

Transformation of Blast Wave by Two-Phase Medium

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Criminal usage of explosives has been constantly growing, and a large range of blast protection equipment, especially, those that protect against harmful shock wave effects and fragments are required. Upgrading protective devices and increasing their effectiveness is one of the main directions of scientific investigations, most of which are based on studying the ‘controlling’ mechanism of blast effects and ways of their attenuation.

Gas-liquid blast inhibition devices using gas-liquid layer screens for blast energy suppression [1-3] have been in great demand recently. Such a device is a multi-camera container in an elastic envelope filled with liquid. The design of the containers allows screening dangerous objects without touching them. It is very important for safety in operation since it reduces the risk of detonation in case of an accident impact.

It has been found experimentally that shock blast waves produced by HE detonation are weakened while passing through the liquid screen, much blast energy is consumed for the blast device destruction and the liquid kinetic energy. A shock blast wave is the sharp pressure rise with constantly decreasing pressure level. Due to the energy consumption and shock wave transformation inside the screen, the shock wave pressure near the inhibition device decreases several times in comparison with the same distance at ‘uncovered’ HE charge detonation. There is a good reason to think that blast two-phase inhibition devices attenuate not only a shock wave pressure, but also time-and- frequency parameters. But this question is to be studied.

Investigations [4-6] have shown the crucial role of the liquid compressibility in blast wave attenuation and transformation. The effectiveness of the blast inhibitors increases with replacing the liquid by the two-phase liquid-gas medium. The two-phase liquid-gas medium transforming the blast energy multiplies the medium compressibility by many times. Partial increase of liquid screen compressibility was achieved in [7] due to using an elastic envelope confining the liquid. The phenomenon and special features of blast shock wave transformation, while the shock wave is passing through the two-phase gas-liquid medium are of interest. Introducing gas bubbles into the liquid significantly influences the liquid compressibility, changes the speed of acoustic and shock waves within the liquid [7-10]. In two-phase (liquid+gas bubbles) medium the sound speed depends on the pressure, this fact ensures the effectiveness of blast wave attenuation. Multiple reduction of linear and non-linear waves speed in the two-phase medium effects the blast wave pressure profile extending it in time. The shock wave propagation through a gas-liquid medium has been studied in previous investigations. By shock wave is

meant the wave with constant parameters behind the blast wave front. Previously obtained data relate to very strong blast waves (pressure of several HPa [8,11,12]) or comparatively weak waves of 1 MPa [8,11,12]. Time of a compression phase was so long, that it would have made no sense to speak about frequency. The blast wave pressure resulted from a typical for criminals HE detonation inside gas-liquid blast inhibitors is 0.1-1.0 HPa.

Blast waves propagation through the two-phase gas-liquid medium has been investigated in [7,13]. It was proved that the shock blast wave speed was reduced and the following incident waves effectively attenuate the pressure.

A bubble gas phase included in the liquid significantly increases the time of the container destruction and changes the duration of all interactions. Additional to [7] testing has been carried out for evaluating consequences of replacing the liquid by the two-phase gas-liquid medium.

Testing Procedure and its Verification

75 g HE charges with electric sensors of ED-8 type have been used. Samples for the testing were containers made of 3mm corrugated cardboard. In the middle of the inner opposite containers' walls tensoresistive sensors were fixed. Distance between the sensors – 115 mm, width of the container – 300 mm, height of the liquid level – 300 mm. Waterproof reservoir filled with either a liquid or a two-phase liquid-gas bubble medium with a gas volume fraction of 50-60% was tightly placed inside the container.

HE charges were detonated in the open. The samples were placed on a steel plate, and HE charge was suspended on the pole, the center of the charge was on the axis crossing the sensors and perpendicular to the container wall. Distance from the charge center to the nearest sensors was 0.1 m, to the plate surface – 0.17 m.

Testing scheme is given in fig. 1.

Tensoresistive sensors recording a strong blast wave arrival were made of electrically conducting paper, its resistance decreases at compression. The signals were recorded and processed at a 16-channel computer oscillographs with frequency discretization 3MHz.

Based on the oscillograph-recorded signals from the sensors the time intervals between the impulse on the first and the second sensor were evaluated. The average speed of the shock wave in the medium was determined with the equation:

$$D = \delta / \Delta t,$$

where Δt – time interval between the impulses.

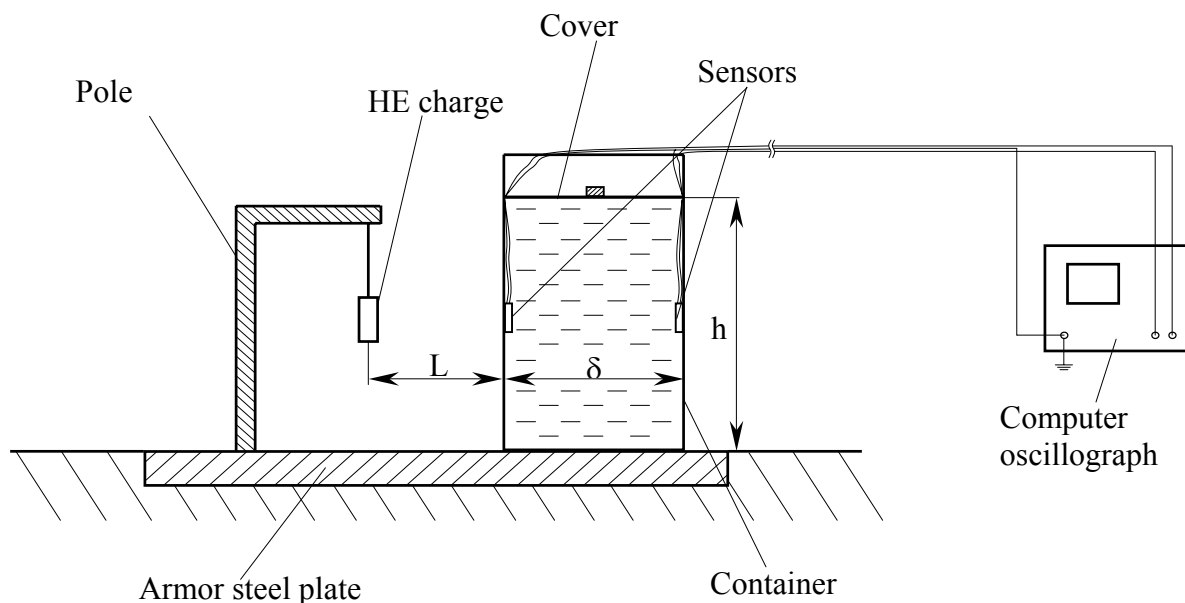


Fig.1. Testing scheme

Electric scheme of measuring conduit is given in fig.2.

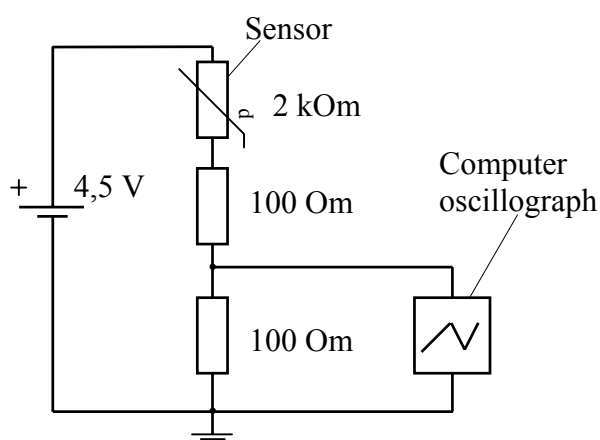


Fig.2. Electric scheme of measuring conduit

To verify the testing procedure of measurements, the calibration testing using samples filled with water was carried out. An example of the typical oscillogram obtained is given in fig.3. Channel 1 signal coming from the nearest to HE sensor and channel, 2 signal coming from the sensor placed behind the screen are given in the same time scale.

Results obtained in calibration testing are presented in the first line of the table, where τ_{fr1} , τ_{fr2} – time of output signal growth from the nearest and the remote sensors.

$D = \sigma / \Delta t$ – average blast wave speed between the sensors. The table shows maximum parameter spread obtained in the testing. The average blast wave speed

$$D_{ex} = 1380 \pm 30 \text{ m/s.}$$

Maximum overpressure of the blast wave P_m at the container's wall nearest to the HE has been found according to measurement results obtained in [14], at the given scheme of testing $\Delta P_m \approx 10 \text{ MPa}$. Wave reflection from the front screen wall results in ΔP_m inside the screen $\approx 80 \text{ MPa}$.

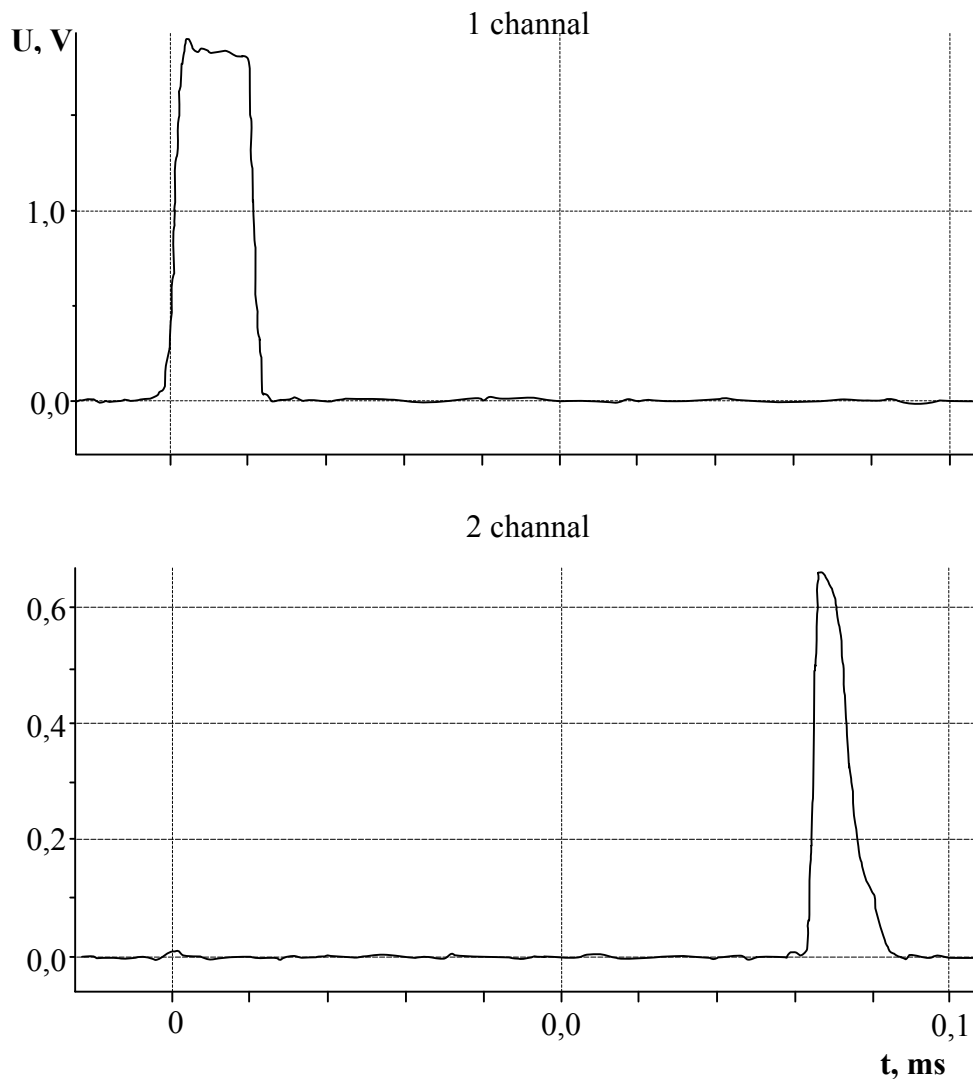


Fig.3. Oscillograms of output signals from tensoresistive sensors, samples filled with water without gas phase

Found from the constitutive equation [7,10] theta [15] we have had the speed of the blast wave in water, $D_s = 1580 \text{ m/s}$.

The difference between the calculated and the experimentally obtained speed (D_{ex} and D_s) is 12,3%, which is quite reasonable accuracy for the testing procedure applied. The gap between the calculated and experimentally obtained values can be explained by the elasticity of the container walls confining water. Besides, the water was not subjected to special degassing.

Results Obtained in Testing of Two-Phase Gas-Liquid Screens

Let us study the transformation of the blast wave by the two-phase gas-liquid medium.

Typical output signals oscillograms recorded by U-t resistive-strain sensors are presented in fig.4.

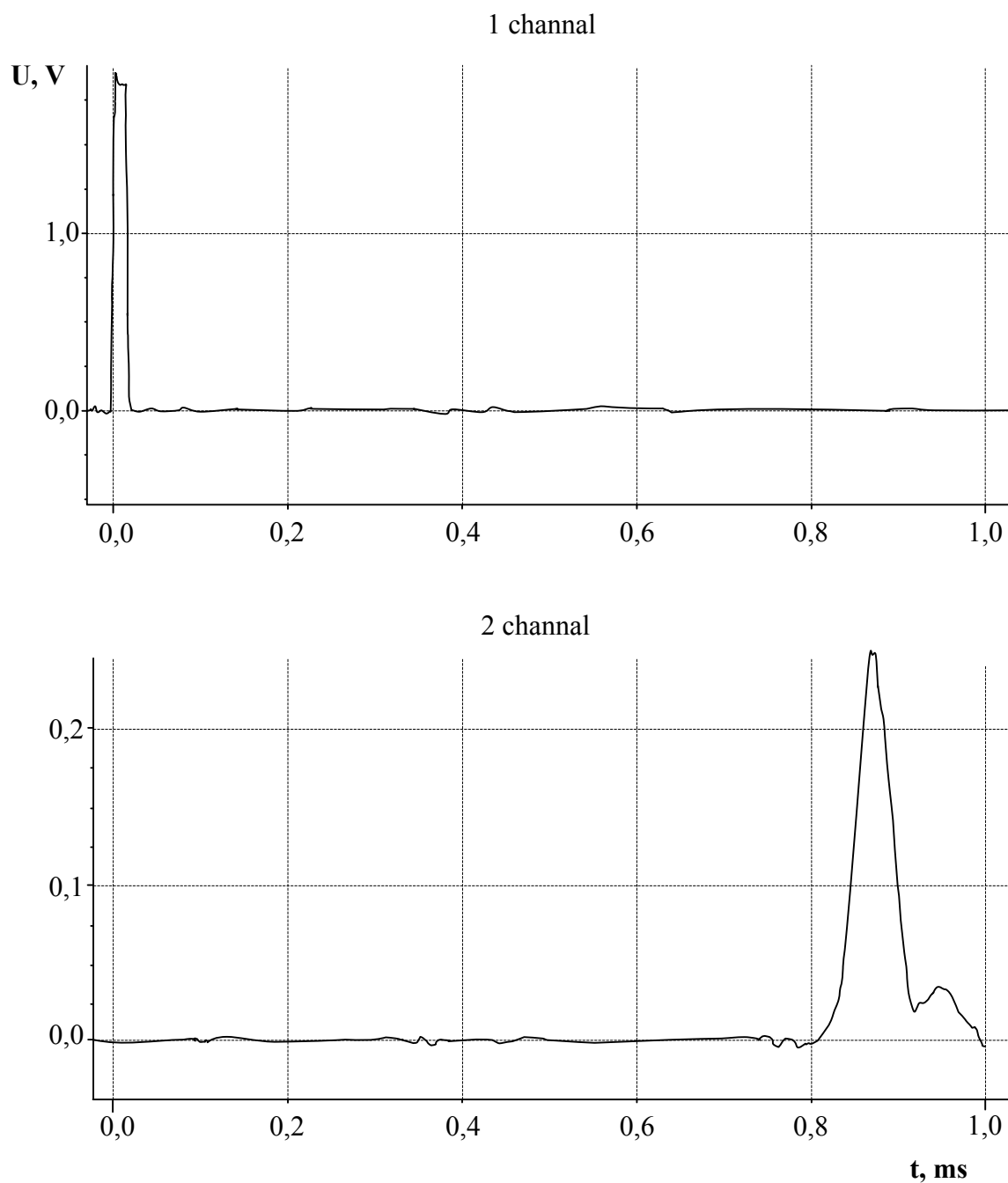


Fig.4 Oscillograms obtained in the testing of two-phase gas-liquid medium

The main parameters are given in the second line of the table 1.

Table 1.

Measurement results

| Type of medium | $\tau_{fr1}, \mu s$ | $\tau_{fr2}, \mu s$ | D, m/s |
|-------------------|---------------------|---------------------|---------------|
| Water | $2,4 \pm 1,3$ | $1,5 \pm 0,5$ | 1380 ± 30 |
| Gas-liquid medium | $1,8 \pm 0,9$ | 56 ± 14 | 134 ± 16 |

Comparing results of the blast wave transformation recorded by the sensors in the tests with the water layer (fig.3) and with the gas-liquid screen (4), one can see the qualitative difference between them. The time of the blast pressure rise in the water is not growing. In the gas-liquid medium the time of the blast pressure rise increases significantly. The blast wave speed in the two-phase medium decreases nearly 10 times compared to the water medium. Figure5 illustrates the output signals from the nearest to the charge sensor (1) and the remote sensor: for the water medium (2) and for the gas-liquid medium (3). Besides, the signal recorded by the remote sensor in water is 3 times bigger than that recorded in two-phase medium.

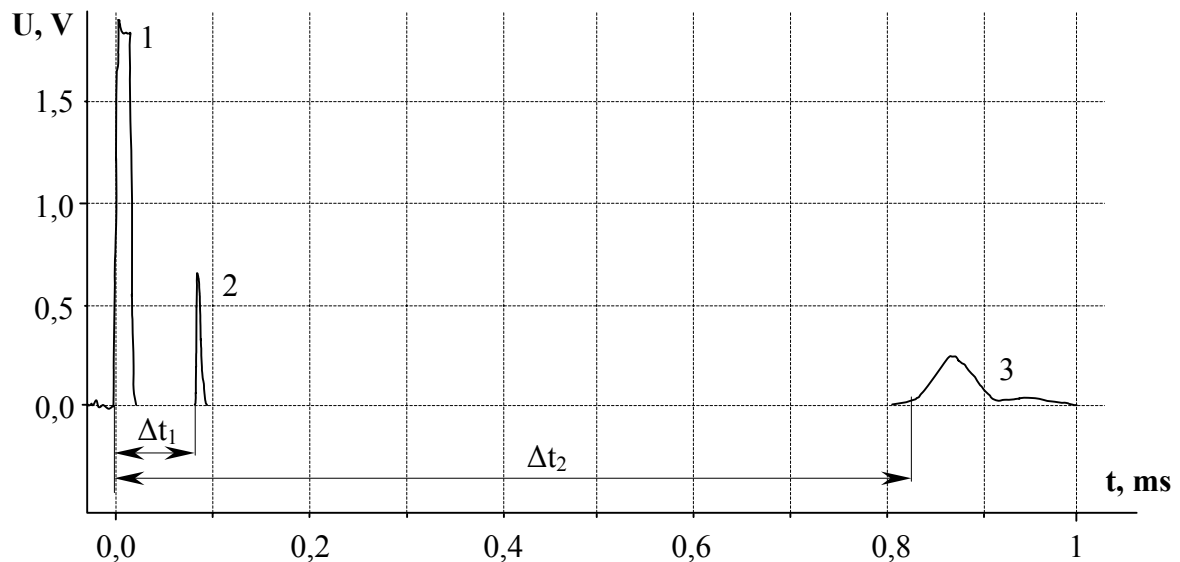


Fig.5 Comparison of output U-t oscillagrams obtained for blast wave transformation in the water layer and in the two-phase gas-liquid medium.

Δt_1 – time of the blast wave crossing the water layer

Δt_2 – time of the blast wave crossing the two-phase gas-liquid layer.

Fig. 6 presents qualitative and quantitative difference between the output signals.

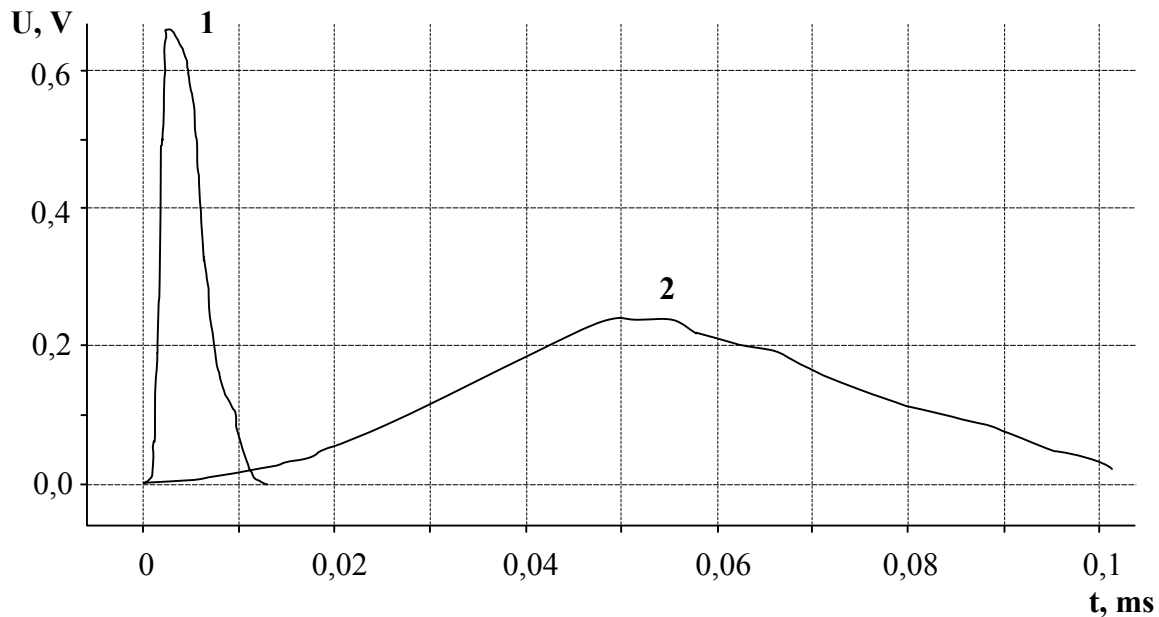


Fig. 6. Signals from the remote sensor obtained in testing of the samples with water (1) and of the samples with gas-liquid medium (2).

Discussion

The choice of a medium to fill the blast inhibitor is based on the main property of gas-liquid mediums. It is known from [7] that the equilibrium speed in such mediums can be found from $A^2 = P_0 [\rho_1 \alpha (1 - \alpha)]^{-1}$.

The minimum sound speed is obtained at gas volume fraction $\alpha = 0.5$, when a $(1 - \alpha)$ is maximum – 0.25. At the initial value of $P_0 = 0.1 \text{ MPa}$ in the water-air system A_{min} is 20 m/s. Thus, sound speed alternation on the way of a blast wave propagation medium is as follows:

340 m/s (air) – 20 m/s (two-phase screen) – 340 m/s (air)

It means that the average Mach number of the blast wave inside the medium between the container's walls is $M \geq 6.8$. The front blast wave overpressure $P_1/P_0 \approx M^2 \geq 46$. The pressure of a wave passing through the two-phase medium has been evaluated before as $P^*_1 \approx 800 P$, it corresponds to $M \approx 28.2$. By this means the blast wave speed in two-phase medium with $\alpha = 0.5$ decreases four times on the 115 mm distance, and the overpressure in the blast wave front – not less than 16 times.

The two-phase layer reduces not only the pressure of the passing blast wave, but also transforms the time-and-frequency parameters.

Instead of the sharp front blast wave recorded ahead of the screen, we have got a time

dilated low frequency compression wave.

Taking into account data obtained in [16], it is necessary to note universality of the mentioned phenomenon. Transformation of blast wave pressures resulted from the detonation of the water submerged HE charges has been studied in [16]. A polyurethane foam sheet (density - $27\div 64\text{kg/m}^3$, thickness - $1\div 10\text{ cm}$) was placed on the way of the underwater blast waves. The sound speed alternation on the way of the blast waves was:

$1470\text{ m/s (water)} - 60\div 100\text{ m/s (polyurethane foam sheet)} - 1470\text{ m/s (water)}$.

The results obtained in the investigation of the underwater blast waves [16] are qualitatively and quantitatively close to the results achieved in the testing of air blast waves transformation.

The underwater blast wave pressure in [16] is $30\div 50$ times less while passing the layer with a sound under-speed material. Time of the blast pressure rise in the shock wave front increases by 40 times, the blast pressure is transformed into the time-dilated compression wave. Agreement between results obtained in testing on suppression underwater blast waves and air blast ways allows us to assume that there is a possibility of developing universal blast protective devices on the bases of air blast waves attenuation stated in [1-7].

Conclusions

The speed of blast wave of 80 MPa measured by tensoresistive sensors in the water occurred to be close to the calculated value to 12,5% accuracy.

The testing procedure verified by the tests conducted in the water has been applied for finding the speed of overpressure blast waves inside two-phase protective mediums with the minimum equilibrium sound of speed. Average measured speed of the overpressure blast wave inside the two-phase gas-liquid medium is nearly 10 times less than the sound speed in a degassing liquid.

Time of the pressure rise in the shock wave front on entering the water is about $2.4\ \mu\text{s}$. The time does not increase when the waves passing through the 115 mm-water layer.

Time of the pressure rise in the shock wave front on entering the two-phase medium is about $1.8\ \mu\text{s}$ and it increases up to $56\ \mu\text{s}$ (37 times) inside the gas-liquid layer.

Based on the underwater blast waves data, we may confirm that two-phase mediums are effective gain-frequency transformers of blast effects resulted from the detonation of HE charges: blast wave pressure decreases several times, high-frequencies are eliminated.

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