OSCILLOSCOPIC METHOD FOR MEASURING THE SPEED OF SOUND ACCORDING TO LATERAL UNLOADING

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The methods of lateral and overrun unloading are currently used to measure the speed of sound in shock-compressed materials [1]. In the lateral unloading method a high-speed streak camera is customarily used to assess the dimensions of the lateral unloading zone in the investigated samples, and then the speed of sound is calculated from those dimensions.

In the technique proposed here, a resistance-type sensing element is used, and the recording instrument is an oscilloscope. An abrupt change in the resistance of the element due to interaction with the investigated sample and high-speed sweep on the part of the oscilloscopes distinguish the proposed technique favorably from the photochronographic method.

Let a stepped cylindrical sample be subjected to shock compression by a plane shockwave (Fig. 1). After the shockwave passes the corner O, the shock front begins to be attenuated near point O by lateral unloading, thereby diminishing the shock velocity in this zone. The central part of the shock front, on the other hand, being unaffected by the unloading process, remains planar. At a time t after passing the corner O, the shock wave moves away with velocity D to a distance Dt, and the material is transported ahead at the particle velocity u to a distance ut.

The earliest disturbances, which arise at the instant of passage of the shock wave past the corner O and propagate with the speed of sound c, at this instant reach the sphere of radius ct described around point A.

Thus, the attenuation of the shock wave at time t begins at point B.

It is evident from an inspection of the triangles OBF and ABF that the speed of sound is related to the velocities D, u and the unloading angle α:

$$c = D\left[\mathrm{tg}^2\alpha + \left(\frac{D-u}{D}\right)^2\right]^{\frac{1}{2}}.$$

The position of point B is determined from the change in resistance of a sensing element placed above the surface of the investigated sample due to the bridging of the conducting part of the element by the driven surface.

The sensing element comprises either a flat thin-film resistance or a piece of Kh20N80 0.06-mm-diam. wire. The test arrangement is shown schematically in Fig. 2: 1) pressure plate; 2) sample; 3) outer electrode; 4) substrate; 5) conducting part; 6) inner electrode. The thin-film element is made by spray-depositing first a layer of chromium and then, coaxially, two copper electrodes onto a glass substrate (Fig. 2a). The resistance of the electrodes is negligible in comparison with the resistance of the chromium layer. For the wire element (Fig. 2b) a Nichrome wire is stretched between two coaxial brass electrodes and is soldered to them.

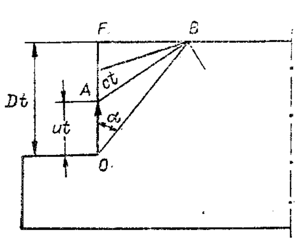

Fig. 1

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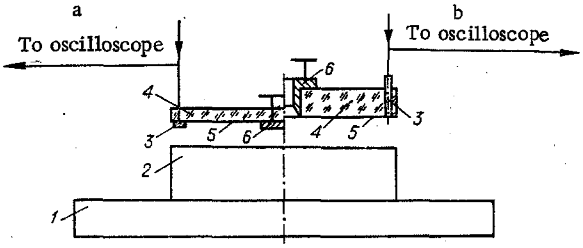

Fig. 2

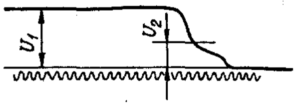

Fig. 3

TABLE 1

Thickness of 50-mm-diam. copper sample, mm	Measured radius r, m	tan α	Sound speed c, km/sec	Average sound speed, km/sec	Sound speed in [1], km/sec
13,98	16,40	0,616	5,39	5,36±0,05	5,30
14,00	16,30	0,621	5,41		
13,97	16,37	0,618	5,40		
13,96	16,55	0,606	5,37		
13,95	16,73	0,593	5,32		
13,98	16,92	0,578	5,28		

The conductance of the thin-film element is calculated according to Govorkov [2]. The conductance before the test is

$$G_1 = \frac{I}{U_1} = \frac{2\pi\gamma}{\ln\frac{r_2}{r_1}} \tag{1}$$

and at the instant of shorting by the driven surface it is

$$G_2 = \frac{I}{U_2} = \frac{2\pi\gamma}{\ln\frac{r_2}{r_3}}, \tag{2}$$

where I is the constant current through the sensing element from a pulsed source of the type normally used in shock conductance measurements [3], U_1 and U_2 are the voltages measured by the oscilloscope before shock driving and at the instant when the surface is driven toward the sensing element (Fig. 3, which gives an oscillogram obtained in an explosive-loading test on a copper sample having a diameter of 50 mm and a thickness of 14 mm; the reference sine wave has a frequency of 10 MHz), γ is the conductivity of the spray-deposited layer, r_1 and r_2 are the radii of the inner and outer electrodes, and r_3 is the radius of the central zone unaffected by lateral unloading.

The position of point B is obtained from expressions (1) and (2): $\ln r_3 = \ln r_2 - \frac{U_2}{U_1}\ln\frac{r_2}{r_1}$. In measurements with the wire element the position of point B is determined from the direct proportionality between the measured voltage and the length of the wire for the same supply source:

$$r_3 = r_2 - (U_2/U_1)(r_2 - r_1).$$

Tests were conducted on charges of alloy TG50/50 with a diameter of 120 mm. A plane shock wave was generated in an aluminum pressure plate having a thickness of 10 mm by stopping of the explosion products from a high-explosive charge with a length of 220 mm.

The state in the copper samples on the pressure plate was determined by the reflection method with the use of the results of [4]: p=368 kbar, D=5.15 km/sec, u=0.80 km/sec, $\rho_0 = 8.93$ g/cm^3. A flying indicator was used for better observation of the motion of the surface. It was made of copper foil with a thickness of 0.03 mm and was attached to the sample surface by rubbing it on VM-4 oil. The measurements were carried out with an S1-24 oscilloscope. The supply source was a 10-μF capacitor, which was discharged into the sensing element circuit with a limiting resistance R = 400Ω. The initial resistance of the elements in the test was 10-12 Ω.

The initial data and experimental results are summarized in Table 1. Also given in the table is the result of Al'tshuler et al. [1], which exhibits good agreement with our result.

It is evident from the given example that the proposed method can be used successfully in investigations of the properties of materials under high pressures. The application of the proposed method affords the possibility of determining unloading angles in complex shock waveforms and of determining wave profiles.

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ASYMPTOTIC OF THE FLOW IN THE NEIGHBORHOOD OF A CENTER DURING COLLAPSE OF A SPHERICAL CAVITY

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1. The problem of the collapse of a spherical cavity is examined in [1, 2] and the limit mode for gas flow outside the cavity in the neighborhood of the center is presented as the cavity radius tends to zero R → 0.* The equation of state of the gas in the customary notation has the form

$$p = \rho_0 \frac{c_0^2}{\varkappa}(\delta^\varkappa S - 1), \tag{1.1}$$

where p is the pressure, ρ is the density, $\delta = \rho/\rho_0$, c is the speed of sound, S in an entropy quantity, and the subscript 0 corresponds to the unperturbed state. The flow up to the time of collapse was assumed isentropic $S = S_0$ in the approximation under consideration. Zero pressure; and therefore, constant, nonzero specific density $\delta = \delta_0$ and speed of sound $c_0/\sqrt{\delta_0}$ corresponded to the cavity boundary, where $\delta_0^\varkappa S_0 = 1$. Without limiting the generality, it can be considered that $S_0 = \delta_0 = 1$ and, correspondingly, the sound speed on the free boundary equals c_0 because the gasdynamics equations in combination with the equation of state (1.1) are invariant relative to a similarity transformation:

$$r = r_0 r,\ t = t_0 t,\ u = u_0 u,\ \delta = \delta_0 \delta,\ S = S_0 S,$$

where

$$u_0 = r_0/t_0;\ S_0\delta_0^\varkappa = 1;\ u_0 = 1/\sqrt{\delta_0}.$$

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*All the personal references associated with the self-similar solution of the appropriate problem are presented in [1].

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