EQUIVALENCE OF THE RECORDING OF MECHANICAL-STRESS WAVES WITH A QUARTZ SENSOR IN DIFFERENT TIME INTERVALS

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As is known [1], the current passing through a low-resistance quartz sensor is connected in the following manner with the mechanical stresses acting on its surface normal to the surface:

$$i(t) = (kSc_0/l)[P_1(t) - P_2(t)]. \tag{1}$$

Here, k is the sensitivity coefficient of quartz; S is the surface area of the sensor; c_0 is the speed of sound in quartz; ℓ is the thickness of the quartz; $P_1(t)$ and $P_2(t)$ are the stresses acting on the front and rear surfaces of the sensor, respectively.

In accordance with (1), when the stresses are recorded over a period of time greater than the time of passage of the wave through the quartz, during the time ℓ/c_0 the current i(t) is proportional to $P_1(t)$, while at $t > \ell/c_0$ it is proportional to the difference in the stresses $P_1(t)$ and $P_2(t)$. Thus, to facilitate interpretation of the form of the recorded signal, a restriction is usually imposed on its duration. The duration of the signal should not exceed ℓ/c_0. Then $P_2(t) = 0$, and Eq. (1) reduces to $i(t) = (kSc_0/\ell)P_1(t)$ for $0 < t < \ell/c_0$. If this restriction is kept and the same sensor is used to obtain measurements in another time interval ($\ell/c_0 < t < 2\ell/c_0$), then it can be seen from (1) that the recorded current will be determined by the stress acting on the rear surface of the sensor:

$$i(t) = -(kSc_0/l)\,(1 + R)P_1(t - l/c_0) \quad \text{for } l/c_0 < t < 2l/c_0, \tag{2}$$

where R is the reflection coefficient for the rear surface; $R = (z_1 - z_2)/(z_1 + z_2)$; z_1 and z_2 are the wave impedances of the quartz and the material bounding the rear surface of the sensor.

The feasibility of obtaining measurements with a quartz sensor after the passage of stress waves through its thickness was argued in [2] without experimental corroboration. Below, we present results of an experimental verification of Eq. (2) with a restriction on the duration of the recorded process: ℓ/c_0.

As the source of short mechanical-stress waves, we used pulse-type electronic units similar to those employed in [3]. The duration of the electron pulses was $(0.4\text{-}2)\cdot 10^{-7}$ sec, while the mean energy of the electrons was about 1.8 MeV. The electron beam was directed onto a plate made of an absorbent material in which we could form mechanical-stress waves with an amplitude up to 0.6 GPa. The quartz sensor (a plate of X-cut quartz) was glued to the absorber. The rear surface of the sensor was either left free or was covered with a plate made of alloy AMg6 or copper M1 (the coupler). We used sensors without a protective ring and characterized by different ratios of diameter to thickness. The maximum sensor diameter was 40 mm, while the minimum ratio of diameter to thickness was 5.

With this method of creating stresses, a bipolar compression-rarefaction pressure pulse is formed in the absorber [4, 5]. We took steps to ensure that only the compression pulse acted on the sensor. To do this, we made the absorber out of two plates, with the thickness of the first (irradiated) plate being somewhat greater than the mean free path of the electrons. It should be noted that, from a practical viewpoint, the same result can be obtained if the amplitude of the rarefaction pulse is significantly greater than the strength of the adhesive bond between the absorber and the sensor.

We recorded the form and amplitude of the current pulses generated in the sensor in two time intervals: $0 < t < \ell/c_0$ (positive pulse) and $\ell/c_0 < t < 2\ell/c_0$ (negative pulse). Figure 1 shows a typical oscillogram of the signal received from the sensor. The markings correspond to a duration of 0.1 μsec.

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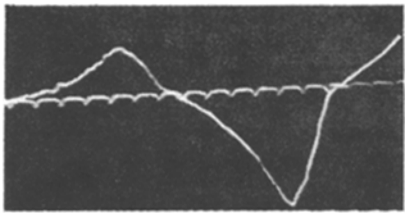

Fig. 1

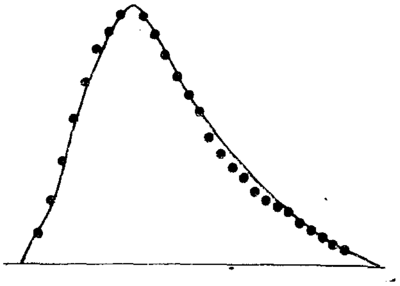

Fig. 2

TABLE 1

Coupler	$1+R$	i_-/i_+
Copper, M1 (soft)	0,6	0,63±0,045
Alloy AMg6	0,95	1,01±0,083
None (free surface)	2,0	2,08±0,13

Table 1 shows calculated values of 1 + R and measured values of the ratio of the amplitudes of the positive and negative pulses. Also shown is the standard deviation of the measurements. It can be seen from the table that the ratio of the amplitudes of the sensor current pulses measured in different time intervals agrees satisfactorily with the calculated values of 1 + R with a change in the conditions on the rear surface of the sensor. It should be noted that in the case where the duration of the compression pulse is close to ℓ/c_0, the calculated values 1 + R are sometimes considerably greater. This is evidently attributable to excitation of the quartz.

The coincidence of the forms of the sensor current pulses recorded in different time intervals was checked graphically. Here, the pulses were normalized with respect to the maximum. Figure 2 shows the result of superposition of the current pulse recorded in the time interval $0 - \ell/c_0$ (line) on the pulse recorded in the interval $\ell/c_0\text{-}2\ell/c_0$ (points) with coincidence of the maxima (see Fig. 1). The satisfactory correspondence between the forms of the signals is evident.

Thus, it can be concluded that for the recording of signals with a duration less than the time of passage of the stress wave through quartz within the pressure range up to 0.6 MPa, Eq. (2) is valid and measurements made in the time intervals $0 - \ell/c_0$ and $\ell/c_0\text{-}2\ell/c_0$ are equivalent.

This conclusion has practical application. For example, in conducting studies of mechanical stresses on pulse-type electronic units – where the noise level due to the operation of the instrument is high – being able to record a useful signal with the reflection of the stress wave from the rear surface makes it possible to make the measurements less liable to distortion by interference. This is done by acoustically delaying the signal relative to the electron pulse through the use of the sensor itself and by increasing the amplitude of the signal and thus improving the signal/noise ratio. The above-described method of recording also makes it possible to expeditiously measure the wave impedance of an unknown material, using the latter as the coupler.

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