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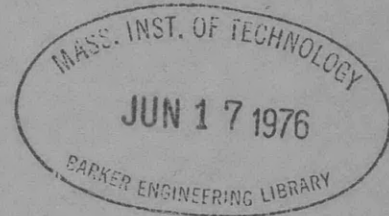
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DAVID TAYLOR MODEL BASIN
WASHINGTON, D. C.

CALIBRATION OF PIEZOELECTRIC GAGES
AT THE DAVID TAYLOR MODEL BASIN

by

A. Borden, Ph.D.



~~CONFIDENTIAL~~

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The work described was done by Dr. A. Borden with the assistance of A.R. Cohen. Many valuable suggestions were made by Dr. M.A. Greenfield and Lt. D. Bancroft, USNR. The report was written by Dr. Borden.

CALIBRATION OF PIEZOELECTRIC GAGES AT THE DAVID TAYLOR MODEL BASIN

ABSTRACT

Piezoelectric gages are calibrated at the David Taylor Model Basin by subjecting them to known hydrostatic pressures and by measuring the charge developed on the surfaces of the crystals when the pressure is released. Results accurate to 1 per cent are obtained when the pressure is released in a fraction of a millisecond by bursting a thin diaphragm and the record is photographed on a cathode-ray oscillograph. The results obtained with slow-responding instruments, such as a microcoulometer or electrometer, are unsatisfactory. This is caused by a change of temperature in the medium about the crystal which occurs with the release of pressure. In the few seconds which elapse before the instruments respond, the crystal develops a pyroelectric charge which is an appreciable fraction of the piezoelectric effect.

INTRODUCTION

The purpose of this report is to present a reliable method for the calibration of piezoelectric gages and to discuss the difficulties which were encountered at the David Taylor Model Basin in early attempts to calibrate these gages. Although many of the difficulties have been described in TMB progress reports (1) (2),* the present report summarizes this material and recounts all of the research which has been done in developing a standard method for calibrating piezoelectric gages. The assembly and use of tourmaline gages in measuring underwater explosions are described in other reports (3) (4).

Small piezoelectric gages are particularly useful in investigating underwater explosions where it is essential to obtain an accurate pressure-time curve of the explosion. Since the charges developed on the surfaces of the crystal follow the changes in pressure, these gages give a more accurate record of the variation of pressure with time than any other type of gage now available. As the amount of charge developed per unit change in pressure depends not only on the piezoelectric constant of the material but also on the area of the crystal, each gage must be carefully calibrated before it is used.

The methods of calibration studied at the Taylor Model Basin fall into two classes: In the first the charge developed on the surfaces of the crystal is measured with instruments which require an appreciable time to respond; in the second the output of the gage is applied to the Y-plates of

* Numbers in parentheses indicate references on page 20 of this report.

a cathode-ray oscillograph and the record is photographed instantaneously. The second method has given very satisfactory results and has been adopted as the standard method of calibration. The inferiority of the first method is due to the slow response of the instruments. Errors introduced by this delay are discussed in this report.

In calibrating gages it is necessary to simulate as closely as possible the conditions under which they will be used. It is important to study how the manner of mounting the crystal and the type of coating applied to insulate it affect the calibration. Since the transient shock waves encountered in explosions are much faster than pressure releases produced in the laboratory, studies are needed to make sure that the gage constants are the same in both cases.

PIEZOELECTRIC CONSTANT

The piezoelectric constant K is defined as the quantity of charge generated per unit area per unit change in pressure

$$K = \frac{Q}{A \times P} \text{ coulombs per pound}$$

where Q is the charge in coulombs,

A is the effective area of the crystal in square inches, and

P is the change in pressure in pounds per square inch.

Because the response of a gage is proportional to the area as well as to the piezoelectric constant K , the product KA is used as the constant of the gage. Then

$$KA = \frac{Q}{P} \text{ coulombs per pound per square inch}$$

The value of the piezoelectric constant of tourmaline depends upon the way in which the crystal is cut and, since the chemical composition varies in different deposits, also upon its geographical source. When the crystals are cut normal to the optical axis and subjected to hydrostatic pressures, the K values given in the International Critical Tables range from 9.8×10^{-12} to 10.9×10^{-12} coulombs per pound. Most of the crystals used at the Taylor Model Basin have K values between 10.6×10^{-12} and 12.0×10^{-12} coulombs per pound.

HIGH-PRESSURE SYSTEM

Provision has been made for calibrating tourmaline crystals either before they are mounted on a cable or as completed gages. In either case they are sealed into a pressure chamber and subjected to known hydrostatic pressures. The charge developed is measured when the pressure is released.

If slow-recording instruments are to be used for measuring the charge, the pressure is released by turning a hand valve. A faster release is needed when the gage response is to be recorded on an oscillograph, and therefore provision has been made for releasing the pressure in 0.2 millisecond by bursting a diaphragm. Static pressures are read with an accuracy of better than 1 per cent on either of two Bourdon gages which are calibrated periodically at the National Bureau of Standards. One gage has a range of 2000 pounds per square inch and the other a range of 5000 pounds per square inch.

PRESSURE CHAMBER

Figure 1 shows the cylindrical pressure chamber with the appropriate fittings for sealing in a rubber molded gage. The chamber is supported on either side by a heavy stand and may be rotated about a horizontal axis

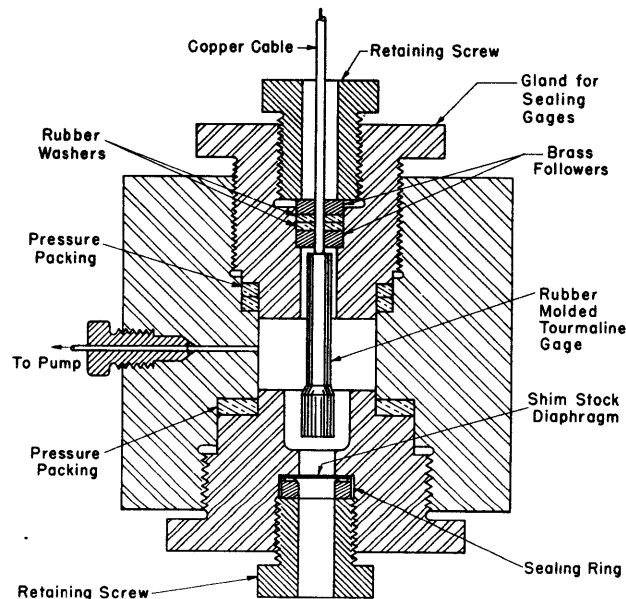


Figure 1 - Cylindrical Pressure Chamber

The rubber washers and brass followers, which fit around the cable of the gage and provide the pressure seal, are split to make the system easy to assemble. A rust-inhibiting solution of potassium dichromate and sodium carbonate is used as the fluid in the chamber. The change in pressure is obtained by first applying a static pressure by pumping fluid into the chamber and then releasing it suddenly by puncturing the diaphragm.

by loosening two nuts. Each end of the chamber is fitted with removable glands; one provides the seal for the gages and the other contains a small hole and recess which may be sealed in either of two ways.

The change in pressure used for calibrating the gage is obtained by first applying a known static pressure to the cavity containing the gage and then releasing it suddenly. If the pressure is to be released by turning the

hand valve, a brass plug with a rubber washer is pressed into the hole and sealed by tightening the retaining screw. If a fast release is to be employed, a thin brass diaphragm is placed over the hole and is sealed by applying pressure to a brass ring. The ring has two slightly raised ridges which press into the diaphragm when the retaining screw is tightened. This type of pressure seal is shown in Figure 1.

To insure a fast pressure release the diaphragm must be close to its bursting point when struck so that it tears over a large area. A screw driver is found to be the best tool for puncturing the diaphragms as it starts a larger hole than a sharp-pointed instrument. Brass shim stock of thicknesses between 0.003 and 0.010 inch is found to make satisfactory diaphragms for pressures between 500 to 3500 pounds per square inch.

The thickness t of a diaphragm of radius a , which will burst spontaneously at a pressure p , is given approximately by (5)

$$t = \frac{1 + \left(\frac{z}{a}\right)^2}{4\sigma\left(\frac{z}{a}\right)} ap$$

where z is the central deflection of the diaphragm just before bursting and σ is the yield stress. Since the diaphragm bursts when z/a is about 0.5, it is possible to calculate the approximate thicknesses needed for each pressure. The previous history and treatment of the material affect its behavior.

CALIBRATION OF BARE CRYSTAL ELEMENTS

Unmounted crystals can be calibrated in the same pressure chamber used for the completed gage. The gland for sealing gages into the pressure chamber can be replaced by another gland containing a small oil chamber. The latter can be sealed off from the fluid of the chamber with a thin rubber diaphragm. Two such glands for calibrating bare crystals have been constructed, and these will be designated as Chambers 1 and 2 respectively. Sketches of these chambers are shown in Figures 2 and 3. Since Chamber 2 is easier to assemble, Chamber 1 is seldom used now for calibrating gages.

DYNAMIC METHOD OF CALIBRATION

The most successful method of calibrating gages at the Taylor Model Basin requires the use of a fast pressure release, and a cathode-ray oscillograph for recording the signal. The gage is connected to the Y-plates of a

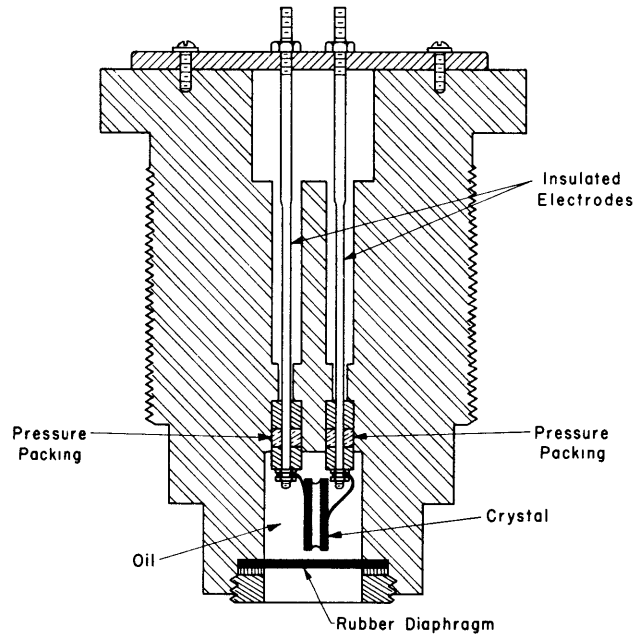


Figure 2 - Oil Chamber 1 for the Calibration of Bare Tourmaline Crystals

The binding posts are two thin rods, one or both of which may be insulated from the walls of the chamber with a coating of Bostik cement. Each rod is supported at one end by plastic cylinders and a rubber washer, which fit into small recesses and provide the pressure seal. The other ends protrude through holes in a bakelite cover which is screwed into the top of the chamber. Wires with small lugs are soldered to a crystal, and the crystal is connected across the two binding posts.

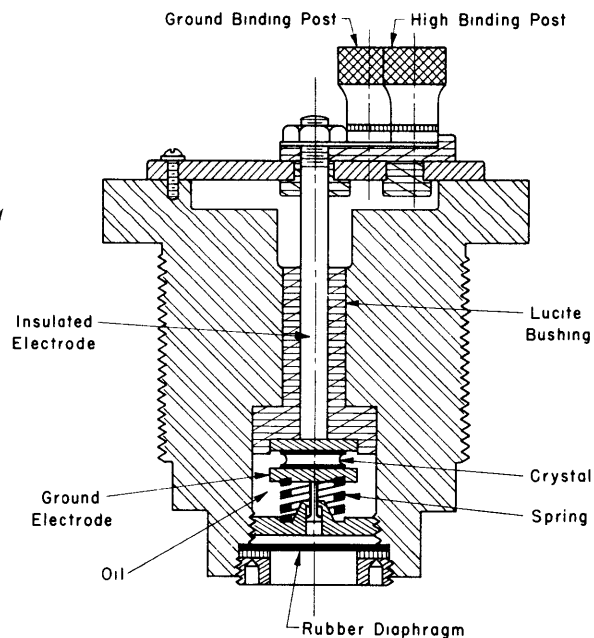


Figure 3 - Oil Chamber 2 for the Calibration of Bare Tourmaline Crystals

The insulated electrode is sealed into the gland by a Lucite bushing. The second electrode, which is at ground potential, is screwed into the chamber and holds the crystal in place by the action of a spring.

Du Mont Type 208 oscillograph through its internal amplifier. The circuit is shown schematically in Figure 4. To insure a sufficiently long time constant the gages are constructed so that they have a high impedance. Moreover, a 0.02-microfarad capacitor is placed in parallel with the gage. Since the input resistance of the oscillograph is 2 megohms, the time constant is of the order of 40 milliseconds. Hence, the relative decay of the signal due to d-c leakage is less than 1 per cent during the 0.2 millisecond required for the pressure release.

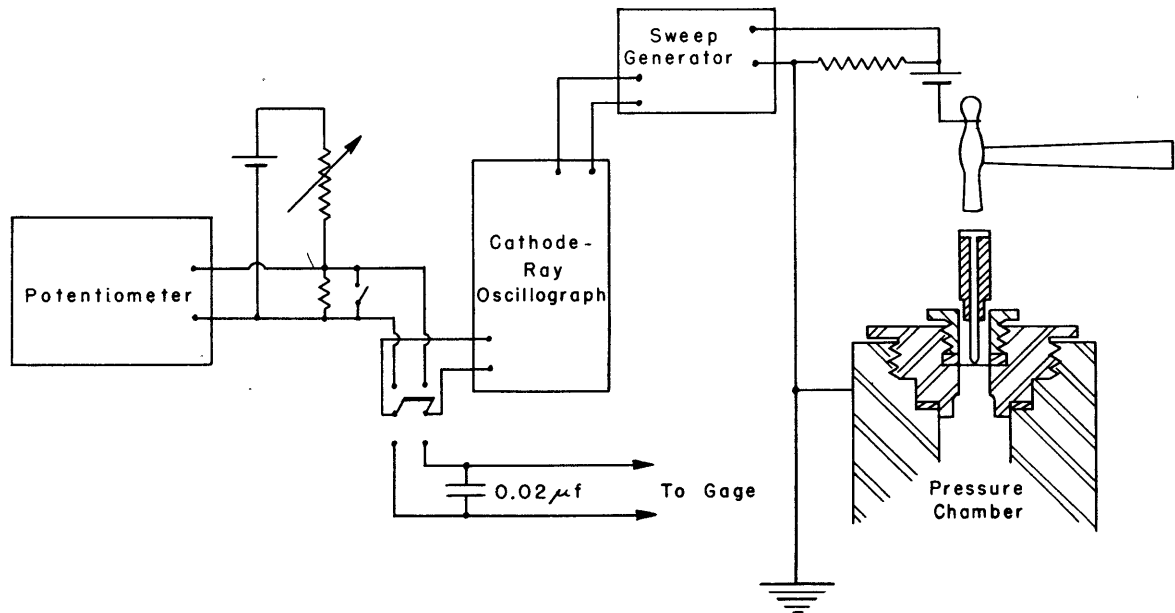


Figure 4 - Circuit for the Oscillographic Bursting-Diaphragm Method of Calibration

The horizontal sweep of the oscillograph is initiated at the same time that the diaphragm is punctured, by having the hammer close the trigger circuit when it strikes a contact on top of the screw driver. A typical pressure record, photographed with an Eastman Ektra camera, is shown in Figure 5. The height of the signal is measured with a micrometer microscope.

A voltage calibration is made by applying a known voltage, precisely measured on a Leeds and Northup Type K potentiometer, to the plates of the oscillograph in the form of a step pulse. This is done by opening or closing the key in the potentiometer circuit. The sweep is started when the key is struck with the hammer. A typical calibration record is shown in Figure 6.

Five crystals supplied and calibrated by the Stanolind Oil and Gas Company were studied very carefully by this method. One of the crystals had also been calibrated at the Underwater Explosives Research Laboratory at

very wide range of frequencies. Since most of the rubber cables exhibited a large dissipation, they were eliminated from the circuit wherever possible. Where shielded cables were needed, wax-filled copper tubes (3) (4) with low dissipation were used. In every case a high quality mica capacitor constituted the major portion of the capacitance.

INVESTIGATION OF SIGNAL DECAY WITH A STRING OSCILLOGRAPH

The previously described technique of gage calibration with the microcoulometer was followed as nearly as possible, using a string oscillograph instead of a galvanometer as a recording instrument. The pressure was released by bursting a diaphragm, and records were made over a period of 4 seconds with the string oscillograph. Typical records are shown in Figures 10, 11, and 13. Although the system was carefully shielded and grounded, a

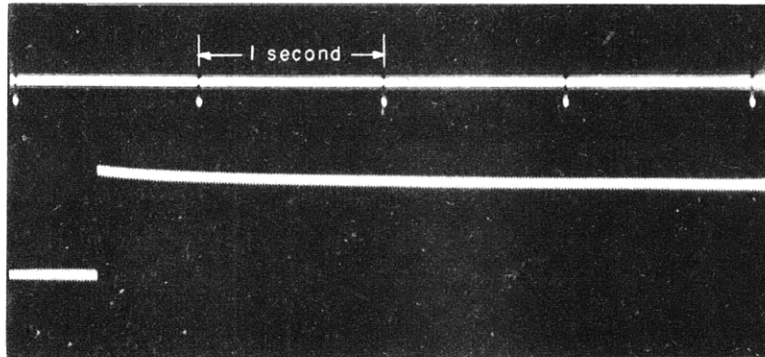


Figure 10 - String-Oscillograph Pressure Record for a Crystal Immersed in Machine Oil

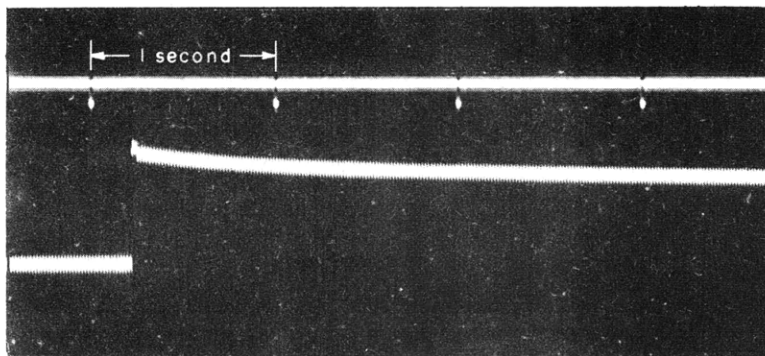


Figure 11 - String-Oscillograph Pressure Record for a Crystal Immersed in Carbon Tetrachloride

certain amount of a-c pickup could not be avoided. In some instances the records show a slight overshoot which was neglected in reading the films.

TABLE 1
Calibrations of Tourmaline Crystals by the Dynamic Method

Gage	Area square inch	Stanolind		TMB - Unmounted			TMB - Mounted		
		$KA \times 10^{12}$	$K \times 10^{12}$	Number of Trials	$KA \times 10^{12}$	$K \times 10^{12}$	Number of Trials	$KA \times 10^{12}$	$K \times 10^{12}$
275	0.0865	0.921	10.64	27	0.916 ± 0.008	10.58	12	0.927 ± 0.004	10.72
282	0.084	0.887	10.58	30	0.902 ± 0.006	10.74	25	0.901 ± 0.007	10.72
284	0.085	0.902	10.61	17	0.910 ± 0.011	10.70	12	0.893 ± 0.010	10.51
285	0.074	0.789	10.66	28	0.785 ± 0.018	10.61	15	0.789 ± 0.007	10.66
XT 503	0.1122	1.206	10.74	27	1.182 ± 0.011	10.53	15	1.196 ± 0.010	10.66

SLOW-RECORDING METHODS OF CALIBRATION

A large number of gages have been calibrated with slow-recording instruments. For each gage a series of 10 or 12 pressure readings were made in which the deviations of the plotted points from linearity seldom exceeded 1 or 2 per cent. Furthermore, a second calibration usually checks the first within the experimental error. Despite the internal consistency of the results for a given gage, the KA values are between 8 and 15 per cent lower than those obtained by the dynamic method. In addition, the computed values of K show considerable dispersion.

MICROCOULOMETER

Most of the calibrations by the slow-recording method were made with a microcoulometer. This instrument is used as an impedance coupler between the gage and a galvanometer. The microcoulometer, which is a modification of a micromicroammeter described by S. Roberts (6), was designed by C. Starr for use with high-impedance gages. The circuit is as shown in Figure 7. The variable resistances which control the plate current of the second tube are adjusted so that no current flows in the output circuit when the input is shorted. When a small difference of potential is applied across the input, a voltage appears on the control grid of the first tube which upsets the balance and causes a current to flow in the output circuit. The complete circuit for gage calibrations is shown in Figure 8. For the voltage calibration the gage is replaced by a potential divider which supplies an accurately measured electromotive force.

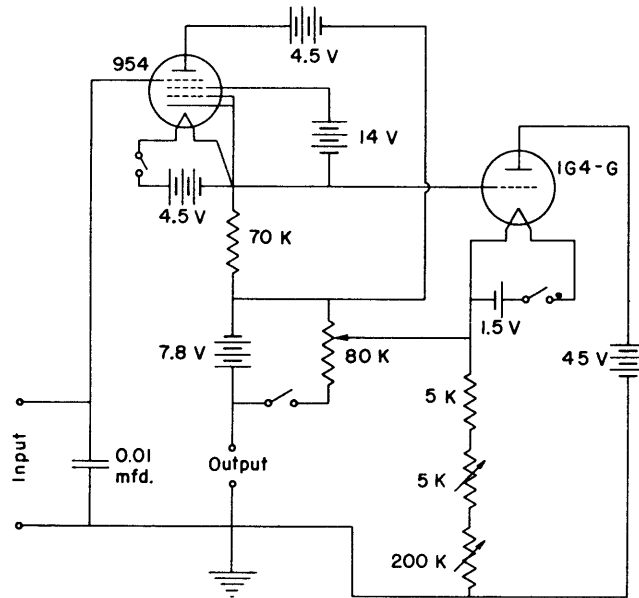


Figure 7 - Microcoulometer Circuit

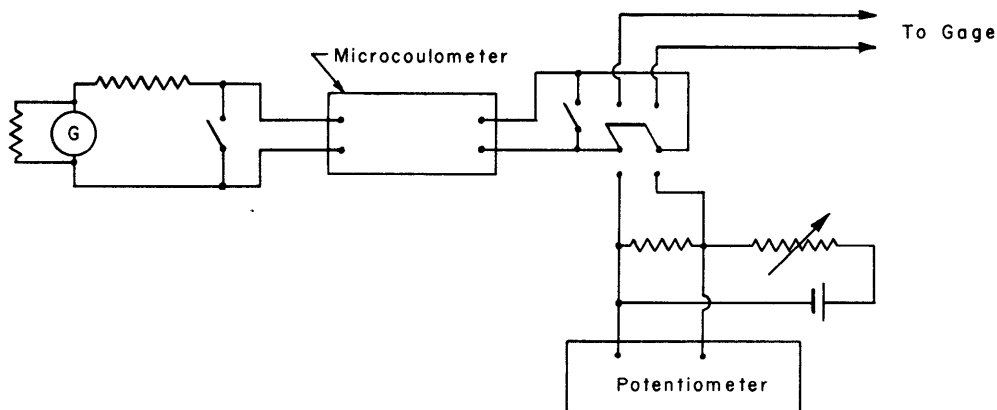


Figure 8 - Circuit for Gage Calibrations with Microcoulometer

ELECTROMETER

Since very little was known at first about the microcoulometer, many of the measurements were repeated with a Compton quadrant electrometer. The circuit which is shown in Figure 9 is essentially the same as the circuit for the microcoulometer. Although the behavior of each circuit was internally consistent, discrepancies of 5 per cent were often encountered between the results from the two methods. In most cases the KA values obtained with the electrometer were lower than those obtained with the microcoulometer. It was suspected that this discrepancy was due to the period of 6 seconds required for the electrometer needle to make a deflection, as compared with 2 seconds

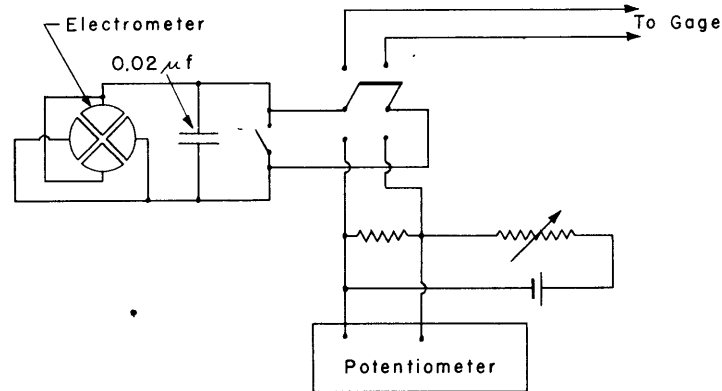


Figure 9 - Circuit for Gage Calibrations with Electrometer

for the microcoulometer. As the impedance of the system was kept high enough to insure a time constant of 5 minutes, these errors were not due to d-c leakage.

INVESTIGATION OF DISCREPANCIES IN THE SLOW-RECORDING METHODS

Since calibrations could be made more quickly and conveniently with the slow-recording method than with the dynamic method, studies were undertaken to account for the discrepancies encountered in the former method. As the microcoulometer lent itself to this investigation more conveniently and was easier to operate than the electrometer, all tests were made with the microcoulometer.

RESPONSE OF THE MICROCOULOMETER

The behavior of the microcoulometer was investigated by making a complete gage calibration with the microcoulometer connected in the circuit between the gage and the oscillograph. The pressure records had the same appearance as those obtained with the gage connected directly to the oscillograph, and the gage constant differed by less than 1 per cent. This proved that the microcoulometer was behaving properly, at least during the first few milliseconds.

INVESTIGATION OF CAPACITORS

The capacitances of all the capacitors used in this investigation were measured on a General Radio capacitance bridge of the Schering type, whose calibration had been checked at the National Bureau of Standards. This bridge was used with an external oscillator which made it possible to measure the capacitance and dielectric absorption over a wide range of frequencies. All the capacitors used in the circuit showed a constant capacitance over a

very wide range of frequencies. Since most of the rubber cables exhibited a large dissipation, they were eliminated from the circuit wherever possible. Where shielded cables were needed, wax-filled copper tubes (3) (4) with low dissipation were used. In every case a high quality mica capacitor constituted the major portion of the capacitance.

INVESTIGATION OF SIGNAL DECAY WITH A STRING OSCILLOGRAPH

The previously described technique of gage calibration with the microcoulometer was followed as nearly as possible, using a string oscillograph instead of a galvanometer as a recording instrument. The pressure was released by bursting a diaphragm, and records were made over a period of 4 seconds with the string oscillograph. Typical records are shown in Figures 10, 11, and 13. Although the system was carefully shielded and grounded, a

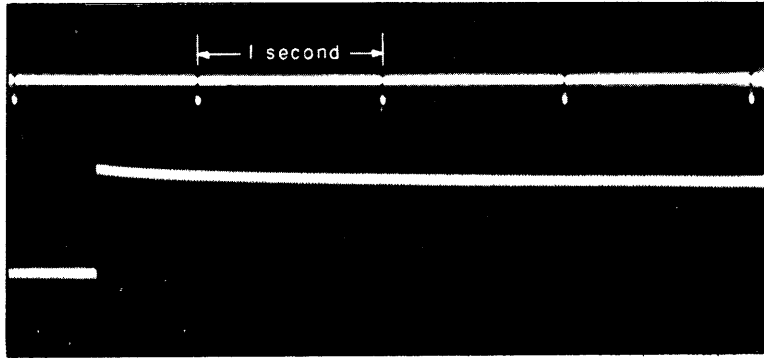


Figure 10 - String-Oscillograph Pressure Record for a Crystal Immersed in Machine Oil

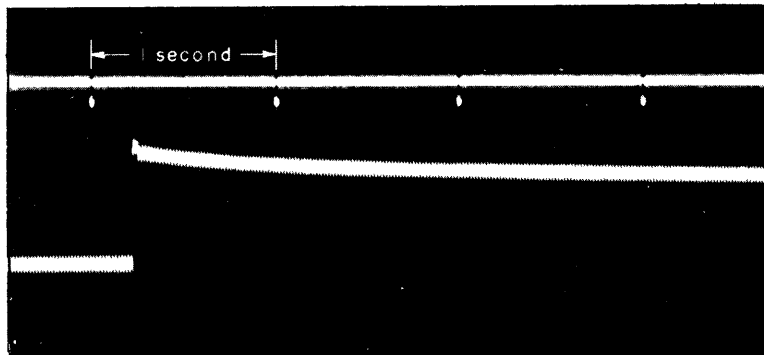


Figure 11 - String-Oscillograph Pressure Record for a Crystal Immersed in Carbon Tetrachloride

certain amount of a-c pickup could not be avoided. In some instances the records show a slight overshoot which was neglected in reading the films.

Whereas the initial heights give a fairly good determination of the gage constant, the records show a decay which starts immediately, continues for several seconds, and then flattens out.

Although no dissipation had been observed in measuring the capacitance of the Cornell Dubilier 4 LST mica capacitor used on the input of the microcoulometer, string-oscillograph records were made with other standard capacitors substituted in the circuit. One of these standards was a 0.01-microfarad air capacitor which was borrowed from the National Bureau of Standards. The other was a General Radio Type 509 mica capacitor. Each of the three capacitors was connected in turn across the input of the microcoulometer. The KA of the gage was measured from the initial height of the curve, and the relative decay in two seconds was computed. These results for a crystal immersed in machine oil are recorded in Table 2. It is apparent that the quality of the capacitors is not at fault since the KA values are nearly identical and the rate of decay is about the same in every case.

TABLE 2

Effect of Different Parallel Capacitors upon the Response of a Tourmaline Crystal

Capacitor	$KA \times 10^{12}$	Per Cent Decay in 2 seconds
General Radio	11.95	11
Air Condenser	11.93	12
C D 4 LST Mica	11.94	11

EFFECT OF THE MEDIUM SURROUNDING THE CRYSTAL

The effect of the medium surrounding the crystal was studied with a string oscillograph in the same way. The media investigated were machine oil, castor oil, petroleum jelly, carbon tetrachloride, Zophar Mills wax 1340, and rubber. In the last instance a rubber-molded gage was studied. In the other cases the crystal was mounted in Oil Chamber 1, which is shown in Figure 2. This chamber is particularly well suited for this investigation since the gage is in direct contact with the medium on all sides.

The impedance of the system was measured in each case on a General Radio Type 544-B megohm bridge to insure a time constant of at least 3 minutes. Thus the d-c leakage could not account for more than 1 per cent of the decay. In Table 3, Columns 5 and 6, the KA values and the relative decay in 2 seconds are given for each medium. The KA values obtained when the crystal

TABLE 3

Effect of the Medium on the Calibrations of Piezoelectric Crystals

1	2	3	4	5	6
Gage	Medium	Impedance Megohms	CRO* $KA \times 10^{12}$	S.O.** $KA \times 10^{12}$	Per Cent Decay in 2 seconds
499	Petroleum Jelly	30,000	1.215	1.20	14
499	Machine Oil	30,000	1.215	1.20	11
XT 503	Castor Oil	30,000	1.196	1.20	12
XT 503	C C ₁₄	24,000	1.196	1.19	20
499	Zophar Mills Wax	30,000	1.215	1.03	4
XT B13	Rubber Molded	50,000	0.857	0.847	5

* Cathode-ray oscillograph
** String oscillograph

was surrounded by wax is low because the medium is too stiff to transmit the pressure faithfully. The results from a careful determination of the gage constant of each crystal are given in Column 4. In most cases the crystal was immersed in machine oil and not in the medium indicated for the investigation with the string oscillograph. The results indicate that the magnitude of the decay depends upon the medium surrounding the crystal.

EFFECT OF CHANGE IN TEMPERATURE ASSOCIATED WITH THE RELEASE OF PRESSURE

It was suggested* that, since many liquids show an appreciable temperature change with a sudden release of pressure, the decay might arise from a pyroelectric effect in the crystal. From thermodynamic considerations, the adiabatic change in temperature is given by the relation

$$\left(\frac{\partial T}{\partial p}\right)_s = \frac{T\alpha_p}{\rho c_p} \quad [1]$$

where T is the absolute temperature,
 α_p is the thermal coefficient of volume expansion,
 ρ is the density,
 c_p is the specific heat at constant pressure, and
 s is a subscript which indicates constant entropy.

* The suggestion was offered by Lieut. D. Bancroft, USNR, of the Electronics Section of the Taylor Model Basin.

Calculations made for the various media are recorded in Table 4. Although the effect in the tourmaline crystal itself is negligibly small, the different media used to surround the crystal show a temperature change between 0.6 and 1.9 degrees centigrade for a pressure change of 1000 pounds per square inch.

TABLE 4

Adiabatic Temperature Change in Degrees Centigrade Accompanying a Pressure Change of 1000 Pounds per Square Inch and the Ratio between the Pyroelectric Effect and the Piezoelectric Effect

1	2	3	4
Medium	Calculated $\left(\frac{\partial T}{\partial p}\right)_s \times 10^3$	Observed $\left(\frac{\partial T}{\partial p}\right)_s \times 10^3$	Observed $\frac{\Delta Q_{\text{pyro}}}{\Delta Q_{\text{piezo}}}$
Tourmaline	0.01*		0.0033 (calc)
Petroleum	1.10	1.07	0.26
C C1 ₄	2.15	1.87	0.454
Castor Oil		0.61	0.148
Machine Oil		0.93	0.226
Rubber	0.55	0.811	0.197
Z M 1340 Wax		0.62	0.150
* This value was taken from Reference (7).			

From data in the International Critical Tables the pyroelectric constant of tourmaline is computed to be 2.58×10^{-9} coulombs per square inch per degree centigrade. The piezoelectric constant per unit area for most of the crystals is 10.63×10^{-12} coulombs per pound per square inch. The charges produced by the pyroelectric and piezoelectric effects respectively are

$$\Delta Q_{\text{pyro}} = 2.58 \times 10^{-9} (\Delta T)_s \text{ coulombs}$$

$$\Delta Q_{\text{piezo}} = 10.63 \times 10^{-12} (\Delta p)_s \text{ coulombs}$$

The ratio of the pyroelectric effect to the piezoelectric effect is thus

$$\frac{\Delta Q_{\text{pyro}}}{\Delta Q_{\text{piezo}}} = 243 \left(\frac{\Delta T}{\Delta p}\right)_s \quad [2]$$

Since $\left(\frac{\Delta T}{\Delta p}\right)_s$ is a constant for a given medium at a given temperature, the ratio of the two effects is independent of the pressure and depends entirely upon the value of this coefficient for the particular medium. Thus, if a substance should undergo a temperature change of 1 degree during a change of pressure of 1000 pounds per square inch, the magnitude of the pyroelectric effect would be 24.3 per cent of that of the piezoelectric effect. This is the order of magnitude of the effect measured in most of the media investigated. Since the charge developed during a fall in temperature is opposite to that developed during a drop in pressure, this effect would act to lower the observed piezoelectric effect. However, a somewhat smaller discrepancy is to be expected, since the crystal and chamber have an appreciable heat capacity and since the medium surrounding the crystal does not conduct heat readily.

Oil Chamber 1, shown in Figure 2, which had formerly been used for calibrating bare crystals, was modified slightly for the insertion of a thermocouple. One of the iron binding posts was replaced by an insulated brass rod, and a brass-iron thermocouple was soldered in place between the two posts. Each of the media formerly used in the crystal investigations was tested for temperature change upon the release of pressure. The thermocouple was connected to a Leeds and Northrup galvanometer through a suitable series resistance. Observations were made for a pressure range between 1500 and 3500 pounds per square inch. The thermocouple was then calibrated by using a number of fixed temperature points.

The observed temperature changes are listed in Column 3 of Table 4. The accuracy is probably no better than 5 per cent. The calculated temperature changes were computed from the constants given in the various handbooks and tables. Since the chemical composition of rubber is variable and since carbon tetrachloride is near a change of state at the pressures employed, these values cannot be relied upon except to indicate the order of magnitude to be expected. The ratio of the pyroelectric to the piezoelectric effect, computed from Equation [2] by multiplying the observed temperature change per 1000 pounds per square inch change in pressure by 0.243, is listed for each medium in Column 4 of Table 4.

Since the crystal with its copper electrodes has an appreciable heat capacity, the following experiments were performed to find out what fraction of the total temperature change is communicated to the crystal during the first few seconds. Parts of two broken crystals were cemented over the thermocouple in the chamber. The resulting crystal was somewhat thicker than usual. It was possible, however, to study the variation of temperature with time after the pressure was released.

Measurements were first made with the thermocouple embedded in the crystal and then were repeated after removing the crystal. Since the galvanometer used to investigate the temperature change deflected too slowly to give a true temperature-time curve, it was replaced by a small milliammeter, which deflected in a fraction of a second. A d-c amplifier, borrowed from the Naval Research Laboratory, was employed to amplify the voltage sufficiently to permit the use of this milliammeter. The meter readings were photographed with a motion-picture camera at the rate of 16 frames per second. From these pictures the temperature-time curves shown in Figure 12 were drawn.

From these curves it is possible to estimate the change in temperature taking place in the crystal during the first few seconds and to calculate the expected rate of decay of the piezoelectric signal. From the relative heights of the two curves in Figure 12 it is possible to compute

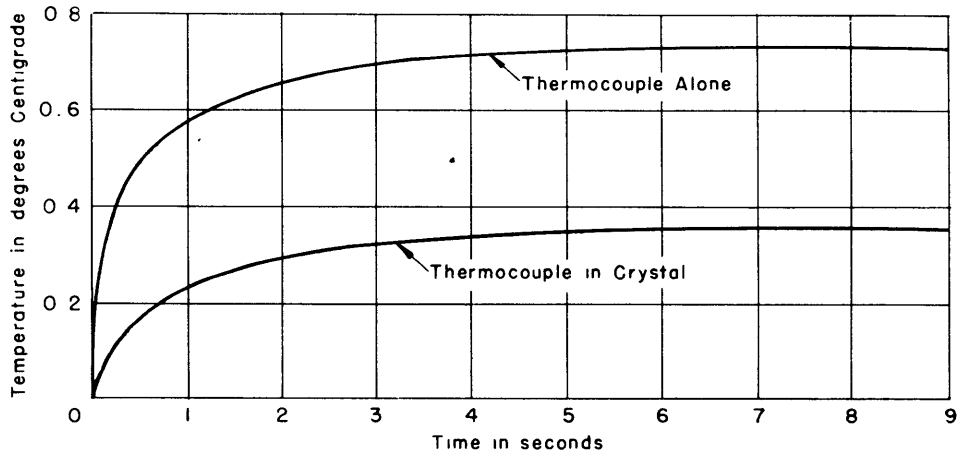


Figure 12a - Change of Temperature in Machine Oil

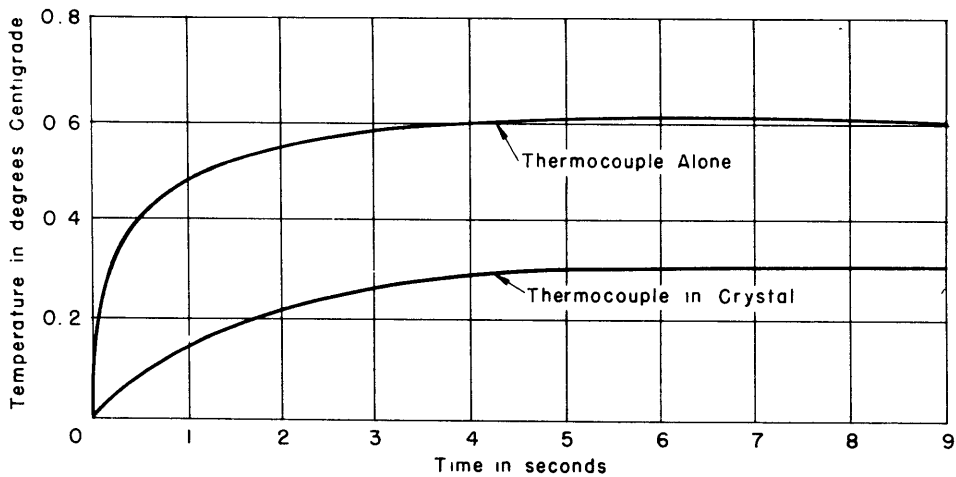


Figure 12b - Change of Temperature in Castor Oil

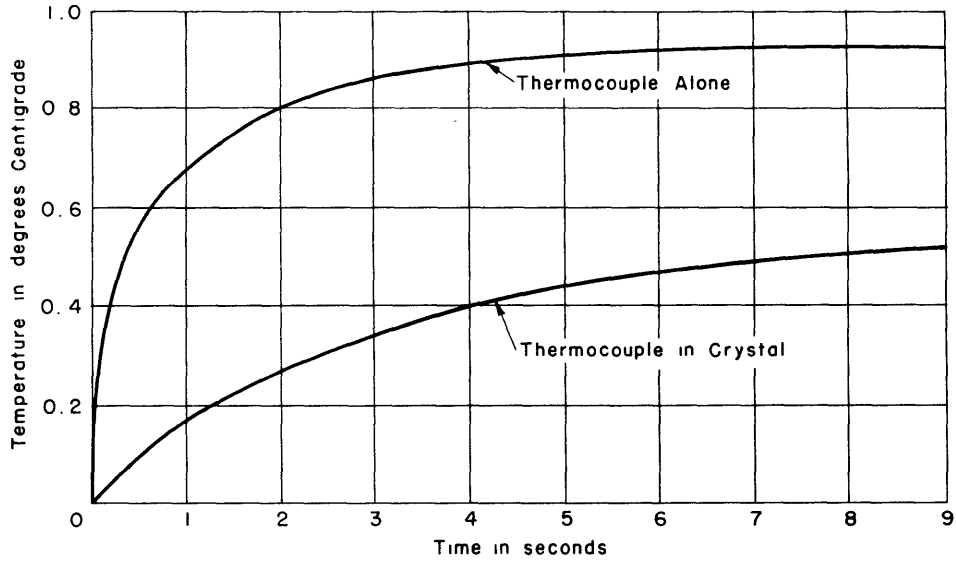


Figure 12c - Change of Temperature in Petroleum

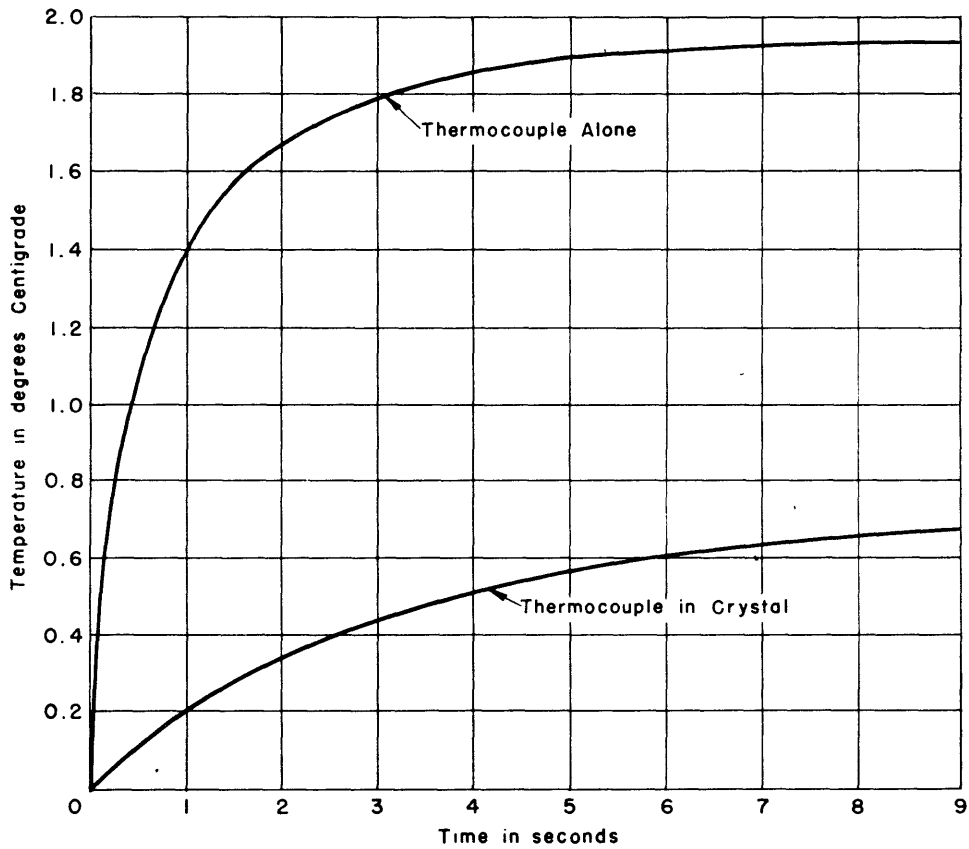


Figure 12d - Change of Temperature in Carbon Tetrachloride

Figure 12 - Change of Temperature Following a Pressure Change of 1000 Pounds per Square Inch

the fraction of the temperature change communicated to the crystal at any time. Multiplying the ratio of the pyroelectric to the piezoelectric effects given in Table 4 by the fraction of the temperature change communicated to the crystal after 2 seconds gives the relative decay of the signal. These calculated values as well as the corresponding experimental values taken from Column 6 of Table 3 are listed respectively in Columns 4 and 5 of Table 5.

TABLE 5

Relative Decay of the Piezoelectric Signal Calculated from the Temperature Change in the Crystal for Various Media

1	2	3	4	5
Medium	$\frac{\Delta Q_{\text{pyro}}}{\Delta Q_{\text{piezo}}}$	$\frac{\Delta T_{\text{crystal}}}{\Delta T_{\text{medium}}}$	Per Cent Decay in 2 Seconds	
			Calculated Col. 2 \times Col. 3	Observed
Petroleum	0.26	0.35	9.1	14
Machine Oil	0.226	0.43	9.7	11
Castor Oil	0.148	0.43	6.4	12
C C ₁₄	0.454	0.20	9.0	20

Since the crystal used was somewhat thicker than usual and since the crack between the two parts was filled with Duco cement, the actual conditions were only approximately realized. Furthermore, owing to a non-linear calibration scale for the d-c-amplifier-milliammeter system, it was difficult to measure the temperature changes accurately. In spite of these difficulties the calculated decays are of the same order of magnitude as the observed decays.

During the course of this investigation a new chamber was built for calibrating unmounted crystals. This was previously referred to as Oil Chamber 2 and is shown in Figure 3. At one time it was thought that the packing around the insulated terminal in Oil Chamber 1 might be producing cable signal. Following the recommendations of the group at the Underwater Explosives Research Laboratory, Woods Hole, Massachusetts, the insulated terminal was sealed into the second chamber with a Lucite bushing. In the construction of this chamber, large electrodes were employed for clamping the crystal in place; these permitted more convenient assembly than was possible with the old chamber.

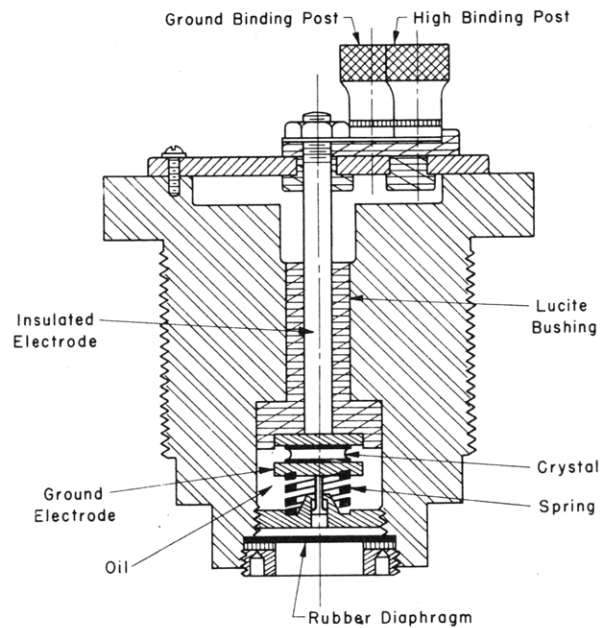


Figure 3 - Oil Chamber 2 for the Calibration of Bare Tourmaline Crystals

Figure 13 shows a record made with the string oscillograph with Chamber 2 filled with machine oil. Here the decay is only 5 per cent in 2 seconds. This should be compared with the record in Figure 10 where Chamber 1 and the same oil were used. There the decay was 11 per cent in the same time. The smaller discrepancy encountered with Chamber 2 is due not to the elimination of cable signal but rather to the reduction in the magnitude of the pyroelectric effect, which can be attributed to the large heat capacity of the electrodes.

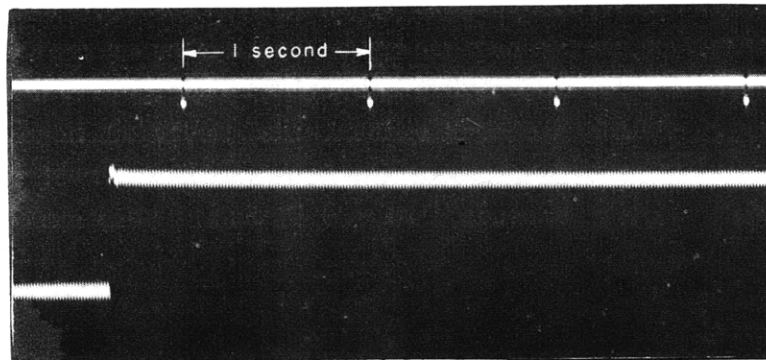


Figure 13 - String-Oscillograph Pressure Record

The record was made with the crystal mounted in Oil Chamber 2 and immersed in machine oil.

Gage calibrations were tried with Chamber 2, using a Leeds and Northup galvanometer having a somewhat shorter period than the one employed in the early experiments. The results were better but the gage constants were still about 3 per cent lower than those measured by the dynamic method. It is possible that with an even faster galvanometer the discrepancy might be further reduced. It is doubtful, however, that mounted gages can ever be calibrated accurately by this method.

CONCLUSIONS

In the light of these experiments it is concluded that only fast methods of pressure release and recording should be used for the calibration of piezoelectric gages. The pressure must be released fast enough so that the crystal does not have time to experience a change in temperature before the record is made. In the oscillographic bursting-diaphragm method, which has been adopted as standard at the Taylor Model Basin, the pressure is released in 0.2 millisecond. Since this method of calibration closely approaches the conditions of transient shock waves, gages calibrated in this way can be relied upon to give accurate information on underwater explosions.

REFERENCES

- (1) "Progress Report on Underwater Explosion Research, Bureau of Ships Symbol E139 - Part 8 - The Effect of Temperature Changes on Calibrations of Piezoelectric Gages," by A. Borden, TMB CONFIDENTIAL Report R-244, April 1944.
- (2) "Progress Report on Underwater Explosion Research, Bureau of Ships Symbol E139 - Part 11 - Errors Encountered in Calibrating Piezoelectric Gages with Slow-Recording Instruments," by A. Borden, CONFIDENTIAL Report R-248, May 1944.
- (3) "A Tourmaline Crystal Gage for Underwater Explosion Pressure," by A.R. Cohen and B. Stiller, TMB Report R-157, December 1943.
- (4) "Instrumentation for the Measurement of Underwater Explosions," by M.A. Greenfield and M.M. Shapiro, TMB CONFIDENTIAL Report 523, September 1944.
- (5) "Protection Against Underwater Explosion - Plastic Deformation of a Circular Plate," by A.N. Gleyzal, TMB Report 490, September 1942.
- (6) "A Feedback Micromicroammeter," by Shepard Roberts, Review of Scientific Instruments, Vol. 10, 1930, p. 181.
- (7) "Adiabatic and Isothermal Piezoelectric Constants of Tourmaline," by D.A. Keys, Philosophical Magazine, Vol. 46, 1923, p. 999.

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