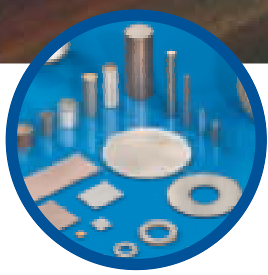
Piezotechnology

Piezoelectric Ceramic Products



Moving the NanoWorld www.piceramic.com

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For Piezoelectric Actuators & Nanopositioning Systems see other PI Ceramic and PI Catalogs at: http://www.piceramic.com


PI

Who We Are

PI Ceramic, founded in 1992, is a subsidiary of Physik Instrumente (PI) GmbH & Co. KG, one of the world's leading companies in the field of ultra-high-precision piezo-electric nanopositioning systems.

In the tradition of the former *Hermsdorf-Schomburger Isolatorengesellschaft* (HESCHO AG, until 1945) and in continuance of the work of the former *Keramische Werke Hermsdorf* (KWH, until 1990), our staff embody more than 40 years of knowledge and expertise in the fields of piezo-electric ceramics technology.

Our know-how opens up possibilities for the custom-engineered and application-specific design and production of actuator and sensor piezo products ranging far beyond the classic piezoceramic component.

Since 1992, PI Ceramic has been developing and producing its own piezoceramic materials, known all over the world under the name **PIC**, an acronym for **PI** piezo **C**eramics.

Our Strengths

- State-of-the-art piezo components, ultrasonic transducers, actuators and system solutions
- Development and production of highly reliable components for today's most important markets
- Custom-engineered and standard solutions available
- High degree of flexibility in the engineering process guarantees short lead times
- Key technologies and the appropriate equipment for ceramic production available in-house
- ISO 9001-2000 certified

PI Ceramic is a customer-focused company. Early contact between the user and our application and design engineers guarantees the best possible technical and economic solutions. Our design department is always striving to transform new ideas and concepts into technologies and products to meet the demands of the market.

In addition to the broad spectrum of standard products, our main priority is the fastest possible realization of custom-engineered solutions. Our design and manufacturing processes are optimized for medium-sized production runs (up to a few thousand pieces) and guarantee maximum quality and reliability in a wide range of applications. The flexibility of our production processes guarantees reasonable prices, even for small production runs. A quality management system certified in accordance with ISO 9001-2000 guarantees the continuous improvement of all company processes.

Excellent design and manufacturing conditions prevail on our almost 7000 m² of floor space, which is equipped with state-of-the-art production and laboratory equipment.

Moreover, close cooperation with renowned research institutions and universities, both domestic and abroad, guarantees continuous further development of our potential and efficient solutions to application-specific tasks.

Markets and applications
PI Ceramic supplies piezoceramic solutions for all important high-tech markets

- Industrial automation
- Semiconductor industry
- Medical engineering
- Mechanical and high-precision engineering
- Aerospace
- Automotive industry
- Telecommunications
- etc.

Our Mission

Our mission is the reliable delivery of products, whether standard or custom-engineered, which are of the greatest possible utility for the application, and which provide the greatest satisfaction of our customers. This is achieved by close contact between our design and application departments and the technical divisions of the customer firms. It is thus even more important that there be early contact in the design and prototype phases of the project and that this continue to the finished product and beyond.

We do not measure ourselves solely against the latest technical developments. We measure ourselves against the vision of what is necessary and achievable in the future!

Our relationship to our customers

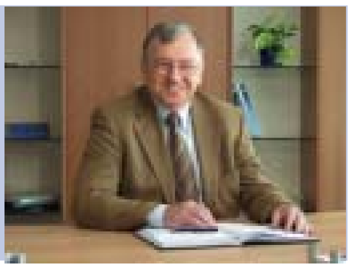
All employees at PI Ceramic are constantly striving to establish and cultivate a close relationship of trust with our customers on a daily basis. We are committed to professionalism, absolute customer satisfaction and quality products.

Customers do not buy products, they buy per-formance, whether in a standard product or in one custom-engineered for their application.

The success of our customers is the success of PI Ceramic. The emphasis of our daily work is on assisting our customers to further increase their competitiveness with existing and new technologies. The trust required is built and maintained by our reliability, the close contact we maintain with our customers and the speed with which we move from drawing up the offer to delivering.

"Long-term business relationships, reliability, open and friendly communication with customers and suppliers are of the essence for PI Ceramic and all members of the worldwide PI Group and far more important than short-term gain."

Dr. Karl Spanner
President



Historical Review

The development of piezoelectric materials and components and their applications are determined by the results of research in the fields of insulating materials and dielectrics. The most important physical properties of these materials have been known for a long time.

In 1758, Carl Wilcke discovered that dielectrics are polarized; his discovery came so early, however, that this piece of knowledge was soon lost again. The Leyden jar, an early form of capacitor, was described by van Musschen-brock around 1750. In 1837, Faraday demonstrated the influence of dielectric material on electrostatic phenomena.

The piezoelectric effect in natural crystals (Rochelle salt, tourmaline and quartz) was discovered in 1880 by the brothers Jaques and Pierre Curie. They were able to establish that certain crystals become charged (electrically polarized) in different ways under a mechanical load (deformation) and vice versa.

The technological utilization of dielectrics was, and still is, a difficult materials problem. It began to develop rapidly after crucial advances in the ceramics industry. In the 1930s, the development of ceramic capacitors based on barium titanate laid the decisive foundation. A principle player was HESCHO AG (*Hermsdorf-Schomburger-Isolatoren-gesellschaft*), the world leader in this field until 1945.

Since its foundation in 1992, PI Ceramic GmbH has been continuing this regional tradition at its site in Lederhose / Thuringia, in the center of Germany.

The first practical uses of the piezoelectric effect were driven by military applications. In 1916, Langevin developed sandwich transducers comprising Rochelle salt and steel which were used for acoustic wave conversion in echo sounders for submarine detection until the 1940s. Telecommunication applications with quartz oscillators were a further broad operational area.

The triumphant advance of the utilization of piezoelectric ceramics began with the discovery of the piezo-ferroelectric properties of barium titanate in 1945/46 by American and Russian scientists and the synthesis of the first PZT (lead-zirconate-titanate) compounds in the 1950's. Their excellent properties makes them the predominant piezoelectric material to this day.

The Piezoelectric Effect

Piezoelectric ceramics belong to the group of ferroelectric materials. Ferroelectric materials are crystals which are polar without an electric field being applied. This state is also termed spontaneous polarization. Characteristic of this state is the thermo-dynamically stable reversibility of the axis of polarization under the influence of an electric field, described graphically by a hysteresis loop (see page 10). The reversibility of the polarization, and the coupling between mechanical and electrical effects are of crucial signifi-cance for the wide techno-logical utilization of piezo-ceramics.

From a crystallographic point of view, these piezoelectric materials exhibit what is called Perovskite crystalline structure. This applies to a series of com-pounds with three types of atoms with the general formula ABC_3.

The main piezoceramics in use today, $PbTiO_3$–$PbZrO_3$ are sythesized from the oxides of lead, titanium and zirconium. $BaTiO_3$ is also used.

Special dopings of these lead-zirconate-titanate ceramics (PZT) with, for example, Ni, Bi, Sb, Nb ions etc., make it possible to adjust individual piezoelectric and dielectric parameters as required.

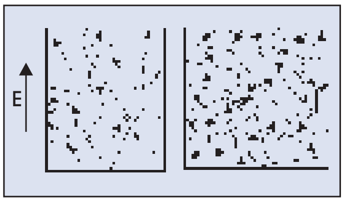
These materials are not ferroelectric above a characteristic temperature, known as the Curie tempera-ture. They are in a paraelectric state, i.e. no dipoles are present. The relative dielectric constant has a distinct maxi-mum in the vicinity of the Curie temperature.

Below the Curie point of the material, the cubic, electrically neutral crystalline form gives way to lattice distortions, resulting in the formation of dipoles and rhombohedral and tetragonal crystallite phases, which are of interest for piezo technology.

Ferroelectric domains and polarization of piezo ceramic

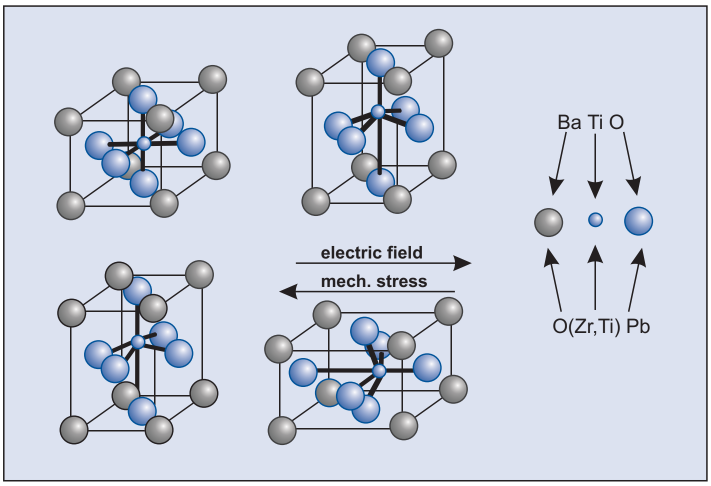
A ferroelectric crystal can be divided into spatial regions having different directions of polarization, called ferroelectric domains. What is generally meant by a domain in a solid body is a physically bounded spatial region in which a vector quantity characterizing the state at a point in the solid body has the same direction everywhere. For a ferroelectric domain this characteristic quantity consists in the same alignment and the same absolute value of the sponta-neous polarization. Depending on the particle size of the poly-crystalline ceramic material, the individual crystallites contain only a few domains, bounded by domain walls.

In the event of large changes of the electric field or mechanical stress, shifting occurs and the polarity of whole regions can be reversed as a result of domain re-forming. These processes, and the irreversible displacement of domain walls, are some of the reasons for the familiar phenomenon of ferro-electric hysteresis.

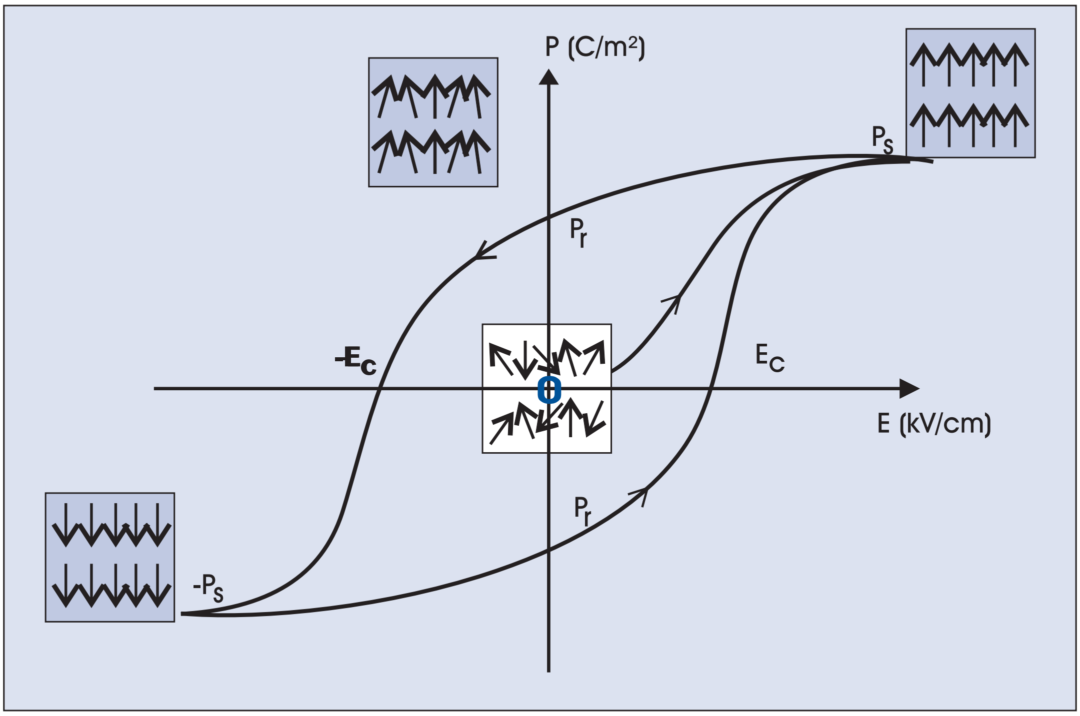


Symbolic representation of the electrical reorientation processes in piezoelectric ceramic crystallite and domain structure.

During manufacture, after the sintering process the poly-crystalline piezoelectric ceramics are in a thermally depolarized state after the sintering process. From a statistical point of view, there is an almost uniform distri-bution of spontaneous polarization directions among the domains, and the material is isotropic, i.e. not piezo-electric. By applying a strong electric field E, the spon-taneous polarization is ferroelectrically reoriented to the saturation polarization P_3. This produces a residual polarization parallel to the direction of the field, and the material is anisotropic, i.e. piezoelectric.



Cubic (paraelectric) and tetragonal (ferroelectric) structure of PZT and $BaTiO_3$ before and after an electric field has been applied or a mechanical stress taken effect.



An opposing electric field will only depolarize the material if it exceeds the coercivity strength. A further increase in the opposing field leads to repolarization, but in the opposite direction.

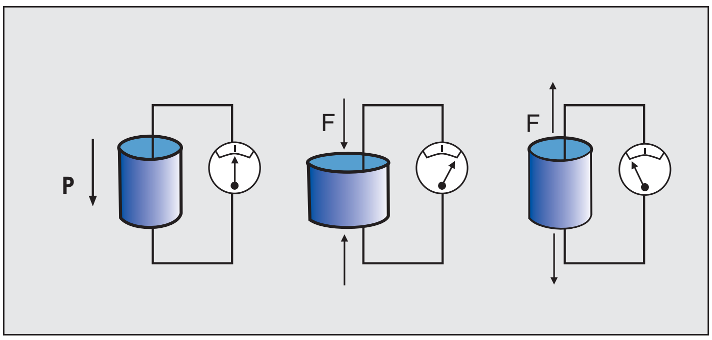
Ferroelectric hysteresis

Direct piezo effect

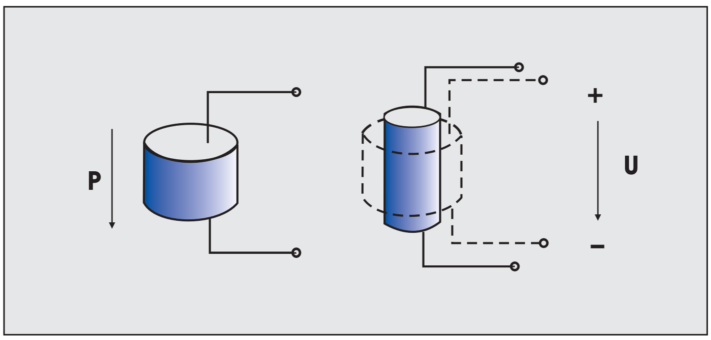
Mechanical stresses arising as the result of an external force acting on the piezoelectric body induce displacements in the positive and negative lattice elements which manifest themselves in dipole moments. The resulting formation of an electric field puts an electric potential on the insulated electrodes. This direct piezo effect is frequently referred to as the generator effect in the literature.

Inverse piezo effect

The application of an electric voltage to an unrestrained piezoceramic body results in ist deformation. The amount of movement is a function of the polarity of the voltage applied and the direction of the polarization vector. Applying an AC voltage generates a cyclical change in the geometry (e. g. increase or reduction in the diameter of a disk). If the body is clamped, i.e. if free deformation is constrained, a mechanical stress or force is generated. This effect is frequently also called the motor effect.



The effect of a force on a piezoelectric cylinder



Deformation of a piezoceramic body when a voltage is applied

Electromechanical Interactions

The following is a brief qualitative description of the most important dielectric, electromechanical and piezoelectric relationships, including parameter definitions. For detailed mathematical formulas, solid state physics relationships, methods of parameter determination, etc., please consult the appropriate specialist literature (see recommendations on page 38).

Basic electromechanical equations

The following relationships apply only to small electrical and mechanical amplitudes, i.e. small-signal values

Only in this region is it possible for polarized piezoelectric ceramics to be described by linear rela-tionships between the mechanical strain (S) or mechanical stress (T) components and the com-ponents of the electric field E or the dielectric displacement D. These linear relationships are derived using dielectric, piezoelectric and elasticity “constants”. Because they depend on the anisotropy of the piezoelectric material, these physical quantities can only be defined in terms of tensors which reflect the directionality of the electric field, the mechanical stresses, etc.

In simplified form, the basic relationships between the electrical and elastic properties (for a static or quasistatic application) can be repre-sented as follows

$$D = d \cdot T + \varepsilon^{T} \cdot E$$

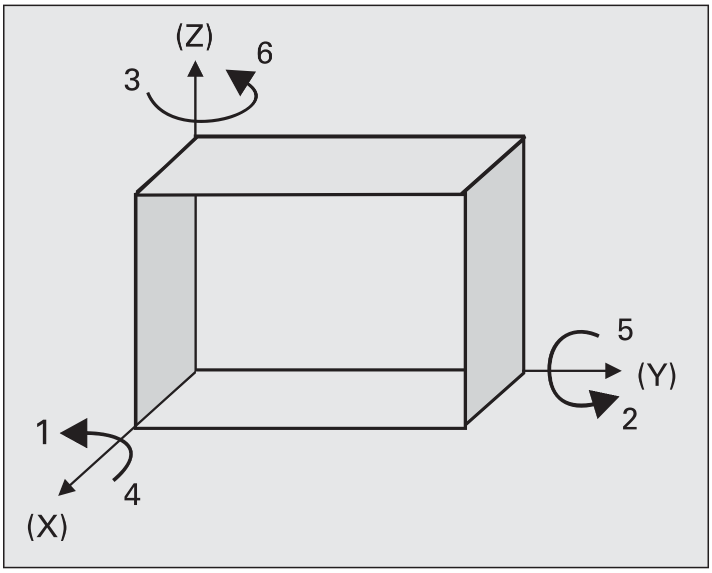
$$S = s^{E} \cdot T + d \cdot E$$

where:

D dielectric displacement
T mechanical stress
E electric field
S mechanical strain
d piezoelectric charge constant
ε^{T} permittivity (for T = constant)
s^{E} elasticity constant (E = constant)

The piezoelectric constants relating the electric field E, the dielectric displacement D, the mechanical stress T and the strain S require directionality indexing. Analogous to crystallographic descriptions for piezo-ferroelectric ceramics, the polarization vector is usually set parallel to the z or 3rd axis of a right-handed Cartesian coordinate system.

The directional parameters are given the subscripts 1,2 and 3 corresponding to the directions of x, y and z, respectively. Mechanical shear stresses (couples) about x, y and z, and the corresponding shear strains, are designated with the subscripts 4, 5 and 6, respectively.



Orthogonal system
to describe piezoelectric materials

Parameter Definitions

Permittivity ε

The **permittivity**, or relative dielectric constant, ε is a measure of the polarizability of the material.

The directionality of the permittivity is expressed by tensor components, whereby the same component indexes are used as for th electric field and dielectric displacement.

For example,

ε_{33}^T describes the permittivity value in the polarization direction (direction 3) when an electric field is applied also in the polarization direction, under conditions of constant mechanical stress (T = 0: "free" permittivity)

ε_{11}^S is the electric field and dielectric displacement in direction 1, perpendicularto to the polarization direction at constant deformation (S = 0: clamped permittivity)

Piezoelectric charge constant d_{ij}

The **piezoelectric charge or strain constant d** is a measure of the electric charge induced in response to a mechanical stress, or the achievable mechanical strain when an electric field is applied (T = constant).

For example,

d_{33} is the charge density developed per mechanical stress, or, alternatively, strain developed per unit of electric field strength, all in the polarization direction.

Piezoelectric voltage constant g_{ij}

The **piezoelectric voltage constant g** defines the ratio of the electric field strength E to the effective mechanical stress T. If one divides the respective piezoelectric charge constants d_{ij} by the corresponding permittivity value one gets the corresponding g_{ij} constant.

For example,

g_{31} describes the electric field induced in direction 3 by a mechanical stress acting in direction 1.

Elastic constant s_{ij}

The **elastic constant or compliance s_{ij}** is a measure of the ratio of the relative deformation S to the mechanical stress T. Because it depends on the interaction of mechanical and electrical energy, the electrical boundary conditions must be taken into consideration.

For example,

s_{33}^E describes the ratio of the mechanical strain in direction 3 to the mechanical stress in direction 3, with constant electric field (for E = 0: short circuit)

s_{55}^D is the ratio of a shear strain to the effective shear stress with constant dielectric displacement (for D = 0: open circuit)

Note:

Young's modulus Y, which is often used in the English-speaking world, is the reciprocal of the compliance constant.

Frequency constant N_i

The **frequency constant N** corresponds to half the speed of the sound wave propagating in the ceramic body (with the exception N_p, the planar oscillation). The indexes identify the corresponding direction of oscillation, for which the respective dimension A determines the (series) resonant frequency f_s: $N = f_s \cdot A$.

For example,

N_L describes the frequency constant for the longitudinal oscillation of a slim rod polarized in the longitudinal direction

N_1 is the frequency constant for the transverse oscillation of a slim rod polarized direction 3

N_p is the frequency constant of the surface (planar) oscillation of a round disk

N_t is the frequency constant of the thickness oscillation of a thin disk polarized in the thickness direction.

Mechanical quality factor Q_m

The **mechanical quality factor Q_m** characterizes the "sharpness of the resonance" of a piezoelectric body (resonator) and is primarily determined from the 3 dB bandwidth of the series resonance of the resonating system. The reciprocal value of the Q-factor is the ratio of resistance to reactance, the mechanical loss factor, tan δ.

Coupling factor k

The **coupling factor k** is a measure of the effectiveness of the piezoelectric effect (not the efficiency, as it is frequently incorrectly called!). It describes the ability of a piezoelectric material to transform electrical energy into mechanical energy and vice versa. Mathematically, the size of the coupling factor is determined by the square root of the ratio of stored mechanical energy to the total energy applied. At resonance, k is a function of the form of oscillation of the piezoelectric body.

For example,

k_{33} is the coupling factor for the longitudinal oscillation

k_{31} is the coupling factor for the transverse longitudinal oscillation

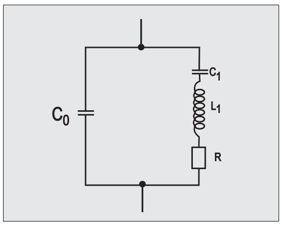
k_p is the coupling factor for the radial oscillation (planar) of a round disk

K_t is the coupling factor for the thickness oscillation of a plate

k_{15} is the coupling factor for the thickness shear oscillation of a plate

Dynamic behavior

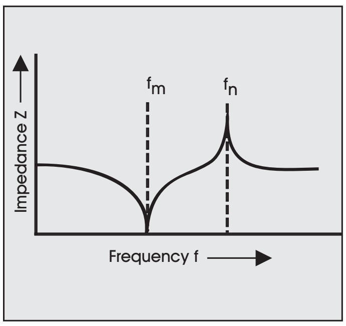
The electromechanical behavior of a piezoelectric body in oscillation can be represented by an electrical equivalent circuit.



Equivalent circuit
of a piezoelectric resonator

$C_0 + C_1$ is the capacitance of the dielectric. The series circuit, consisting of C, L, and R, models the change in the mechanical properties of elastic deformation, effective mass (inertia) and mechanical losses resulting from internal friction. This description of the oscillatory circuit can only be used for frequencies in the vicinity of the lowest natural resonant frequency, however.

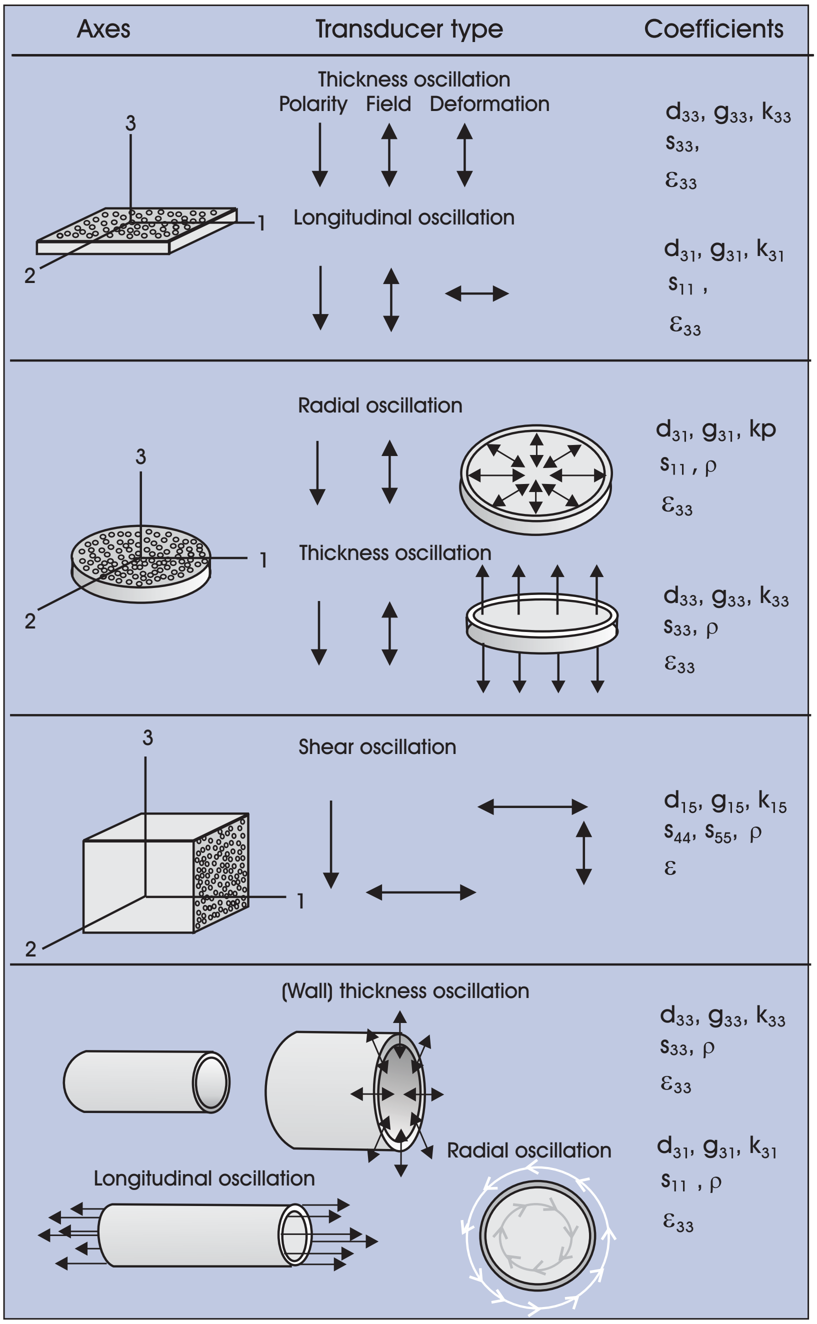
Most piezoelectric material parameters are determined by means of impedance measurements on special test bodies at resonance (see page 17, Comments to Table). The following diagram illustrates a typical impedance curve.



Typical impedance curve

Oscillation states or modes are determined by the geometry of the body, its mechanoelastic properties and the direction of polarization.

The most important oscillation states of common resonators are shown with the corresponding constants in the following illustration.



Oscillation modes
of piezoelectric components

Piezoceramic Materials

General Description

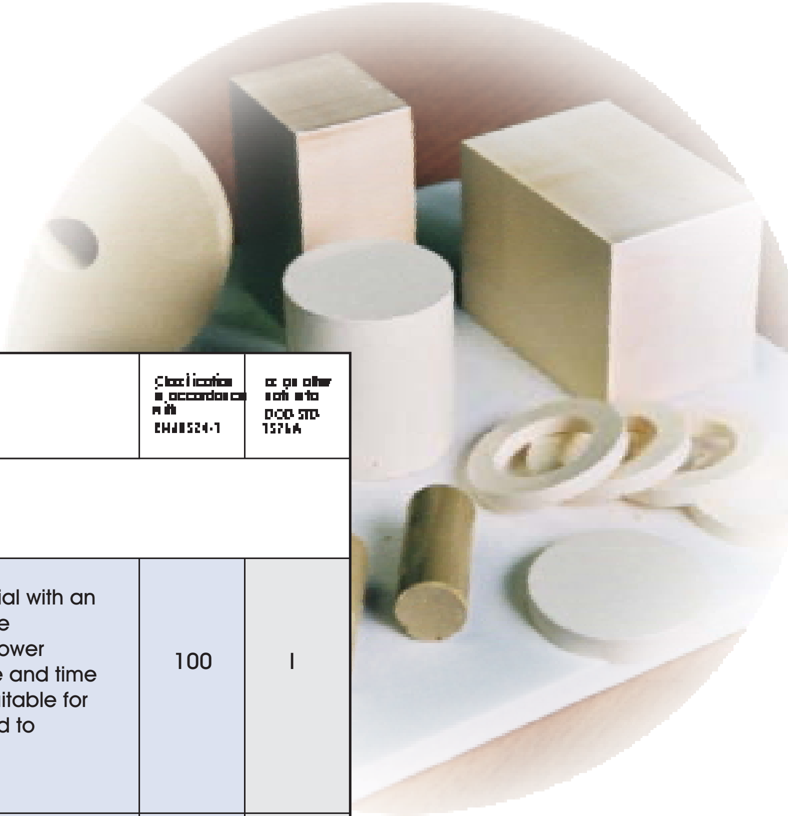
PI Ceramic offers a wide selection of piezoelectric ceramic materials based on modified lead zirconate titanate (PZT) and barium titanate, tailor-made for diverse applications. Apart from the standard types described in detail below, we can perform a multitude of application-specific and custom-engineered modifications. PIC materials compare favorably with the best materials internationally available today. The properties are specified according to the EN 50324 European Standard.

On an international basis, it is usual to divide piezo ceramics into two groups. The antonyms “soft” and “hard” PZT ceramics refer to the ferro-electric properties, i.e. the mobility of the dipoles or domains and hence also to the polarization / depolarization behavior.

“Soft” piezo ceramics are characterized by a comparitively high domain mobility and a resulting “ferroelectrically soft” behavior, i.e. relatively easy polarization.

In contrast, ferroelectrically “hard” PZT materials can be subjected to high electrical and mechanical stresses. The stability of their properties destines them for high-power applications.

Material designation	General description of the material properties	Classification in accordance with EN 50324-1	According to [illegible] DOD-STD-1376A
"Soft" PZT			
PIC 151	PIC 151 is a modified lead zirconate - lead titanate material with high permittivity, high coupling factor and high piezoelectric charge constant. This material is the standard material for actuators (PICA Series) and suitable for low-power ultrasonic transducers and low-frequency sound transducers.	600	II
PIC 255	PIC 255 is a modified PZT material with extremely high Curie temperature, high permittivity, high coupling factor and high charge constant. The material has been optimized for actuator applications under dynamic conditions and high ambient temperatures. The high coupling factor, low mechanical quality factor and low temperature coefficient make this material particularly suitable for low-power ultrasonic transducers, nonresonant broadband systems, and for force and acoustic pickups.	200	II
PIC 155	PIC 155 is a modification of the PIC 255 material distinguished by high piezoelectric stress coefficients and lower frequency constants. It is used in applications where a high g-constant is required, such as in microphones and vibration pickups with preamplifier.	200	II
PIC 153	PIC 153 is a modified lead zirconate - lead titanate material with extremely high permittivity and coupling factors, a high charge constant, and a Curie temperature of around 185 °C. This material is suitable for hydrophones, transducers in medical diagnostics and PZT translators.	600	VI
PIC 152	PIC 152 is a PZT material whose permittivity has an especially low temperature coefficient.	200	II



Material Designation	General description of the material properties	Classification in accordance with EN 50324-1	according to DOD-STD 1376A
	"Hard" PZT		
PIC 181	PIC 181 is a modified lead zirconate - lead titanate material with an extremely high mechanical quality factor and a high Curie temperature. This material is destined for the use in high-power acoustic applications. Furthermore, the good temperature and time stability of its dielectric and elasticity constants makes it suitable for resonance-mode ultrasonic applications and it has proved to be particularly successful in piezomotor drives.	100	I
PIC 141	PIC 141 is a modified PZT material with high a mechanical quality factor and a comparatively moderate permittivity. This material is designed for use in high-power acoustic applications and is also used for pharmaceutical atomizers.	100	I
PIC 241	PIC 241 PZT ceramic is distinguished by its high mechanical quality factor and comparatively high permittivity. Its fields of application lie in high-power ultrasonic devices and it is used for piezomotor drives.	100	I
PIC 300	PIC 300 is a modified lead zirconate - lead titanate material with a very high Curie temperature. It is suitable for applications at temperatures up to 250°C (300°C for short durations).	100	I
	Barium lead titanate		
PIC 110	PIC 110 is a modified barium titanate material with a Curie temperature of 150°C. Its low acoustic impedance makes this material especially suitable for sonar and hydrophonic applications.	400	IV

Material Data

Material type			PIC 151	PIC 255	PIC 155	PIC 153	PIC 152
Parameter							
Physical and dielectric properties							
Density	ρ	(g/cm³)	7.80	7.80	7.80	7.60	7.70
Curie temperature	Tc	(°C)	250	350	345	185	340
Permittivity, in the polarization direction	$\varepsilon_{33}^{T} / \varepsilon_0$		2400	1750	1450	4200	1350
Permittivity, perpendicular to the polarity	ε ε		1980	1650	1400		
Dielectric loss factor	tanδ		20	20	20	30	15
Electromechanical properties							
Coupling factors	k_p		0.62	0.62	0.62	0.62	0.48
	k_t		0.53	0.47	0.48		
	k_{31}		0.38	0.35	0.35		
	k_{33}		0.69	0.69	0.69		0.58
	k_{15}			0.66			
Piezoelectric charge constants	d_{31}	$(10^{12}$ C/N)	-210	-180	-165		
	d_{33}		500	400	360	600	300
	d_{15}			550			
Piezoelectric voltage constants	g_{31}	$(10^{3}$ Vm/N)	-11.5	-11.3	-12.9		
	g_{33}		22	25	27	16	25
Acousto-mechanical properties							
Frequency constants	N_p	(Hzm)	1950	2000	1960	1960	2250
	N_1		1500	1420	1500		
	N_3		1750		1780		
	N_t		1950	2000	1990	1960	1920
Elastic constants (compliance)	S_{11}^{E}	$(10^{-12}$ m²/N)	15.0	16.1	15.6		
	S_{33}^{E}		19.0	20.7	19.7		
Elastic constants (stiffness)	C_{33}^{D}	$(10^{10}$ N/m²)	10.0		11.1		
Mechanical quality factor	Qm		100	80	80	50	100
Temperature stability							
Temperature coefficient of ε_{33} (in the range -20°C up to +125°C)	TK ε_{33}	$(\times 10^{-3}$/K)	6	4	6	5	2
Aging stability (relative change of the parameter per decade in %)							
Relative dielectric constant	C	(%)		-1.0	-2.0		
Coupling factor	C_K			-1.0	-2.0		

Further information:

The following values are valid approximations for all PZT materials from PI Ceramic.

Specific heat capacity: HC = approx. 350 J / kg K

Specific thermal conductivity: TC = approx. 1.1 W / m K

Poisson's ratio: σ = approx. 0.34

Coefficient of thermal expansion: α_3 = approx. -4 to -6 x 10^{-6} / K (in the polarization direction, shorted)

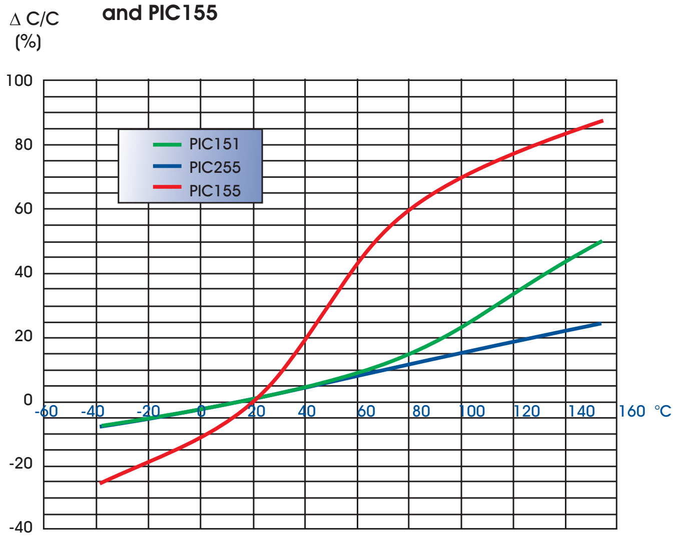
α_1 = approx. 4 to 8 x 10^{-6} / K ($\perp$ to the polarization direction, shorted)

Static compressive strength: larger than 600 Mpa

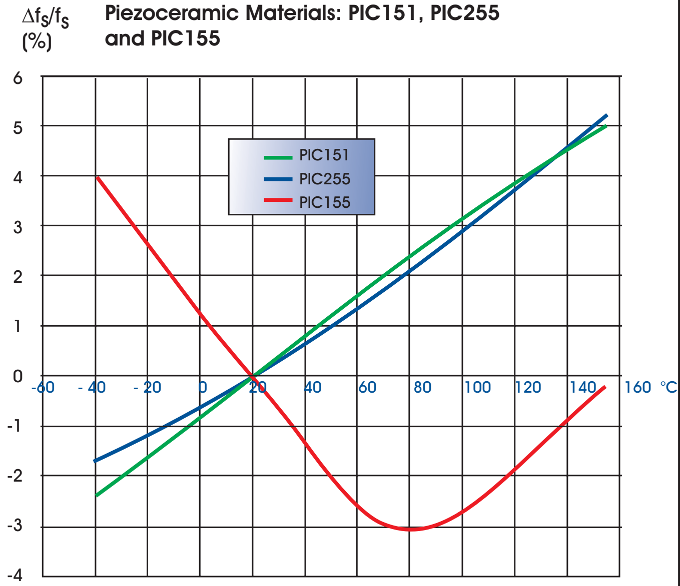
PIC 181	PIC 141	PIC 241	PIC 300	PIC 110
7.80	7.80	7.80	7.80	5.50
330	295	270	370	150
1200	1250	1650	1050	950
1500	1500	1550	950	
3	5	5	3	15
0.56	0.55	0.50	0.48	0.30
0.46	0.48	0.46	0.43	0.42
0.32	0.31	0.32	0.25	0.18
0.66	0.66	0.64	0.46	
0.63	0.67	0.63	0.32	
-120	-140	-130	-80	-50
265	310	290	155	120
475	475	265	155	
-11.2	-13.1	-9.8	-9.5	
25	29	21	16	-11.9
2270	2250	2190	2350	3150
1640	1610	1590	1700	2300
2010	1925	1550	1700	2500
2110	2060	2140	2100	
11.8	12.4	12.6	11.1	
14.2	13.0	14.3	11.8	
16.6	15.8	13.8	16.4	
2000	1500	1200	1400	250
3	5		2	
	-4.0			-5.0
	-2.0			-8.0

1. The data in the following tables was determined using test bodies with geometries and dimensions in accordance with European Standard EN 50324 2, and are typical values.
2. The data given represents nominal values which were determined on these test bodies 24 h - 48 h after polarization and at an ambient temperature of 23 ± 2 °C.
3. Conformance to these typical values is documented by constant testing of the individual material batches before they are released.
4. The properties of the products are determined in relation to the geometry, variations of the manufacturing process and measurement or control conditions.
5. Questions regarding interpretation of the material properties of a product are best clarified with PI Ceramic's specialists.
6. A complete coefficient matrix of the materials is available on request.

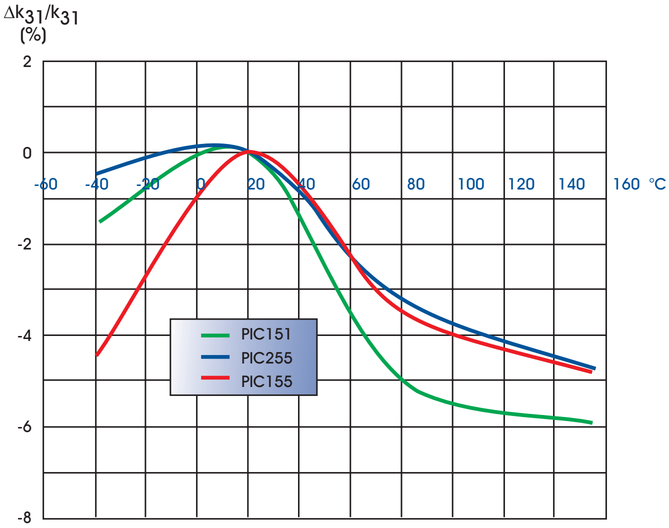
Temperature dependence of capacitance C
Piezoceramic Materials: PIC151, PIC255 and PIC155



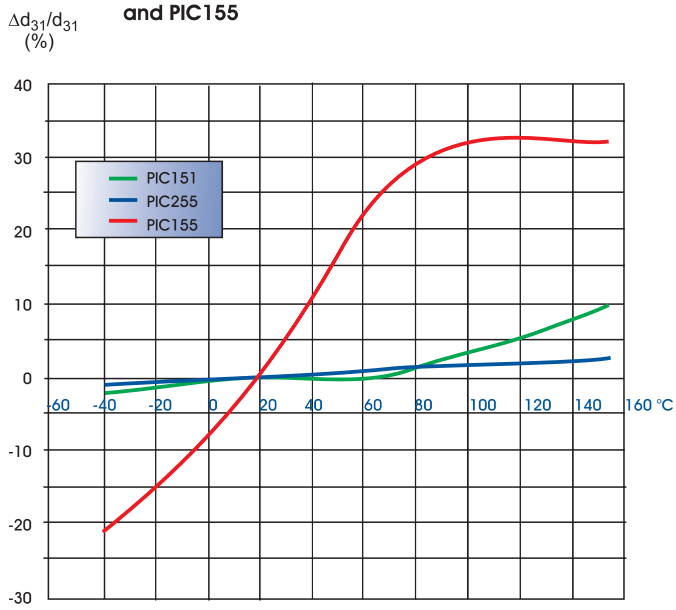
Temperature dependence of resonant frequency for the longitudinal oscillation f_s
Piezoceramic Materials: PIC151, PIC255 and PIC155



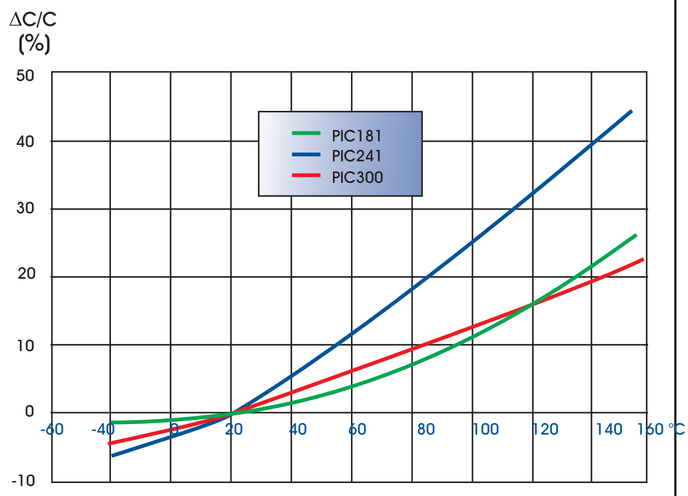
Temperature dependence of transverse oscillation coupling factor k_{31}:
Piezoceramic Materials: PIC151, PIC255 and PIC155



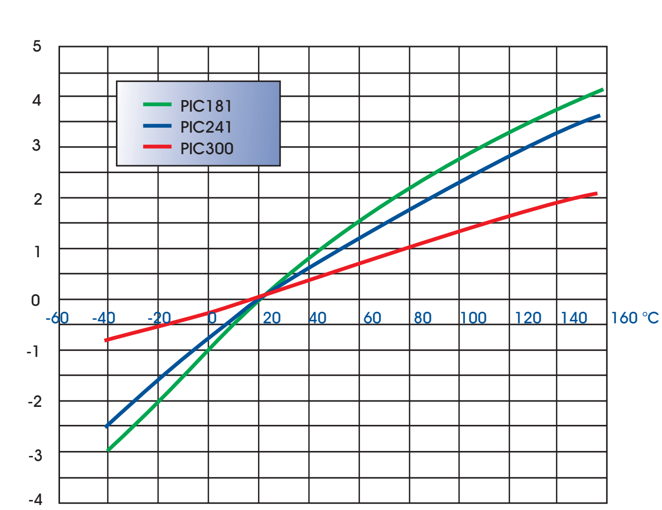
Temperature dependence of the piezoelectric charge constant d_{31}:
Piezoceramic Materials: PIC151, PIC255 and PIC155



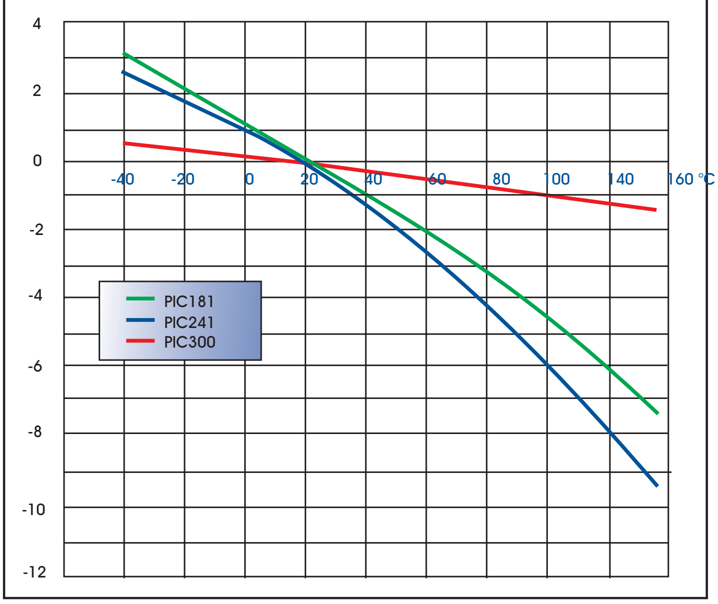
Temperature dependence of capacitance C
Piezoceramic Materials: PIC181, PIC241
and PIC300



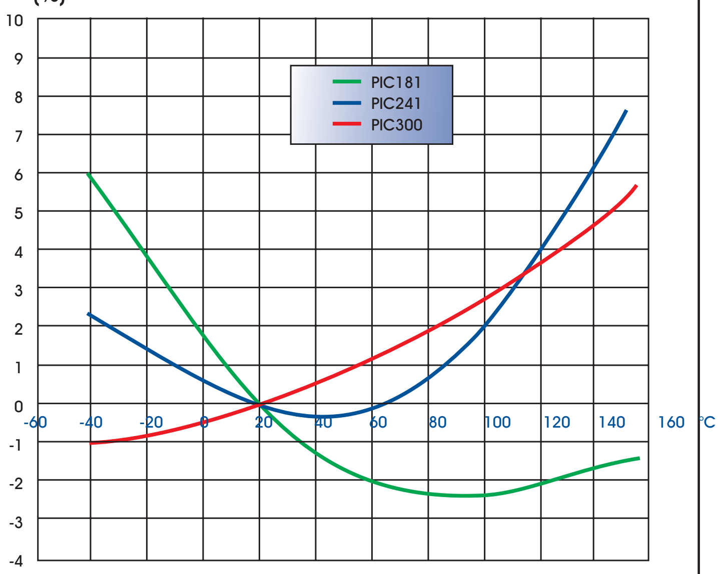
Temperature dependence of resonant frequency
for the longitudinal oscillation f_s
Piezoceramic Materials: PIC181, PIC241
and PIC300



Temperature dependence of transverse
oscillation coupling factor k_{31}:
Piezoceramic Materials PIC181, PIC241
and PIC300



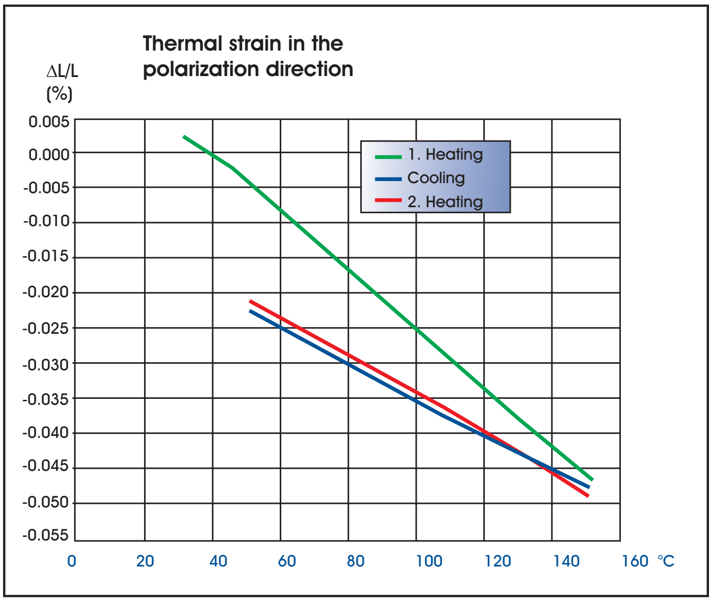
Temperature dependence of the piezoelectric
charge constant d_{31}:
Piezoceramic Materials PIC181, PIC241
and PIC300



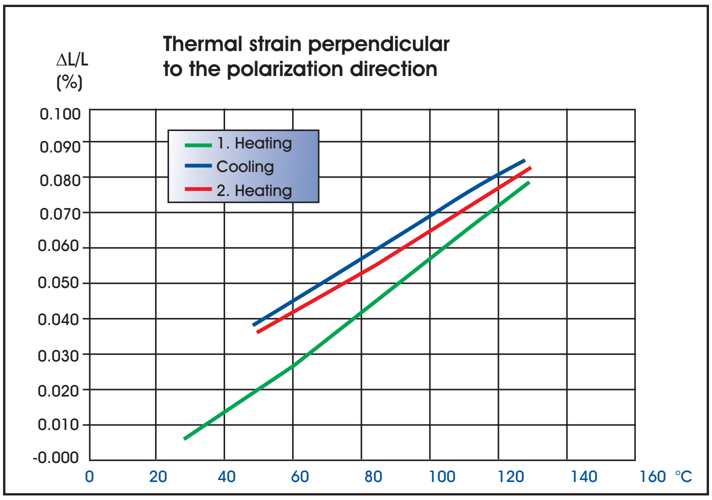
Specific Characteristics

Thermal expansion example with PZT ceramic PIC 255

- The thermal strain exhibits different behavior in the polarization direction and perpendicular to it.
- The preferred orientation of the domains in a polarized PZT body leads to an anisotropy. This is the cause of the varying thermal expansion behavior.
- Non-polarized piezo ceramic is isotropic. The coefficient of expansion is approximately linear with a CTE of approx. 2×10^{-6} / K.
- The effect of successive temperature changes must be given particular consideration in the application. Large changes in the curve can occur especially in the first temperature cycle.
- Depending on the material, it is possible that the curves deviate substantially from those illustrated.



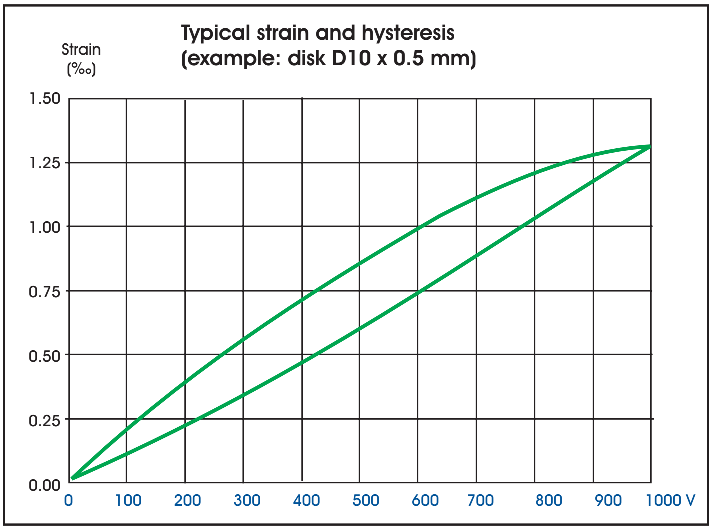
Thermal strain in the polarization direction



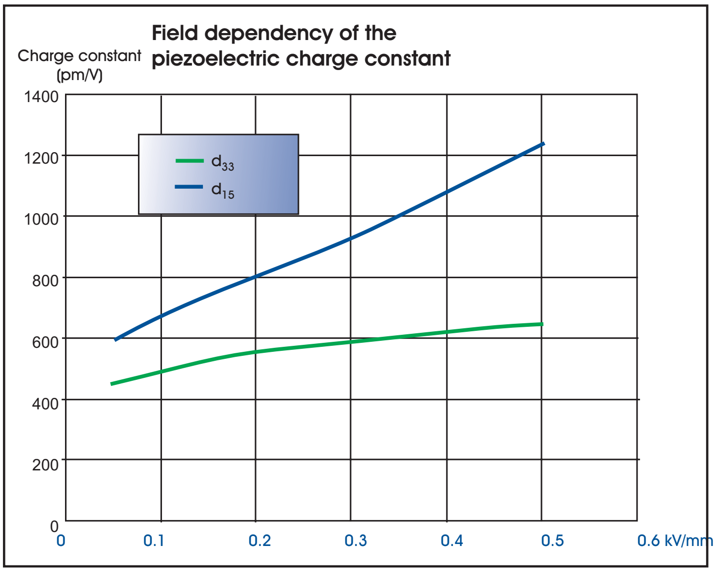
Thermal strain perpendicular to the polarization direction

Deformation behavior example with PZT ceramic PIC 255

- In the case of large-signal fields (max. 2 kV/mm), the strain of a piezoceramic is associated with reversible and irreversible domain reorientation processes.
- The domain reorientations cause larger deformations in the ceramic elements than can be calculated from the piezo coefficients given in the table (small-signal values).
- The irreversible domain reorientations lead to hysteresis in the strain behavior.



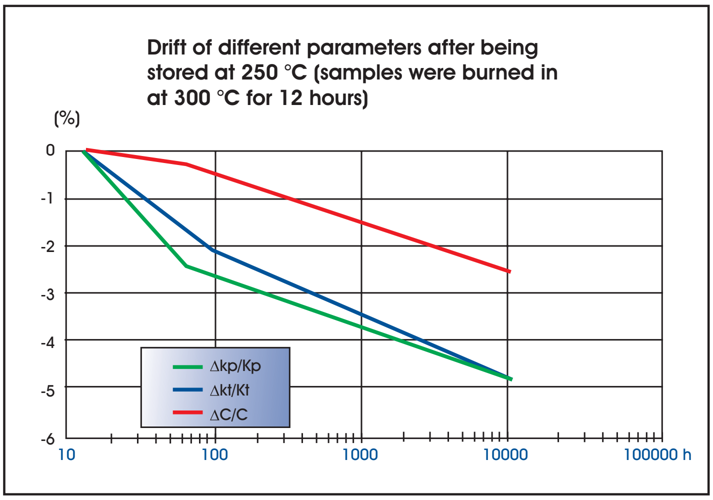
Typical strain and hysteresis (example: disk D10 x 0.5 mm)



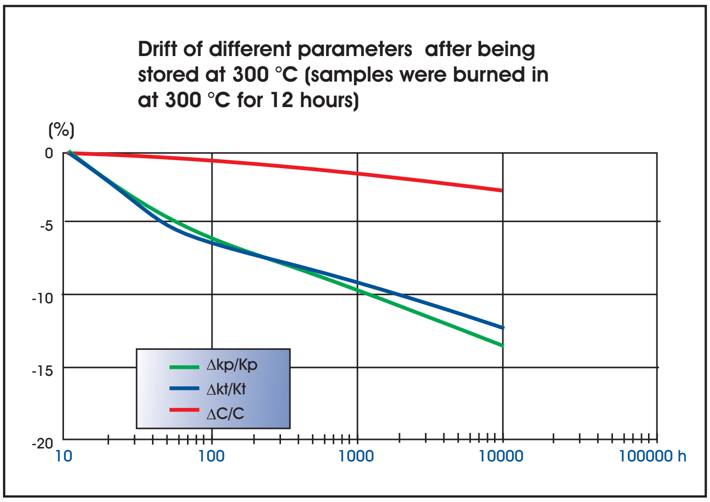
Field dependency of the piezoelectric charge constant

Parameter stability at high temperatures: example with PIC300

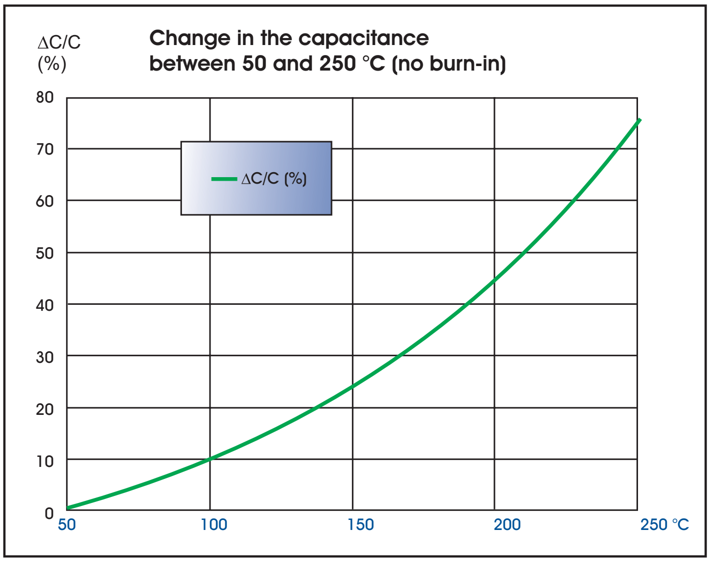
- PIC300 is suitable for use at temperatures up to 250 °C (for short durations, to 300 °C).
- The drift of the measured value for the coupling factor and the capacitance can be significantly reduced by burn-in of over 12 h at 300 °C.
- The expected percentage changes are shown in diagrams A and B.
- PIC300 capacitance exhibits a low temperature dependency in the temperature range up to 250 °C (Diagram C).



A

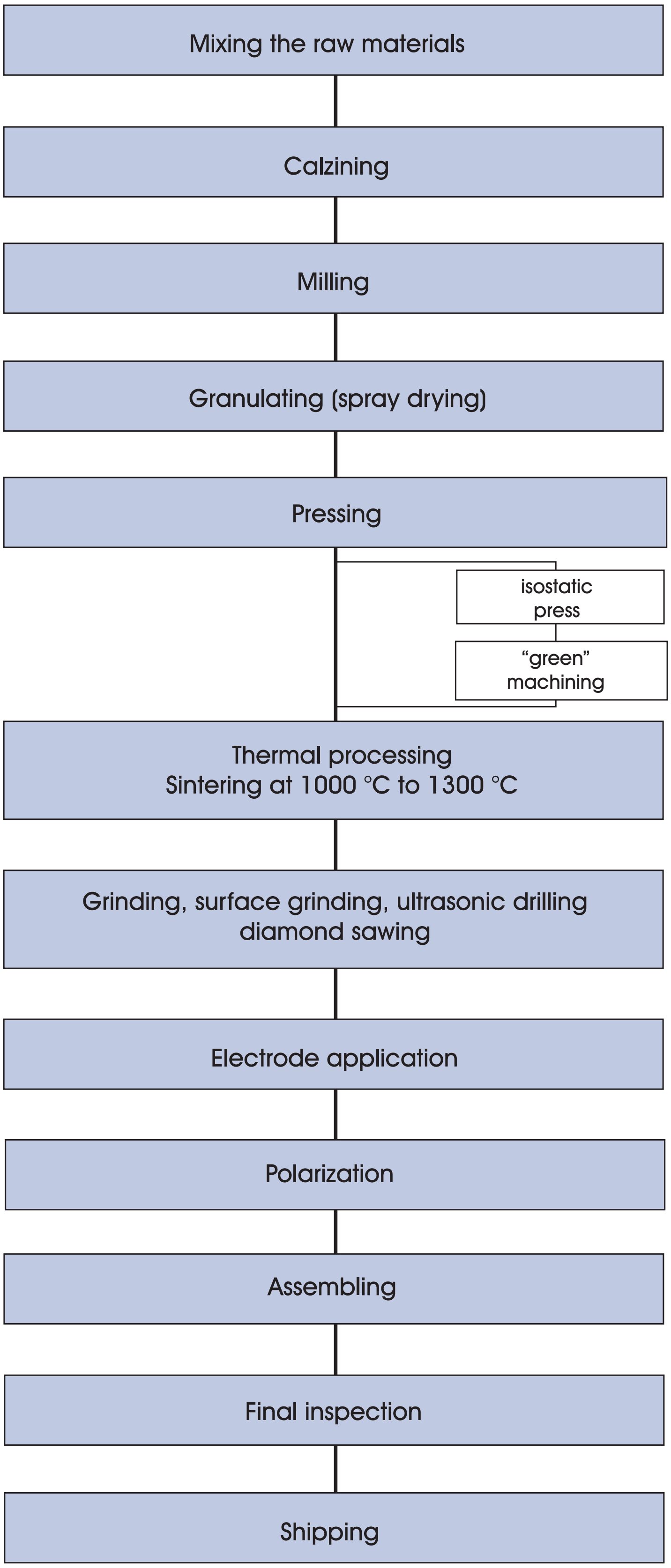


B



C

Manufacturing Technology

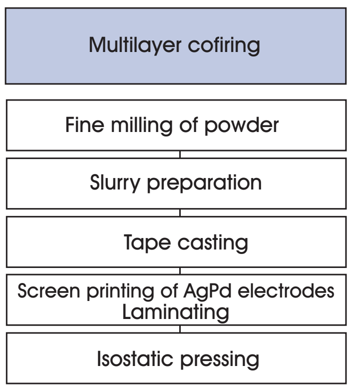


PI Ceramic employs a large number of modern production techniques which make it possible to fulfill custom-engineered requirements for medium-sized and small production runs in very short times, as well as to manage the transition to large production runs reliably and inexpensively.

Ceramic shaping processes

The basic technology for the manufactoring of piezoceramic components is the pressing of shaped bodies using spray-dried granular material. This is achieved using high-capacity presses with up to 1 MN compacting force. The shaped bodies are either manufactured true-to-size, taking into account the sintering contraction, or with machining excesses which are removed to achieve the required precision. By using high-production inboard diamond sawing equipment, it is possible to manufacture reasonably priced components (disks, plates, etc.) with a thickness as low as 0.2 mm. Modern ultrasonic machining techniques are used to manufacture thin-walled tubes with wall thicknesses of 0.5 mm as standard products.

Cofiring technology is available, in particular for the production of multilayer components (PICMA series). In it, after the application of noble metal electrodes by means of special screen printing techniques and subsequent lamination, a ceramic film of at least 25 µm - made in a pro-cess known as tape casting - is applied and sintered in a one-step process.



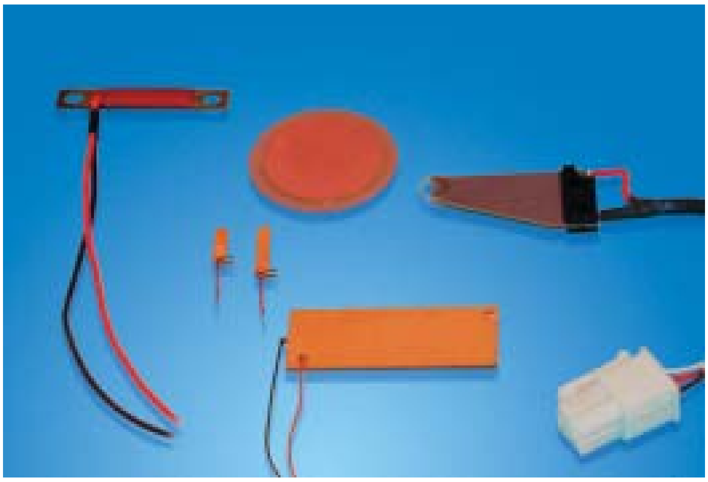
Jointing and assembling technology at PI Ceramic

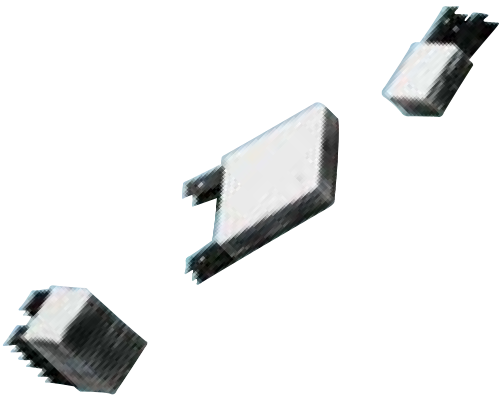
PI Ceramic has comprehensive know-how and many years of experience in the manufacture of piezoceramic components and subsystems.

Soldering processes at PI Ceramic:
Ready-made piezo components with connecting wires are manufactured by trained staff using hand-soldering processes. We have modern automatic soldering devices at our disposal to solder to miniaturized components. Soldered joints which are required to be extremely reliable undergo special visual inspections. This is done by using optical methods ranging from stereo microscopes to camera inspection systems, depending on the specific requirements.

Mounting and assembling technology at PI Ceramic:
The jointing of components, e. g. with adhesive, is carried out in batch production using automated equipment which executes the necessary jointing procedure (e. g. curing of epoxy adhesives) and hence guarantees uniform quality. The choice of adhesive and the curing regime are optimized for each product, taking into consideration the properties of the materials being joined and the intended operational conditions. Dosing and positioning devices which have been designed in-house are used for complicated special orders.

Our own piezoceramic stack actuators (PICA series), high-voltage bender actuators and high-power acoustic components, all of which are manufactured using jointing processes, have proved themselves repeatedly in the semiconductor industry and in medicine, thanks to their high reliability.





Piezoceramic Components

Dimensions

Geometric manufacturing limits

The **maximum dimensions** of bulk ceramic components are determined by the equipment and instruments available.

Max. diameter	**OD 80 mm**
Max. length / height	**L 70 mm**
Max. thickness (polarization)	**H 20 mm**

The **minimum dimensions** are determined by the physical and processing limits, e. g. the minimum thickness is determined by the mechanical strength of the ceramic during machining.

Min. diameter	**OD 1.50 mm**
Min. thickness	**TH 0.15 mm**

The geometric manufacturing limits are shown in the following tables for different combinations of dimensions:

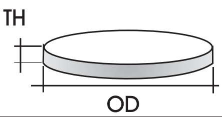


	Plate / Rod	
	TH (mm)	OD (mm)
max. thickness	30	10 to 80
	20	5 to 80
	10	2 to 5
min. thickness	0.15	2 to 20
	0.3	2 to 60
	0.5	2 to 80

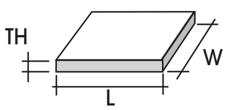
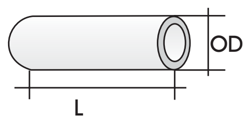


	Plate / Block		
	TH (mm)	L (mm)	W (mm)
max. thickness	40	1 to 80	1 to 20
	40	1 to 60	1 to 60
min. thickness	0.15	1 to 20	1 to 20
	0.3	1 to 80	1 to 30
	0.5	1 to 60	1 to 60



	Tube	
	OD (mm)	ID (mm)
max. diameter	< 78	< 70
min. diameter	> 2	> 0.8
length	1 to 70 mm	

Preferred Dimensions

Within the manufacturing limits, we recommend the use of components with preferred dimensions. These products can be delivered in very short time and with no special tooling costs, thanks to the standard semi-finished products, assembly devices, such as sputter masks, screen printing tools, adhesive molds etc., which we have on hand.

Preferred dimensions: disks by size

Thickness TH / mm	OD / mm									
	3	5	10	16	20	25	35	40	45	50
0.20										
0.25										
0.30										
0.40										
0.50										
0.75										
1.00										
2.00										
3.00										
4.00										
5.00										
10.00										
20.00										

Electrode system options:
fired silver (thick film)
or
thin film (CuNi, Au, etc.)

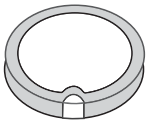
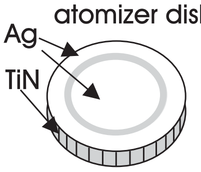
Preferred dimensions: disks by frequency (thickness oscillation)

Frequency in MHz	OD / mm									
	3	5	10	16	20	25	35	40	45	50
10.00										
5.00										
4.00										
3.00										
2.00										
1.00										
0.75										
0.50										
0.40										
0.25										
0.20										

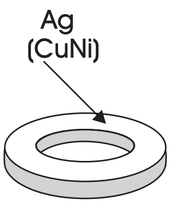
Electrode system options:
fired silver (thick film)
or
thin film (CuNi, Au, etc.)

Other geometries are available on request.

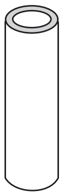
Preferred dimensions: disks with special electrodes

Design	Diameter OD / mm	Thickness TH / mm	Electrode system options
Wrapped electrode 	10	0.5 1.0 2.0	fired silver
	16		
	20		
	25		
	40		
Special design atomizer disk 	10	1 MHz	electrode layer = silver function layer = TiN
	16	2.5 MHz and 1.7 MHz	
	20		
	25		

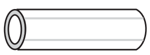
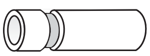
Preferred dimensions: rings

Design	Outside diameter OD / mm	Inside diameter ID / mm	Thickness TH / mm	Electrode system options
	3	0.85	0.5	CuNi / Ag
	10	2.7	0.5; 1.0; 2.0	fired silver or CuNi
	10*	4.3*		
	10*	5*		
	12.7	5.2*		
	25	16*		
	38	13*	5.0; 6.0	
	50	19.7*	5.0; 6.0; 9.5	
	* Tolerances as sintered, see table p. 29			

Preferred dimensions: tubes

Design	Outside diameter OD / mm	Inside diameter ID / mm	Length L / mm	Electrode system options
	76	60	50	Inner surface: fired silver Outer surface: fired silver or CuNi (thin film)
	40	38	40	
	20	18	30	
	10	9	30	
	10	8	30	
	6.35	5.35	30	
	3.2	2.2	30	
	2.2	1	20	

Preferred dimensions: tubes

Design	Outside diameter OD / mm	Inside diameter ID / mm	Length L / mm	Electrode system options
 	20	18	30	Inner surface: fired silver Outer surface: fired silver or CuNi (thin film)
	10	9	30	
	10	8	30	
	6.35	5.35	30	
	3.2	2.2	30	
	2.2	1	20	

Preferred dimensions: plates

(■ = preferred dimension, shaded in the original)

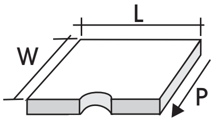
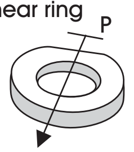
Thickness mm	4x4	5x5	10x10	15x15	20x20	25x20	25x25	50x30	50x50	70x25
	L x W / mm^2									
0.20	■	■	■	■	■					
0.25	■	■	■	■	■					
0.30	■	■	■	■	■	■	■			
0.40	■	■	■	■	■	■	■			
0.50	■	■	■	■	■	■	■	■	■	
0.75	■	■	■	■	■	■	■	■	■	■
1.00	■	■	■	■	■	■	■	■	■	■
2.00	■	■	■	■	■	■	■	■	■	■
3.00	■	■	■	■	■	■	■	■	■	■
4.00	■	■	■	■	■	■	■	■	■	■
5.00	■	■	■	■	■	■	■	■	■	■
10.00	■	■	■	■	■	■	■	■	■	■
20.00	■	■	■	■	■	■	■	■		

Electrode system options:

fired silver or thin film layer (CuNi or Au)

A combination of extreme values is not always possible!
The lateral dimensions are manufactured by using a diamond sawing procedure.

Preferred dimensions; rectangular shear plates and shear rings

Design	Width W / mm	Length L / mm	Thickness TH / mm	Eelectrode system options
Shear plate 	3 4 5 10 16	3 4 5 10 16 (20; 30; 40)	0.5 0.75 1.0	CuNi or gold (thin film)
Shear ring 	Outside diameter OD/mm	Inside diameter ID/mm	Thickness TH / mm	
	38	19	6	
	36	19	6	

Application Notes

Thick-film electrodes

Screen printing is a standard procedure for applying metallic electrodes to piezo ceramic. Various silver pastes are used in this process. After the screen printing, these pastes are baked at temperatures above 500 °C and adhesion of the electrodes is obtained by the burning on of the glass frit contained. The typical elec-trode thickness is around 10 µm. With thin ceramic plates, the effect of the glass frit must be taken into account. The nature of these thick-film electrodes generally leads to a reduction of the piezoelectric parameters.

Electrode adhesion is around 5 Mpa.

Thin-film electrodes

Thin-film electrodes are applied by the the latest sputtering techniques. The typical thickness of the metallization is in the range of 1 µm.

Shear elements, which are metallized in the polarized state, are always manufactured with thin-film electrodes.

PI Ceramic has high-productivity sputtering equipment which facilitates the application of electrodes made of metal alloys, preferably CuNi composites and noble metals such as gold. The achievable bond-strength values of the electrodes are similar to those of the thick-film electrodes.

Soldering instructions for users

Soldering is the usual way of making electrical contact with piezoceramic components. All of our standard metallizations are compatible with the use of lead-free solders. We recommend, for example, the use of a solder with the composition Sn 95.5% Ag 3.8% Cu 0.7%. All soldered contacts must be point contacts, and the specified soldering temperatures must be re-spected. The soldering time must be as brief as possible. Quick, punctual soldering at temperatures above the Curie temperature does not result in significant depolarization losses or degradation of the piezoelectric parameters.

Polarity labeling

The positive electrode is the one that is labelled (marked). This is done with a dot or a cross on the surface of the electrode or by a (reddish) coloring of the electrode itself.

Standard tolerances

Parameter	Symbol	Tolerance
Length / Width	L / W	< 15 mm: ± 0.15 mm < 20 mm: ± 0.20 mm < 40 mm: ± 0.25 mm < 80 mm: ± 0.30 mm
Diameter, outside	OD	< 15 mm: ± 0.15 mm < 20 mm: ± 0.20 mm < 40 mm: ± 0.25 mm < 80 mm: ± 0.30 mm
Diameter, inside	ID	
Thickness	TH	< 10 mm: ± 0.05 mm < 20 mm: ± 0.10 mm < 40 mm: ± 0.15 mm < 80 mm: ± 0.20 mm
Dimensions, (as fired): ± 0.3 mm or ± 3%		

Deviation from flatness	⏥	< 0.02 mm, small bending of thin disks or plates is not taken into account!
Deviation from the parallelism	//	< 0.02 mm
Deviation from the concentricity	◎	< 0.2 mm
Frequency tolerances		± 5% to 2 MHz ± 10% above 2 MHz
Capacitance tolerances		± 20%

Testing Procedures for PZT Components

Electrical testing

Small-signal measurements

The reference measuring instrument for the measure-ment of piezoelectric and dielectric small-signal data such as frequencies, impe-dances, coupling factors, capacitances and loss factors, is the Precision Impedance Analyzer 4194A from Agilent Technologies (formerly HP).

Large-signal measurements

DC measurements with voltages of up to 1200V are carried out in an automated test routine on actuators to determine the strain, hysteresis and dielectric strength. AC measurements in the high-power acoustic range are used to determine acoustic performance.

Geometric and visual testing processes

In general, calibrated measuring equipment of appropiate precision is used to verify the geometry of the components.

Modern 3D measuring microscopes are available for complicated measurements and visual inspections.

Visual limits

Ceramic components must be conform to visual specifi-cations and criteria.

In accordance with the specifications in MIL-STD-1376, PI Ceramic has created its own finish criteria for the purpose of evaluating quality and has defined a series of categories for the various application requirements. The finish criteria relate to:

- Surface finish of the electrodes
- Pores in the ceramic
- Chipping of the edges

Unless specified otherwise, it is held that visual peculiarities do not necessarily affect the functioning of the component. PI Ceramic's finish criteria incorporate this principle in the visual limit values. The volume of these specifications makes it impossible to include them in this catalog.

Quality monitoring, quality level

PI Ceramic works with quality management systems and is certified in accordance with ISO 9001-2000.

This certification assures our customers of the quality of our products and manufacturing procedures.

This certification assures our costumers of the quality of our products and manufacturing procedures. The quality of the raw materials, intermediate and end-products is monitored according to specific quality assurance plans. Quality management documentation assures that only approved parts, which conform to the quality specifications, pass the processing and delivery stage.

Quality level

We carry out all tests of the electrical, mechanical and visual properties in accordance with standardized sampling methods. The level of testing is in accordance with DIN ISO 2859 Part 1.
For custom products, we strive to reach mutual agreement on quality and testing stipulations. If the customer so requires, it can also be agreed that this includes providing copies of the respective release docu-ments, metrology reports or,
in special cases, individual test reports on samples or entire batches.

Applications of PZT Components

With the development and improvement of the lead-zirconate - lead titanate ceramic materials (PZT) and components based on them, the number of applications grew very rapidly and continues to do so to this day.

A comprehensive description of all applications is practically impossible. The following is intended only to outline the characteristic features of typical applications and to illustrate them with selected PI Ceramic OEM product lines.

When selecting the best possible solution for an application of our piezo components and assemblies in new projects, it is important that there be early contact between your development and engineering departments and PI Ceramic. We have years of experience in the conception, development, design and manufacture of custom solutions and can accompany you from the idea to the implementation of the finished system.

Applications by Piezo Effect

Piezoelectric ceramic components are electro-mechanical transducers. As already explained in the previous sections of this catalog, they are able to:

Convert mechanical forces from pressure, strain or acceleration into an electrical potential **(direct piezo effect)**

and

Convert an electrical potential into mechanical motion **(inverse piezo effect)**

These effects open up a wide range of applications in all areas of engineering.

Use is made both of converting electrical voltages into mechanical motion (piezoelectric actuators) or vibrations (sonic and ultrasonic transmitters), and of the conversion of mechanical forces and accelerations (sensors) or acoustic signals (sonic and ultrasonic receivers) into electrical signals. The ultrasonic signal processing, whether using the direct or inverse piezo effect, is based on the evaluation of propagation times, reflection and phase shift, etc. of ultrasonic waves. Operation is possible in a wide frequency range (a few Hz to a few MHz).

Use of the direct piezo effect	**Use of the inverse piezo effect**
Mechano-electrical	Electro-mechanical
- Accelerometers - Igniters - Piezo keyboards - Generators (stand-alone energy sources) - Passive damping - etc.	Actuators, e. g. translators, bender elements, piezo motors, for: - Micro- and nanopositioning - Laser tuning - Active vibration damping - Micropumps - Pneumatic valves - etc.
Acousto-electrical	Electro-acoustical
- Acoustic and ultrasonic receivers - Noise analysis - Acoustic emission spectroscopy - etc.	- Signal generator (buzzer) - High-voltage sources / transformers - Delay lines - High-powered ultrasonic generators (cleaning, welding, aerosol production) - etc.

Use of both effects
- Level measurement - Flow-rate measurement - Object recognition - Medical diagnostics - High-resolution materials testing - Sonar and echo sounders - Adaptive structures - etc.

Applications by type of ceramic material

As already explained in the “Piezoceramic Materials” section, a distinction is made between “soft“ and “hard“ PZT ceramics. The differences in the parameters manifest themselves in the respective applications.

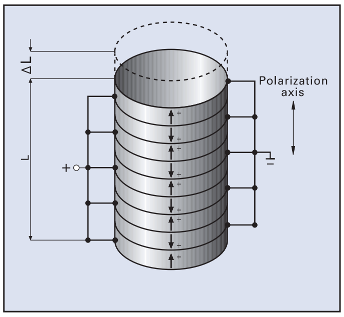
The most important fields of application of the “soft“ piezoelectric ceramics are actuators for micro- and nanopositioning, sensors and electro-acoustic applications (sound transmitters and receivers). Advantages of the “soft“ PZT materials lie in the high piezo modulus, moderately high permittivity and high coupling coefficients.

Piezoceramic actuators make use of the deformation of the piezoelectric material when an electric field is applied. The high resolution of the change in length and large mechanical load capacity of piezoelectric ceramic are of particular interest in high-tech fields (semi-conductors, optics and telecommunications, etc.), and also, to an increasing extent, in the automotive field (fuel injection systems), for micropumps, pneumatic valve technology and vibration damping.

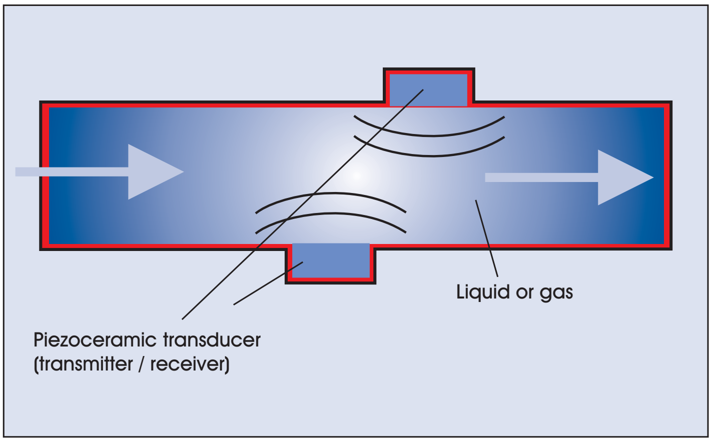
Sensors represent another broad area of piezoelectric applications. Apart from classical vibration recorders to detect imbalances of rotating machine parts or in crash detectors in the automotive industry, they are being used more and more in ultrasonic level measurement and flow rate measurement appli-cations. There, for example, the propagation time of the reflec-ted echo of an ultrasonic wave is evaluated. Flow rate measurements are based on propagation time measure-ments or on the Doppler effect (measurement of phase difference). Further typical applications of “soft“ piezo ceramics are to be found in object identification and surveillance (e. g. surveillance sensors for cars, glass tampering detectors, etc.), sound transmitters (buzzers) and sound receivers (microphones), to their use in the sound pickups of musical instruments.

The most important appli-cations of the “hard“ piezo ceramic materials are for the generation of high-powered ultrasonic waves. The advan-tages of these PZT materials are their moderate permittivity, piezoelectric high coupling factors, high Q-factors and very good stability under high mechanical loads and operating field strengths. Low dielectric losses facilitate their continuous use in resonance mode with only low intrinsic warming of the component.

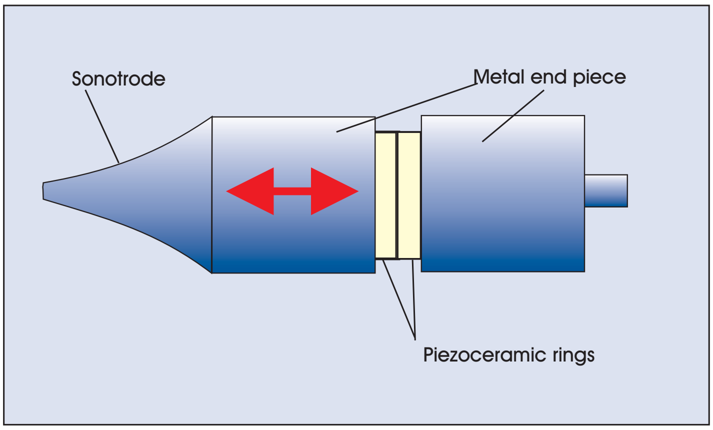
Practical examples of their applications can be found in the fields of ultrasonic cleaning (typically kHz range), the machining of materials (ultrasonic welding, bonding, drilling etc.), ultrasonic pro-cessing (e. g. liquid dispersion), in the medical field (ultrasonic dental scale removal, surgical instruments, etc.) and also in sonar technology. And many cannot imagine everyday life without the familiar piezo igniters!



Piezoelectric stack actuator



Principle of flow-rate measurement



Design principle of a composite transducer

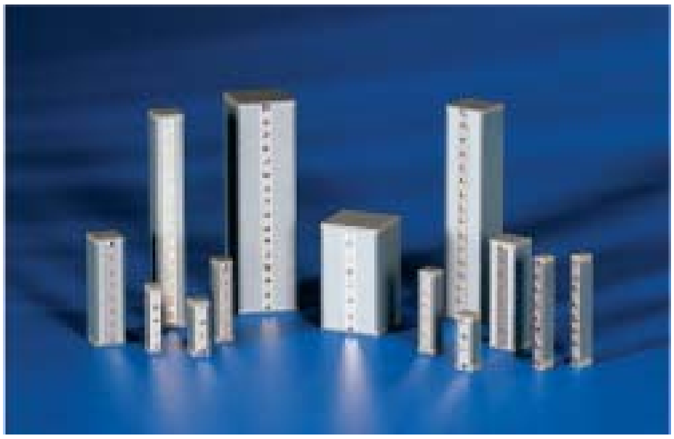
OEM Applications

Piezoceramic actuators

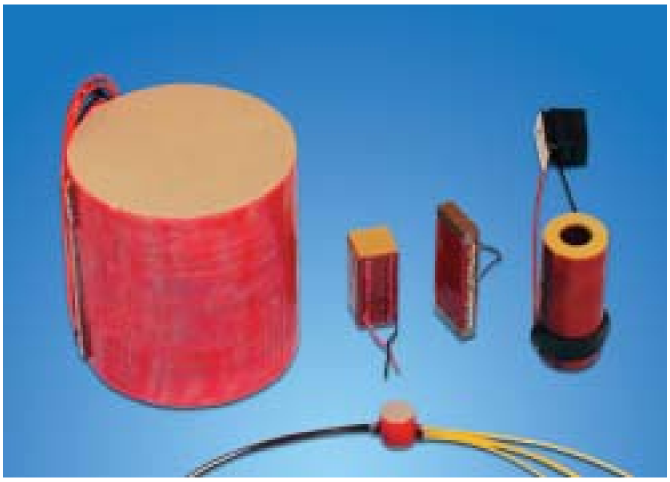
Piezoceramic actuators use the effect of the relative change in length (up to approx. 1.5 ‰) when an electric field is applied. They are characterized in particular by high mechanical load capacities (up to 100 MPa), extremely low power dissipation or very low energy loss (zero current when not moving), short response times (in the submillisecond range), extremely high motion resolution (in the subnano-meter range) and high reliability (more than 10^{11} switching cycles).

These elements are therefore destined for use in high-tech fields (semi-conductors, optics, telecommunications, etc.), and also, to an increasing extent, in the automotive field (fuel injection systems), for micro-pumps, pneumatic valve technology and vibration damping.

(See also the specialized catalog, "Piezo Ceramic Actuators & Custom Subassemblies", PI Ceramic, 2003)



Assortment of multilayer actuators (PICMA series)



Assortment of piezoceramic stack actuators (high-voltage versions)

Piezoelectric micropumps

There are currently two basic design types for micropumps and dosing systems. They are the drop-on-demand design, which is also familiar from ink-jet printers, and the piezoelectric diaphragm pump, which is gaining ground.

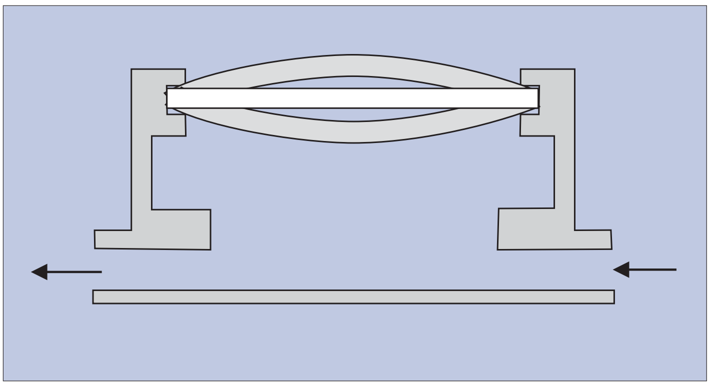
Piezoelectric microdispensers (as found in the drop-on-demand system) consist of a capillary drawn out to a nozzle with defined diameter. The capillary is surrounded by a piezoceramic tube actuator which contracts when voltage is applied.

This creates a pressure wave in the column of liquid which propagates to the end of the capillary. The pressure energy is transformed into kinetic energy. Individual drops are generated and accelerated to a velocity of a few meters per second so that, when delivered in an arbitrary direction, they can travel over a path of a few centimeters. The volume of the drops emitted (picoliters) is a function of the properties of the medium to be transported, the dimensions of the capillary and the drive parameters of the PZT actuator.

A microdiaphragm pump comprises a valve unit and the pump diaphragm, which, together with the piezoelectric actuator, forms the pump drive. Operation is based on the deformation of a piezo element (disk, plate, etc.) connected to the diaphragm. Applying a voltage deforms the diaphragm (bending effect).

The bending of the diaphragm (metal or silicon) brings about a change in volume of the pump chamber and the medium is transported under the control of the inlet and outlet valves.

The fields of application for piezoelectric pumps are in medical engineering, biotechnology, chemical analysis and process engineering, where reliable dosing of minute amounts of liquids and gases is frequently required. In the automotive industry, fuel injection systems driven by multilayer stack actuators are also piezoelectric micropumps!



Sketch of a membrane pump

Active vibration damping

The damping of undesired vibrations in mechanical structures by means of piezoelectric components can be carried out either actively or passively. These methods are characterized as follows:

Active vibration damping

- External power source and control electronics required
- Application of countermovements in the control loop

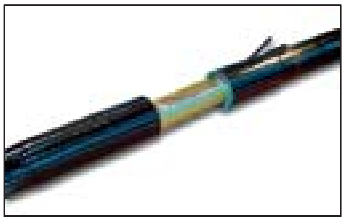
Passive vibration damping

- Energy conversion in the material itself
- The electrical energy generated by the structural vibrations (mechanical energy) in the piezo elements is converted into heat for example, by means of resistors

In active vibration damping a structure exhibiting undesirable, weakly damped natural resonances is equipped with special actuators and sensors connected in a servoloop. The controller is set up so that in the vicinity of the intrinsic frequencies, the actuator behaves like a high-viscosity damper.

If one integrates piezoelectric elements (also termed adaptive materials), e. g. actuators, in the form of piezoceramic plates or disks, into a structure, it can then be equipped with sensor and actuator functions. With suitable control algorithms, it can then adapt itself to the desired conditions.

The principle consists in exciting vibrations in the piezo actuator by means of an electronic amplifier. Because the piezo is closely coupled with the mass of the assembly to be damped, if the force from the vibration introduced is opposite in phase from the unwanted vibrations, they can be neutralized or minimized. Piezoelectric actuators, including multilayered elements (e. g. PICMA multilayer actuators), can be used anywhere where precisely dosed periodic counterforces are needed in structures.



PICA series actuator, embedded in a CFK structure

The applications are currently mainly in the fields of aerospace (e. g. for saving fuel; vibration damping of lattice structures for antennas, etc.), vehicle manufacture (e. g. noise minimization), and also increasingly in mechanical engineering (rotating drives), etc.

Ultrasonic level measurement

There are two fundamental level measurement techniques. On the one hand, there are the tuning-fork sensors or submersible transducers. These are used almost exclusively as level switches. The principle is that a resonator running freely at its natural resonant frequency is detuned when it comes into contact with the medium being measured. The advantage of this solution lies in its robustness and a certain independence from the type of medium.

The most widespread other method uses measurement of the propagation time of an emitted ultrasonic pulse which is reflected by the filling material. This means that non-contact in-situ measurements are possible. With this solution, a piezo transducer operates as both transmitter and receiver. The resolution and accuracy of the level measurement is a function of the wavelength used, in conjunction with the reflexion properties of the surface of the medium.

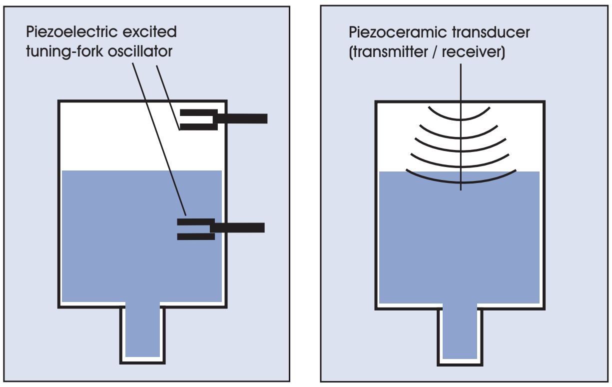
Ultrasonic flow rate measurement

The measurement of the propagation time and the Doppler effect are the two fundamental measurement techniques used in ultrasonic flow rate measurement. The piezo transducers used in each generate ultrasonic waves which are introduced into the liquid at an angle to the direction of flow.

The measurement of the propagation time, also called the traveling principle, is based on transmitting and receiving ultrasonic pulses on alternating sides, i.e. in the direction of flow and against it. Here, two piezo transducers operating as both transmitter and receiver are arranged diagonally to the direction of flow in an acoustic cell. Emission of the wave burst in the flowing medium (liquid or gaseous) causes a superposition of sound propagation speed and flow speed.

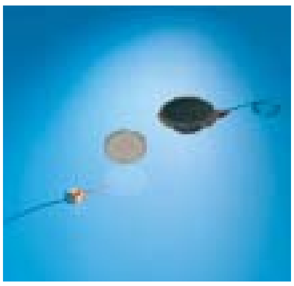
The flow speed is proportional to the reciprocal of the difference in the propagation times in the direction of the flow and in the opposite direction.

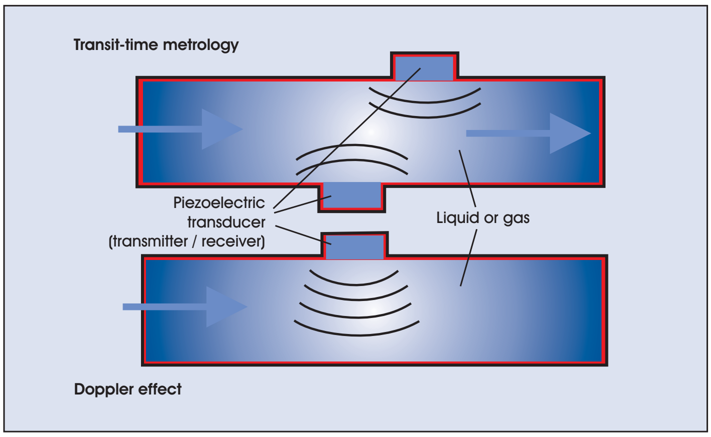
With the Doppler principle, the phase and frequency shift of the ultrasonic waves which are scattered and reflected by particles of liquid are evaluated. The frequency shift between the wavefront emitted and received by the same piezo transducer is a measure of the flow speed ($v \sim \Delta f$).



Working principles of ultrasonic level measurement

OEM products





Ultrasonic flowmeters, working principles

Sonar technology and hydroacoustics

Sonar technology systems and hydroacoustics are used for measuring and locating tasks, especially in the maritime field. For many years, the develop-ment of high-resolution sonar systems was motivated mainly by military requirements (see also, "Historical Review") but now it is being increasingly extended by civil applications, including recreational ones.

Apart from classical submarine-locating systems sonar is used, for example, for finding schools of fish, for subsurface relief surveying in shallow waters, underwater communication, etc.

A diverse range of piezo components is used, ranging from the simple disk, plate and stacked transducers through to sonar arrays which permit linear deflec-tion of the directivity pattern of the ultrasonic wave.

OEM products for hydroacoustics

Ultrasonic applications in medicine

The inverse piezo effect, i.e. the conversion of electrical energy into mechanical vibrations, is used for various applications in the life sciences. In addition to the familiar systems of medical diagnostics, dental scale removal, scalpels in eye surgery and also the production of aerosols, systems based on ultrasound are gaining in importance in the detection of air bubbles.

Aerosol production

Ultrasound makes it possible to atomize liquids without increasing the pressure or the temperature, a fact which is of crucial importance particularly for sensitive substances such as drugs.

Two processes are used at present. As it is the case with high-frequency ultrasonic cleaning (MHz range), a piezoceramic disk is fixed to the bottom of a liquid container and is vibrating at resonance. It generates high-intensity ultrasonic waves in the medium to be nebulized. The capillary waves which form on the surface of the liquid make it possible for minute droplets to "break off".

With direct nebulization, the piezo element vibrating at high frequency (1 to 3 MHz) is in direct contact with the liquid. Special surface finishes are used for aggressive substances. The ultrasonic waves propagating in the medium reach their maximum intensity at a specific height of the liquid, at which the liquid droplets break off. In both processes, the diameter of the aerosol droplets is determined by the frequency of the ultrasonic waves. The higher the frequency, the smaller the droplets.

Dental scale removal

The previously, often painful removal of mineral coatings from teeth is nowadays carried out throughly using ultrasonic tools. Piezoceramic composite systems comprising ring disks clamped together are used. As is the case with ultrasonic machining systems (see page 37), vibration amplitudes in the μm range at working frequencies of around 40 kHz are transmitted by means of a sonotrode in the form of a dental tool.

OEM products for medicine

Ultrasound therapy

This term is used for a therapeutic method in which ultrasonic waves are used to irradiate the tissue in a type of micromassage. During the application of ultrasound, the deflection of the vibrating particles propagates in a longitudinal wave in liquids and soft tissue. Mechanical longitudinal waves generate mechanical vibrations in the tissue, while at the same time part of the ultrasonic energy is converted into heat. The core of this system of therapy is an ultrasonic transmitter com-prising a piezo ceramic disk connected to a metallic sound transmission diaphragm. Typical working frequencies are in the range of 0.8 MHz (deeper penetration) to more than 3 MHz. Both continuous-wave and pulsed-wave ultrasonic techniques are used in this application. The vibration amplitudes trans-mitted are in the range of one micrometer. A special coupling substance is required before the sound can be transferred onto the tissue. The sound would otherwise be 100% reflected at the transition between the ultrasonic transmitter and the air (the acoustic impedance of aluminum, for example, is 35000 times greater than that of air!).

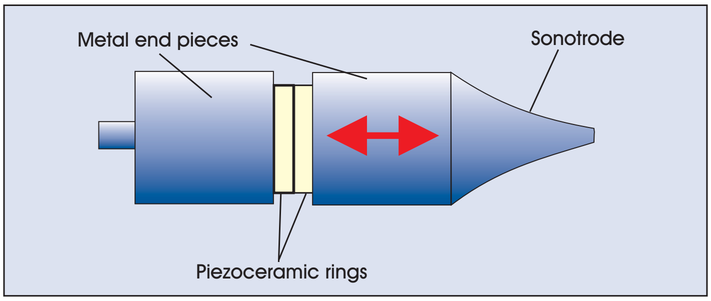
In addition to the treatment of bone and tissue condi-tions, ultrasonophoresis, i.e. the introduction of medicines under the skin, is also gaining in importance especially in the field of cosmetology. Here, salves and medicinal gels also serve as the coupling layer.

High-power ultrasonic machining

Ultrasonic jointing devices, such as wire bonders in the semi-conductor industry and ultrasonic welding systems, are based on jointing by fusion in the region of the joint. The fusion is achieved using frictional heat.

In an assembly similar to that of the dental scaler, the ultrasonic energy, which is generated by means of mechanically pre-stressed piezoceramic rings, is concentrated using a special sonotrode and fed to the joint.

In addition to welding processes, the ultrasonic machining of hard mineral or crystalline materials, especially by drilling or cutting, is increasingly gaining in importance. Specially shaped sonotrodes serve as the appropiate machining tools.



Recommended Literature

To increase your understanding of the physical solid-state relationships between piezoelectric materials, the basic mathematical description of piezoelectric effects and the applications of piezoelectric components, we draw your attention to the following publications:

B. Jaffe, W. Cook und H.Jaffe.
Piezoelectric Ceramics
Academic Press Limited © 1971

N. Setter
Piezoelectric Materials in Devices
published by N. Setter, EPFL-CH © 2002

H.-J. Martin
Die Ferroelektrika
Akademische Verlagsgesellschaft Geest & Portig Leipzig © 1964 (in German)

A.Bauer, D.Bühling, H.-J.Gesemann
G.Helke, W.Schreckenbach.
Technologie und Anwendung von Ferroelektrika
Akademische Verlagsgesellschaft Geest & Portig Leipzig © 1976 (in German)

K. Ruschmeyer, u.a.
Piezokeramik - Grundlagen, Werkstoffe, Applikationen
Expert Verlag Renningen © 1995 (in German)

G. Gautschi
Piezoelectric Sensorics
Springer-Verlag Berlin Heidelberg © 2001

T. Ikeda
Fundamentals of Piezoelectricity
Oxford University Press © 1990

P. Pertsch
Das Großsignalverhalten elektromechanischer Festkörperaktoren
ISLE-Verlag Ilmenau © 2003 (in German)

Diverse Standards

European Standard EN 50324
IEC 60483 und IEC 60302
DOD-STD-1376(A)
ROHS 2002/95/EG

In addition, we will be happy to supply you with literature from the extensive range of our own publications, application examples and descriptions, etc. on request.

Piezotechnology

For Piezoelectric Actuators & Nanopositioning Systems see other PI Ceramic and PI Catalogs at: http://www.piceramic.com

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Dr. Karl Spanner, President

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