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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

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Measurement of Sound Velocity in Detonation Products

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The velocity of sound in detonation products is an important characteristic of a detonation wave. Direct measurement of the sound velocity makes it possible to verify the Chapman–Jouguet condition at the front of the detonation wave and also, as will be shown below, to calculate the distribution of density and pressure behind the front of the detonation wave. The present article gives a brief description of the method developed by us and the results of measuring the velocity of sound in the detonation products of charges of TNT and the alloy TG 50/50 (an alloy of equal weight parts of TNT and RDX). The method for measuring the velocity of sound in detonation products is based on the reflection of a detonation wave from a plate of inert material pressed against the end of the charge. If the dynamic rigidity of the plate is less than the dynamic rigidity of the explosive substance (e.s.) (paraffin satisfies this condition well), then upon reflection of the detonation wave from such a plate a shock wave will travel through the plate, while a reflected rarefaction wave will travel through the products. The latter, like any weak discontinuity, propagates with the local velocity of sound (^{1}).

Using the electromagnetic method for measuring the mass velocity of explosion products (^{2}), one can use the same method to measure the velocity of sound in detonation products.

Fig. 1. a) Motion of the pickup. 1 –e.s., 2 –paraffin, 3 –pickup; D –direction of motion of the plane detonation front, u –direction of motion of the explosion products behind the detonation front, c –direction of motion of the reflected rarefaction wave. b) Photograph of the recording of the e.m.f. induced in the moving pickup

Let us consider the motion of the pickup and the oscillogram of Fig. 1. At the moment $t = 0$ (point A, Fig. 1b), the front of the detonation wave reaches the pickup, and the latter begins to move with the mass velocity behind the detonation front.

At the time $t = S/D$, the front of the detonation wave reaches the boundary between the e.s. and the inert material, and a reflected rarefaction wave travels through the detonation products. At the time

$$t = \frac{S}{D} + \frac{S - \bar{u}t}{c - u}$$

(point B, Fig. 1b), the rarefaction wave meets the pickup and it sharply increases its velo-

velocity (since in the rarefaction wave the substance moves in the direction opposite to the motion of the wave), which is also noted on the oscillogram. Measuring S—the initial distance from the sensor to the interface boundary h.e.—inert, D—the detonation velocity, $\bar{u}$—the average velocity of motion of the sensor during the time t—the time of motion of the sensor from the moment the detonation front passes (point A, Fig. 1, b) until it meets the rarefaction wave (point B, Fig. 1, b), one can calculate the average sound velocity in the time interval t:

$$c = \frac{S(D - \bar{u})}{Dt - S}.$$

Fig. 2. Dependence of the sound velocity in detonation products in the Chapman—Jouguet plane on time. Time is reckoned from the detonation front: 1—TG 50/50; 2—TNT, charge length 90 mm; points a refer to a cast charge; 3—TNT, charge length 48 mm

By varying the distance S, one can obtain the distribution of the sound velocity behind the front of the detonation wave. The results of measuring the sound velocity are given in Table 1 and in Fig. 2, where the dependence of the sound velocity on time behind the front of the detonation wave is presented graphically. The mean error in measuring the sound velocity from a series of 3-5 experiments does not exceed 4-5%.

We shall now use the equation of state of the explosion products proposed by L. D. Landau and K. P. Stanyukovich, $P = A\rho^n$; the isentropic relation for the sound velocity $c^2 = \frac{\partial P}{\partial \rho}$ and the known relations at the Jouguet point $\rho = \rho_0 \frac{n+1}{n}$, where ρ_0 is the initial density of the explosive, and ρ is the density of the explosion products at the Jouguet point, and $P = \rho_0 \frac{D^2}{n+1}$, where P is the pressure at the Jouguet point.

Table 1

Explosive	Charge diameter, mm	Charge height with lens, mm	D, km/sec	u , km/sec	c , km/sec	S, mm	t, μsec	$\bar{u}$, km/sec	c, km/sec
Cast TNT, $\rho_0 =$ 1.6 g/cm^3	40	48	7.00	1.81	5.19	2.53	0.755	1.62	4.95
Cast TNT, $\rho_0 =$ 1.6 g/cm^3	40	48	7.00	1.81	5.19	4.09	1.255	1.47	4.82
Cast TNT, $\rho_0 =$ 1.6 g/cm^3	40	48	7.00	1.81	5.19	5.50	1.720	1.36	4.76
Cast TNT, $\rho_0 =$ 1.6 g/cm^3	40	90	7.00	1.81	5.19	3.09	0.912	1.68	5.03
Cast TNT, $\rho_0 =$ 1.6 g/cm^3	40	90	7.00	1.81	5.19	6.16	1.848	1.56	4.94
Pressed TNT, $\rho_0 =$ 1.6 g/cm^3	40	90	7.00	1.81	5.19	2.78	0.809	1.71	5.10
Pressed TNT, $\rho_0 =$ 1.6 g/cm^3	40	90	7.00	1.81	5.19	4.84	1.435	1.61	5.02
Pressed TNT, $\rho_0 =$ 1.6 g/cm^3	40	90	7.00	1.81	5.19	6.90	2.080	1.52	4.93
TG 50/50, cast, $\rho_0 =$ 1.68 g/cm^3	40	95	7.65	2.03	5.62	2.64	0.706	1.91	5.49

Fig. 3

Figure 2: Fig. 3

Fig. 4

Figure 3: Fig. 4

Explosive	Charge diameter, mm	Charge height with lens, mm	D, km/sec	u , km/sec	c , km/sec	S, mm	t, μsec	$\bar{u}$, km/sec	c, km/sec
TG 50/50, cast, $\rho_0 =$ 1.68 g/cm^3	40	95	7.65	2.03	5.62	3.70	1.000	1.87	5.43
TG 50/50, cast, $\rho_0 =$ 1.68 g/cm^3	40	95	7.65	2.03	5.62	7.30	2.020	1.71	5.32

For the case of one-dimensional flow, i.e., in the region not covered by the unloading wave coming from the side surface, one can obtain the distribution of density and pressure behind the Jouguet point (^{3})

$$\rho_* = \frac{n+1}{n}\rho_0 \left(\frac{c_*}{c}\right)^{\frac{2}{n-1}}; \qquad P_* = \frac{\rho_0 D^2}{n+1}\left(\frac{c_*}{c}\right)^{\frac{2n}{n-1}},$$

where ρ_*, P_*, c_* are, respectively, the current values of the density, pressure, and sound velocity in the detonation wave behind the Jouguet point.

As was found in work (^{2}), the exponent n remains constant for the above-mentioned explosives over the time interval 3–3.5 μsec. Thus, from the measured sound velocities in the detonation products, using the formulas given above, one can calculate the distribution of density and pressure behind the Jouguet point.

Fig. 3. Dependence of the density of the explosion products behind the Chapman–Jouguet plane on time:
1 –TG 50/50; 2 –TNT, charge length 90 mm; 3 –TNT, charge length 48 mm

Fig. 4. Dependence of the pressure of the explosion products behind the Chapman–Jouguet plane on time:

1 –TG 50/50; 2 –TNT, charge length 90 mm; 3 –TNT, charge length 48 mm

The results of the calculations carried out for the above-mentioned charges of explosives are given in Table 2 and in Figs. 3, 4.

Table 2

Explosive	Charge height, mm	t, μsec	ρ, g/cm^3	$P \cdot 10^3$, atm.	Explosive	Charge height, mm	t, μsec	ρ, g/cm^3	$P \cdot 10^3$, atm.
Cast TNT	48	0	2.16	203	Cast and pressed TNT	90	3.0	1.82	122
Cast TNT	48	0.5	2.05	175	Cast and pressed TNT	90	3.5	1.76	113
Cast TNT	48	1.0	1.95	151	Cast TG 50/50	95	0	2.30	262
Cast TNT	48	1.5	1.84	128	Cast TG 50/50	95	0.5	2.22	237
Cast TNT	48	2.0	1.74	108	Cast TG 50/50	95	1.0	2.14	216
Cast and pressed TNT	90	0	2.16	203	Cast TG 50/50	95	1.5	2.06	194
Cast and pressed TNT	90	0.5	2.10	188	Cast TG 50/50	95	2.0	1.98	175
Cast and pressed TNT	90	1.0	2.04	173	Cast TG 50/50	95	2.5	1.90	156
Cast and pressed TNT	90	1.5	1.99	160	Cast TG 50/50	95	3.0	1.82	139

Explosive	Charge height, mm	t, μsec	ρ, g/cm^3	$P \cdot 10^3$, atm.	Explosive	Charge height, mm	t, μsec	ρ, g/cm^3	$P \cdot 10^3$, atm.
Cast and pressed TNT	90	2.0	1.93	147	Cast TG 50/50	95	3.5	1.75	124
Cast and pressed TNT	90	2.5	1.87	135					

These data will make it possible, after studying the region of one-dimensional flow of the explosion products, to calculate the impulse of a charge of explosive.

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References

[1] Ya. B. Zel' dovich, A. S. Kompaneets, *Theory of Detonation*, 1955.
[2] V. M. Zaitsev, P. F. Pokhil, K. K. Shvedov, *DAN*, **132**, No. 6 (1960).
[3] K. P. Stanyukovich, *Unsteady Motions of a Continuous Medium*, 1955.