Method of determining of energy intensive materials' work efficiency, using parameters of degenerated shock waves

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Abstract. The paper describes the method of the working efficiency determining, which involves determining the acoustic TNT equivalent or its expression through the air shock wave parameters such as amplitude, duration, and pulse compression phase or energy values of recorded acoustic oscillations, generated by the detonation of the material sample.

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Introduction

TNT equivalent is an important parameter of explosive, which is used to determine safe distances, norms of equipment loading in production and transportation, etc. For experimental evaluation of power-intensive materials work efficiency the following methods are used: the lead bomb method, the method of ballistic mortar and pendulum. For industrial explosives work efficiency is determined by the volume of the funnel ejection, formed by an explosion in the ground. These methods of power-intensive materials work efficiency determining have several drawbacks, among which, the main difference is between the values, obtained in different laboratories [1], an ambiguous compliance of values, obtained by usage of different techniques and the need of large numbers of samples of tested substances. Studies, dedicated to a communication setup between work efficiency with fundamental parameters of explosive, such as specific heat and volume of explosive products, are given in [2]. In standard methods, samples of substances, weighing 10 grams (method of Trautsel lead bomb and ballistic mortar) and 200 grams (ballistic pendulum method) are used. At the same time, the usage of smaller masses of samples provides safety and economic efficiency. In particular, in the work [3] there proposed a method of calculation of TNT equivalent of silver azide by speed of detonation products, measured by the analysis of high-speed photo registration of explosion process images. Taking into an account that small weigh of explosives, which are able to detonate, are sources of shock waves within an explosion, you can develop a method of explosive work efficiency testing, in accordance with the values of shock waves parameters of in close and far zone. In this case it is possible to zoom an explosive mass, distances, times and pressures in a wide-range [4]. Measured values in tests may be a wave compression impulse phase or excessive pressure in its front. As an impulse meter a pendulum, piston and other devices are used [5]. An excessive pressure is measured directly or it is calculated by a measured speed of shock waves.

Methods for determination of TNT equivalent of explosives may be built on a basis of the well-known empirical relations of Sadowskiy, linking a pressure of shock wave, a distance from a charge to an explosion epicenter and a mass of equivalent TNT charge. In these relations, a Sadowskiy – Gopkinson' variable is used [6]

$$R_* = R/G^{0.33}, \quad (1)$$

where R_* – a given distance, R – a distance from an explosion epicenter to a charge, G – a charge mass.

On the basis of the sources [3] it is known that many empirical relations, connecting a pressure in the front of AB with a given mass or length has the form of:

$$\Delta P = A \cdot \frac{1}{R_*} + B \cdot \frac{1}{R_*^2} + C \cdot \frac{1}{R_*^3} + D \quad , (2)$$

where A, B, C, D – coefficients, found from tests.

If we substitute the expression for a given distance, we receive

$$\Delta P = A\frac{\sqrt[3]{M_{TNT}}}{R} + B\frac{(\sqrt[3]{M_{TNT}})^2}{R^2} + C\frac{(\sqrt[3]{M_{TNT}})^3}{R^3} + D \quad (3)$$

where M_{TNT} – TNT charge mass.

When we enter (3) to an expression, relative to a charge mass. Take $X = \sqrt[3]{M}$, then

$$X^3 + BCR \cdot X^2 + ACR^2 \cdot X + (D - \Delta P)CR^3 = 0 \quad (4)$$

Having found from (4) the values of TNT charge mass we may make an assumption about data generalization, obtained for TNT for other substances.

Further, in this method a TNT equivalent value is determined by the known mass of tested substance charge and calculated equivalent mass of TNT as

$$E_{TNT} = \frac{M}{M_{TNT}}. \quad (5)$$

Thus, substituting to the expression (5) the known mass value tested charge and the value of an equivalent TNT charge, found from (4), we can determine the TNT equivalent and take it as a measure of work efficiency. A solution of the equation (4) can be easily performed by numerical methods directly on the computing device of TNT equivalent measurement system.

Despite the usefulness of such methods usage, on their basis there no developed and tested techniques have been found. At the same time, the use of (AB) parameters allows us to reduce material intensiveness of work efficiency measurements' works and intensify the process of synthesis of new power-intensive materials, in particular, using a micro-sized components. For materials with small critical detonation diameter there is no need to use large number of substance for tests.

To measure work efficiency it is offered to use a similarity of AB parameters of large and small explosions and determine work efficiency as an acoustic TNT equivalent. With this approach, we use the result of a mechanical action of an explosion, as in the case of standard techniques, but the impact on the sensing element is transmitted through an elastic medium – air.

The main advantages of the offered method of work efficiency determining, in comparison with the standards ones are:

1) Work efficiency determining by the offered method is carried out within samples with a mass as tens and hundreds times as less than in standard techniques;

2) During testing expensive materials are not used, such as cylindrical block of high purity lead, weighing 80kg in the method of lead bomb (the lead is not used twice);

3) A process of initiating and registration of the measurement information is carried out automatically and synchronously;

4) In the offered method it is available to implement an measurement atomization, including recording and statistical data processing, as well as maintaining a database of tested substances.

The experiment description

A practical interest is a connection between parameters of detonation acoustic oscillations in the points, located at distances, where the speed of the AB becomes equal to the speed of sound within a work efficiency of brisant explosive. To determine method realization conditions, a series of experiments was conducted, during which small weighs of explosives were initiated and sound pressure was recorded at certain distances from a tested sample.

During a method development, various ways to maintain and initiate explosives weighs were considered. In particular, depending on the type of a tested material (initiating or brisant) substance distribution and pressing in standard small capsules was used. Also, depending on a type of a substance, a continuous initiation by heat flow was implemented, thermal impulse, created by the laser unit, by the transmission of detonation from the intermediate layer of an initiating substance, etc. Moreover, in the process of detonation fragments' distribution of formed explosive charge and cladding occurs. Movement of burning fragments and detonation products, a front of parasitic AB is created, which precedes shock wave, generated by a detonation of main portion of a substance, placed in the tested charge. At the same time, in a recorded signal, an acoustic noise, preceded by main semi-wave, the intensity of which may be significant and often distorts the results.

The presented results are obtained within using the method, in which explosives weigh is enclosed in a roller device. Fragment distribution of a detonating substance in such construction is excluded. Thus, realizations of the received signals we can see a sharp jump of a sound pressure in a front longitudinal compression wave and no "parasitic" oscillations are present.

To initiate the explosive transformation of explosives, mechanical impact of falling weight of 10 kg from a height of 1m was used. A drop hammer K-44-2 was used for given loads creation. Selection, preparing and weighing of samples was carried out in accordance with the procedure, described in GOST 4545-88 [7, 8]. During the experiments, the test substance, weighing 50mg, weighed in the scales, providing an absolute error of no more than 1 mg and was placed in roller device. The scheme of the experiment is represented in picture 1, where 1 – sound pressure sensor (microphone), 2 – amplifier, 3 – power source and the polarization, 4 – ATS, 5 – ECM, 6 – drop-hammer column, 7 – weight, 8 – roller device with the test sample, 9 – anvil.

Sound pressure signal, caused by the process of explosion EV transformation, recorded microphone of free field with a sensitivity of 4mV/Pa of 40BF type of the GRAS company with preamplifier of 26AA. Microphone was placed in the direction of the test sample at a distance of 1 meter. An output of preamplifier was connected with an input of the power supply unit and voltage of polarization of 12AR type. An output signal was subjected to analog-to-digital conversion with an accuracy, corresponding to 13 binary bits to voltage range of ±10V.

It was carried out several series of experiments of ten tests with each substance, which have different values of work efficiency (octogene, hexogen, PT, TG). Sample, weighing 50 mg were tested.

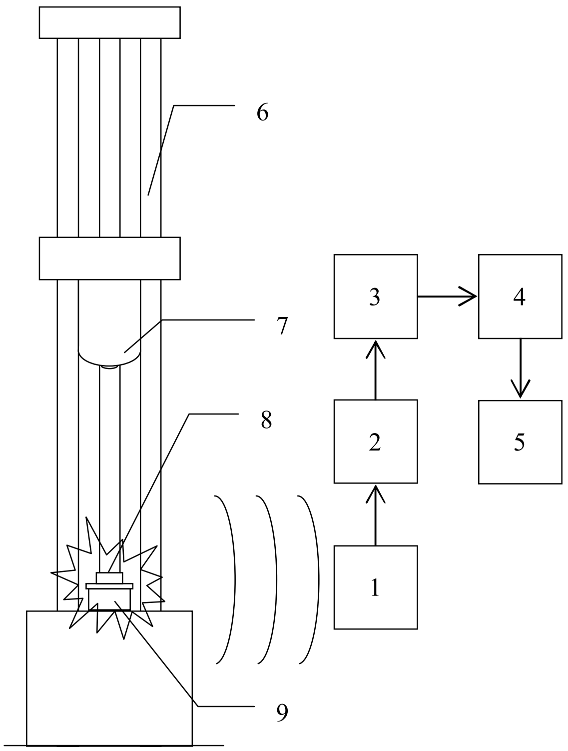

Fig. 1. 1 – sound pressure sensor (microphone), 2 – amplifier, 3 – power source and the polarization voltage, 4 – ATS, 5 – ECM, 6 – drop-hammer column, 7 – weight, 8 – roller device with the test sample, 9 – anvil

Results and discussion

A work efficiency of explosive on a basis of sound analysis, generated by the detonation, is proposed to be calculated by the formula

$$\sigma = \max\left(\frac{1}{t}\int_0^t s^2 dt\right) \quad (6)$$

where s – realization of changed signal of sound pressure, t – time.

At the same time it is possible to consider other variants of the calculating algorithms of absolute values of work efficiency, which must have the property of uniqueness. One of such algorithm is based on measuring of an extreme of specific energy of sound pressure signal, normalized by time. If we equate the derivative of this ratio to zero, we obtain:

$$\frac{d\left(\frac{1}{t}\int_0^t s^2 dt\right)}{dt} = 0, \quad (7)$$

On the basis of (7) extreme points are determined, from which you selects the maximum value.

When we use the analog-to-digital conversion of sound pressure signal with a uniform discretization and quantization, the expression (1) is transformed to the form (2):

$$\sigma = \max\left(\left.\frac{\sum_{i=0}^{j} s_i^2}{j\Delta t}\right|_{j=0..N}\right) \quad (8)$$

where s_i – value of sound pressure counting, Δt – an interval of discretization of sound pressure signal , N – number of the last counting of a signal realization.

Registered sound pressure signals in a digital form are aligned in time, averaged and accumulated sums of the signal counting's squares were determined.

Data processing procedure contains the procedure of time signals' alignment. Moreover, as a zero count is taken such a moment of time, from which a dispersion of signal realizations in an area of m counts, corresponding to the selected time interval analysis, exceeds the previous value to a predetermined value ε_1.

$$\frac{1}{m}\sum_{i=0}^{m}\left(s_i - \frac{\sum_{i=0}^{m} s_i}{m}\right)^2 < \varepsilon_1 \quad (9)$$

Having determined an acoustic work efficiency equivalent (relative work efficiency) by explosion parameters of reference substance (TNT) as:

$$B = \frac{\sum_{i=0}^{n} s_{xi}^2}{\sum_{i=0}^{n} s_{0i}^2}, \quad (10)$$

where s_x – a signal, obtained by "testing" of a sample with a work efficiency to be found, s_0 – a signal obtained by "testing" of a substance with an ideal work efficiency (TNT).

Signal ***B(t),*** with the same statistical noise characteristics tends asymptotically to some fixed value. Work efficiency (latest count) is determined at a point, where a dispersion of a signal does not exceed a preselected value ε_2, which corresponds to a noise dispersion.

The maximum recorded value of sound pressure does not exceed 3000 Pa or 165 dB. The duration of the first positive semi wave oscillations is less than 150 microseconds. The duration of the first negative semi wave does not exceed 800 microseconds. The calculation of wok efficiency is carried out in the interval of 14 milliseconds.

Time diagrams of a specific energy of a signal within an interval between 90 ms and 2 ms, normalized by time, are shown in Figure 2.

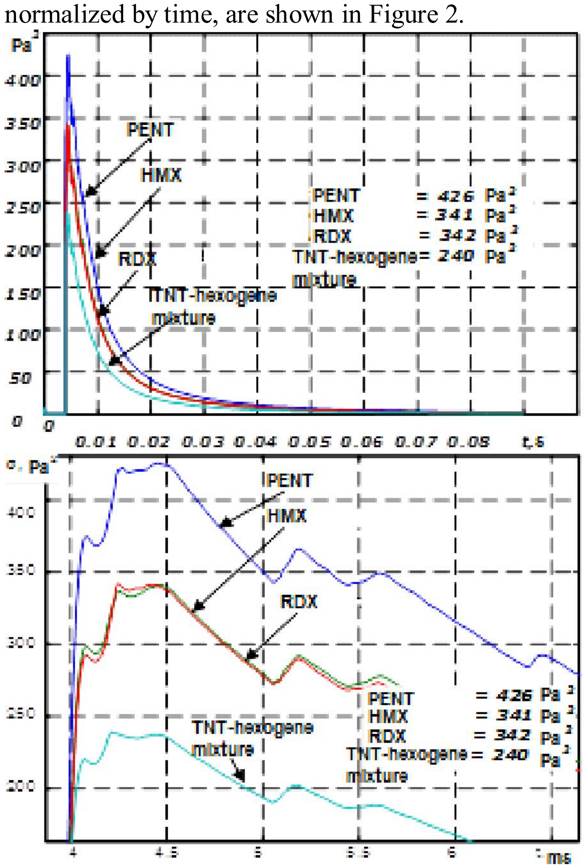

Fig. 2. Time diagrams of the saved-up sums of squares of sound pressure (specific energy) rated on the cumulative sum of counting of time and an illustration to determination of value of working capacity on sound effect of explosion of a sample of explosive (the maximum values are used)

Work efficiency, calculated in accordance with (8) has the value 240 PS^2 (TG) 342 PS^2 (Hexogen), 341 PS^2 (Octogene), 426 PS^2 (PT).

As it can be seen, the drawback of algorithm calculation (7) is the ambiguity of the characteristic maximum value determining, as maximum can occur in the first, second or third semi wave oscillations of a medium.

Obtained values of an absolute equivalent of work efficiency have dimension [PS^2]. Accuracy and repeatability of measurement results can be improved if work efficiency is defined as the ratio of received value to an additional measured acoustic impedance of a medium. Thus, inserted value receives the dimension of power stream density value.

Figure 3 presents charts, which illustrate the relationship between the work efficiency, produced according to (10) and standard values, obtained by a lead bomb testing. The principle of determining work efficiency by a sound signal of an explosion is also demonstrated, in which specific energy of sound pressure signal is found as well as a value of this characteristic at the transition point of an averaged signal through zero. At this point, a characteristic of a specific energy of sound pressure signal has an extreme. The figure shows the time diagram of accumulated sum of squares of a sound pressure (specific energy), the Heaviside's function of the average value of the time diagram of one of the tested substances and the mechanism of work efficiency absolute values determining.

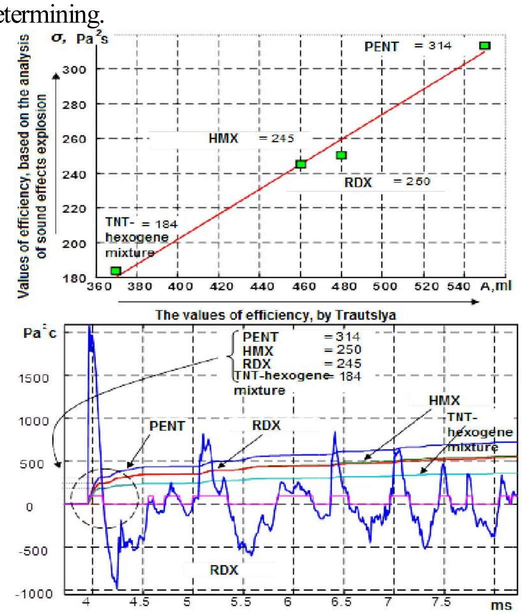

Fig. 3. Illustration to determination the value of performance for sound effects explosion explosive sample (used first extreme specific energy signal sound pressure) and the ratio of equivalent acoustic performance and explosive performance obtained by lead bomb

The calculation algorithm (6) – (10) allows using only the normalized values of work efficiency, and requires the need for preliminary testing of samples of reference substances, such as TNT. It is a common practice for other methods as, for example, the amount of lead bomb expansion volume, ballistic pendulum deviation and a height mortar is not in a linear relationship with the true work efficiency [9, 10]. Results, obtained by all the methods, characterize only relative work efficiency. They are usually compared with the work efficiency of crystalline TNT, accepted as a standard.

The values σ, calculated by the formula (2) are correlated with explosive work efficiency estimations, obtained by standard methods that justifies the applicability of the method.

Conclusion

Obviously, the analysis of sound oscillations' parameters, generated by the detonation of explosives is of practical interest. In particular, there may be constructed a method of efficiency determining of explosive materials' mechanical action, synthesized in small quantities, with the masses of the tested samples tens or hundreds times smaller than it is required in standard methods (from 10g up to 200g). It is possible to simplify a testing of explosives for high-explosive and brisant action by reducing the weight of the test samples, material consumption and self-cost. Striking confirmation is a result of comparison of relative work efficiency, received by acoustic method with the results of tests of lead bomb explosives. An important fact is a qualitative correlation of data, obtained with the standard procedure, since data of standard methods in relative values are not quantitatively the same.

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