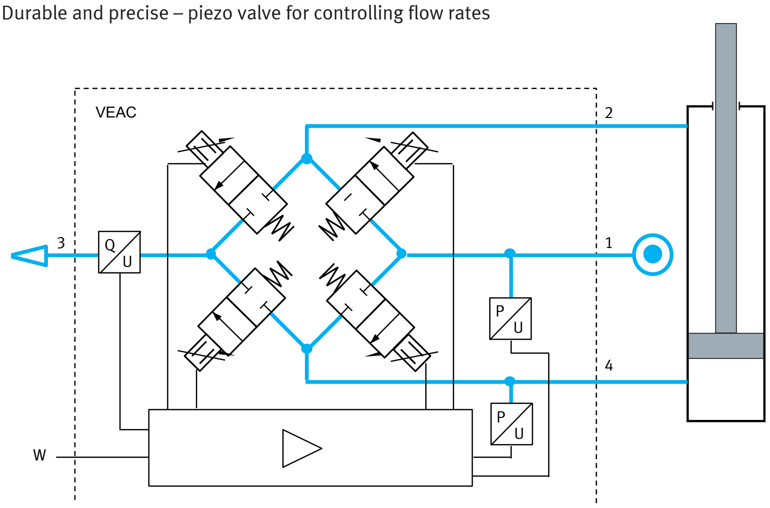
Industrial applications with potential for piezo valves



Durable and precise – piezo valve for controlling flow rates



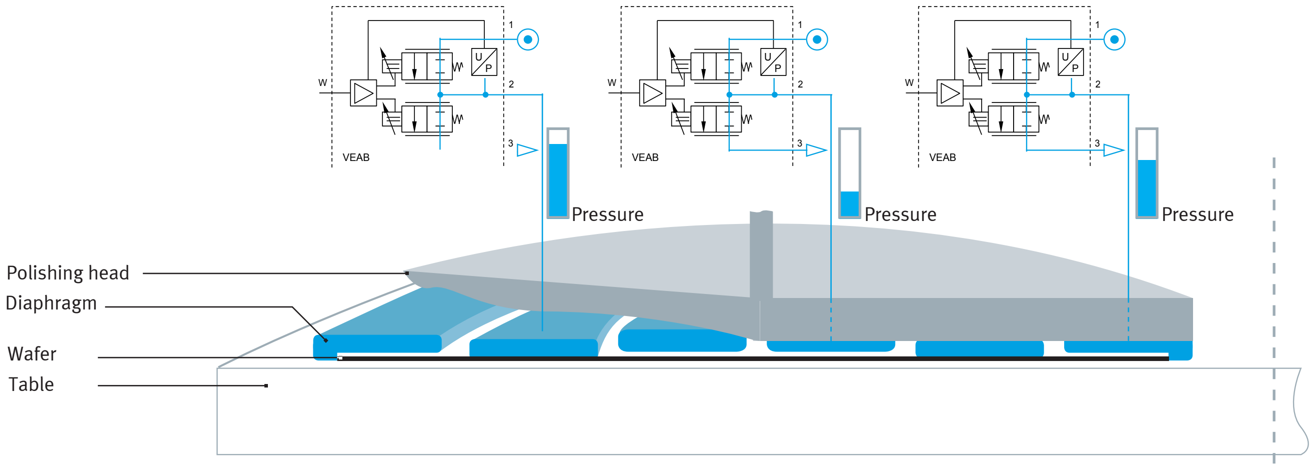
Precise metering, even with very small quantities:
piezo valves make adhesive application processes simpler.



Piezo valves control speeds gently, jerk-free, and without a displacement encoder.

Production of semiconductors: polishing wafers
Piezo valves offer high accuracy and can reach preselected setpoint values quickly, which makes them ideal for applications in semiconductor production. There is a need here to precisely meter extremely small amounts of air in order to meet the high demand for precision machining of the workpieces. When polishing wafers, for example, the challenge is to press the wafers against a rotating polishing table with an accurately controlled pressure. This is the only way a perfectly flat surface can be obtained. In order to achieve a perfect result, a number of diaphragm rings are pressed onto the wafers with a varying amount of force. These rings must be controlled extremely precisely in terms of both vacuum and pressure.
Piezo valves combine both of these functions in a single compact device.

Medical technology: mobile ventilators
The mobile ventilators used in medical technology have special requirements with regard to their components. To ensure patients remain mobile despite the ventilator, a compact design and minimal weight are very important. Furthermore, the units are operated on battery power and must not consume too much energy. Since many patients depend on these units for their oxygen supply at night, the technology should make as little noise as possible. Piezo valves are already being used successfully for this purpose and are able to display many of their strengths to the full.



High precision thanks to piezo valves: polishing wafers

Surgical tool: ophthalmology
Piezo valves are used to control pneumatically powered tools for cataract surgery, which is one of the most common of all surgical procedures. This surgery is the only possible treatment for progressive, or age-related clouding of the lens. The patient's clouded lens is removed from the eye and replaced with an artificial intraocular lens (IOL).
The surgical tools used are operated pneumatically. Piezo valves are important for the control of pressure and vacuum. It is also necessary to handle various liquids including aqueous humour (the fluid in the eye) and substitute solutions (infusions). Piezo valves provide precise metering and regulate the flow of fluids and the replacement of the aqueous humour solution.

Comfort in the car seat: inflating air cushions
Piezo valves are already being used in car seats too. They provide a fast, accurate and above all silent means of filling and emptying air cushions, which means more comfort and a more pleasant environment for the driver. Built into seat side panels and backrests, the air chambers are filled as appropriate to the driving situation.
To provide drivers and front passengers with optimum side support, the pressure and volume of the side air chambers in the seat backs can be varied in seconds via centrally arranged piezo valves.
This variation is carried out as a function of the steering angle, lateral acceleration and travel speed. For example, the system inflates the air chambers on the right-hand side of the backrest more strongly during left-hand turns.

Innovative applications for piezo technology:
[1] Medical technology [2] Car seats [3] Bionic Handling Assistant

The future of piezo valves
Thanks to its properties, piezo valve technology is opening up completely new opportunities for future products. It is already being used in Festo's award-winning Bionic Handling Assistant. The reason for choosing piezo valves was their ability to meter compressed air precisely and purposefully and the fact that the installation space required was considerably less than for other valves.

5. Various versions of piezo valves and their advantages

Piezo valves can carry out a variety of valve functions for various applications.
This is explained below using the piezo valves currently offered by Festo as an example.

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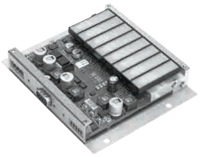

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Festo piezo valves:
1 2/2-way valve VEMR
2 3/3-way valve VEMC/VOMP
3 Proportional pressure valve terminal VEMA
4 Directly controlled proportional pressure regulator VEAB
5 3/3-way valve VEAA

2/2-way valve VEMR
Thanks to their interchangeable seat insert, these valves can be used in a wide variety of applications because the pressure and flow rate ranges are essentially determined by the seat diameter. In oxygen therapy devices, the VEMR closely controls oxygen supply and metering during inhalation. The VEMR can be combined with a flow sensor to create a proportional flow control valve.

3/3-way valve VEMC or VOMP
These valves are also known as gap transducer valves.
They incorporate a special bender actuator which works on the basis of differential movements and thus provides almost complete compensation for temperature-related errors. VEMC and VOMP are especially well suited for pressure control, for example in lymph drainage devices, but can also be used as switch valves, for example to select one of two different flow rates. VEMC and VOMP can be combined with a flow sensor and electronic control to create a proportional pressure regulator.

Proportional pressure valve terminal VEMA
Piezo technology is also able to demonstrate its strengths in this field – with eight channels, microprocessor control and combined with a fieldbus.
- 8 x VEMC valves: required installation space reduced by a factor of 10 since no dangerous heat is generated during operation
- Easy installation through one central vacuum connection and one central pressure supply for all valves
- CAN-Bus control: simple interconnection of the valve terminals to each other or to other devices
- Cover with LEDs for quick recognition of operating status

3/3-way valve VEAA
Also known as a rocker transducer valve, this incorporates a trimorph transducer which is able to move in two directions, thus closing port P or R. The very broad range of vacuum supply pressure of up to 12 bar makes it ideal for many industrial applications with pressure regulation.

Directly controlled proportional pressure regulator VEAB
Valves of this design are fully-fledged proportional valves which provide an output pressure via an integrated electronic unit with a pressure sensor. The setpoint can be specified as a voltage of 0 ... 5 V or 0 ... 10 V, or a current of 4... 20 mA. The valve also provides a reference signal in the same range. The ratio of the valve's physical sizes to its flow rate is worth noting, as well as the following special features: short response times of ‹ 10 ms, highly accurate pressure regulation, very low power consumption, no switching noise.

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