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Performance of Three 500 °F Crystal Accelerometers

Technical Paper 200

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ENDEVCO CORPORATION

PERFORMANCE OF THREE 500° F CRYSTAL ACCELEROMETERS

Summary

The need for measuring and telemetering vibration and shock at high temperatures has prompted the development of several piezoelectric sensing materials for use in crystal pickups at the higher temperatures. Three promising materials for operation to 500° F have been evaluated; they are Lead Zirconate-Lead Titanate, Lead Metaniobate and PIEZITE Element Type II. Room temperature performance characteristics of experimental accelerometers using all three materials indicate high sensitivity (E) and capacity (C) advantages of Lead Zirconate-Lead Titanate combination. Individual properties of each material are tested to determine their stability to 500° F and above. From this data the accelerometer performance of each material is accurately predictable under specified loading and environmental conditions. Test results confirm the design predictions to 500° F. The results indicate the poor temperature linearity of Lead Zirconate-Lead Titanate accelerometers due to changing sensitivity and insulation resistance. Lead Metaniobate accelerometers exhibit good compensated linearity dependent on loading to 500° F although insulation resistance becomes marginal and low frequency response is sacrificed. PIEZITE Element Type II accelerometers provide the best linearity to 500° F without sacrifice of low frequency response. Based on test results PIEZITE Element Type II was chosen for use in high temperature accelerometers.

Desirable Specifications

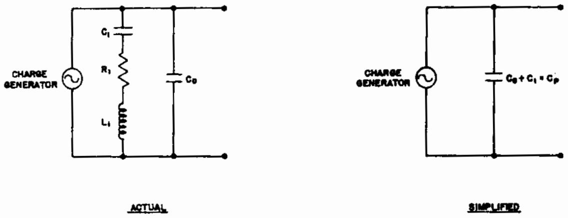
Standard crystal accelerometers are widely used to measure vibration and shock under low to medium temperature conditions. Their large, self-generated sensitivity, wide linear frequency range from below 5 cps to as high as 20,000 cps and small size have made them extremely useful for these purposes. Their upper temperature limit is determined by the Curie temperature where loss of sensitivity and permanent damage occur. This temperature has been somewhere between 200° F and 300° F for the commonly used piezoelectric materials.

To utilize the advantages of a crystal accelerometer to measure vibrations at higher temperatures, it has been necessary to develop new crystal materials and elements. They should provide the same wide range specifications as above. In addition, extreme linearity with temperature to 500° F is desirable so that measurements can be made without cooling or correction. The characteristics of the accelerometer should require only normal high impedance matching up to 1000 megohms for wide frequency performance. Dependence on higher impedance electrometer type circuits is not recommended because it is hard to maintain their high input impedance levels under conditions other than laboratory.

To be useful at high temperatures a crystal accelerometer should have high temperature accessories, including a noise-treated sub-miniature coaxial cable for use at the same temperatures and preferably a high temperature cathode follower or other high impedance matching circuit.

Electrical and Mechanical Design

A crystal accelerometer is effectively a capacitor which produces a charge Q across its plates proportional to an inertial force applied to the crystal. The equivalent circuit for the sensing element is shown in Figure 1. The simplified circuit is adequate for our analyses here. The voltage produced by the crystal is the total charge generated by the crystal (Q) divided by the capacity of the crystal and any additional external shunt capacity (Cp). An evaluation of both the variation of Q with temperature and the variation of C with temperature will determine the overall performance of the crystal at high temperatures.



EQUIVALENT CIRCUIT
PIEZOELECTRIC TRANSDUCER

Figure 1

A Technical Paper prepared for the National Telemetering Conference in El Paso, May 1957, by Wilson Bradley, Jr.

High Temperature Sensing Materials

During the past few years numerous laboratories have been working on the development of higher temperature piezoelectric crystal materials. Three of the most promising materials are Lead Zirconate-Lead Titanate combination,[1] Lead Metaniobate,[2] and PIEZITE Element Type II.[3]

To measure their characteristics each material was evaluated when used as the sensing element in a clamped crystal type of accelerometer design. This type of design appears to be most useful since it provides much higher sensitivities for any given natural frequency than is possible with any other type of design. Another reason for using the clamped crystal design is to provide the best signal to noise ratios under high audio noise fields often encountered in flight testing and engine testing. Higher initial signal levels combined with higher mechanical impedance that provides less response to the audio noise are the reasons for the improved performance.

The actual configuration used in the following comparisons was as shown in Figure 2. This crystal accelerometer in which the different materials were used was approximately $\frac{5}{8}''$ high and weighed approximately 1 ounce.

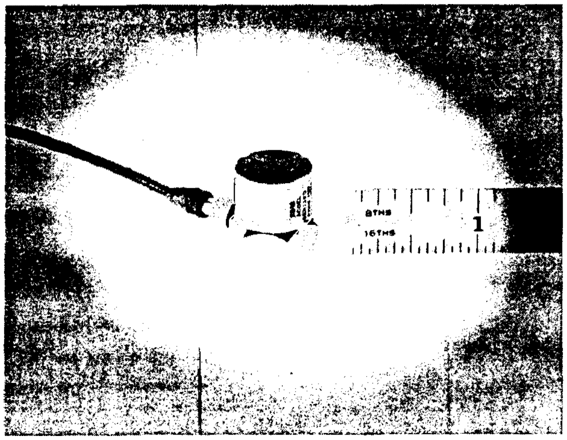


Figure 2

The performance of the three materials at room temperature is shown in Figure 3. PIEZITE Element Type I is a medium temperature (230° F) sensing material and is shown for purposes of comparison. The Lead Zirconate-Lead Titanate combination and Lead Metaniobate showed about equal sensitivities but the Lead Metaniobate lacked the high dielectric constant of the Lead Zirconate and Lead Titanate and therefore provided only 1/3 as much capacity. The PIEZITE Element Type II provided lower sensitivity with capacity slightly under that of the Lead Metaniobate.

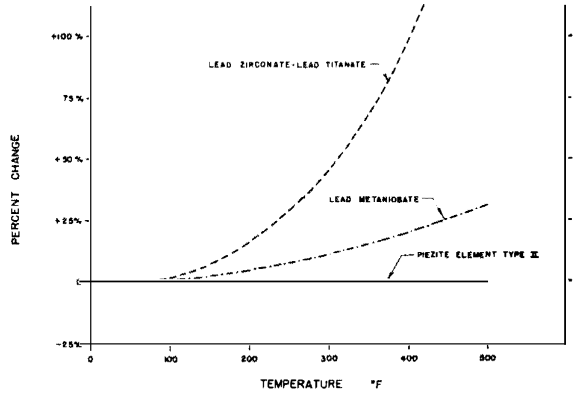
ROOM TEMPERATURE CHARACTERISTICS

SENSING ELEMENT	SENSITIVITY (WITH 3' CABLE)	NATURAL	CAPACITY (WITH 3' CABLE)
PIEZITE ELEMENT TYPE I *	12 MV/G	35 KC	500 MMFD
LEAD ZIRCONATE - LEAD TITANATE	12 MV/G	35 KC	1000 MMFD
LEAD METANIOBATE	14 MV/G	35 KC	300 MMFD
PIEZITE ELEMENT TYPE II	8 MV/G	35 KC	210 MMFD

* LIMITED TO 230° F. OPERATION — FOR COMPARISON PURPOSES ONLY.

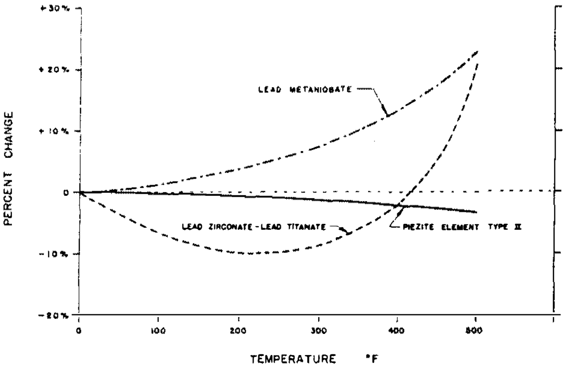
Figure 3

The importance of these materials, however, is their linearity with temperature. Figures 4 through 8 show temperature characteristics to 500° F. Figure 6 shows the voltage linearity with temperature of the three materials. Lead Zirconate-Lead Titanate, which was most desirable at room temperature above, was shown to be extremely nonlinear with temperature and required large correction factors to obtain any degree of accuracy in measurement. Lead Metaniobate and PIEZITE Element Type II had a very linear voltage coefficient up to 500° F. It is important here to note that the voltage coefficient is equal to the charge Q divided by the capacity C. Both the capacity and charge coefficients of PIEZITE Element Type II as shown in Figures 4 and 5 were exactly linear with temperature, while in the case of Lead Metaniobate the capacity and charge both increased about 30%, thus cancelling each other out for the voltage linearity. This pointed out one of the possible drawbacks of Lead Metaniobate; its temperature linearity will change depending on how much external



CAPACITY (C) VS. TEMPERATURE

Figure 4



CHARGE SENSITIVITY (q) VS. TEMPERATURE

Figure 5

capacity is added to the pickup. Added external capacity will unbalance the compensating factors that have produced the linear voltage curve and it may be necessary to make large correction factors to maintain measurement accuracies.

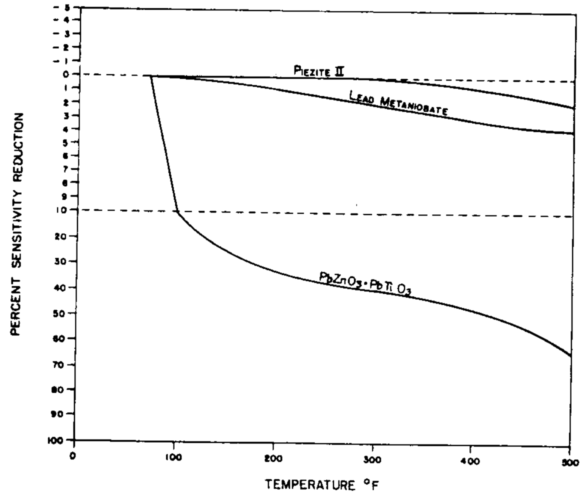
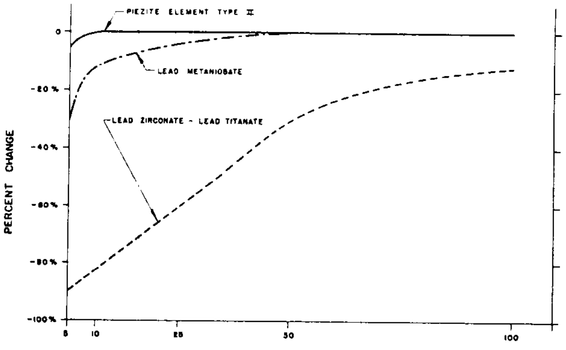


Figure 6

Low frequency response of the three materials is as shown in Figure 7. Again, the PIEZITE Element Type II is the most stable providing low frequency response flat within 5% down to 5 cps as compared to 30% down and 90% down for Lead Metaniobate and Lead Zirconate-Lead Titanate, respectively. The response of a crystal accelerometer is determined by the time constant of the total shunt capacity and crystal capacity (C) in the system times the total system resistance (R) per the equation:



LOW FREQUENCY RESPONSE AT 500° F.
WITH 1000 MEGOHM MATCHING IMPEDANCE

Figure 7

$$\text{Response} = \frac{2\pi fRC}{[1 + (2\pi fRC)^2]^{1/2}}$$

Normally, the resistance (R) of the system is determined by the input impedance of the high impedance matching amplifiers which may range between 50 and 1000 megohms. In the case of many high temperature crystal sensing materials, however, the actual insulation resistance in the crystal drops well below 1000 megohms so that it is the determining factor of the resistance of the system. Figure 8 shows the insulation resistance of the three materials versus temperature and explains the reason for low frequency fall off in the materials whose insulation resistance drops below 1000 megohms before 500° F is reached.

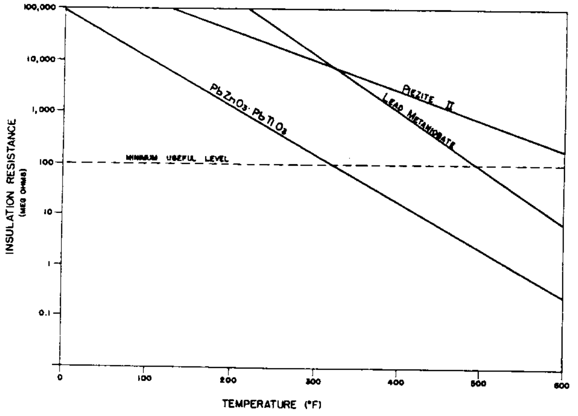


Figure 8

High Temperature Accessories

To utilize the characteristics of a high temperature accelerometer it was necessary to develop a 500° F subminiature noise-treated cable. The resulting design was a cable of approximately 0.100 inch in diameter, which had a solid Teflon dielectric and a fused Teflon jacket. Noise treatment was achieved by wrapping conducting material about the inner dielectric to electrically couple it to the shield at all points. This cable[4] is as noise-free and reliable as subminiature coaxial cables used for lower temperature vibration measurements and is only slightly stiffer due to the Teflon dielectric. The capacity of a 3-foot length of this cable is approximately 100 mmfd. which drops approximately 10% at 500° F, introducing very little error into the system. Its insulation resistance is maintained above 100,000 megohms at temperatures of 500° F.

A 500° F cathode follower[5] is shown in Figure 9. It provided 100 megohms input impedance, gain of 0.94, and flat frequency response to 20 KC. These electrical characteristics were independent of temperature up to 500° F. It is approximately 1.1 inches in diameter and 2.4 inches long. The advantage of a cathode follower in this case was to provide high impedance match to the accelerometer in the high temperature area without the need for running long leads that would attenuate the signal if the cathode follower were located in a distant low temperature area.

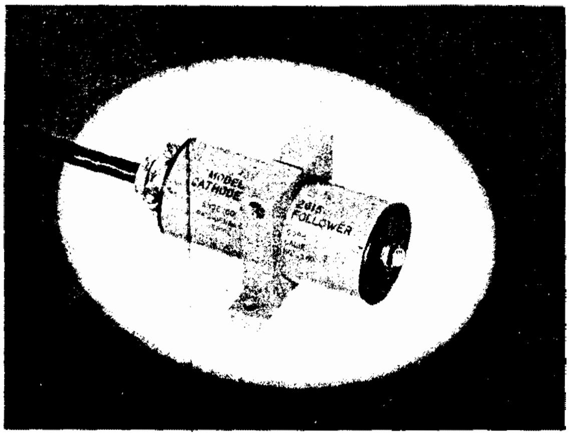


Figure 9

Conclusions

Of the three sensing materials tested, PIEZITE Element Type II offered the most advantage for vibration and shock measurements to 500° F. It had medium sensitivity and capacity and provided extreme linearity with temperature up to 500° F. It could be capacitively loaded without changing its temperature linearity. It further provided high insulation resistance at 500° F that insured good low frequency response again regardless of temperature. It was the only one of the materials tested that could be used to 500° F for reliable measurements without correction. Because of the above characteristics PIEZITE Element Type II was chosen as the sensing element for high temperature accelerometers[6] linear to 500° F.

NOTES

1. JOURNAL OF RESEARCH OF THE NATIONAL BUREAU OF STANDARDS; Vol. 55, No. 5, November 1955; Research Paper 2626.
2. JOURNAL OF AMERICAN CERAMIC SOCIETY; Vol. 36, No. 11, November 1954; pages 368-372.
3. Developed by Endevco Corporation, Pasadena, California.
4. Model 3090 Cable Assembly, Endevco Corporation.
5. Model 2615 Cathode Follower, Endevco Corporation.
6. Model 2242 Accelerometer, Endevco Corporation.

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