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REPORT NO. NADC-AE-6608 21 MAR 1966

QUALITY CONTROL FOR TRANSDUCER CERAMICS

PHASE REPORT
WEPTASK NO. ASW213000/2021/F101-13-01
Problem No. 414
WEPTASK NO. R360FR102/2021/R011-01-01
Problem No. EY-5-03

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DEPARTMENT OF THE NAVY
U. S. NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE
WARMINSTER, PA. 18974

Aero-Electronic Technology Department

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A detailed description of the construction and operation of a piezoelectric constant tester for transducer ceramics is given.

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SUMMARY

The piezoelectric d_{ij} constant of a material may be defined as the ratio of the charge density in a plane normal to the i direction to the applied stress in the j direction.

Simple and rapid quality control for the poling process of ceramic hydrophone elements may be achieved by direct static measurement[1] of the piezoelectric d_{ij} constant and determination of the dielectric constant after the poling process. Since the d_{ij} constant and the dielectric constant are approximately linear functions of the degree of poling in the region near saturation[2], these values are indicative of the quality of poling achieved.

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1. *Standards on piezoelectric crystals: Measurements of piezoelectric ceramics, 1961, Procedings of the IRE, 49, 1167 (1961).*

2. *Land, C.E., Smith, G.W., and Westgate, C.R., The dependence of the small-signal parameters of ferroelectric ceramic resonators upon state of polarization, Sandia Corporation Reprint SC-R-64-128.*

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INTRODUCTION

This study is part of the materials information program of WEPTASK No. ASW213000/2021/F101-13-01, Problem No. 414, and Foundational Research WEPTASK No. R360FR102/2021/R011-01-01, Problem No. EY-5-03.

In this method for direct measurement of d a known stress is applied to a sample by means of a "Rockwell" hardness tester[3] and the total charge generated is transferred to a low-loss storage capacitor. The voltage is then measured across the storage capacitor by means of a high impedance VTVM and total charge calculated from the relation Q = CV. The d constant is then obtained.

Schwartz[4] shows that a static method of measuring d_{ij} can produce results with an accuracy of about 4 percent. It was found that by a careful selection of components error can be kept below 2 percent.

DETAILS

EQUIPMENT

ACCO Rockwell Hardness Tester - Normal Tester Keithley Electrometer (VTVM with input impedance >10^{14} ohms). Assortment of low-loss capacitors. The test setup is shown in figure 1.

Notes on equipment and wiring - The electrometer has an input resistance of 10^{14} ohms in parallel with a capacitance of 6 mmf across the terminals. Voltage readings cannot be taken until the 6-mmf capacitor is fully charged; the full charging period is about 20 sec. The electrometer is very sensitive to static charge, such as that caused by switching or lead movement, especially on the lower scales. Performance is stabilized considerably by providing shielding for the high terminal and using shielded wire for the electrometer circuit. Wiring in all cases should be as short as possible and should be insulated heavily to avoid leakage to the shielding or other metal objects.

The plates between which the sample is held are insulated by a layer of fish paper. The major load should be applied and released several times until the needle readings are reproducible. The action of the hardness tester is more rapid in the release of the major load than in the application of the major load, and the release mode is more desirable for this reason.

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3. As suggested by the Ceramics Department at Honeywell Incorporated.

4. Schwartz, D.S., An impact tester for low force sensitivity measurements on piezoelectric ceramic materials, Ceramic Bulletin 38 [8] 405 (1959).

The terminals of the switch must have at least 10^{16} ohms between them to prevent leakage across the switch. Teflon, for instance, is a suitable base for the switch.

OPERATING PROCEDURE

1. Let electrometer warm up 15 min. Adjust zero.

2. Place sample in Rockwell hardness tester and apply the minor load of 10 kg with electrodes of sample short-circuited. This minor load eliminates errors resulting from surface effects. (See Rockwell hardness tester manual for detailed instructions on application of minor load.)

3. Put main switch in position 1 and select a storage capacitor. Values which give full scale voltage readings are more accurate than those which result in readings at the low end of a voltage scale.

4. Remove short circuit between sample electrodes and apply major load on sample if load application mode is to be used. (See Rockwell hardness tester manual for instructions on the application of the major load.) If load release mode is to be used, do not remove short cirtuit until just before major load is released. Major loads of 60, 100, or 150 kg may be applied. A 1360 kg/sq in. major load approaches the non-linear response region of PZT-5A and should not be used in this case. If the linear range is not known for a material, measurements should be made for all three loads and the results compared.

5. Put main switch in position 2 and read voltage on proper scale.

6. Discharge circuit by shorting the terminals or by pressing the "input switch" on top of electrometer cabinet. However, when the input switch is depressed, there is a 20-mego resistance across the terminals and discharge of the storage capacitor takes several seconds.

7. Take several readings and average the result.

CALCULATIONS

The basic equation is:

$$d = \frac{\text{charge density}}{\text{stress}} = \frac{\text{total charge/electrode area}}{\text{total weight/area supporting weight}} .$$

Total charge is calculated from the relationship: $Q = CV$

where Q = total charge in coulombs
C = capacitance of storage capacitor in farads
V = peak voltage of storage capacitor in volts.

An estimate should be made to determine if corrections should be made for the 6-pf capacitance across the terminals, the capacitance of the sample, and the capacitance of the wiring.

Electrode area and area supporting weight should be in the same units. These two quantities are equal and will cancel out in most measurements of d_{33}. The electrode area may not be obvious in some cases. For instance, if d_{31} of a radially-poled, thin-walled cylindrical tube is being measured, the electrode area is πdh, where d is the mean diameter of the tube and h is the axial height.

Total weight is the product of the mass of the load and the acceleration of gravity. At Philadelphia, for instance $g = 9.80196$ m/sec^2.

Load	Weight
60 kg	588 newton
100 kg	980 newton
150 kg	1470 newton

Total error estimated from experiment ≈ 2 percent.

Source of Error	Magnitude of Error
Electrometer voltage reading	±2 percent at full scale ±5 percent at low end of scale
Rockwell tester	Error undetermined
Temperature variation of d value of transducer material in 25° C range (T is in Celcius degrees)	PZT-5A $\Delta d_{31}/\Delta T = +0.5$ $100\ \Delta d_{31}/d_{31}/\Delta T = +0.4$ percent PZT-4 $\Delta d_{31}/\Delta T = -0.1$ $100\ \Delta d_{31}/\Delta T = 0.1$ percent CERAMIC B $\Delta d_{31}/\Delta T = -0.5$ $100\ \Delta d_{31}/d_{31}/\Delta T = -0.8$ percent
Measured capacitance of storage capacitors	< ±1 percent
Temperature variation of storage capacitors in 25° C range	< 0.1 percent/degree. Practically flat

Source of Error	Magnitude of Error
Leakage across storage capacitors	$C = 10^{-6}$ f
	$R = 10^{11}$ ohms
	$RC = 10^{5}$ sec
Capacitance of single-conductor shielded wire	50 pf/ft
D-C resistance of single-conductor shielded wire between shield and primary lead	$2(10)^{6}$ mego/ft

CONCLUSIONS

Measurement of the d constant of various commercially produced ceramics yielded values of d which agreed with values specified in the literature within about 2 percent. Each measurement takes approximately 30 sec. It is concluded that this method constitutes a rapid and accurate way to test the quality of a large number of poled ceramics.

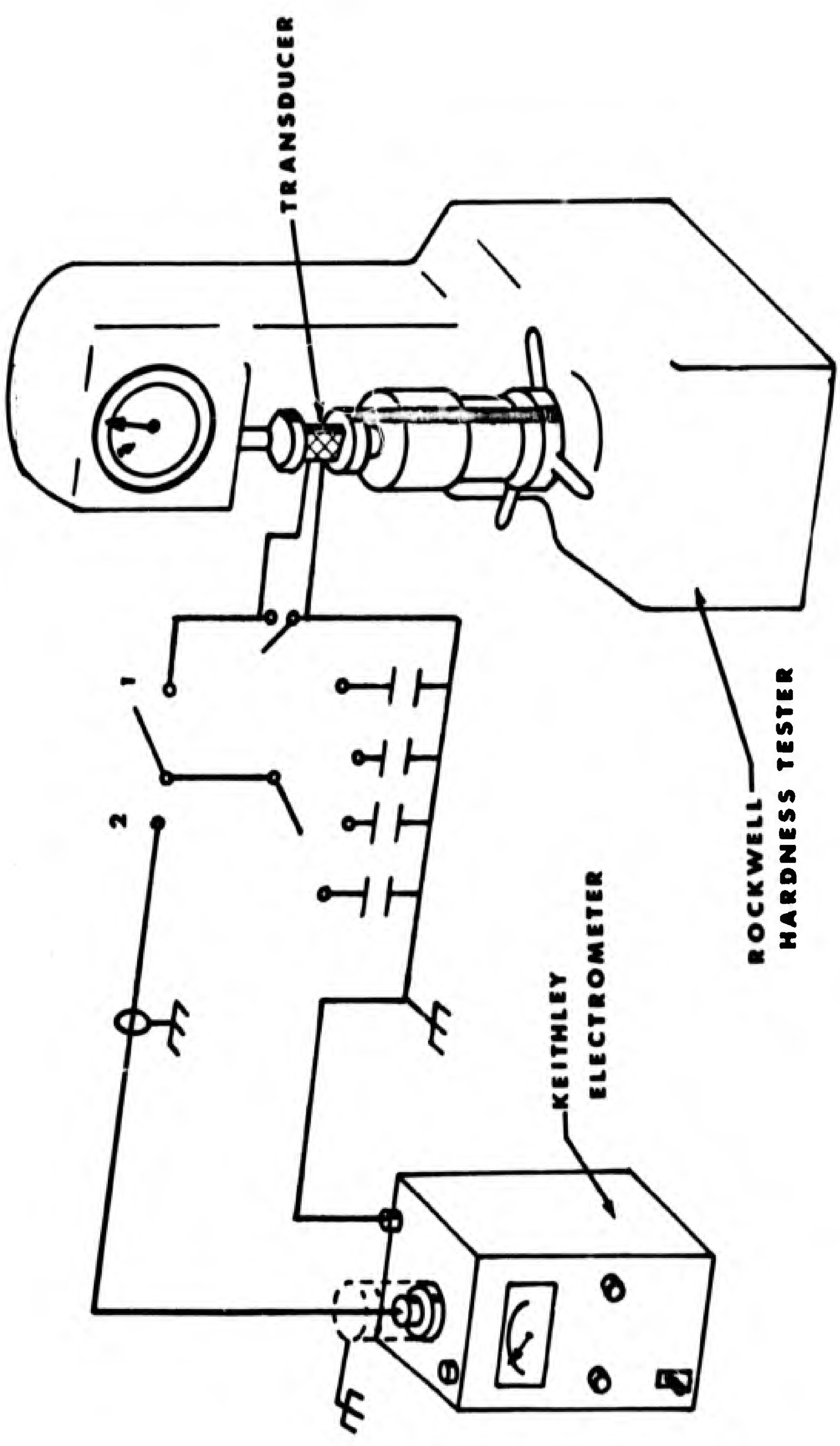

FIGURE 1 - Test Setup

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13. ABSTRACT

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