PRESSURE AT SHOCK WAVE FRONT NEAR LASER SPARK BREAKDOWN IN WATER

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Results are presented of an experimental determination of the pressures at the front of the shock wave which develops during breakdown in water caused by ruby laser radiation at distances from 0.4 to 3 mm from the focal spot along the direction normal to the radiation axis with the aid of the liquid spalling method upon reflection of the shock wave from the free surface.

It is known [1, 2] that when powerful monopulse laser radiation is focused in a liquid,phenomena are observed which are characteristic of an underwater explosion – formation of shock waves and a pulsating cavity. Measurement of the pressure field during a microexplosion in a liquid obtained by focusing laser radiation is a complex procedural task. The factors complicating the measurement include the brevity of the action of the first compression pulse, the presence of a complex series of compression and rarefaction waves [2], and the large curvature of the wave front near the breakdown. While at distances greater than 1 cm from the ray focus it is possible to record the pressure patterns with controllable errors withthe aid of miniature piezosensors [3], in the zone closest to the breakdown location such measurements are practically impossible. In our formulation the initial velocity of the liquid surface layer was determined in the acoustic approximation as the sum of the mass flow velocities behind the shock wave incident on the free surface and the reflected rarefaction wave [4]

$$U = \frac{2P\cos\alpha}{\rho c} \tag{1}$$

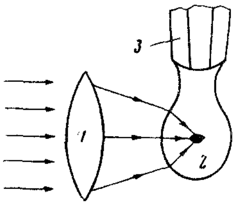

Fig. 1

Here U is the liquid velocity normal to the free surface, P the pressure in the incident shock wave, ρ the liquid density, c the sound speed in the liquid, α the angle of incidence of the shock wave on the free surface.

Equation (1) in the initial velocity range from 15-20 up to 300-500 m/sec is confirmed well by the experimental data for the case of spherical chemical explosive charge blasts. Outside this range of initial velocities corrections are

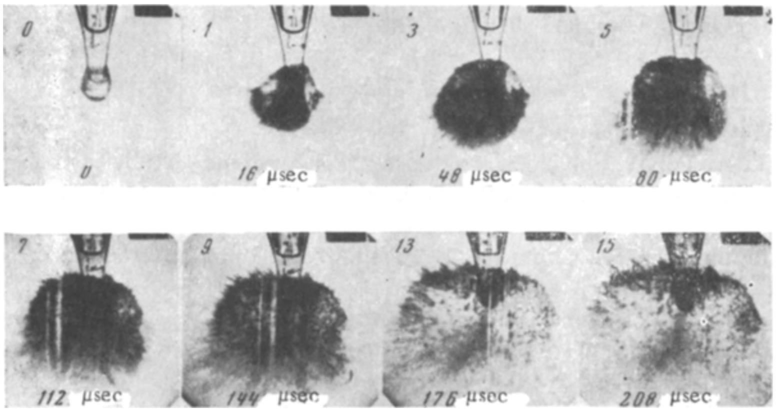

Fig. 2

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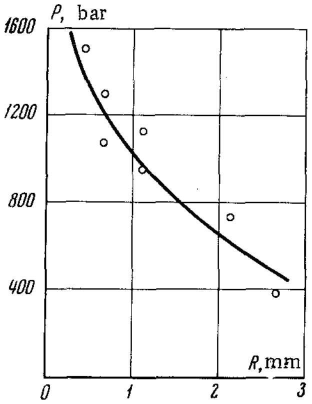

Fig. 3

necessary, since at higher flow velocities the elastic properties of the air have considerable influence on the motion of the spall layers. Moreover, in (1) the speed of sound c must be replaced by the shock wave front velocity, which begins to differ markedly from c. The strength properties of the water [5] begin to show up markedly at lower velocities. The observed initial water separation velocity is determined by the spall phenomena proper and not by the piston action of the vapor-gas cavity; this is seen convincingly in [2], where it is shown that the compression energy in the shock wave, which transitions into the kinetic energy of motion of the spall layers, is at least no less than the energy stored by the pulsating cavity.

Since the breakdown region is not spherically symmetric but rather elongated along the radiation axis [2], measurements by this method can be made only along the normal to the radiation axis. Measurements along and opposite the radiation axis are complicated by the difficulty in determining the breakdown center, and also by the presence of a series of compression waves which develop during formation of the individual vapor-gas bubbles located along the axis. Since it is not possible to focus the laser ray parallel to a flat water surface near this surface and, moreover, at small ray depths the shock wave front has high curvature, in our experiments the ray was focused in a water drop.

Figure 1 shows a schematic of the experiment. The ray of a ruby laser with emission energy about 0.5 J and emission duration 50 nsec was focused by the lens 1 in the water drop 2 hanging at the tip of the dropper 3. The explosion of the water drop was recorded by a SFR-IM high-speed camera using a shadow setup. One of the cinegrams is shown in Fig. 2. The optical system was arranged so that after refraction at the drop surface the ray was focused exactly at the axis of the dropper at a definite distance from the lower point of the drop, and the optical axis of the ray inside the drop was horizontal. Analysis of the cinegrams made it possible to determine the initial water spreading velocity in the direction normal to the radiation axis, and then by use of (1) to find the pressure at the shock wave front at various distances from the breakdown center.

The results of the pressure measurements are shown in Fig. 3. In the calculations we took $\cos \alpha = 1$; the strength properties of the water and surface tension were not taken into account. It is interesting to note that the data obtained merge with the results of pressure measurements at the shock wave front made in [2]. However the data must be considered preliminary, since the water separation mechanism under conditions of a microexplosion near the surface has not yet received adequate study.

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LITERATURE CITED

1. Laser Radiation Action [Russian translation], Mir, Moscow (1968).
2. A. A. Buzukov, Yu. A. Popov, and V. S. Teslenko, "Experimental study of the explosive process caused by focusing monopulse laser radiation in water," PMTF (J. Appl. Mech. and Tech. Phys.), 10, No. 5 (1969).
3. Yu. E. Nesterikhin and R. I. Soloukhin, High-Speed Measurement Methods in Gasdynamics and Plasma Physics [in Russian], Nauka, Moscow (1967).
4. R. H. Cole, Underwater Explosions, Dover (1965).
5. B. V. Zamyshlyaev and Yu. S. Yakovlev, Dynamic Loads in Underwater Explosions [in Russian], Sudostroenie, Leningrad (1967).