Reprinted from JOURNAL OF APPLIED PHYSICS, Vol. 32, No. 3, 555, March, 1961

Piezoelectric Behavior of Impacted Quartz

R. A. GRAHAM
Sandia Corporation, Albuquerque, New Mexico
(Received October 3, 1960)

QUARTZ is a widely used piezoelectric material and as such its properties have been thoroughly investigated under low-signal conditions. The piezoelectric behavior of quartz under high-intensity stress and transient loading conditions has not been thoroughly investigated. An experimental investigation is currently being conducted to determine the relation between impact stress and the electrical charge release from quartz resulting from the passage of a stress wave produced by impact. Of particular interest is a determination of the stress at which the charge release ceases to be proportional to stress; a comparison of high-signal transient data to the low-signal piezoelectric constants is also of interest.

The Hugoniot conservation-of-momentum relation and the relations governing the impact of flat cylinders are utilized to determine the stress produced by impact. Flat-faced cylinders of a known elastic material are impacted at high velocity upon a stationary specimen of x-cut synthetic quartz in the form of a cylindrical disk. The X axis is oriented perpendicular to the plane of impact and the charge release resulting from the initial passage of the stress wave is observed. It can be shown that the particle velocity imparted to the specimen is:

$$U_p = KV_0, \tag{1}$$

where K is a coefficient depending upon the acoustic impedance of the specimen relative to that of the projectile, V_0 is the impact velocity, and U_p the particle velocity imparted to the specimen. When projectile and specimen are of the same material, K becomes $\frac{1}{2}$.

From the conservation of momentum,

$$\sigma = \rho_0 U_s U_p \tag{2}$$

where σ is the stress jump for a time-independent stress profile, ρ_0 is the mass density of the undisturbed material, U_s is the wave-front propagation velocity, and U_p the particle velocity imparted by the stress wave front.

It follows from Eq. (2) that if the particle velocity is known and the product $\rho_0 U_s$, the specific acoustic impedance, is known, the impact stress may be calculated. If the low-signal acoustic impedance of quartz is constant for stresses within the elastic range, this acoustic impedance and an experimentally determined impact velocity are sufficient to determine the stress caused by impact. Our experimental evidence indicates that the elastic stress wave propagation velocity is equal to the low-signal propagation velocity to within 1%.

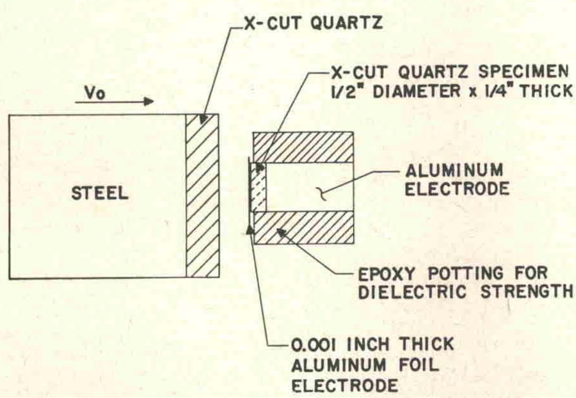

FIG. 1. Geometry of the experimental arrangements.

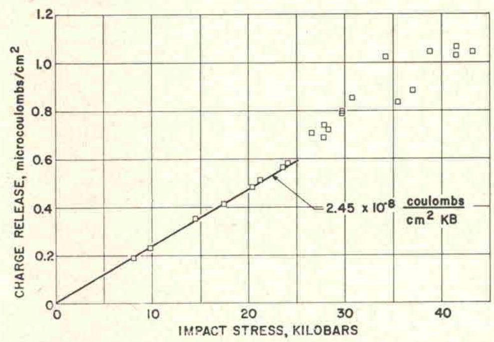

FIG. 2. Experimental relationship between impact stress and charge release.

The geometry of the experimental arrangement is as shown in Fig. 1. Extreme precautions are taken to achieve "instantaneous" contact over the flat surfaces. The charge release is instrumented with a low-resistance current-viewing resistor or with a capacitive loading of suitable time-constant characteristics. The guns which propel the projectile have the capability of carefully controlled impacts at velocities from 100 fps–3000 fps. A vacuum of about 5 μ is obtained in the barrel between the projectile and the specimen.

Experiments are performed in which the relation between impact velocity and charge release is determined. Each data point represents a separate specimen since the specimen is fractured after an impact. With the use of Eqs. (1) and (2), the relation between impact stress and charge release is obtained.

Figure 2 shows the current results. There is a definite departure from linear behavior for stresses greater than 25 kbars (1 kbar $=986.92$ atm$=14\,504$ psi). A linear least-squares fit to the data yields a charge/stress coefficient of 2.45×10^{-8} coulombs/cm² kbar. The low-signal d_{11} constant for quartz is 2.25×10^{-8} coulombs/cm² kbar.[1] For one-dimensional strain, one would expect the charge/stress relation to be governed by e_{11}/c_{11}. The low-signal value for e_{11}/c_{11} is 1.94×10^{-8} coulombs/cm² kbar. One would expect that the e_{11}/c_{11} constant would be more applicable under the conditions of this experiment. The actual value of the coefficient reported here is no doubt influenced by the geometry of the specimen. Further studies are in progress to determine the effects of geometry on charge release and to differentiate between mechanical and electrical nonlinear effects.

[1] W. P. Mason, *Piezoelectric Crystals and Their Application to Ultrasonics* (D. Van Nostrand Company, Inc., Princeton, New Jersey, 1950).