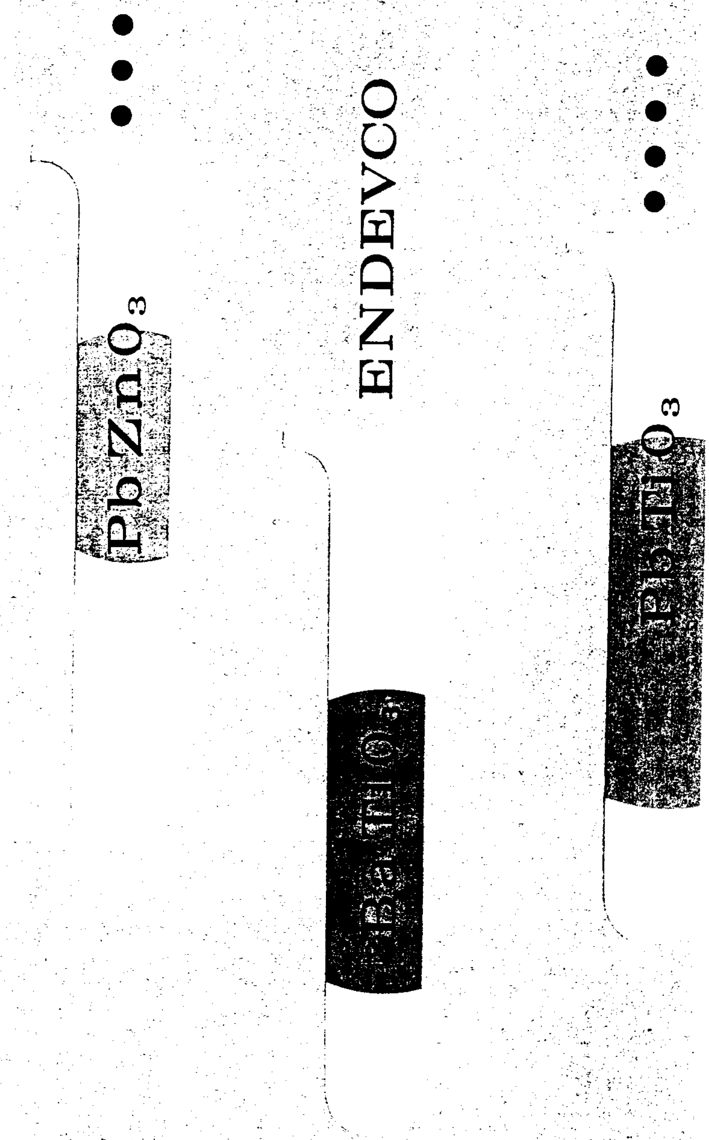
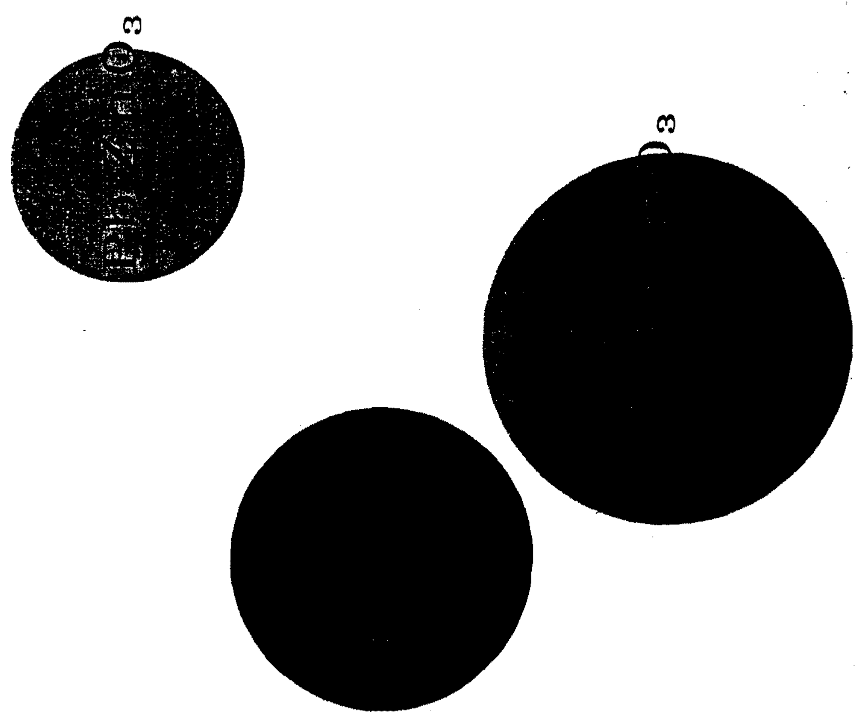


CURRENT PIEZOELECTRIC TECHNOLOGY



contents

* * * * *

A piezoelectric material is one which generates an electrical output when subjected to a mechanical stress. (The word is derived from the Greek "piezein," meaning to squeeze or press.) Although the possibility of the piezoelectric effect was suggested by Coulomb as early as the eighteenth century, its existence was not verified until the work of Jacques and Pierre Curie in 1800. These two investigated the properties of quartz, Rochelle salt, tourmaline and cane sugar among other materials and were able to prove that the effect predicted by Coulomb did indeed exist. After examining the results obtained by the Curie brothers, Lippmann predicted that the piezoelectric effect should be reversible and this reversibility was confirmed by the Curies shortly thereafter. From this period until the outbreak of World War I most of the work done in piezoelectric materials was purely theoretical. An outstanding example was the book by Voigt entitled "Lehrbuch der Kristallphysik" dated 1910 which is still considered the basic reference work in this area.

By the time of World War I, renewed interest in piezoelectrics had occurred. Langevin in France had begun experimenting with quartz crystal plates as underwater detectors and transmitters of supersonic acoustic waves in an attempt to build a submarine detecting device. In so doing he initiated the modern field of ultrasonics. At the same time, Nicholson in the U. S. was investigating Rochelle salt for the same functions at sonic frequencies. He patented several piezoelectric devices in 1918 including a crystal oscillator which used Rochelle salt as the frequency control device. Cady appears to have been the first, however, to recognize the wide range of potential applications for piezoelectric materials including their use as wave filters, couplers, and so forth. As a result of his extensive investigations, he is considered the American dean of piezoelectricity.

Between the two wars the major emphasis in piezoelectric work was on quartz crystals and their use as oscillator frequency control devices. Considerable work was done on finding new cuts which would reduce the dependence of resonant frequency on temperature in these devices. Then, in the early 1940's the discovery was made that certain ferroelectric ceramics could be made to exhibit piezoelectricity by a poling process. This discovery has led to a tremendous increase in the field of piezoelectric materials technology and applications. Since the 1950's these ceramic materials have surpassed the natural crystals in importance in most piezoelectric applications.

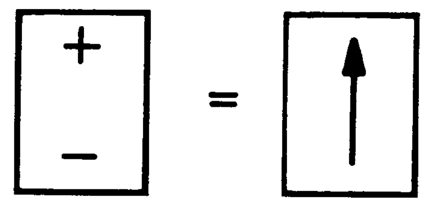


Figure 1

what is it all about?

In order to understand the piezoelectric effect let us consider a crystal cell which has a dipole (Fig. l). This dipole is due to the average location of positive and negative charges of equal strength within the unit cell. Now, if a crystal composed of a large number of identical unit cells containing these dipoles has its end faces electroded and an external field is applied, electrostatic repulsion and attraction will distort the dipole, thus producing a mechanical deformation of the crystal. Conversely, if the crystal is distorted mechanically, a charge will appear on the electroded faces. In actual practice, a dipole is not really necessary as long as the crystal lattice exhibits no center of symmetry.

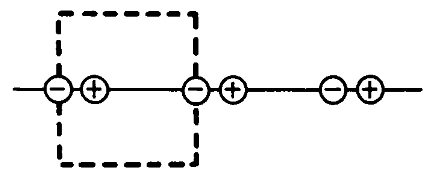

Asymmetric Structure

Figure 2a

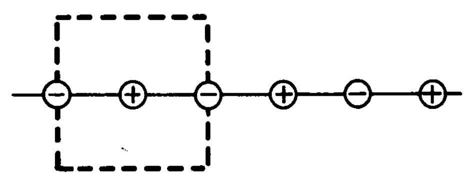

Centrosymmetric Structure

Figure 2b

The atomic lattice of piezoelectric crystals is assumed to consist of rows of alternating centers of positive and negative charges (ions) so arranged that the structure as a whole has no center of symmetry. In the unit cell of Fig. 2(a), a compressive force will tend to move one of the negative charges (ions) closer to the positive ion than the other. The result will be a net displacement of the center of charge in this unit cell. This displacement results in a net dipole moment, thus producing a piezoelectric charge. The polarity of the charge produced depends upon the previous equilibrium positions of the positive and the negative centers of charge and the direction of displacement. In a crystal with a center of symmetry, Fig. 2(b), a uniform strain in the crystal results in no net shift of the centers of charge, and as a result no dipole moment results.

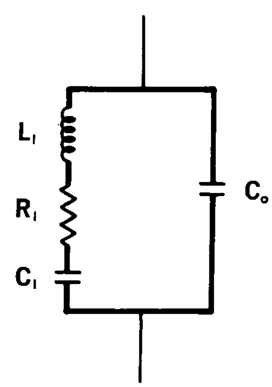


Figure 3

The equivalent circuit of a piezoelectric crystal is shown in Fig. 3. C_0 is the capacity of the crystal if the piezoelectric effect were suppressed and L_1, C_1 and R_1 are, respectively, the mass, compliance and damping of the crystal which are reflected in electrical behavior through the phenomenon of the piezoelectric effect.

some physics

True crystals, such as quartz and tourmaline, which exhibit piezoelectricity do so as a result of their fundamental crystalline structure. In other words, they are naturally piezoelectric. In addition to these crystals, there exists a group of poly-crystalline ceramic materials which can be made to exhibit piezoelectricity: the ferroelectric oxides. The great importance of the ferroelectric materials is that their piezoelectric properties can be controlled in the manufacturing process.

A ferroelectric material is one which exhibits a polarization curve analogous to the magnetization curve of a ferromagnetic material. The ability to permanently polarize these materials depends on the reversal of ferroelectric domains.

Within a ferroelectric material the dipoles are arranged in domains within which all the dipoles have the same orientation. These areas are separated by domain walls which are boundaries through which the dipole direction changes. Each domain can actually be considered as a crystal with definite piezoelectric coefficients. If a strong enough external field is applied, uniform domain orientation can be induced; that is, all the dipoles will become parallel and the domain walls disappear. This occurs through a phenomenon known as "domain reversal." The alignment of ferroelectric domains during polarization is analogous to the magnetic dipole alignment which occurs when iron is subjected to a strong magnetic field.

If heated, most ferroelectric crystals lose their dipole arrangement and become paraelectric (non-polar). The temperature at which this change occurs is known as the Curie temperature. At the Curie temperature ferroelectric materials tend toward greater symmetry and some acquire a true center of symmetry. In addition, the dielectric constant becomes very high. When cooled from the paraelectric range through the Curie temperature, these materials again show domain structure.

In the commonest ferroelectric materials used as piezoelectric ceramics such as barium titanate and lead titanate, the existence of the piezoelectric effect is due entirely to the fact that these materials are ferroelectric and, thus, can be poled. They exhibit no piezoelectricity above the Curie temperature. Variations in their properties are obtainable by modifying the composition of the basic material (adding impurities). The principal effects are shifting of Curie temperature and changing of the piezoelectric activity with temperature within the operating range.

Depolarization of these materials may be caused in several ways. Exceeding the Curie temperature causes a change in crystal structure and a loss of the fundamental asymmetry required for piezoelectric effect. In addition, application of a very strong electric field opposing the polarizing field can result in depolarization. Excessive pressure (usually above 20,000 psi) in the poled direction can also produce depolarization.

An outstanding feature of the ferroelectric ceramics is their stiffness; that is, deflections due to electrical excitation are small but very strong. In the reverse direction they are very sensitive, in other words, a very small force applied can produce large electrical outputs.

building a vocabulary

Among the important properties of piezoelectric materials are the various piezoelectric constants, normally written as tensor components with subscripts; for example, d_{ij}. In this notation the subscript $_i$ refers to the electrical direction while the $_j$ subscript refers to the mechanical direction. Common practice uses 1 for the x axis, 2 for the y axis and 3 for the z axis, while 4, 5 and 6 are used to represent shear about the x, y and z axes respectively.

piezoelectric strain constant (d_{ij})

This constant describes the fundamental sensitivity of a piezoelectric material and is a measure of the amount of charge generated by an applied force. This constant is also numerically equal for the inverse effect; that is, it is a measure of the deflection which occurs due to an applied voltage. It may be defined as either $d_{ij} = \frac{q}{F}$ (in units of picocoulombs per Newton) or as $d_{ij} = \frac{d}{E}$ (in units of picometers per volt). The definition of this constant leads directly to the fundamental equation of piezoelectric materials:

$$d_{ij} = \frac{q}{F} = \frac{CE}{F}.$$

This is the basic relationship of the various mechanical and electrical parameters within a piezoelectric material and may be considered as an Ohm's law of piezoelectricity. In artificially polarized ferroelectric ceramics there exist three independent d constants. They are d_{33}, d_{31}, and d_{15}. The most familiar are the d_{33} constant, which is the value used in determining the output in compressive loading and the d_{15} constant which is a measure of the output obtainable in shear.

Open circuit voltage constant (g_{ij})

This constant describes the voltage sensitivity of a piezoelectric element and is defined as the open circuit voltage generated per unit of applied force. More specifically it measures the field produced by a given stress. It is defined:

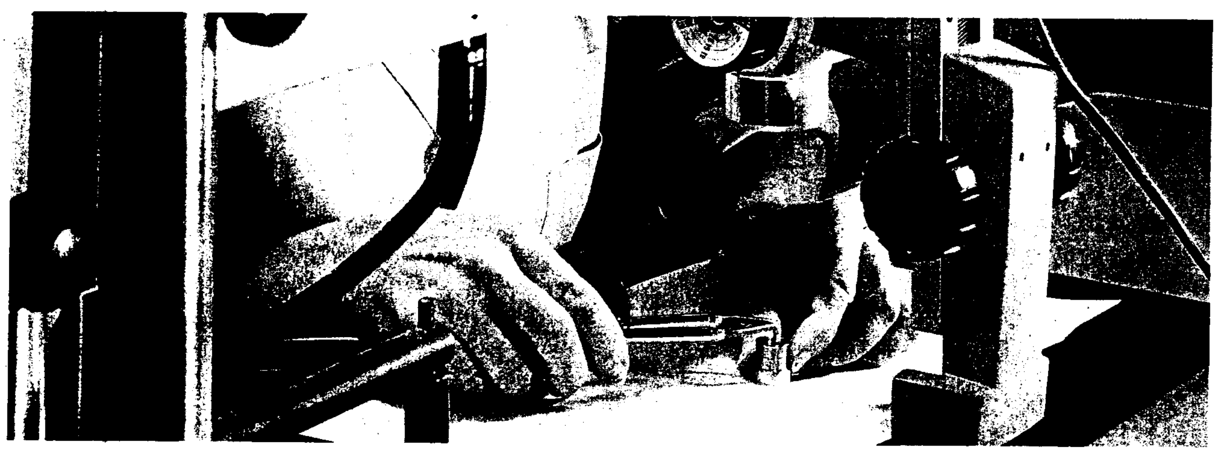
$$g_{ij} = \frac{\frac{E}{d}}{\frac{N}{d^2}} \quad \text{(in units of Volts per Newton)}$$

In terms of the piezoelectric strain constant:

$$g_{ij} = \frac{d_{ij}}{\epsilon \cdot \epsilon_o} \text{(where } \epsilon_o \text{ is the permittivity of free space).}$$

young's modulus (Y)

Since in transducers the piezoelectric element usually acts mechanically as a spring, the over-all transducer characteristics including resonant frequency will be affected by the element's elasticity. Young's Modulus, the ratio of stress to resulting strain, is a measure of this elasticity. It is related to the electromechanical coupling coefficient by $Y_{oc}^{(1-k^2)} = Y_{sc}$ where Y_{oc} is the modulus obtained with the material open circuit, and Y_{sc} is the value obtained when the electrodes are short-circuited. It can be seen that when the electrodes are shorted, the material will be "softer."



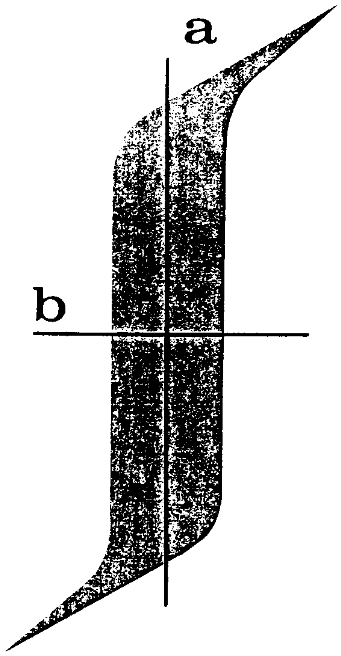
dielectric constant (ϵ)

This is a measure of the charge storage ability of an electroded slab of material and is defined as the ratio of the charge which can be stored to that which could be stored by the same electrodes if separated only by air. When coupled with the piezoelectric strain constant this value determines the open circuit voltage sensitivity. It is related to the electromechanical coupling coefficient by the following equation: $\epsilon_{free}^{(1-k^2)} = \epsilon_{clamped}$. The free and clamped values of the dielectric constant may differ considerably. The free value is measured at low frequencies where the slab is free to vibrate while the clamped value is measured above the mechanical resonant frequency where the slab is effectively clamped by its own inertial mass.

electromechanical coupling coefficient (k)

This constant is the best measure of the strength of the piezoelectric effect in a given material and describes its ability to convert energy from one form to another; that is, to act as a transducer. It is defined:

$$k^2 = \frac{\text{mechanical energy converted to electric charge}}{\text{mechanical energy input}}$$



It is important that this constant not be confused with efficiency which is the ratio of the power out to the power in regardless of form. Piezoelectrics with high values of k are considered as active materials and are desirable. The value of the coupling coefficient is easily measured, typically by determining the frequency difference between the resonant and anti-resonant frequencies of a given specimen. It follows then that a value of k exists for each of the resonant frequencies of a given shape and, thus, there should be several values of k. The most commonly reported is the planar coupling coefficient which is the most easily measured.

The electromechanical coupling coefficient provides an excellent figure of merit for a given material since it is related to several other important constants by the following equation: $k^2 = gdY$.

volume resistivity

This constant, plus the element geometry, determines the internal resistance of the piezoelectric device. High internal resistance is needed in transducer elements to prevent the charge generated from leaking off. Resistivity can be seriously reduced by both humidity and temperature.

curie temperature (T_c)

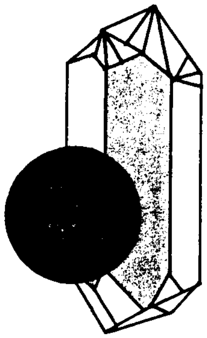
This is the temperature at which (due to thermal energy) the crystal lattice structure changes to a new configuration. This newer configuration may or may not be piezoelectric. In general, as the temperature of a material is raised toward the Curie point, the lattice becomes more and more unstable and, therefore, more active from a piezoelectric standpoint; thus, d_{ij} increases with temperatures approaching the Curie point.

amplitude linearity

Amplitude linearity is a measure of the variation of d_{ij} with applied stress. As an example, barium titanate is generally linear with pressures as high as 200 psi. As the pressure is increased beyond this point, the fundamental sensitivity of the material will change. (When the pressure reaches 20,000 psi, the applied stress will cause depolarization to begin and at pressures of 50,000 psi, the element begins to fail mechanically.) Other ferroelectrics such as lead zirconate titanate have a similar reaction.

frequency constant (N)

Frequency constants relate the dimensions of a ceramic element to the natural resonant frequency that each of the dimensions propagates. For example, in a disc shaped element the product of the



resonant frequency times the diameter must equal the radial frequency constant. Thus, a two inch diameter disc with N = 50 kc-inches will have a resonant frequency of 25 kc.

mechanical Q

Mechanical Q is important as a measure of the heat generated when electrical power is put into a ceramic. High Q materials generate less heat and thus are important in power applications. For sensor materials, however, low Q materials are satisfactory. In general, barium titanate has a Q of 500 while lead zirconate titanates are available with either low or high Q's.

some interesting idiosyncrasies

pyroelectricity

A pyroelectric material is one which produces an electrical output when subjected to a change in temperature. Ten of the 32 possible crystal classes are pyroelectric. There are three types of pyroelectricity:

1. Primary, in which charge is generated due to a change in temperature of the material when there is no temperature gradient across the material and when the material is constrained.
2. Secondary, in which charge is generated due to a change in dimensions in the material which occurs as a result of a change in temperature. This occurs when there is no temperature gradient across the material and the crystal is not constrained.
3. Tertiary, in which charge is generated due to a temperature gradient and when the crystal is constrained.

(It is interesting to note that in certain transducers, an additional effect due to temperature change may also be noticed. It is not a true pyroelectric effect but is, in fact, due to differential expansions of the case materials.)

Of the important piezoelectric materials, quartz exhibits no primary or secondary pyroelectricity. All the ferroelectric ceramics exhibit primary, secondary, and tertiary pyroelectricity. In general, the tertiary effect is insignificant. It is possible to generate large pyroelectric voltages in piezoelectric materials which are left electrically unloaded. (This can provide an unforgettable experience for the bare handed technician.)

electrostriction

This is an effect common to all dielectric materials. It is similar to but should not be confused with the piezoelectric effect. It is similar in that a deformation of the dielectric material occurs due to electric stress while the electroded material is being charged. However, it differs in that the magnitude of this deformation varies with the square of the applied field in electrostriction, while in piezoelectricity, it varies linearly with the applied field. In piezoelectric materials this effect is quite small compared to the piezoelectric effect.

twinning

Twinning is described as the intergrowth of two crystal regions having oppositely oriented axes. Two types of twinning may occur: electrical and optical. In electrical twinning the electrical sense of the crystal axes are reversed and the twinned regions will interfere with one another piezoelectrically. It is this effect which limits the high temperature utility of quartz as a piezoelectric material.

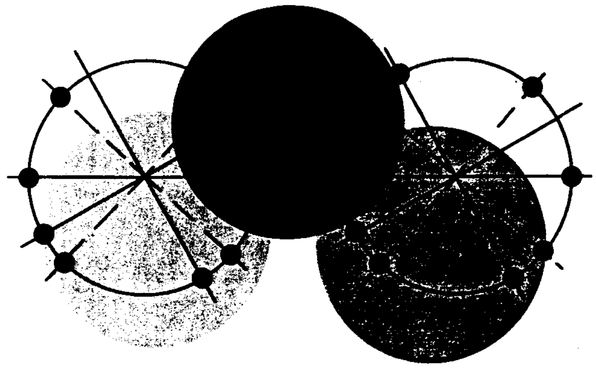
SOME IMPORTANT PIEZOELECTRICS

ROCHELLE SALT (also Seignette Salt) ($NaKC_4H_4O_6 \cdot 4H_2O$) (Sodium Potassium Tartrate plus four molecules of water of crystallization)

Rochelle salt, first synthesized by Pierre Seignette, an apothecary of La Rochelle, France, was used primarily for its medicinal properties. It exhibits a very large piezoelectric effect between −18°C and +24°C. It is, however, quite temperature sensitive and in the presence of extreme humidity it disintegrates due to the presence of water of crystallization. These drawbacks have limited the utility of Rochelle salt in practical transducers despite its history as one of the earliest materials studied.

ADP ($NH_4H_2PO_4$) (Ammonium Dihydrogen Phosphate)

ADP, discovered during World War II, was used as a successful substitute for Rochelle salt in underwater sound transducers. It has the chief advantage that it has no water of crystallization. As a result, there are no dehydration limits and ADP is usable to 100°C. It also is mechanically more durable than Rochelle salt, and can be readily grown in commercial quantities.

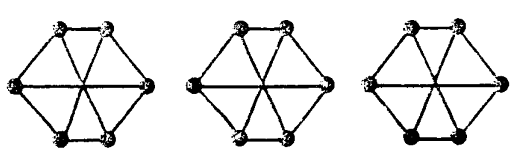


QUARTZ (SiO_2) (Silicon Dioxide)

Quartz is a form of silicon dioxide which is crystallized in hard, glass-like, six-sided prisms. Its normal piezoelectric configuration is known as alpha quartz. Quartz is harder than glass or soft steel and has a rating of 7 on the Mho scale of hardness. Both naturally occurring and synthetic quartz are used in piezoelectric devices. One of the interesting properties of quartz is the fact that it is enantiomorphous; that is to say, it occurs in both left and right handed crystalline structure forms. Quartz is extremely stable in its characteristics with time. Quartz is also quite useful in transducers for operation at elevated temperatures, but as its temperature is raised above 500°F, it begins to undergo electrical twinning which results in reduced sensitivity. Another of its major drawbacks is that quartz has a very low piezoelectric strain constant and a low dielectric coefficient meaning that electrical outputs are quite low.

BARIUM TITANATE ($BaTiO_3$)

This material was the first of the ferroelectric ceramics to be exploited as a piezoelectric material. Although its Curie temperature is only 120°C, thus yielding a rather limited range of useful operating temperatures, it has an excellent dielectric coefficient and a quite good piezoelectric strain constant. This combination provides substantial outputs. The great value of barium titanate, however, lies in that being a ferroelectric ceramic, its properties can be controlled during the manufacturing process. In addition, it can be fabricated in unusual geometrical configurations.



LEAD ZIRCONATE TITANATE COMPOSITIONS ($Pb(Zr, Ti)O_3$)

These compositions, in general, exhibit quite high Curie temperatures, ranging from 300° to 400°C. In addition, they have a higher electromechanical coupling than barium titanate. The electrical properties of lead zirconate titanate compositions may be varied widely by varying the composition of the particular material. For these reasons zirconate titanates have, in most cases, replaced barium titanate as the workhorse ferroelectric ceramic material used in piezoelectric transducers.

Table A lists several of the important characteristics of the more interesting piezoelectric materials. The data shown for the ceramics are only representative since small variations in composition or processing, either intended or accidental, can cause substantial changes from the values shown here.

piezoelectric materials at work and play

The great value of piezoelectric materials is suggested by the wide range of applications in which they are currently used. Used as a generator, that is, with electrical power applied in order to produce a resulting motion, piezoelectrics find such varied applications as ultrasonic welders and cleaners, and as sonar transducers. A much more common method of utilizing the piezoelectric effect, however, is as a sensor, that is, converting an input force or pressure to an electrical signal. In this mode of operation piezoelectric materials find wide application in phonograph pickups, ignition systems and even as energy generators in impact fuzing. One of

table A

	Curie Temperature (°C)	Electro-mechanical Coupling Coefficient	Dielectric Coefficient	Piezoelectric Strain Coefficient (pC/N)	Youngs Modulus ($N/m^2 \times 10^{-10}$)
ROCHELLE SALT	−18, +24	k_{14} = 0.78	500	d_{14} = 870 d_{25} = −53 d_{36} = 12	2
QUARTZ	—	k_{11} = 0.093	4.6	d_{11} = 2.3 d_{14} = −0.67	8.2
BARIUM TITANATE	120	k_{31} = 0.20 k_{33} = 0.50 k_{15} = 0.50	1500	d_{31} = −56 d_{33} = 150 d_{15} = 260	11.5
LEAD ZIRCONATE TITANATE	360	k_{31} = 0.32 k_{33} = 0.675 k_{15} = 0.655	1500	d_{31} = −140 d_{33} = 320 d_{15} = 495	5.85

the most important applications, however, is as the sensing element in such measurement transducers as microphones, pressure gages, force gages and the well-known piezoelectric accelerometer.

"crystal" accelerometers

Several piezoelectric modes of operation are used in crystal accelerometers. These are shown in Figure 4 and result in three basic accelerometer designs: compression, bender and shear.

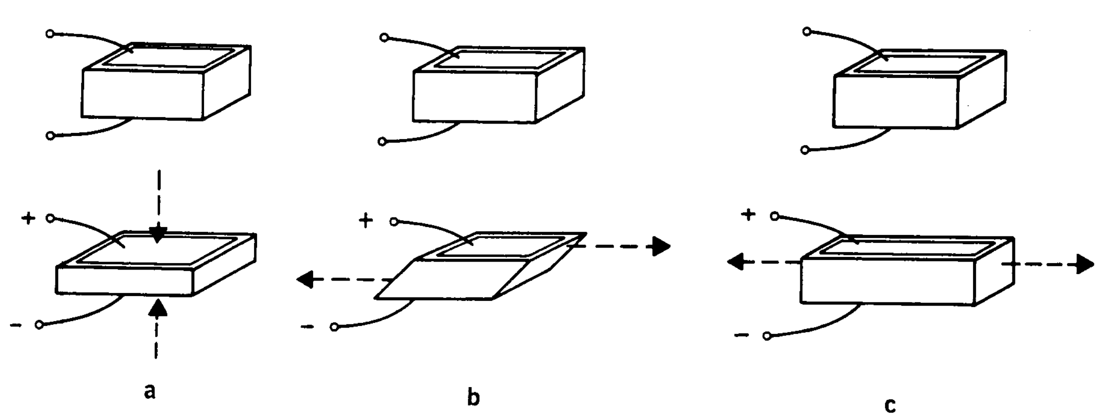


Figure 4

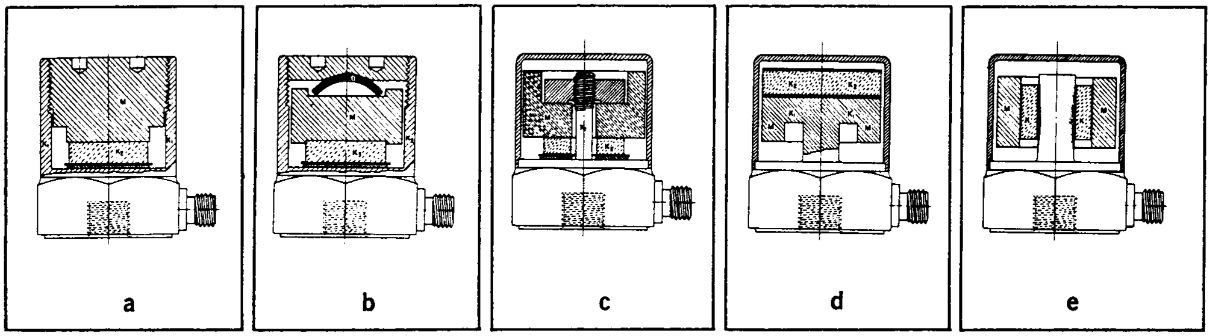


Figure 5

Compression designs provide higher sensitivities for a given resonant frequency than other designs. In addition, since the entire crystal-mass system is mechanically clamped and provides distributed internal loading under stress, it results in an extremely rugged accelerometer.

The simplest compression design is the straight compression accelerometer (Fig. 5(a)). It consists of a case, a piezoelectric ceramic element, and a threaded cap or compression member. The ceramic rests on an insulating pad to keep the lower electrode above case potential. The other electrode is tied to case potential through its contact with the cap. In assembly, the cap is torqued down until the desired preload is attained. As the transducer is accelerated along its vertical axis, the ceramic is compressed (or relieved) by inertial forces acting on the mass. This approach produces the desirable characteristic of high sensitivity and high resonant frequency, but has the disadvantage of case sensitivity.

A more satisfactory design is the isolated compression accelerometer (Fig. 5(b)) in which the basic spring-mass system is isolated from the compression member (and hence from the case walls) by insertion of a second spring. The isolating spring is designed to be slightly "softer" than the case walls and thus, in effect, removes them from the system. This design retains the desirable elements of the clamped crystal but alleviates, to a large extent, the problem of case sensitivity. There is, however, an even better approach.

In compression accelerometers, the highest degree of isolation from extraneous effects is accomplished in the ENDEVCO® single-ended compression design (Fig. 5(c)). Its basic components are a base, a center post, a cylindrical ceramic element, a mass, and a compression member. Pre-stress is accomplished by torquing the compression member down on the threaded center post. The cap, which is simply dropped over the completed assembly and welded to the base, acts only as a protective cover and is not in direct contact with the spring-mass system. This is the single-ended compression design currently used by Endevco and is the only technique which provides the advantages of compression methods without the disadvantages of straight compression.

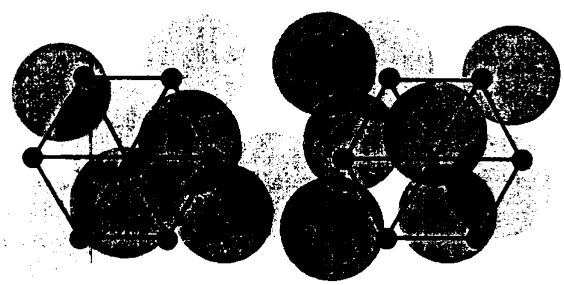
As pointed out, the major advantages of compression designs are the combination of high sensitivity and high natural frequency which can be achieved only in compression modes. The bender approach (Fig. 5(d)) is unable to take advantage of this desirable combination of specifications. In this typical design, the crystal is bonded to the top of a post and operates in a "mushroom" bending mode. As the unit accelerates upward, the effective mass (provided by the thickened outer rim at the top of the post) is forced downward, lengthening the ceramic element. Downward acceleration shortens the element.

For a given crystal element, the only way in which sensitivity can be increased is to add mass to the end of the bending beam. Unfortunately, this also reduces the system natural frequency which limits the transducer frequency range. In addition, bender designs produce concentrated internal loading under stress which results in a relatively fragile accelerometer. For these reasons, Endevco has avoided designs which incorporate bender elements.

In the ENDEVCO® shear design* (Fig. 5(e)) a cylinder of crystal material is bonded to a center post. A concentric cylindrical mass is then bonded to the crystal. When the unit is subjected to an acceleration along the axis of the post, the entire cylinder of crystal is stressed in a shear mode. This design (another Endevco "first") has several unique advantages.

*U.S. Patent No. 3,104,334.

For one thing, as in single-ended compression design, the case acts only as a protective cover and is not in contact with the spring-mass system. Result: no problems with torque sensitivity and other case effects. Another major advantage of the shear approach is that it can quite successfully be reduced in size. The entire line of micro-miniature accelerometers from Endevco is shear units. They are as small as 0.5 grams and less than 1/4 inch high.



you'll need to know this

The equivalent circuit for a piezoelectric transducer is shown in Fig. 6(a). In practice, the internal resistance shown in circuit (a) normally exceeds 20,000 megohms and, thus, can be ignored when considering the over-all transducer performance. Similarly, effects due to the internal inductance are far beyond the upper frequency range of the transducer and can also be ignored. The simplified circuit (Fig. 6(b)) is adequate for applications analysis. The piezoelectric transducer is effectively a capacitor which produces a charge q across its plates proportional to the force applied to the crystal.

The open circuit voltage e out of the transducer is equal to the generated charge divided by the transducer capacity, or $e = \frac{q}{C_p}$. Thus, the transducer can also be represented as a voltage generator and a series capacitance (Fig. 6(c)).

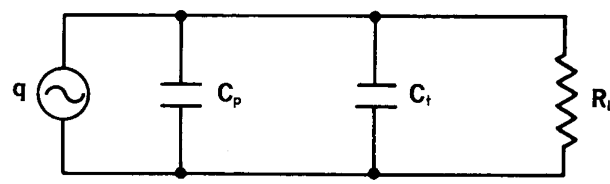


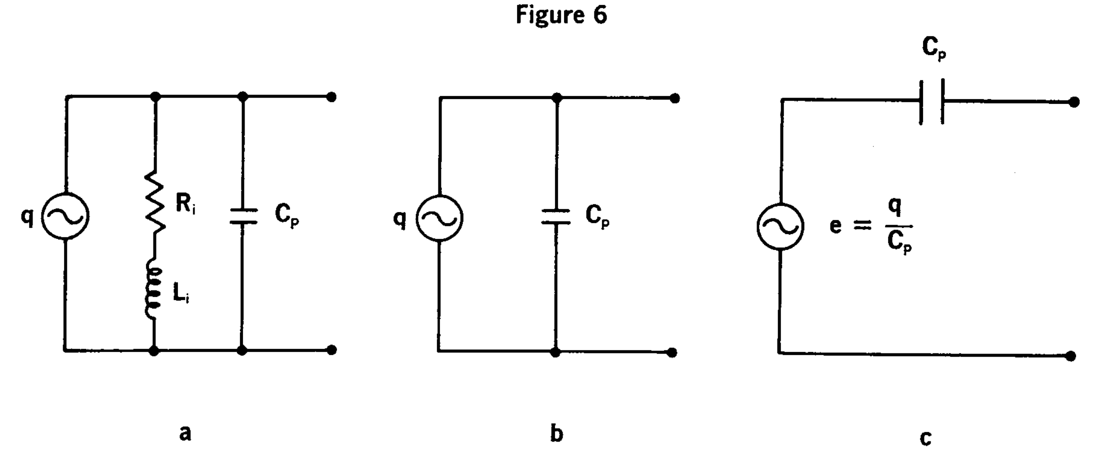
Figure 7

When performing measurements, the circuit involves an external capacitance and a shunt resistance. The external capacitance C_t is commonly cable capacitance plus input capacitance of the associated amplifier. The shunt resistance R_i is commonly the input resistance of the associated amplifier (Fig. 7). With added capacity the output voltage (appearing across R_i) becomes $e = \frac{q}{C_p + C_t}$.

The effect of added shunt capacity on voltage sensitivity can be used to advantage in standardizing transducer output to a desired value. Also, in instances where very high input levels are expected, it may be used to reduce the sensitivity of the transducer by a factor of 10 or more in order not to exceed the five volt limit of most transducer amplifiers.

It is important to note that although voltage output is a function of external capacitance present, the

Figure 6

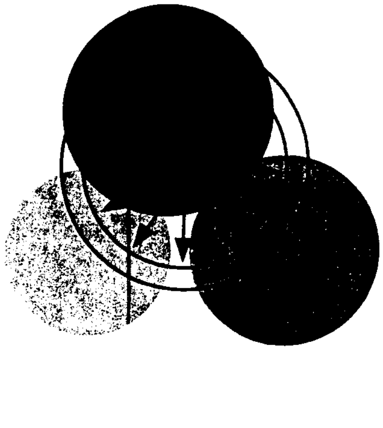


charge generated does not change, regardless of capacity. In other words, a system incorporating charge measuring electronics rather than voltage amplifiers will be unaffected by the length of interconnecting cable.

Piezoelectric accelerometers can be operated into either voltage sensing or charge sensing electronics. Both voltage and charge equipment are available in a wide variety of configurations designed for either (1) laboratory, (2) test stand, or (3) airborne applications.

Voltage amplifiers may provide gain or may be simply a cathode follower, with unity gain. Their high input impedance provides a matched termination for the high internal source impedance of the accelerometer. The high input impedance also permits long RC time constants for good low frequency response. System sensitivity will be reduced as longer interconnecting cables are used between accelerometer and amplifier.

Charge amplifiers sense the actual charge developed in the crystal. They can operate at much lower input impedances than voltage equipment; system low frequency response is not a function of RC time constant and is determined only by the amplifier frequency response characteristic. Lower input impedance reduces problems with noise pickup and with connector contamination. Since charge is the parameter sensed, system sensitivity is unaffected by the length of cable between accelerometer and amplifier. Nor is it affected by changes in cable length. This means that a transducer-amplifier system can be calibrated in the lab with any convenient length of cable and the calibration will still be valid when installed in, say, a missile in which the cable is already installed in a prewired harness.



WHAT'S NEW?

Following the advent of the charge amplifier, it became apparent to instrumentation engineer and transducer manufacturer alike, that a real need existed for a piezoelectric transducer suitable for operation with both voltage and charge electronics. To be truly universal, such a device should not only have large outputs in both charge and voltage regimes, but these outputs should be constant with temperature variations over wide ranges. Ideally, a universal transducer would be usable to the same high temperatures as quartz, and exhibit the same long term stability as is achievable with natural crystals. The sensing material, however, should be versatile; that is, a ceramic whose properties can be controlled easily.

This need has now been met by a totally new development from the Endevco Electroceramic Laboratory. It is Piezite® Element Type 10. This new material, more familiarly known as P-10, is the latest and most exciting of the continuing series of new piezoelectric materials to result from Endevco's research and development programs.

This new ceramic possesses an almost unbelievable combination of performance characteristics:

- A unique capability for high temperature operation, unmatched by any other piezoelectric material available
- Proven long term stability
- High internal capacity
- Flat response, both charge and voltage, over a 1200 degree temperature range
- Utility with any type of instrumentation, charge or voltage.

For the instrumentation engineer faced with shock and vibration measurement at elevated temperatures, P-10 accelerometers are the ideal solution. These instruments will perform all the way to +750 degrees, without the need for any external cooling or other temperature control. This is actually well above the maximum range of quartz. Charge and voltage output remain high and the sensing material does not undergo "twinning," as does quartz. Figure 8 shows the variation in charge output with temperature for some typical piezoelectric materials. Note that only P-10 is rated all the way to +750°F.

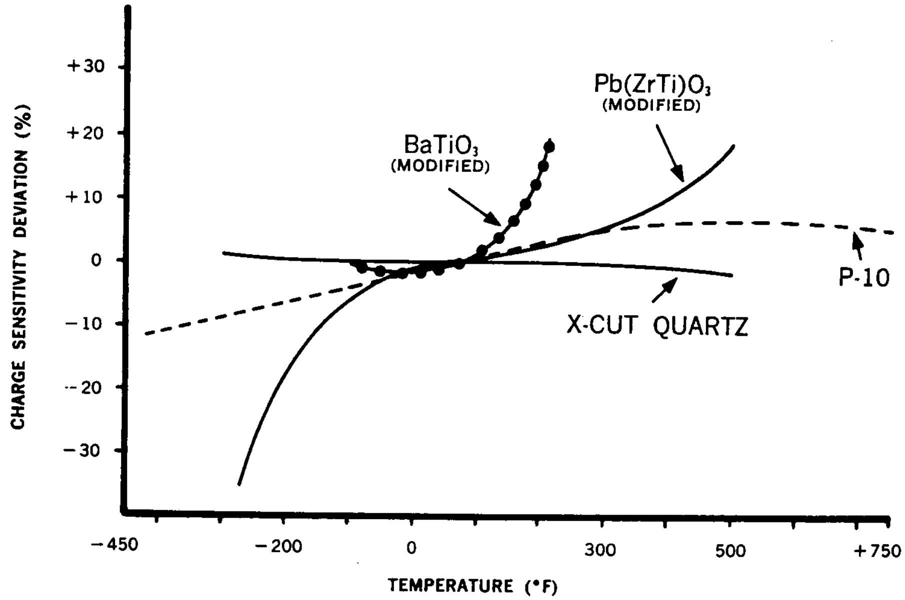


Figure 8

For the metrology specialist, transducers built with P-10 provide the long term stability and no-drift characteristics required in primary standards. This stability, coupled with ruggedness and proven reliability, also makes these units ideal as secondary or transfer standards. This is no idle boast, since these devices have been proven in actual use for more than 18 months with no detectable hysteresis or shelf life deterioration.

Perhaps the most interesting aspect of P-10 transducers, however, is that both charge and voltage output remain essentially flat with temperature from the cryogenic (−452°) to the blistering (+750°). And this is with large outputs, as much as ten times that of quartz.

All of these characteristics, plus the high internal capacity inherent in P-10, mean that transducers can now be built which are truly UNIVERSAL. They may be used with both charge and voltage electronics with equal success. They may be used over a 1200 degree range of temperatures. They may be used for low level vibration as well as high 'g' impacts. They may be used as laboratory standards as well as for everyday measurements.

For more information regarding P-10 transducers, contact your local Endevco Field Engineer or request data on the new 2270 series of piezoelectric accelerometers.

. . . Dale Pennington