Definition of Terms

Dielectric Constant

$$K = \frac{\text{permittivity of material}}{\text{permittivity of free space}}$$

Density

The ratio of mass to volume (Kg/m^3)

Coupling Coefficient

$$k = \frac{\text{mechanical energy stored}}{\text{electrical energy stored}}$$ or vice versa

"d" Constant

$$d = \frac{\text{strain developed}}{\text{applied force}} \text{ or } \frac{\text{short circuit charge density}}{\text{applied stress}}$$

"g" Constant

$$g = \frac{\text{open circuit field}}{\text{applied stress}} \text{ or } \frac{\text{strain developed}}{\text{applied charge density}}$$

Mechanical Q (Q_M)

The ratio of reactance to resistance in the equivalent electric circuit, representing the mechanical vibrating resonant system.

Young's Modulus (Y)

The ratio of stress to strain, while vibrating at its resonant frequency (N/m^2).

Curie Temperature (T_C)

The temperature for a piezoelectric element, above which no piezoelectric action is detected. The crystal suffers permanent and complete depolarization, and changes from nonsymmetrical to symmetrical form.

Frequency Constant

Defined as the resonant frequency (f_r) x the controlling dimension, expressed in KHz-m or KHz-in.

Strain

The ratio of change in length to the original length.

$$\text{Strain} = \frac{\Delta L}{L}$$

Stress

The ratio of applied force to the cross sectional area.

Aging Rate

Aging is the attempt of the ceramic to change back to its original state prior to polarization. Aging is a logarithmic function with time. The aging rate defines the change in material parameters per decade of time, i.e., 1-10 days, 10-100 days, 100-1,000 days.

Conversions & Symbols

Metric/English Conversion

	Multiply	By	To Obtain
AREA	$Meters^2$	1550	$Inches^2$
	$Meters^2$	10.76	$Feet^2$
	$Centimeters^2$	0.1550	$Inches^2$
DENSITY	$Grams/Cm^3$	1000	$Kilograms/Meters^3$
	$Pounds/Inches^3$	27,680	$Kilograms/Meters^3$
	$Pounds/Feet^3$	16.02	$Kilograms/Meters^3$
	$Pounds/Inches^3$	27.68	$Grams/Centimeters^3$
FORCE	Newtons	10^5	Dynes
	Dynes	1.020×10^{-6}	Kilograms
	Kilograms	2.205	Pounds
	Newtons	0.2248	Pounds
	Grams	0.03527	Ounces
LENGTH	Meters	39,370	Mils
	Meters	39.37	Inches
	Meters	3.281	Feet
PRESSURE	$Dynes/Cm^2$	0.1	$Newtons/Meters^2$
	$Dynes/Cm^2$	1.450×10^{-5}	$Pounds/Inches^2$
	$Pounds/Inches^2$	6895	$Newtons/Meters^2$
VOLUME	$Meters^3$	61,020	$Inches^3$
	$Meters^3$	35.31	$Feet^3$
	$Centimeters^3$	0.06102	$Inches^3$
	$Feet^3$	1728	$Inches^3$

Symbol Designations

V	VOLTAGE
Q	ELECTRIC CHARGE
C	CAPACITANCE
F	FORCE
T, W, L & D	DIMENSIONS: Thickness, width, length and diameter, respectively
ΔT, ΔL & ΔD	SMALL CHANGES IN DIMENSIONS
d_{33}	The DIRECT CHARGE COEFFICIENT
d_{31}	The TRANSVERSE CHARGE COEFFICIENT
d_{15}	The SHEAR CHARGE COEFFICIENT
g_{33}	The DIRECT VOLTAGE COEFFICIENT
g_{31}	The TRANSVERSE VOLTAGE COEFFICIENT
g_{15}	The SHEAR VOLTAGE COEFFICIENT
$P\downarrow$	The DIRECTION OF THE POLING AXIS. The arrow is parallel to the poling electric field, pointing toward the negative poling electrode.
k_{33}	The DIRECT ELECTROMECHANICAL COUPLING COEFFICIENT
k_{31}	The TRANSVERSE ELECTROMECHANICAL COUPLING COEFFICIENT
k_{15}	The SHEAR ELECTROMECHANICAL COUPLING COEFFICIENT
k_p	The PLANAR ELECTROMECHANICAL COUPLING COEFFICIENT
K_3	RELATIVE DIELECTRIC CONSTANT MEASURED ALONG THE POLING AXIS
K_1	RELATIVE DIELECTRIC CONSTANT MEASURED AT RIGHT ANGLES TO THE POLING AXIS
ρ	DENSITY OF CERAMIC
Y_{ij}^E	Young's MODULUS measured at constant electric field
Q_m	MECHANICAL Q (QUALITY FACTOR)
P_r	REMANENT POLARIZATION
E_c	COERCIVE FIELD
Z_m	IMPEDANCE AT RESONANCE
ε_{11}^T	FREE PERMITTIVITY
ε_{11}^S	CLAMPED PERMITTIVITY
f_r	RESONANCE FREQUENCY
f_a	ANTIRESONANCE FREQUENCY

Typical Symbols Employed in Describing Properties of Piezoelectric Materials

Strictly speaking, these symbols are used to identify properties of materials only, and should not be used to describe characteristics of actual physical elements made of these materials. However, for convenience, some liberties have been taken in the explanations — electric boundary conditions are identified by indicating locations and connections of electrodes.

S_{11}^{D}

- D — Indicates that compliance is measured with electrode circuit open
- 1 (first subscript) — Indicates that <u>stress</u> or strain is in direction 1
- 1 (second subscript) — Indicates that <u>strain</u> or stress is in direction 1
- S — Compliance = $\frac{\text{strain}}{\text{stress}}$

(All stresses, other than the stress involved in one subscript, are constant.)

S_{36}^{E}

- E — Indicates that compliance is measured with electrodes connected together
- 3 — Indicates that <u>stress</u> or strain is in sheer form around axis 3
- 6 — Indicates that <u>strain</u> or stress is in direction 3
- S — Compliance = $\frac{\text{strain}}{\text{stress}}$

(All stresses, other than the stress involved in one subscript, are constant.)

K_{1}^{T}

- T — Indicates that all stresses on material are constant — for example: zero external forces
- 1 — Indicates that electrodes are perpendicular to axis 1
- K — Relative dielectric constant = $\frac{\varepsilon_1^T}{\varepsilon^\circ}$

K_{3}^{S}

- S — Indicates that all strains in the material are constant — for example: material completely blocked preventing deformation in any direction
- 3 — Indicates that electrodes are perpendicular to axis 3
- K — Relative dielectric constant = $\frac{\varepsilon_3^S}{\varepsilon^\circ}$

k_{15}

- 1 — Indicates that stress or strain is in shear form around axis 2
- 5 — Indicates that electrodes are perpendicular to axis 1
- k — Electromechanical coupling

k_{p}

- k — Electromechanical coupling
- p — This subscript used only for ceramics. Indicate electrodes perpendicular to axis 3 and stress or strain equal in all directions perpendicular to axis 3

d_{33}

- 3 (second subscript) — Indicates that the piezoelectric induced strain, or the applied stress, is in direction 3
- 3 (first subscript) — Indicates that electrodes are perpendicular to axis 3
- d — $\frac{\text{strain}}{\text{applied field}} = \frac{\text{short circuit charge/electrode area}}{\text{applied stress}}$

(All stresses, other than the stress involved in the second subscript, are constant.)

d_{h}

- h — Indicates that stress is applied equally in 1, 2, and 3 directions (hydrostatic stress; and that electrodes are perpendicular to axis 3 for ceramics or axis 2 for Lithium sulfate
- d — $\frac{\text{short circuit charge/electrode area}}{\text{applied stress}}$

g_{31}

- 1 — Indicates that applied stress, or piezoelectrically induced strain, is in direction 1
- 3 — Indicates that electrodes are perpendicular to axis 3
- g — $\frac{\text{field}}{\text{applied stress}} = \frac{\text{strain}}{\text{applied charge/electrode area}}$

(All stresses, other than the stress involved in the second subscript, are constant.)

g_{15}

- 5 — Indicates that applied stress, or piezoelectrically induced strain, is in shear form around axis 2
- 1 — Indicates that electrodes are perpendicular to axis 1
- g — $\frac{\text{field}}{\text{applied stress}} = \frac{\text{strain}}{\text{applied charge/electrode area}}$

(All stresses, other than the stress involved in the second subscript, are constant.)

Lead Zirconate Titanate

Navy Type I (PKI-402 and PKI-406)

It is designed to serve as a driver where high power and low losses are dictated by design. It is primarily well suited for ultrasonic cleaners, fish finders and sonars. PKI 406 is suitable for medical applications.

Navy Type II (PKI-502)

It is designed for applications that require high electromechanical activity and high dielectric constant. These are used primarily as receivers, e.g. hydrophones, phono pickups, sound detectors, accelerometers, delay lines, flow detectors, and flow meters.

Navy Type III (PKI-802 and PKI-804)

It is specifically used as a driver that exhibits low losses under extreme driving conditions and has a high Q. PKI 804 is well suited for medical applications.

Navy Type V (PKI-532)

It is used as sensors that require low impedance, high dielectric constant and high sensitivity.

Navy Type VI (PKI-552 and PKI-556)

Denoted as Navy Type VI, this ceramic is used as sensors that require extremely high dielectric constant and large displacements. PKI 556 material has been slightly modified to give a higher g_{33} value, higher k_{33}, and lower loss factor. This formulation aids the design engineer by giving more flexibility within the type VI class of materials.

PKI 700

This material has low dielectric constant, high Q_M, high shear coupling coefficient, good temperature stability and low aging characteristics. Common use of this material is in delay lines and accelerometers.

Lead Metaniobate

PKI 100

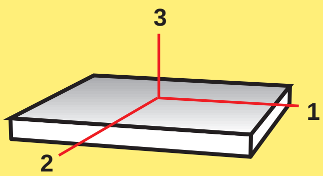
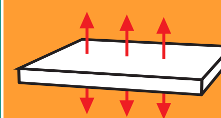
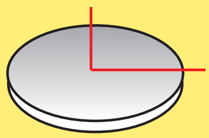
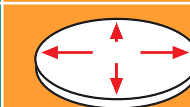
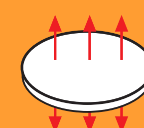
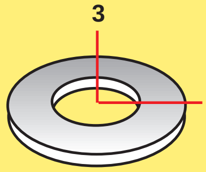
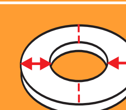
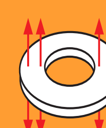
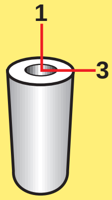
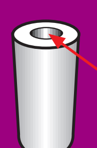
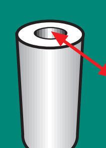
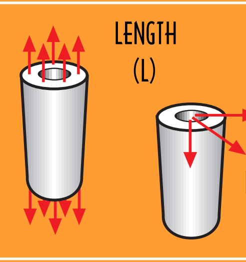
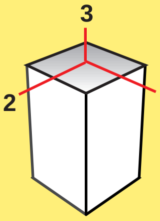
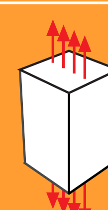
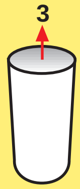
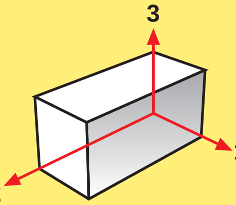
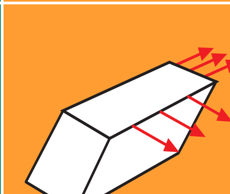
Lead metaniobate exhibits properties not usually present in other types of piezoelectric ceramics. The noteworthy facts are its low mechanical Q_M, negligible aging, wide range of operating temperatures, and small values for lateral and planar coupling compared to longitudinal coupling. The low Q_M enhances the use of PKI 100 material in the construction of wide bandwidth sensors for high frequency pulse echo measurements that require a short pulse and critical resolution. Its negligible aging helps simplify circuit design. Wide variations in temperature have limited effect on its dielectric and piezoelectric properties, making it ideal for high temperature applications. Its high longitudinal coupling compared to lateral and planar coupling allows it to generate a better response under hydrostatic pressures and makes it useful for underwater sonar equipment.

Lead Nickel Niobate

PKI 906

PKI 906 is slightly different in composition than the "general" PZT formulations. Its PZT-doped lead nickel niobate composition was developed to enhance the d_{33} and dielectric properties of Navy Type VI materials. These enhanced properties make it the optimum choice for ultrasound or actuator applications. The increased dielectric constant allows engineers to use the material in smaller (higher frequency) applications while still maintaining the desired or necessary capacitance. The increased d_{33} allows for higher displacement applications.

Modes of Vibration, Displacement,

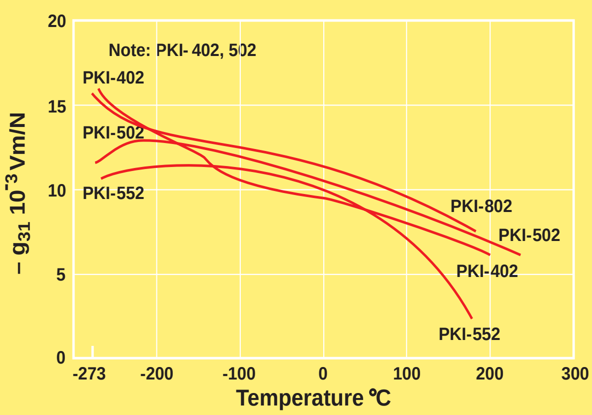
SHAPE	AXES	POLARIZATION DIRECTION	APPLIED FIELD / VOLTAGE OUTPUT	MODE OF VIBRATION OR DISPLACEMENT / APPLIED STRESS
PLATE	 3, 1, 2	↑	↕	 LENGTH OR TRANSVERSE (L or W)  THICKNESS (thk)
THIN DISC	 3, 1 (r)	↑	↕	 RADIAL (r)  THICKNESS (thk)
RING	 3, 1 (r)	↑	↕	 RADIAL (r)  THICKNESS (thk)
TUBE	 1, 3 (r)			 LENGTH (L) RADIAL (r)
BAR	 3, 2, 1	↑	↕	 LENGTH (L)
ROD	 3	↑	↕	 LENGTH (L)
SHEAR PLATE	 3, 1, 2	↑	⤡	 SHEAR (L or W)

and Voltage Output

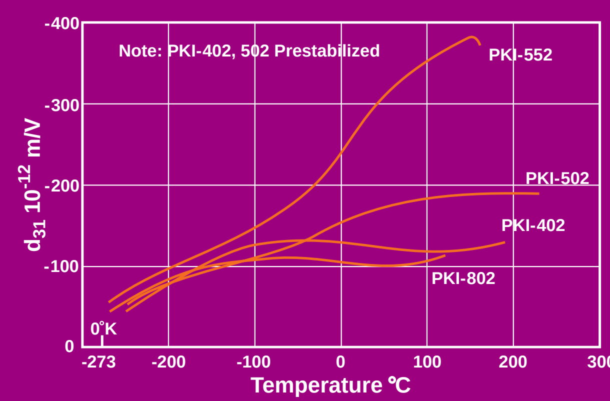
FREQUENCY CONSTANT	CAPACITANCE	(STATIC) DISPLACEMENT	(STATIC) VOLTAGE
$N_1 = f_r L$ $N_1 = f_r W$ $N_t = f_r\ thk$	$Cap = \frac{K^T_{33}\varepsilon_0 LW}{thk}$	$\Delta W = \frac{d_{31}\ VW}{thk}$ $\Delta L = \frac{d_{31}\ VL}{thk}$ $\Delta thk = d_{33}\ V$	$V = \frac{g_{31}\ F_1}{W}$ $V = \frac{g_{31}\ F_2}{L}$ $V = \frac{g_{33}\ F_3\ thk}{LW}$
$N_p = 2 f_r r$ $N_t = f_r\ thk$	$Cap = \frac{K^T_{33}\varepsilon_0 \pi r^2}{thk}$	$\Delta r = \frac{2d_{31}\ Vr}{thk}$ $\Delta thk = d_{33}\ V$	$V = \frac{g_{31}\ F_1}{2\pi r}$ $V = \frac{g_{33}\ F_3\ thk}{\pi r^2}$
$N_p = f_r\ (OD+ID)$ $N_t = f_r\ thk$	$Cap = \frac{K^T_{33}\varepsilon_0 \pi\ (OD^2 - ID^2)}{4\ thk}$	$\Delta r = \frac{d_{31}\ V\ (OD-ID)}{2\ thk}$ $\Delta thk = d_{33}\ V$	$V = \frac{g_{31}\ F_1}{2\pi\ (OD-ID)}$ $V = \frac{4 g_{33}\ F_3\ thk}{\pi (OD^2 - ID^2)}$
$N_1 = f_r\ L$ $N_t = f_r \frac{(OD-ID)}{2}$	$Cap = \frac{2K^T_{33}\varepsilon_0 \pi\ L}{\ln\left(\frac{OD}{ID}\right)}$	$\Delta L = \frac{2d_{31}\ VL}{(OD-ID)}$ $\Delta r = d_{33}\ V$	$V = \frac{g_{31}\ F_1\ (OD-ID)}{L\ (OD+ID)}$ $V = \frac{g_{33}\ F_3\ (OD-ID)}{2(OD^2 - ID^2)}$
$N_3 = f_r\ L$	$Cap = \frac{K^T_{33}\varepsilon_0\ W\ thk}{L}$	$\Delta L = d_{33}\ V$	$V = \frac{g_{33}\ F_3\ L}{W\ thk}$ $V = \frac{g_{31}\ F_1}{W}$ $V = \frac{g_{31}\ F_2}{thk}$
$N_3 = f_r\ L$	$Cap = \frac{K^T_{33}\varepsilon_0 \pi r^2}{4L}$	$\Delta L = d_{33}\ V$	$V = \frac{g_{33}\ F_3\ L}{\pi r^2}$ $V = \frac{g_{31}\ F_1}{2\pi r}$
$N_5 = f_r\ thk$	$Cap = \frac{K^T_{33}\varepsilon_0\ LW}{thk}$	$\Delta W = d_{15}\ V$	$V = \frac{g_{15}\ F_3}{L}$

Electromechanical vs. Temperature

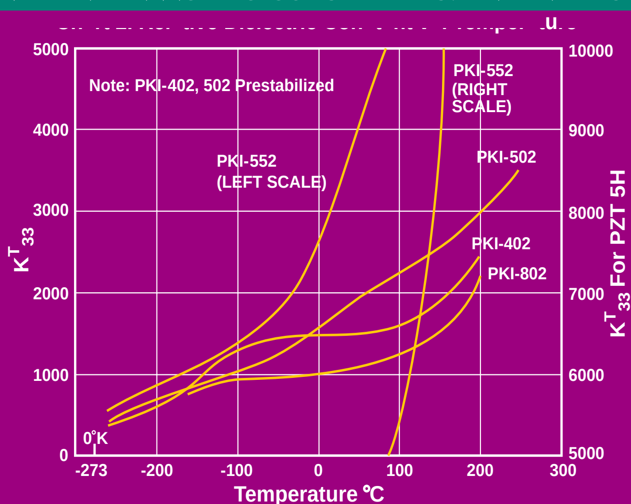
g_{31} vs. Temperature



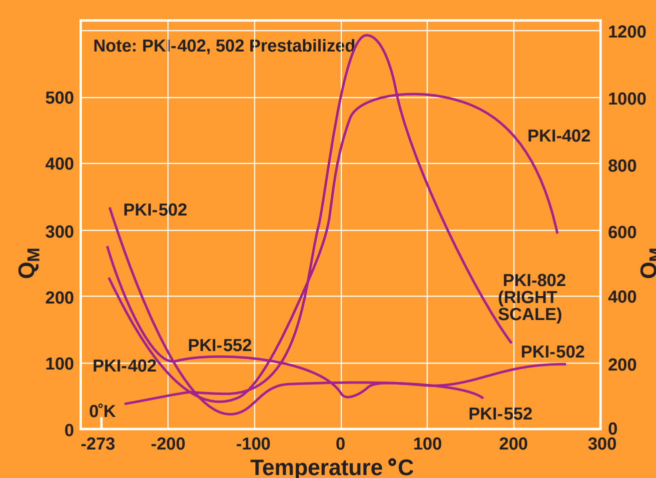
d_{31} vs. Temperature



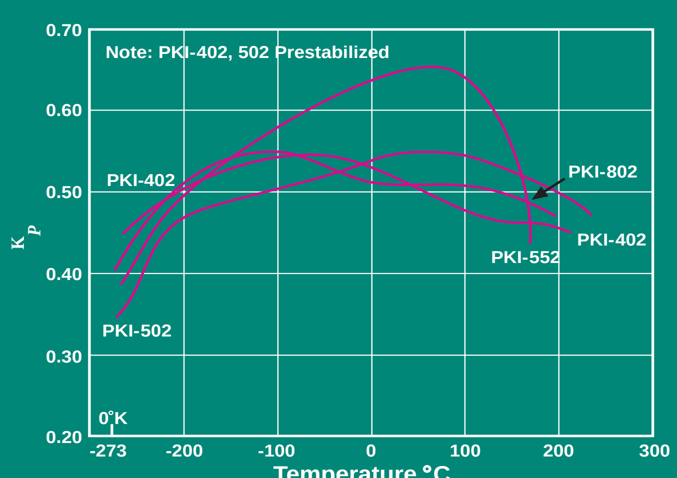
Relative Dielectric Constant vs. Temperature



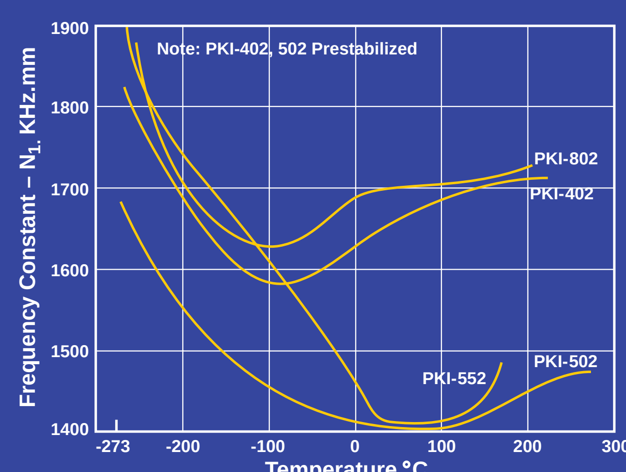
Mechanical Q vs. Temperature



Planar Coupling Factor vs. Temperature



Frequency Constant vs. Temperature



General Information

Resonant Frequency

Though special tolerances to ±1% are possible, standard tolerances are 5%-10%. If their nominal frequency is not as important as matching transducers, specify the permissible deviation, allowing greater latitude in the group's coverage frequency. If you desire a specific frequency within close limits, leave the associated dimension variable to achieve the necessary control.

**You can precisely set only one:
the frequency or a pertinent dimension.**

Resonant frequencies are inversely proportional to the size of a single dimension only for transducers of simple, ideal shapes. The resonant frequencies of intermediate shapes, such as short bars or thick discs, are less predictable. The pattern of vibration may become confused by closely spaced multiple resonances. The two modes may also mutually interfere when two dimensions produce coinciding or proximate resonances. This would happen in a tube with a length of nearly 1.5 times the mean diameter, for example. At this point, frequencies do not follow simple formulas and vibrations become complex.

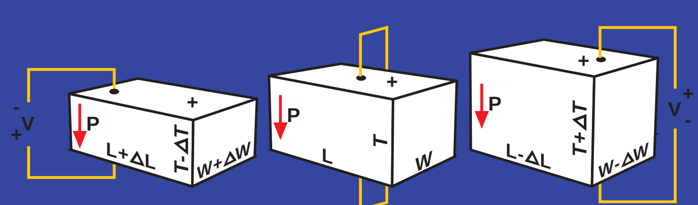
Modes Of Vibration

DC or Low Frequency Relations

Quantities inserted in the following equations must be in compatible units. Since piezoelectric coefficients are usually given in MKS units, the system is most convenient. X, L, W and T should then be in meters, V in volts, Q in Coulombs, F in Newtons, d coefficient in Coulombs/Newton or meters/volt, and g coefficients in volt-meters/Newton.

Equations give magnitudes only. Signs of charge, voltage and displacement are shown on drawing.

Expansion or Contraction

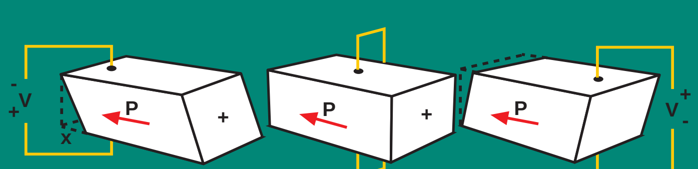


Motor

DIRECT $\Delta T = Vd_{33}$

TRANSVERSE $\frac{\Delta L}{L} = \frac{\Delta W}{W} = \frac{V}{T} d_{31}$

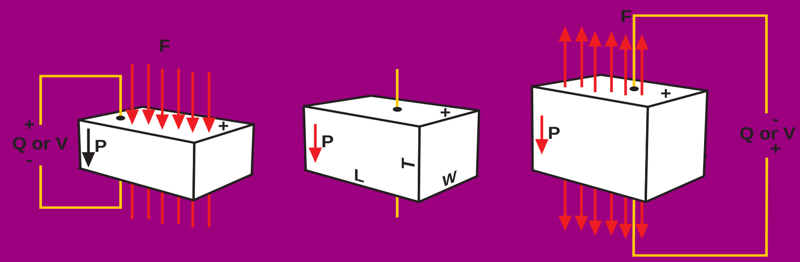
Expansion or Contraction



Motor

$X = Vd_{15}$

Parallel compression or Tension

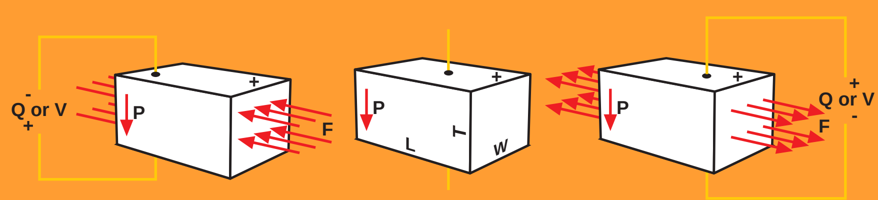


GENERATOR

$$Q = Fd_{33}$$

$$\frac{V}{T} = \frac{Fg_{33}}{LW}$$

Transverse Compression or tension

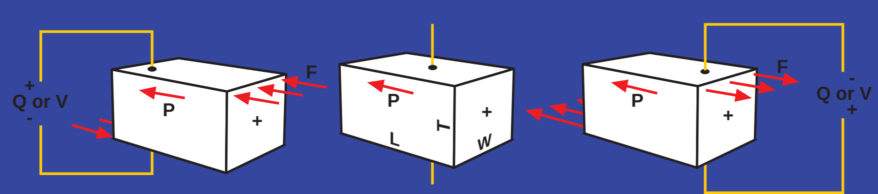


GENERATOR

$$\frac{Q}{LW} = \frac{F}{TW} d_{31}$$

$$\frac{V}{T} = \frac{F}{TW} g_{31}$$

Parallel Shear

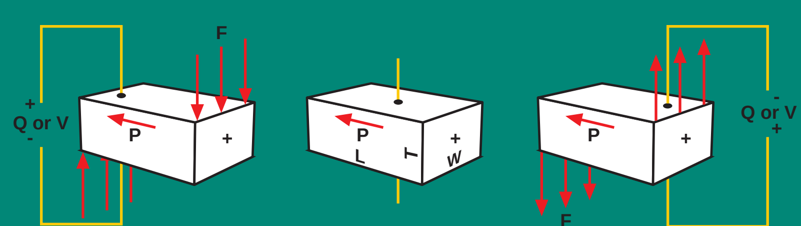


GENERATOR

$$Q = Fd_{15}$$

$$\frac{V}{T} = \frac{F}{LW} g_{15}$$

Transverse Shear



GENERATOR

$$\frac{Q}{LW} = \frac{F}{TW} d_{15}$$

$$\frac{V}{T} = \frac{F}{TW} g_{15}$$

Electrodes & Leads

PKI's piezoelectric ceramics come with electrodes of fired silver or electroless nickel. Silver electrodes are flat-white and the nickel electrodes are gray. Thicknesses are:

Silver 0.0003 - 0.001"   Nickel 0.00005 - 0.0002"

In addition, special electrodes such as electroplated gold and sputtered gold and nickel are available upon request for your special applications.

You can order almost any electrode combination you want. Leads are not normally furnished unless you specify them. The electrode quality is based on the adhesion of the soldered leads, the surface finish, and the conductivity.

Soldering

Because improperly attaching the leads can affect performance, here are some procedures for soldering:

Nickel Electrode & Silver Soldering

MATERIAL REQUIRED:
Soldering iron: 15-25 watts with a few tip sizes
Solder: SN 60, 60% tin, 40% lead, .032" diameter OR
Solder: SN 62, 2% silver, 62% tin, 36% lead, .032" diameter
Flux: Kester 1571, or equivalent
Common pencil eraser, Q-tip, and isopropyl alcohol

1. Preheat your soldering iron.
2. Gently burnish a small area to be soldered with the eraser.
3. Using a Q-tip, clean the surface to be soldered with isopropyl alcohol and let dry.
4. Melt some solder on the tip of the preheated soldering iron.
4. Tin the lead with the solder.
5. Dip the tinned lead into the flux.
6. Place the lead on the electrode area.
7. Using mild pressure, place the tip of the soldering iron on the lead until the solder flows onto the electrode.
8. Remove the soldering iron, but hold the wire until the solder solidifies, approximately 2.5 seconds.
9. Remove flux residue by rinsing with isopropyl alcohol.

Soldering Tips

- Remember, excessive temperatures can actually depolarize your ceramic. Make your soldering joints quickly and keep them as small as possible.
- Use a non-corrosive flux, not containing zinc chloride or other corrosive agents.
- A good solder joint will flow rapidly, wet around the wire and shiny upon solidifying.
- Frequently clean and remove excess solder from the iron's tip, using a damp sponge.
- If you'd like to be consistent in your solder-dot size, precut your bits of solder and clean the tip after each use before picking up the next one.

Piezo Kinetics Incorporated is proud of its ceramic materials, elements, and machining. Our PZT ceramics have contributed to many important missions — from saving lives to exploring space. Our most important mission, however, is pleasing you.

An Invitation

As a small, responsive company, we can customize our operations to suit your applications. Our overhead is low, which nearly always allows us to be more competitive than the industry average. We offer you a quality product at a reduced cost, but do it all with a personal touch.

Make some plans. Ask some questions. Let us know about your specific needs. We will provide piezoelectric ceramics that perform best for your applications. You'll also receive the special, personal attention that is so hard to find in this fast-paced era.

Let's Talk.