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SOME BASIC PROPERTIES OF BARIUM TITANATE

Travis P. Stuart

ABSTRACT

This memo summarizes some experiments performed by 5341 concerning basic properties of Barium Titanate. This data was required as design information for various Barium Titanate projects now under development. All tests were made on Barium Titanate specimens manufactured by the Centralab Division of Globe Union Incorporated. All specimens contained 4 per cent lead titanate.

Studies have been made of properties versus the variables of pressure, temperature, and applied potential field. Properties included in this preliminary investigation are charge developed, dielectric constant, resistance, and dielectric strength.

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Re: Some Basic Properties of Barium Titanate.

- Enclosures:
- (A) Charge developed on ten different $3/8$ " dia. x $1/2$ " long Barium Titanate cylinders vs. pressure in the direction of polarization.
 - (B) Hysteresis curve of charge developed on the faces of a $3/8$ " dia. x $1/2$ " long cylinder vs. pressure.
 - (C) Method of measuring data given on enclosures, (A), and (B).
 - (D) d_{33} vs. load for 1st hysteresis loop in enclosure (B).
 - (E) Charge vs. charging potential for a single $1/2$ " dia. x $3/32$ " long cylinder.
 - (F) Charge vs. charging potential for a single 2" dia. x $3/16$ " long cylinder.
 - (G) Method of measuring charge vs. charging potential.
 - (H) Self-discharge of a polarized Barium Titanate capacitor.
 - (I) Charge developed vs. area at a constant load.

This memo summarizes some experiments performed by 5341, concerning basic properties of barium titanate. This data was required as design information for various barium titanate projects now under development. All tests were made on barium titanate specimens manufactured by the Centralab Division of Globe Union Incorporated. All specimens contained 4 per cent lead titanate.

CHARGE OUTPUT VS. PRESSURE

When a specimen of polarized barium titanate crystal is stressed, a charge is developed on the crystal faces perpendicular to the axis of polarization. The charge produced by applying pressure in the direction of polarization is roughly proportional to the area of the faces. Enclosure (A) is a graph of the charge developed on ten different $3/8$ " dia. x $1/2$ " thick cylinders versus applied pressure in the direction of polarization. It is seen that these curves are not linear, indicating a variation in d_{33} with stress.

Enclosure (D) was obtained by differentiating charge with respect to load on the 1st hysteresis loop shown in Enclosure (B). Charge was measured as shown in Enclosure (C).

Once these crystals have been compressed, considerable hysteresis exists. (Enclosure B). That is, pressure partially depolarizes the crystals, leaving a charge on the faces when the pressure is removed. In the graph this charge was shorted off before recompression. Repeated cycling seems to cause the maximum charge to approach a certain value as a limit.

A curve of charge/area versus pressure can be considered universal for a crystal of any cross sectional area, provided the material in each sample is uniform.

$$Q/A = f(P)$$

$$Q = Af(P) = Af(L/A)$$

This equation defines a surface in Q, L and A. Consider Q as a function of A and P, where P is also a function of L/A.

$$\frac{\partial Q}{\partial L} = d_{33} = \frac{\partial Q}{\partial A} \frac{\partial A}{\partial L} + \frac{\partial Q}{\partial P} \frac{\partial P}{\partial L} = \frac{\partial f(P)}{\partial P}$$

Similarly -

$$\frac{\partial Q}{\partial A} = \frac{\partial Q}{\partial A} \frac{\partial A}{\partial A} + \frac{\partial Q}{\partial P} \frac{\partial P}{\partial A} = f(P) - P \frac{\partial f(P)}{\partial P}$$

So that both d_{33} and $\frac{\partial Q}{\partial A}$ are dependent only on the pressure.

At constant load maximum charge occurs when $\partial Q/\partial A = 0$. Since $\partial Q/\partial A$ is a function only of P, this condition always occurs at a constant pressure. Enclosure (I) is a graph of Q versus A at a constant L equal to 3,000 pounds. The maximum charge occurs at an area corresponding to 15,000 PSI. Enclosure I was obtained from the first hysteresis curve shown in Enclosure (B).

Since $Q = A f(P)$

$$V = \frac{Af(P)}{KA/t} = \frac{tf(P)}{k}$$

$$E = \frac{1}{2} QV = \frac{At(f(P))^2}{2k}$$

Therefore V is a function only of P and t , and E is a function only of the volume (At) and P , provided k remains constant. This is not true except for fields below 65 kv/in (Enc. E) and constant temperatures.

CAPACITANCE

Capacitance was measured by placing a known voltage across a cylinder of barium titanate and measuring the charge on the cylinder. (Enc. F). When a positive charge is placed on the positive crystal face of a polarized specimen, (the positive face delivers positive charge when stressed), the capacitance is seen to be almost constant up to approximately 65 kv/in (Enc. E). The dielectric constant is much greater when a positive potential is applied to the negative face and is also dependent on voltage to some degree even before "saturation" is reached. The charge versus voltage curve for a depolarized crystal lies between that obtained for a positive to positive connection and a negative to positive connection on a polarized crystal.

A possible explanation for this effect might be as follows. When a crystal is polarized, the bound dielectric positive charges are separated from the negative. This causes a positive charge to collect on the face toward which the bound negative charge is displaced, leaving a neutral crystal until stress is applied. (The charge which is measured when stress is applied is this free surface charge).

The dielectric constant is dependent upon motion of the bound charge when a potential is applied. It is, therefore, to be expected that a charging potential polarity tending to displace the negative charges farther will have less effect than a polarity tending to move the bound negative and positive charges together.

VOLTAGE OUTPUT VERSUS PRESSURE

From enclosure (D), the charge versus voltage curve (positive to positive connection) is seen to level off at approximately 80 kv/in and 34 micro coulombs/in². Very often crystals produce a greater surface charge density than this when they are stressed. This excess charge then must appear at a very high potential if there is no stray capacity. It is difficult to predict the maximum voltage attainable by stressing a crystal, since the maximum surface charge density generated by different crystals varies by at least 20 per cent from the mean and since voltage is very sensitive to charge above 80 kv/in.

It is possible that when crystals are stressed they do not follow the positive to positive curve exactly, but a curve somewhere between the positive to

positive curve and the depolarized curve. This might be a consequence of the fact that pressure partially depolarizes a crystal (Enc. B). This would effectively lower the maximum voltage somewhat, but there is no reason to suspect that the new curve would not also reach a "saturation" point, since in Enc. (E), the depolarized curve also appears to be leveling. If this new curve also became flat below the maximum charge the crystal produced, a very high voltage could still be expected.

DIELECTRIC STRENGTH

In the above capacitance test, the 3/16" crystal punctured when 64 kv/in was applied, while as high as 15 kv has been slowly applied to a 1/16" crystal without puncture. Dielectric strength is very inconsistent, even between samples of the same thickness. There is indication that a sudden pulse tends to puncture a specimen easier than slow build-up of the voltage. No outstanding change from that of room temperature, was noted in dielectric strength at -90°F and $+165^{\circ}\text{F}$.

RESISTANCE

Resistance was measured by two methods. The first method involved placing a high voltage across four 2" dia. x 3/16" discs in parallel and measuring the current. The resistance was on the order of 10^7 ohm in.

The second method involved the decay of the voltage across a charged cylinder (Enc. G). This method is believed to be more accurate and yields approximately 3×10^7 ohm in. Enclosure (G) gives a measure of the relative voltage versus time for any dimension barium titanate capacitor. The value is necessarily a lower limit since stray parallel conductivity of the switch and silicone oil in which the crystal was immersed, could also enter.

A drop to very roughly 10^7 ohm in. was noted at the Curie point (120°C).

TRAVIS P. STUART - 5341

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ENCLOSURE "A"

160-006

METHOD OF MEASURING CHARGE DEVELOPED
ON A CRYSTAL AS A FUNCTION OF PRESSURE

CHARGE VS CHARGING POTENTIAL

CYLINDRICAL CRYSTAL

 $\frac{3}{32}$ " LENGTH 1" DIAM.

ENCLOSURE "F"
160-011

12

METHOD OF MEASURING CHARGE VS CHARGING POTENTIAL

$$Q_x = (C + C_x) V$$

$$C \gg C_x$$

$$Q_x = CV$$

160 012

ENCLOSURE "G"

15

13

AC DECAY OF BaTiO_3 DISC
THROUGH RESISTANCE OF DISC

13

ENCLOSURE "450-013"

1-14

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