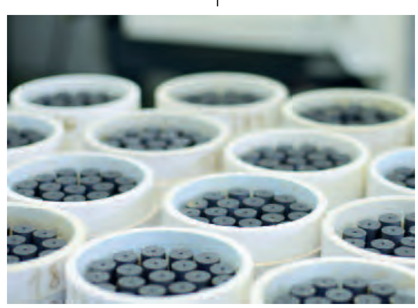
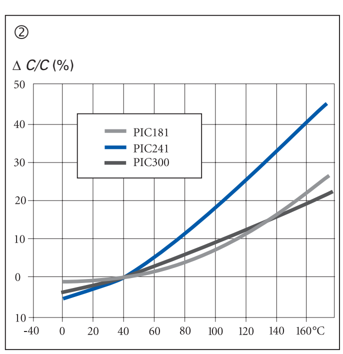
Piezoceramic Materials

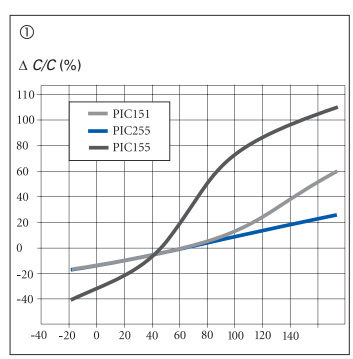
FUNDAMENTALS, CHARACTERISTICS AND APPLICATIONS

PIEZOCERAMIC
MATERIALS



COMPONENTS





INTEGRATION

PI

Piezo Material Data

SPECIFIC PARAMETERS OF THE STANDARD MATERIALS

				“Soft“				
			Unit	PIC151	PIC255	PIC155	PIC153	PIC152
Physical and dielectric properties								
Density		ρ	g/cm³	7.80	7.80	7.80	7.60	7.70
Curie temperature		T_c	°C	250	350	345	185	340
Relative permittivity	in the polarization	$\varepsilon_{33}^T/\varepsilon_0$		2400	1750	1450	4200	1350
	direction ⊥ to polarity	$\varepsilon_{11}^T/\varepsilon_0$		1980	1650	1400		
Dielectric loss factor		$tan\ \delta$	10^{-3}	20	20	20	30	15
Electro-mechanical properties								
Coupling factor		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 voltage coefficient		d_{31}		-210	-180	-165		
		d_{33}	10^{-12} C/N	500	400	360	600	300
		d_{15}			550			
Piezoelectric voltage coefficient		g_{31}	10^{-3} Vm/N	-11.5	-11.3	-12.9		
		g_{33}		22	25	27	16	25
Acousto-mechanical properties								
Frequency coefficients		N_p		1950	2000	1960	1960	2250
of the series resonance frequency		N_1	Hz · m	1500	1420	1500		
		N_3		1750		1780		
		N_t		1950	2000	1990	1960	1920
Elastic compliance coefficient		S_{11}^E	10^{-12} m²/N	15.0	16.1	15.6		
		S_{33}^E		19.0	20.7	19.7		
Elastic stiffness coefficient		C_{33}^D	10^{10} N/m²	10.0		11.1		
Mechanical quality factor		Q_m		100	80	80	50	100
Temperature stability								
Temperature coefficient of ε^T_{33} (in the range -20 °C to +125 °C)		$TK\ \varepsilon_{33}$	10^{-3}/K	6	4	6	5	2
Time stability (relative change of the parameter per decade of time in %)								
Relative permittivity		C_ε	%		-1.0	-2.0		
Coupling factor		C_K	%		-1.0	-2.0		

Flo J lob Fkclo j ^qflk lk Mfbwl J^qbof^ip ^ka @l j mlkbkqp dl ql t t t+mf`bo^ j f`+`l j

Flo J lob Fkclo j ^qflk lk Mfbwl >`qr^qlop ^ka K^klmlpfqflkfkd dl ql t t t+mfbwl+tp

	"Hard"					Lead-free materials	
	PIC181	PIC141	PIC241	PIC300	PIC110	PIC050[1]	PIC700[2]
	7.80	7.80	7.80	7.80	5.50	4.7	5.6
	330	295	270	370	150	>500	200[3]
	1200	1250	1650	1050	950	60	700
	1500	1500	1550	950		85	
	3	5	5	3	15	<1	30
	0.56	0.55	0.50	0.48	0.30		0.15
	0.46	0.48	0.46	0.43	0.42		0.40
	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	40	120
	475	475	265	155		80	
	-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		

Recommended operating temperature:
50 % of Curie temperature.

1) Crystalline material
2) Preliminary data, subject to change
3) Maximum operating temperature

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

Specific heat capacity:
WK = approx. 350 J kg^{-1} K^{-1}

Specific thermal conductivity:
WL = approx. 1.1 W m^{-1} K^{-1}

Poisson's ratio (lateral contraction):
σ = approx. 0.34

Coefficient of thermal expansion:
α_3 = approx. -4 bis -6 x 10^{-6} K^{-1}
(in the polarization direction, shorted)
α_1 = approx. 4 bis 8 x 10^{-6} K^{-1}
(perpendicular to the polarization direction, shorted)

Static compressive strength:
larger than 600 MPa

The data was determined using test pieces with the geometric dimensions laid down in EN 50324-2 standard and are typical values.

All data provided was determined 24 h to 48 h after the time of polarization at an ambient temperature of 23±2 °C .

A complete coefficient matrix of the individual materials is available on request. If you have any questions about the interpretation of the material characteristics please contact PI Ceramic (info@piceramic.de).

Material Properties and Classification

Material designation	General description of the material properties "Soft"-PZT	Classification in accordance with EN 50324-1	ML-Standard DOD-STD-1376A
PIC151	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** High permittivity, large coupling factor, high piezoelectric charge coefficient **Suitable for:** Actuators, low-power ultrasonic transducers, low-frequency sound transducers. Standard material for actuators of the PICA series: PICA Stack, PICA Thru	**600**	**II**
PIC255	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** Very high Curie temperature, high permittivity, high coupling factor, high charge coefficient, low mechanical quality factor, low temperature coefficient **Suitable for:** Actuator applications for dynamic operating conditions and high ambient temperatures (PICA Power series), low-power ultrasonic transducers, non-resonant broadband systems, force and acoustic pickups, DuraAct patch transducers, PICA Shear shear actuators	**200**	**II**
PIC155	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** Very high Curie temperature, low mechanical quality factor, low permittivity, high sensitivity (*g* coefficients) **Suitable for:** Applications which require a high *g* coefficient (piezoelectric voltage coefficient),e.g. for microphones and vibration pickups with preamplifier, vibration measurements at low frequencies	**200**	**II**
PIC153	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** extremely high values for permittivity, coupling factor, high charge coefficient, Curie temperature around 185 °C **Suitable for:** Hydrophones, transducers in medical diagnostics, actuators	**600**	**VI**
PIC152	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** Especially low temperature coefficient of permittivity **Suitable for:** Force and acceleration transducers	**200**	**II**

Material designation	General description of the material properties “Hard“-PZT	Classification in accordance with EN 50324-1	ML-Standard DOD-STD-1376A
PIC181	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** Extremely high mechanical quality factor, good temperature and time constancy of the dielectric and elastic values **Suitable for:** High-power acoustic applications, applications in resonance mode	**100**	**I**
PIC141	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** High mechanical quality factor, permittivity between PIC181 and PIC241 (can be exchanged for comparable types) **Suitable for:** High-power acoustic applications, e.g. atomizing pharmaceuticals	**100**	**I**
PIC241	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** High mechanical quality factor, higher permittivity than PIC181 **Suitable for:** High-power acoustic applications, piezomotor drives	**100**	**I**
PIC300	**Material:** Modified Lead Zirconate-Lead Titanate **Characteristics:** Very high Curie temperature **Suitable for:** Use at temperatures up to 250 °C (briefly up to 300 °C).	**100**	**I**

	Barium Lead Titanate		
PIC110	**Material:** Modified Barium Titanate **Characteristics:** Curie temperature 150 °C, low acoustic impedance **Suitable for:** Sonar and hydrophone applications	**400**	**IV**

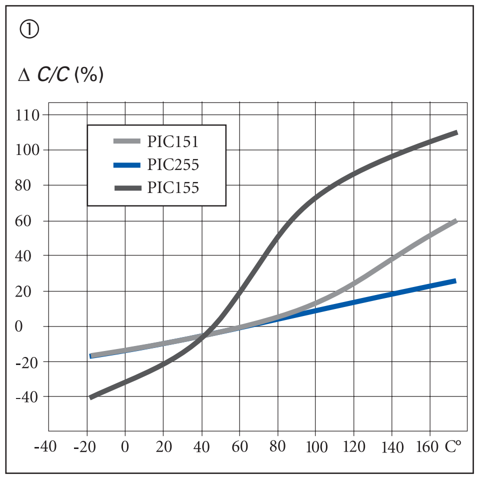
	Lead-Free Materials		
PIC050	**Material:** Spezial crystalline material **Characteristics:** Excellent stability, Curie temperature >500 °C **Suitable for:** High-precision, hysteresis-free positioning in open-loop operation, Picoactuator®		
PIC700	**Material:** Modified Bismuth Sodium Titanate **Characteristics:** Maximum operation temperature 200 °C, low density, high coupling factor of the thickness mode of vibration, low planar coupling factor **Suitable for:** Ultrasonic transducers > 1MHz		

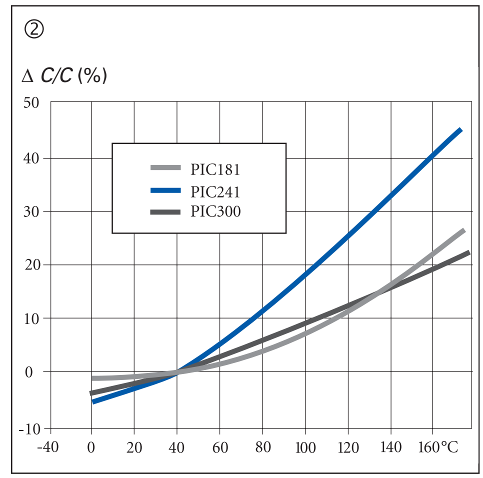
Temperature Dependence of the Coefficients

Temperature curve of the capacitance C

① Materials: PIC151, PIC255 and PIC155

② Materials: PIC181, PIC241 and PIC300

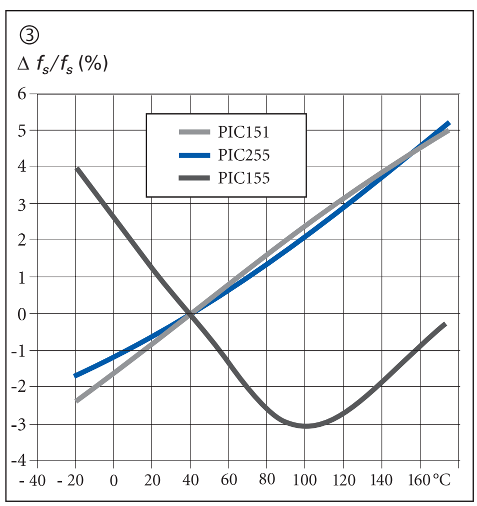


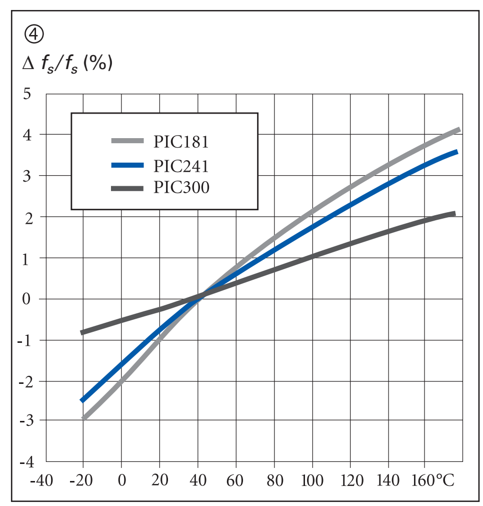


Temperature curve of the resonant frequency of the transverse oscillation f_s

③ Materials: PIC151, PIC255 and PIC155

④ Materials: PIC181, PIC241 and PIC300

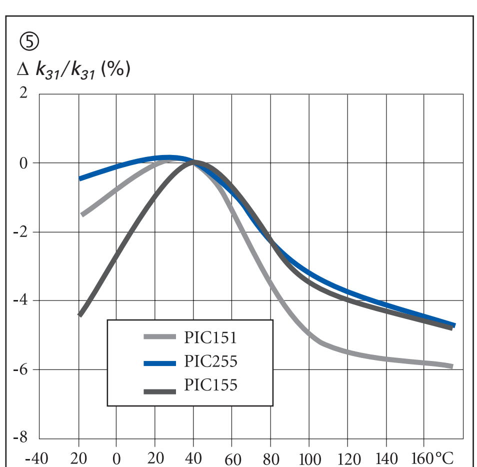


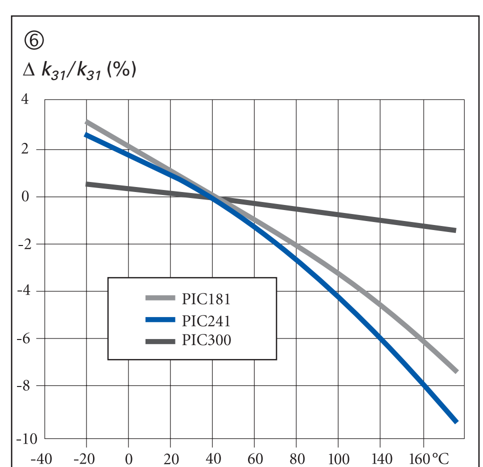


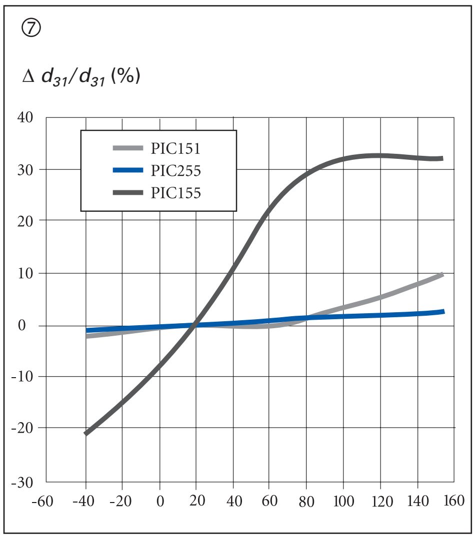
Temperature curve of the coupling factor of the transverse oscillation k_{31}

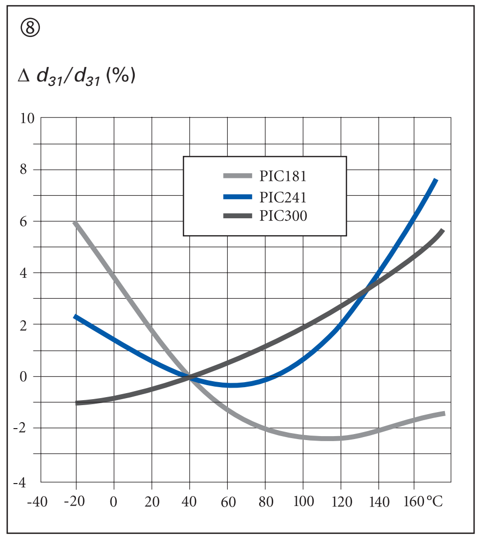
⑤ Materials: PIC151, PIC255 and PIC155

⑥ Materials: PIC181, PIC241 and PIC300









Temperature curve of the piezoelectric charge coefficient d_{31}

⑦ Materials: PIC151, PIC255 and PIC155

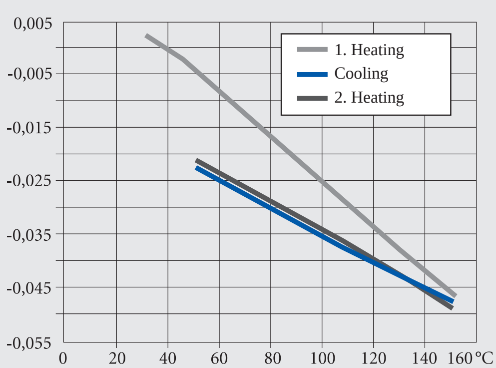
⑧ Materials: PIC181, PIC241 and PIC300

Specific Characteristics

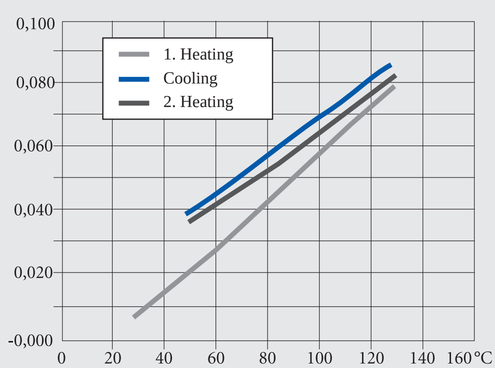
Thermal properties using the example of the PZT ceramic PIC 255

- 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 piezoceramic elements are isotropic. The coefficient of expansion is approximately linear with a TK of approx $2 \cdot 10^{-6}$ / K.
- The effect of successive temperature changes must be heeded particularly in the application. Large changes in the curve can occur particularly in the first temperature cycle.
- Depending on the material, it is possible that the curves deviate strongly from those illustrated.

Thermal strain in the polarization direction
Δ d_{31}/d_{31} (%)



Thermal strain perpendicular to the polarization direction Δ L/L (%)



PI Ceramic

LEADERS IN PIEZOELECTRIC TECHNOLOGY

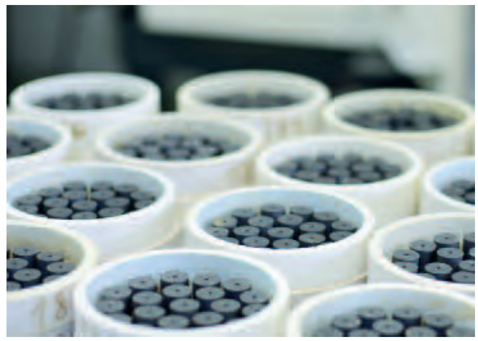
PI Ceramic is one of the world's market leaders for piezoelectric actuators and sensors. PI Ceramic, or PIC for short, provides everything related to piezo ceramics, from the material and components right through to the complete integration. PI Ceramic provides system solutions for research and industry in all high-tech markets including medical engineering, mechanical engineering and automobile manufacture, or semiconductor technology.

Materials Research and Development

PIC develops all its piezoceramic materials itself. To this end PIC maintains its own laboratories, prototype manufacture as well as measurement and testing stations. Moreover, PIC works with leading universities and research institutions at home and abroad in the field of piezoelectricity.

Flexible Production

In addition to the broad spectrum of standard products, the fastest possible realization of customer-specific requirements is a top priority. Our pressing and multilayer technology enables us to shape products with a short lead time. We are able to manufacture individual prototypes as well as high-volume production runs. All processing steps are undertaken in-house and are subject to continuous controls, a process which ensures quality and adherence to deadlines.



Certified Quality

Since 1997, PI Ceramic has been certified according to the ISO 9001 standard, where the emphasis is not only on product quality but primarily on the expectations of the customer and his satisfaction. PIC is also certified according to the ISO 14001 (environmental management) and OHSAS 18001 (occupational safety) standards, which taken together, form an Integrated Management System (IMS). PI Ceramic is a subsidiary of Physik Instrumente (PI) and develops and produces all piezo actuators for PI's nanopositioning systems. The drives for PILine® ultrasonic piezomotors and NEXLINE® high-load stepping drives also originate from PIC.

Core Competences of PI Ceramic

- Standard piezo components for actuators, ultrasonic and sensor applications
- System solutions
- Manufacturing of piezoelectric components of up to several million units per year
- Development of custom-engineered solutions
- High degree of flexibility in the engineering process, short lead times, manufacture of individual units and very small quantities
- All key technologies and state of the art equipment for ceramic production in-house
- Certified in accordance with ISO 9001, ISO 14001 and OHSAS 18001

Company building of PI Ceramic in Lederhose, Thuringia, Germany. By the end of 2011, just in time for the company's 20th anniversary, a new annex (left of picture) will increase the total space available for manufacturing, R&D and engineering, sales and management. This will also increase the current manufacturing capacities by 150%.

PI

PI General Catalog

Request it now!

The 530 page hardbound catalogue from PI is the most comprehensive reference book on the fundamentals of nanopositioning, piezo systems and micropositioning technology yet. The catalog contains 200 product families, with more than 1000 drawings, graphs, images and technical diagrams.

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Piezoceramic Materials

General Description

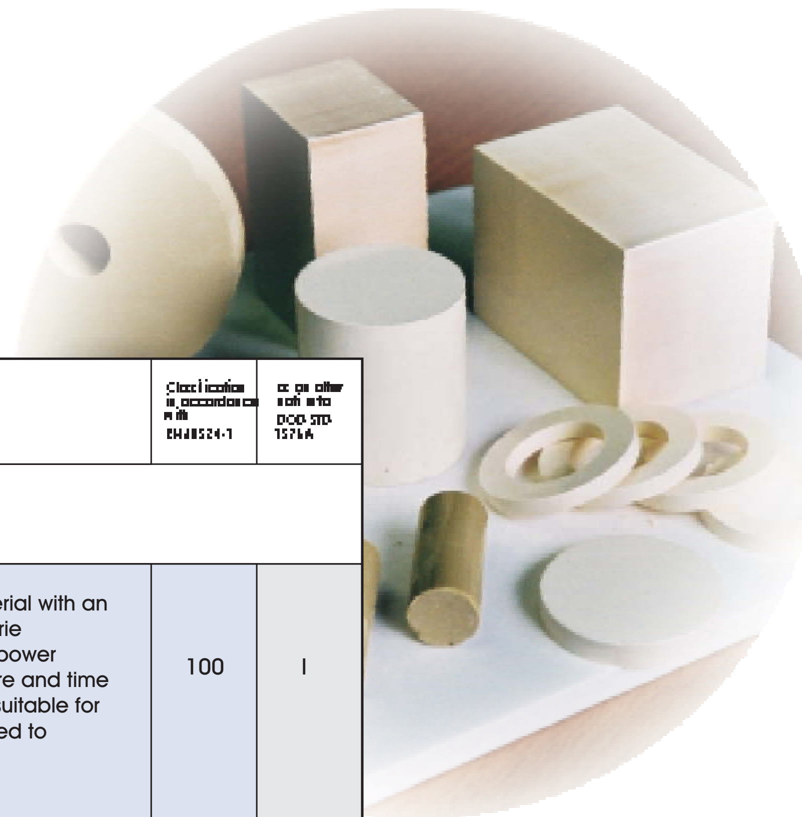
PI Ceramic offers a wide selection of piezoelectric ceramic materials based on modified lead zirconate titanate (PZT) and barium titanate, tailor-made for diverse applications. Apart from the standard types described in detail below, we can perform a multitude of application-specific and custom-engineered 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	[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	or as other conform 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
perpendicular to the polarity	ε ε		1980	1650	1400		
Dielectric loss factor	$\tan\delta$		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}	$(x10^{-3}/K)$	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

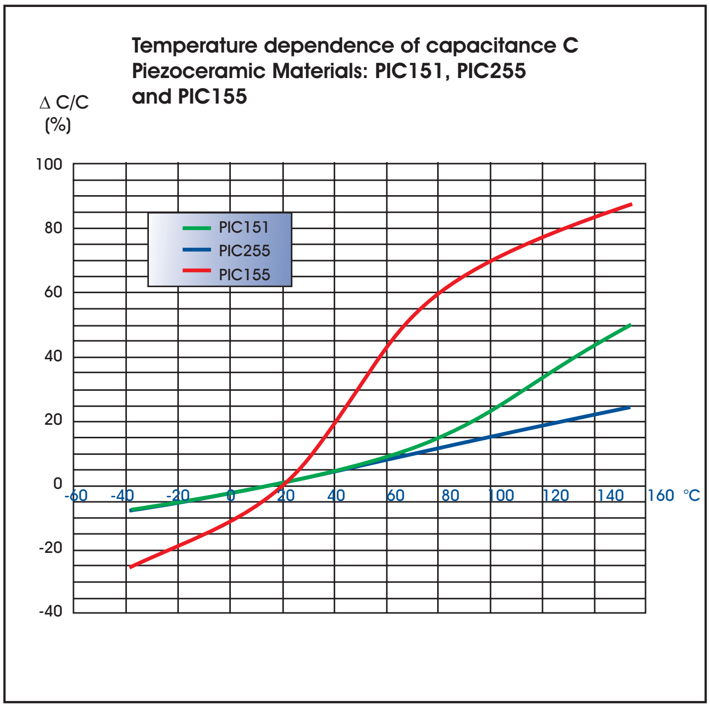
Coefficient of thermal expansion α_3 = approx. -4 to -6 x 10^{-6} / K (in the polarization direction, shorted)

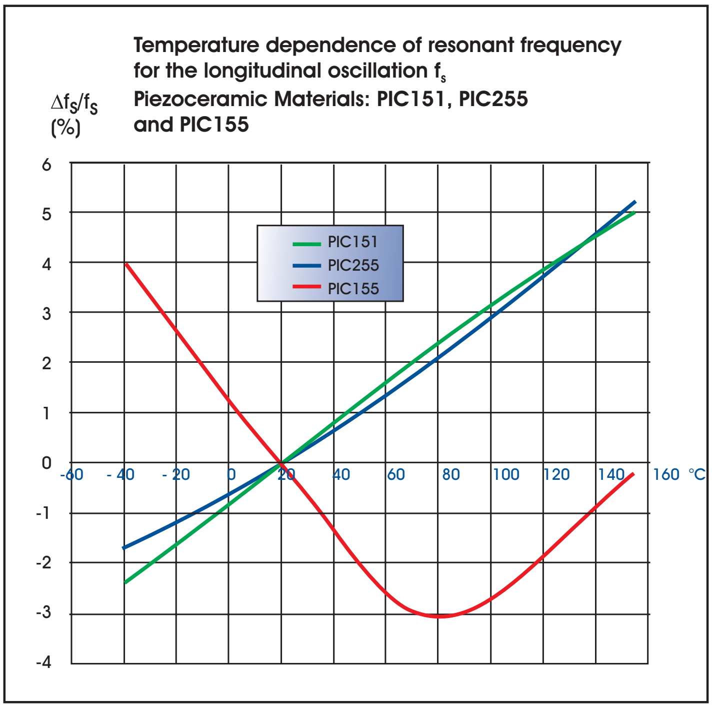
α_1 = approx. 4 to 8 x 10^{-6} / K ⊥ to the polarization direction, shorted)

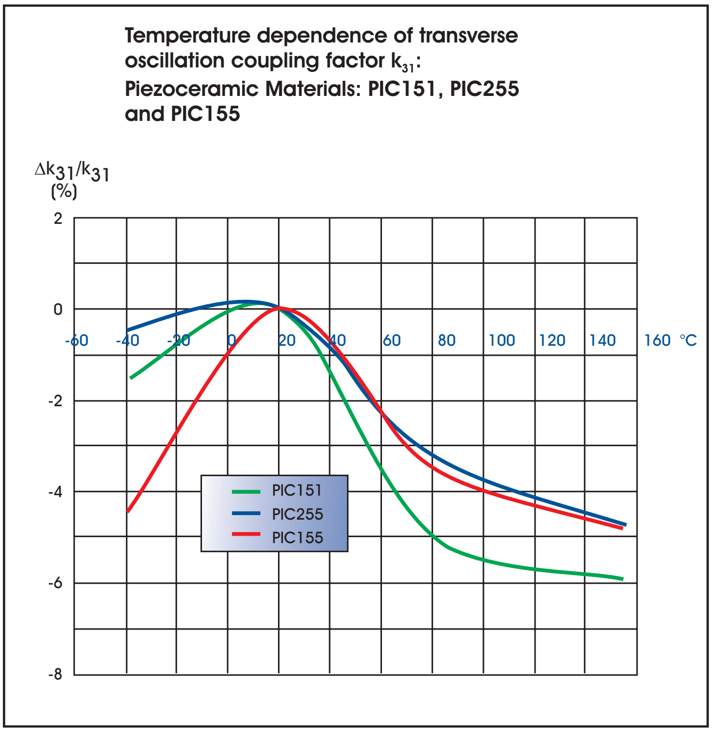
Static compressive strength larger than 600 Mpa

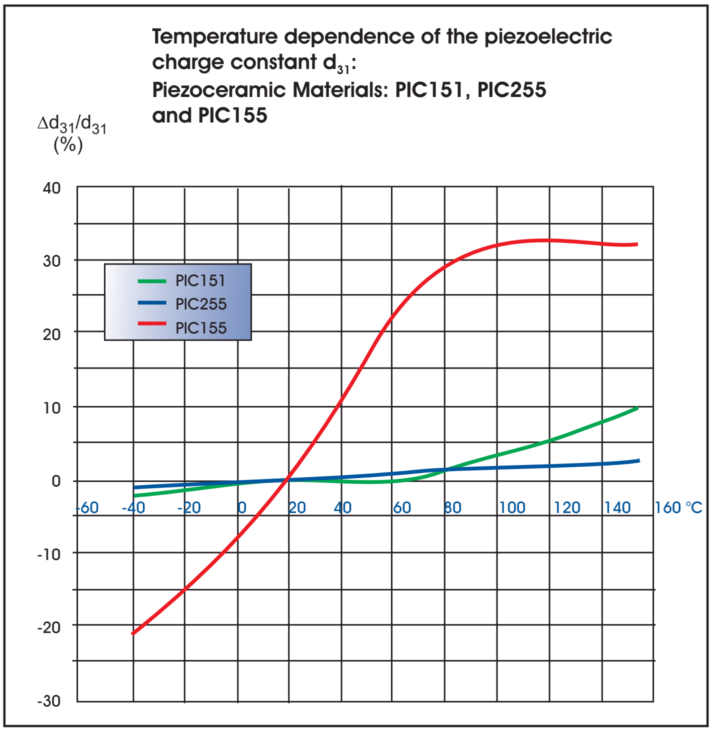
PIC 181	PIC 141	PIC 241	PIC 300	PIC 110
7.80	7.80	7.80	7.80	5.50
330	295	270	370	150
1200	1250	1650	1050	950
1500	1500	1550	950	
3	5	5	3	15
0.56	0.55	0.50	0.48	0.30
0.46	0.48	0.46	0.43	0.42
0.32	0.31	0.32	0.25	0.18
0.66	0.66	0.64	0.46	
0.63	0.67	0.63	0.32	
-120	-140	-130	-80	-50
265	310	290	155	120
475	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.

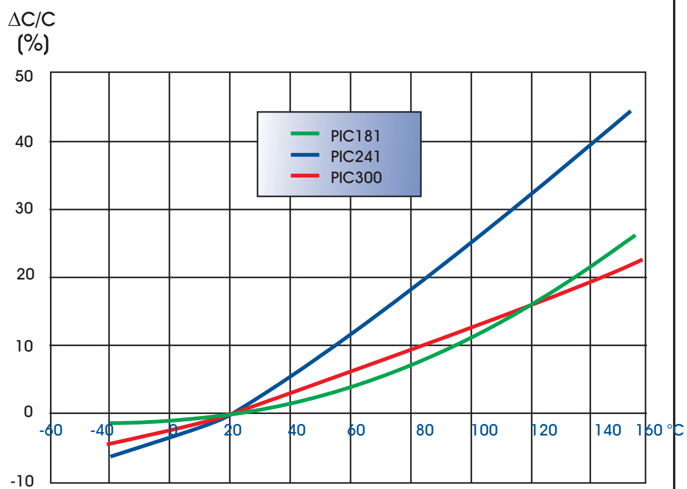

Temperature dependence of capacitance C
Piezoceramic Materials: PIC151, PIC255
and PIC155
Δ C/C
(%)
100
80
60
40
20
0
-20
-40
-60
-40
-20
0
20
40
60
80
100
120
140
160 °C
PIC151
PIC255
PIC155


Temperature dependence of resonant frequency
for the longitudinal oscillation f_s
Piezoceramic Materials: PIC151, PIC255
and PIC155
$\Delta f_S/f_S$
(%)
6
5
4
3
2
1
0
-1
-2
-3
-4
-60
- 40
- 20
0
20
40
60
80
100
120
140
160 °C
PIC151
PIC255
PIC155

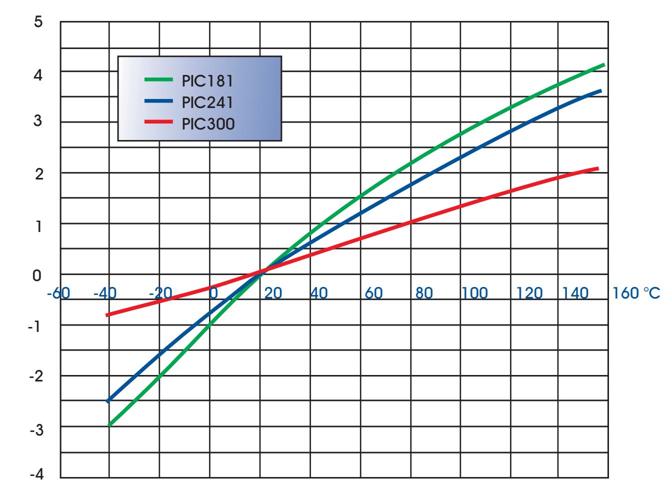

Temperature dependence of transverse
oscillation coupling factor k_{31}:
Piezoceramic Materials: PIC151, PIC255
and PIC155
$\Delta k_{31}/k_{31}$
(%)
2
0
-2
-4
-6
-8
-60
-40
-20
0
20
40
60
80
100
120
140
160 °C
PIC151
PIC255
PIC155


Temperature dependence of the piezoelectric
charge constant d_{31}:
Piezoceramic Materials: PIC151, PIC255
and PIC155
$\Delta d_{31}/d_{31}$
(%)
40
30
20
10
0
-10
-20
-30
-60
-40
-20
0
20
40
60
80
100
120
140
160 °C
PIC151
PIC255
PIC155

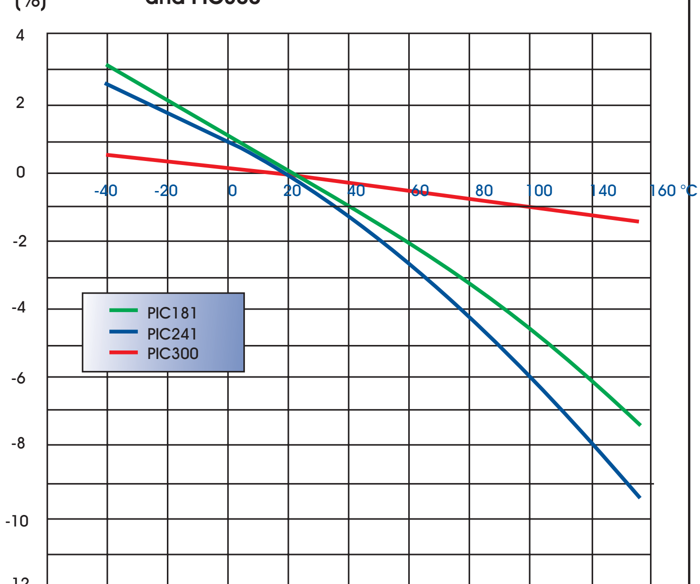
Temperature dependence of capacitance C
Piezoceramic Materials: PIC181, PIC241 and PIC300



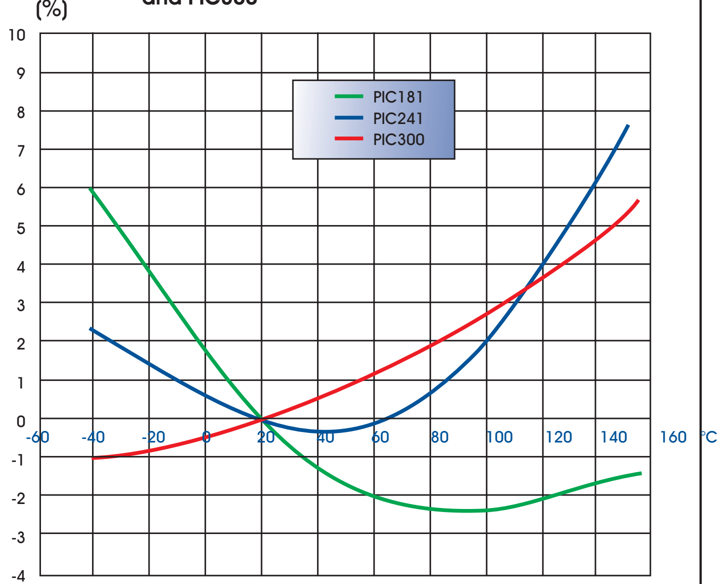
Temperature dependence of resonant frequency for the longitudinal oscillation f_s
Piezoceramic Materials: PIC181, PIC241 and PIC300



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



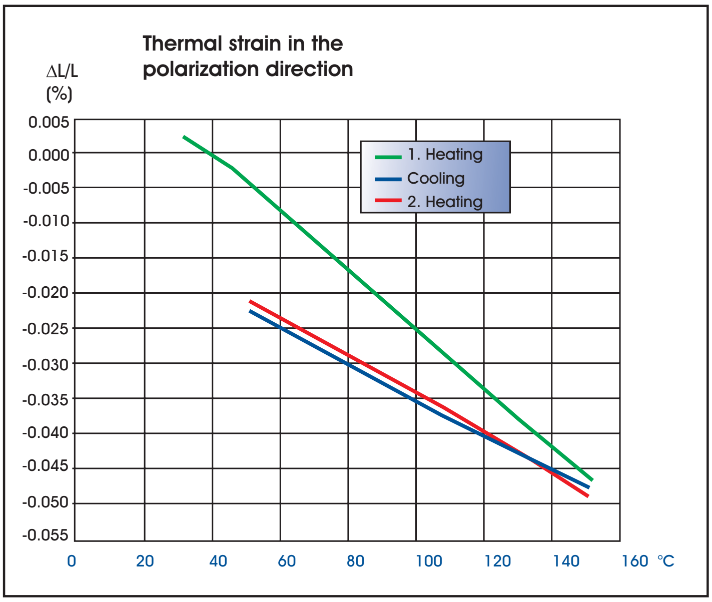
Temperature dependence of the piezoelectric charge constant d_{31}:
Piezoceramic Materials PIC181, PIC241 and PIC300

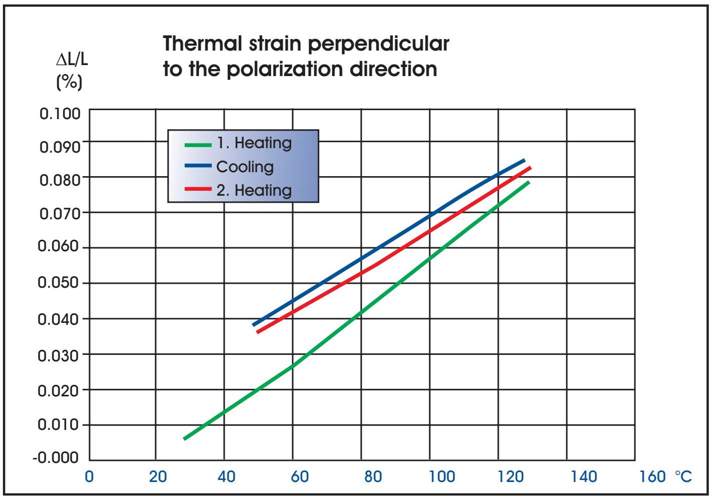


Specific Characteristics

Thermal expansion
example with PZT ceramic PIC 255

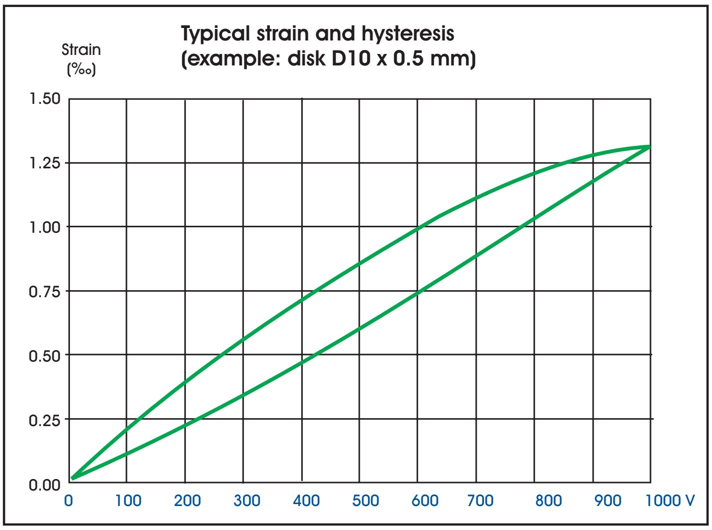
- The thermal strain exhibits different behavior in the polarization direction and perpendicular to it.
- The preferred orientation of the domains in a polarized PZT body leads to an anisotropy. This is the cause of the varying thermal expansion behavior.
- Non-polarized piezo ceramic is isotropic. The 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.

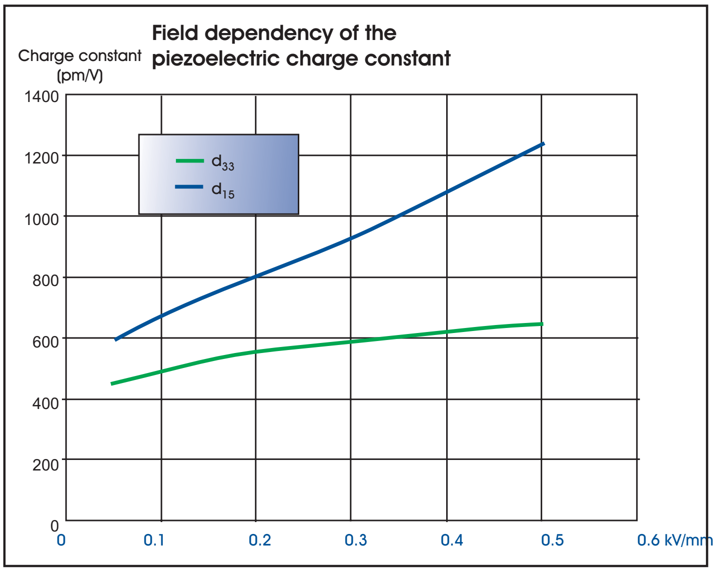




Deformation behavior
example with PZT ceramic PIC 255

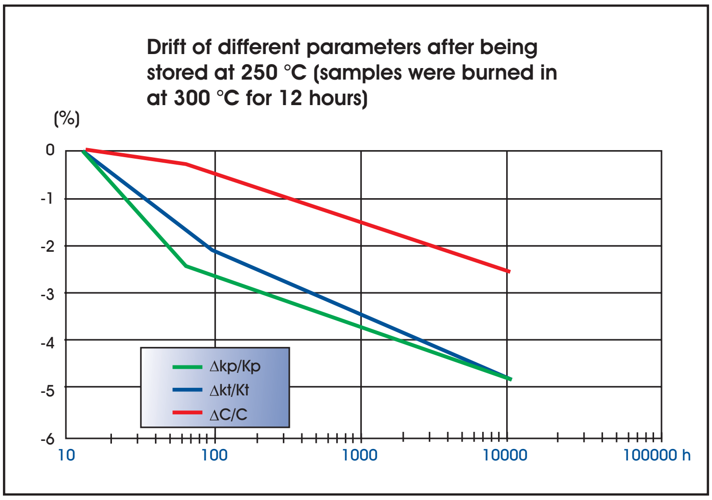
- In the case of large-signal fields (max. 2 kV/mm), the strain of a piezoceramic is associated with reversible and irreversible domain reorientation processes.
- The domain reorientations cause larger deformations in the ceramic elements than can be calculated from the piezo coefficients given in the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



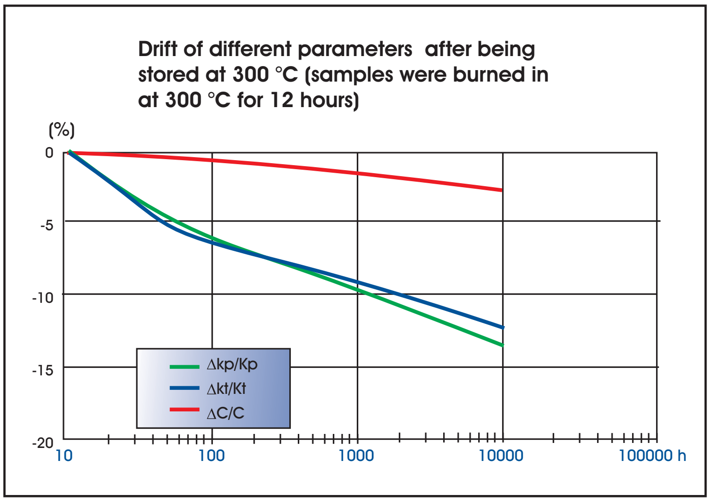


Parameter stability at high temperatures: example with PIC300

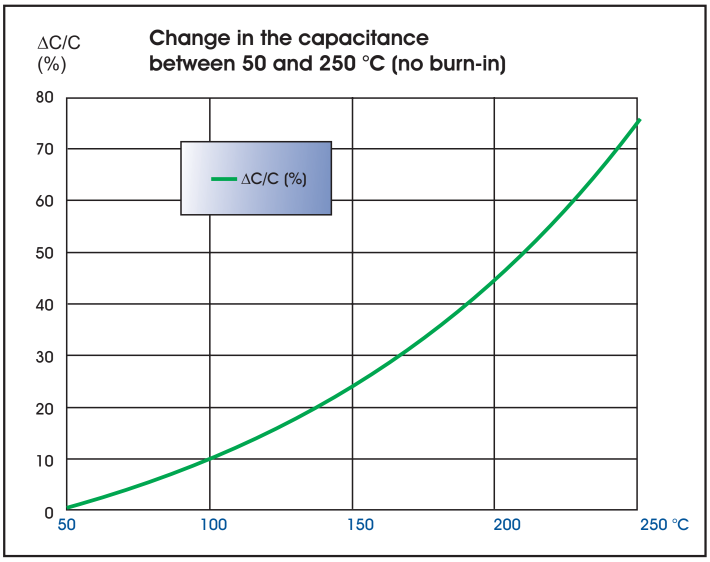
- PIC300 is suitable for use at temperatures up to 250 °C (for short durations, to 300 °C).
- The drift of the measured value for the coupling factor and the capacitance can be significantly reduced by burn-in of over 12 h at 300 °C.
- The expected percentage changes are shown in diagrams A and B.
-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



A



B



C