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USE OF A PHOTOMETRIC METHOD TO MEASURE THE DISPLACEMENT OF METAL SHELLS UNDER AN EXPLOSIVE LOAD

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When measuring small displacements of a moving surface in explosive investigations the case arises when the measuring electric probes (contact, capacitive, or inductive types, etc.) cannot be placed on the surface being investigated or even in the immediate vicinity of it, for example, in experiments with strongly heated specimens, when electromagnetic interference is present, when it is necessary to preserve the measuring instruments because the loaded constructions are destroyed, etc. In such experiments one can successfully use a photometric method based on mechanical modulation of the light beam passing through a narrow slit between the surface being investigated and a fixed limiter. In [1], an experimental arrangement is described for measuring small displacements (down to 10^{-3} mm) of the surface of a cylindrical shell when it is loaded on the inside with a shock wave excited by the electrical explosion of a wire. The required light flux is obtained using a gas laser.

In this investigation the photometric method of measuring displacements was used to study the reaction of closed spherical and cylindrical shells when charges of explosive material were exploded inside them. The displacements of the shells in these experiments reached 150 μm, and the recording time was 400 μsec. The arrangement for carrying out the experiments is shown in Fig. 1. A light beam in the gap between the shell being investigated 1 and a fixed wedge 2 was produced by means of an OKG-11 helium–neon laser 9 and a rectangular diaphragm 3 placed in front of the shell. After passing across the gap, the light beam falls on an FÉU-28 photomultiplier 4 placed at a certain distance (of the order of a meter) from the shell being investigated. To eliminate the effect of external illumination on the output current, the photomultipliers were placed in a light-protecting cylindrical screen 5. Vibrations of the shell were excited by the explosion of a spherical charge 7, placed at the center of the shell. The electrical signals from the photomultiplier were recorded by an S1-18 oscilloscope 6. The calibrated dependence of the deflection of the beam on the oscilloscope screen on the value of the light gap was found using a slit placed at the position occupied by the gap, which was varied from 0.01 mm to 0.4 mm by means of a micrometer screw. The resolving power of the experimental equipment was 10^{-3} mm. The relative error in measuring the displacement was not greater than 6%.

Since the accuracy with which the light gap can be measured in this equipment, as a rule, is less than the accuracy with which the calibrated slit can be measured (due, for example, to roughness or the complex profile of the surface of the moving object, the impossibility of introducing rigid coupling between the fixed object and the movable wedge, etc.), while the laser has a time instability of its radiating power, in the measuring arrangement described in [1] additional components were introduced enabling one to make accurate measurements irrespective of the accuracy with which the gap can be displayed. To do this the light beam from the laser was divided into two parts (a transmitted beam and a reflected beam) by means of a semitransparent mirror 11 placed at an angle to the direction of the beam. The transmitted beam passed through a rectangular diaphragm and was used to measure the displacements of the loaded surface of the shell; the reflected beam was also passed through a rectangular diaphragm, then through the calibrated slit 10, and was received by the photomultiplier 8.

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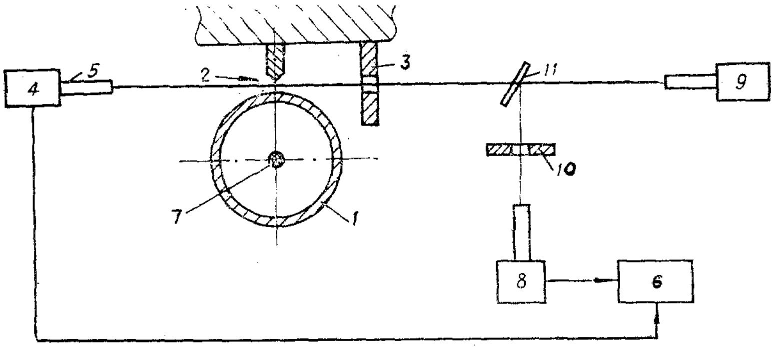

Fig. 1

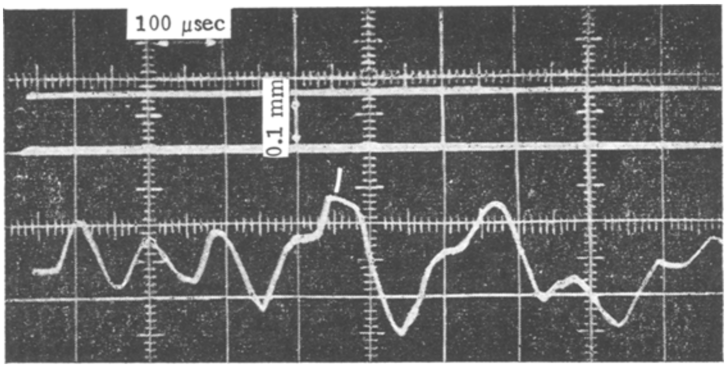

Fig. 2

Calibration was carried out using an accurately measured slit simultaneously in the transmitted and reflected beams, thereby enabling one to obtain the relation between the working characteristics of both recording channels at the same instant of time. During the explosion experiment the accurately measured slit was placed in the reflected beam.

We investigated the oscillations of a closed spherical steel shell (grade 3, external diameter 157 mm and thickness 15 mm), a cylindrical steel shell (grade 3, external diameter 195 mm, length 390 mm, and thickness 7 mm), and a cylindrical copper shell (grade M1) of the same geometrical dimensions. Simultaneously with the measurement of the displacement of the shell by the optical method, we recorded its velocity of motion by means of a capacitive probe as described in [2]. Good agreement between the measurements made by both methods was found.

Figure 2 shows an oscillogram obtained using the photometric method in one of the experiments with a steel spherical shell. Before the experiment we arranged to obtain the same sensitivity in both channels of the S1-18 oscilloscope by means of two micrometer slits of width 0.1 mm. The zero line on the oscillogram was obtained with superposed beams when the light gap in both slits completely overlapped. During the experiment, instead of one of the micrometer slits, we used a gap of width 0.2 mm between the shell being investigated and the fixed wedge. The actual value of this gap was found from the beam deflection from the zero line and was 0.21 mm. The measured displacements of the external surface of the shell are decaying oscillations, while the maximum positive deflection was 0.082 mm. The distortion of the initial pattern 200 μsec after the beginning of the shell vibrations is due to the excitation of mutual oscillations in the shell–wedge system due to the rigid coupling between these components.

In Table 1 (where Q is the total charge, u_{max} is the maximum elastic deformation of the shell, E_s is the energy given to the shell by the explosion, and E_e is the energy of the explosive charge) we give the results of some experiments with a spherical shell in which the vibrations were elastic (the material of the shell did not transfer into the plastic state; after the experiment the shell had no residual deformations).

TABLE 1

Q, g	u_{max}, mm	E_s, J	E_e, J	E_s/E_e
15	0,052	$0{,}58\cdot10^3$	$63\cdot10^3$	$9\cdot10^{-3}$
25	0,078	$1{,}31\cdot10^3$	$105\cdot10^3$	$12\cdot10^{-3}$
37	0,118	$3{,}02\cdot10^3$	$155\cdot10^3$	$19\cdot10^{-3}$

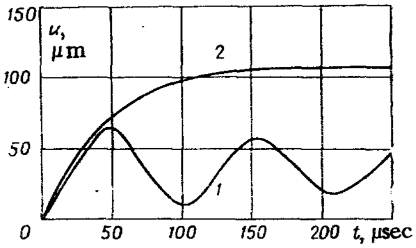

Fig. 3

We exploded spherical charges of 15, 25, and 37 g inside the cavity of the spherical shell. The values obtained for the maximum displacement of the shell in the elastic region enabled the value of the energy given to the shell when an explosive charge of given weight was exploded inside the cavity (the third column of the table) to be determined. In the fifth column of the table this energy is related to the energy of the explosive charge, the ratio being 1-2% (we noted a tendency for the energy taken by the shell to increase as the weight of the explosive charge was increased). In the experiments with cylindrical shells the loading was achieved by an explosion from the end of a cylindrical charge with a specific mass of 0.15 g/cm.

Figure 3 shows typical curves of the displacement of the surface of cylindrical shells as a function of time (curve 1 is for a steel shell and curve 2 is for a copper shell). The oscillations of the steel envelope are elastic and harmonic. The period of the oscillations is 110 μsec (which agrees with the calculated value), and the maximum radial deformation is 0.065 mm. In the experiments with a copper cylindrical envelope the maximum radial displacement of 0.110 mm is achieved after 160 μsec. The measured value of the maximum radial deformation is identical with the residual deformation of the shell. Elastic oscillations of the shell were not recorded (the amplitude of the elastic oscillations are obviously outside the limit of resolution of the method).

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