Acoustic analysis of blast waves caused by gas detonating spraying

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Abstract. This paper describes the method of determining quality parameters of gas detonating mixtures (the amount of gas and presence of powder material in the flow of detonation products) used in the process of detonation spraying based on the analysis of acoustic oscillations during the blast. Experimental data are presented for the dependence of power of the sound source on the amount of gas mixture with powder material and without it.

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Introduction

Detonation spraying technology is widely used in industry, and it is an effective method of applying powder coating of ceramics and metals [1, 2, 3]. In order to achieve the necessary characteristics of coating by various materials, various gas mixtures are used, e.g., acetylene with oxygen, propane with oxygen, etc. [4].

The main technological parameter that determines energy characteristics of the powder coating process, such as particles speed and temperature in the flow, is the amount of detonating gas mixture introduced into the barrel of the detonation machine. Thus, the parameters of coatings obtained using the detonation method are determined by the amount and qualitative composition of the gas mixture [5, 6]. Continuous monitoring of these parameters is an actual problem and is of practical interest. In modern detonation spraying systems, the amount of gas is usually dosed by valves with the self-test function. Possible sources of error may be quality of the gas mixture, gas pressure stabilization error, and change in pneumatic system mechanical parameters. The process requires ensuring reliable correspondence of process indicators to reference values. Process status can be monitored using high-speed photographic recording, video recording and pyrometry [7, 8]. This way, it is possible to determine particles speed and flow temperature. However, at present, this way is not applicable for prompt management due to complexity of autonomous processing of the video signal and insufficiently fine resolution if pyrometers (particles' size is less than 100 μm).

Development of a two-phase flow formed by expanding detonation products and flow of micro-particles starts with an illuminating gaslock on the edge of the barrel that precedes and is dissipated by gas mixture detonation products. The main flow of particles is formed through 2ms after appearance of the initiating pulse. Particles speed in the flow is distributed in the interval between 400 and 600 m/sec [9, 10, 11]. Photographs of the process of particle flux formation obtained with high-speed photo recording camera are shown in Figure 1.

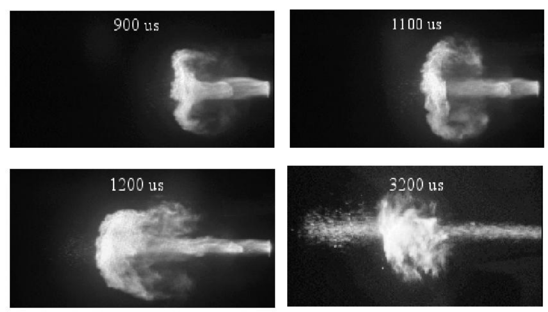

Figure 1. Photographs of detonation throwing of powder particles obtained using a high-speed camera (exposure time 20 microseconds)

In the photographs shown in Figure 1, the time reference point coincides with the moment of detonation initiation from an electric spark.

Another information indicator may be sound. Generated by expanding detonation products air blast generates subsiding sound waves where intensity depends on the quality and amount of detonating gas [12, 13, 14]. It is obvious that parameters of sound are also dependent on presence, size and amount of the powder particles. Gas mixture detonation speed is 2,500 m/sec [15, 16, 17, 18, 19]. In order to determine the nature of sound signal parameters dependence on the amount of gas, several experiments were made.

Description of the experiment

The system of acoustic measurements should provide primary transformation of acoustic waves parameters into an electrical signal, and recording and processing of these signals. These parameters include acoustic pressure, particle velocity, sound intensity (power), and acoustic offset. Explosion sound pressure levels recorded during the experiment at the distance of 1 m during initiation of detonating gas mixtures (30 mg – 300 mg) lie in the region of large values, on a relative scale ranging between 80 dB and 170dB (relative to 20 µPa) that corresponds to values on the absolute scale of 0.2Pa to 6324 Pa. The frequency spectrum of explosion sound vibrations is also wide and lies in the range between subsonic and ultrasonic frequencies.

Objects in the vicinity of the detonation machine exposed during the coating process are subjected to the following factors: detonation products; particles flowing from the barrel and reflected from the workpiece; shock wave. Thus, microphone location should meet the following requirements: microphone location should be safe, i.e., beyond the reach of detonation products and particles flowing from the barrel and reflected from the workpiece coated; microphone orientation should be constant; maximum sound pressure level produced by the shot at the location of microphone capsule should not exceed the maximum working sound pressure values for the microphone used.

Location for microphone capsule was chosen where its axis is parallel to the barrel axis at the distance of 1.5 m from the muzzle.

Series of experiments was made with recording signals of sound pressure in case of acetylene and oxygen gas mixture explosion at the detonation coating machine with barrel length 0.6 m and 20 mm in diameter. Acoustic waves propagation velocity at this distance should be equal to sound velocity [20, 21, 22]. The axis of the sensor element is normal to the direction of gas flow.

Amount of detonating gas mixture was changed by changing the filling volume of the barrel. During the experiments, the fuel to oxygen ratio 1:1 was used. In each mode corresponding to a certain value of barrel filling coefficient, 20 experiments were made (30%, 40%, 50%, 60%, 70%, 80%, 90%). Mass of gas mixture changed from 120 mg (50% barrel filling) to 230 mg (90% barrel filling).

Experiments were performed without the powder and with the powder. In the latter case, tungsten carbide powder (WC – 12) was used. Powder injection point is located at the distance of 300 mm from the muzzle. The mass of each powder dose was 100 mg. Experiments were performed without a target.

One of the algorithms for determining quality indicator is based on measuring the extremum of sound pressure signal s' specific energy, normalized by time t. The extremum point can be clearly defined by equating the derivative of this ratio to zero and choosing the maximum value of the parameter between several extreme points ***max(si)***, where ***i*** is the number of the extremum.

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

$$\frac{1}{t}s^2 - \frac{1}{t^2}\int_0^t s^2 dt = 0, \qquad (2)$$

since the value inverse to time does not turn this expression to zero anywhere except for infinity, we can write:

$$s^2 - \frac{1}{t}\int_0^t s^2 dt = 0 \qquad (3)$$

The recorded sound pressure signals in digital form were aligned in time, averaged, and accumulated sums of squares of signal samples were determined.

The data processing procedure includes the algorithm of time alignment of signals implementations. With that, the zero reference is understood as the moment in time starting from the which dispersion of signal implementation in a window of m references that corresponds to the interval of analysis chosen exceeds the previous value by the predetermined value ε_1

$$\frac{1}{m}\sum_{i=0}^{m}\left(s_i - \frac{\sum_{i=0}^{m} s_i}{m}\right)^2 < \varepsilon_1 \qquad (4)$$

Effective interval of signal action ends in the point where signal dispersion does not exceed the predetermined value ε_2 of the corresponding noise dispersion.

$$\frac{1}{m}\sum_{i=0}^{m}\left(s_i - \frac{\sum_{i=0}^{m} s_i}{m}\right)^2 < \varepsilon_2 \qquad (5)$$

Thus, information parameter used is the value

$$\sigma = \frac{1}{t}\int_0^t s^2 dt \qquad (6)$$

where ***s*** is implementation of measured sound pressure signal, ***t*** is time.

Results of experiments processed in accordance with (1), for the case with and without powder are shown in Figure 2.

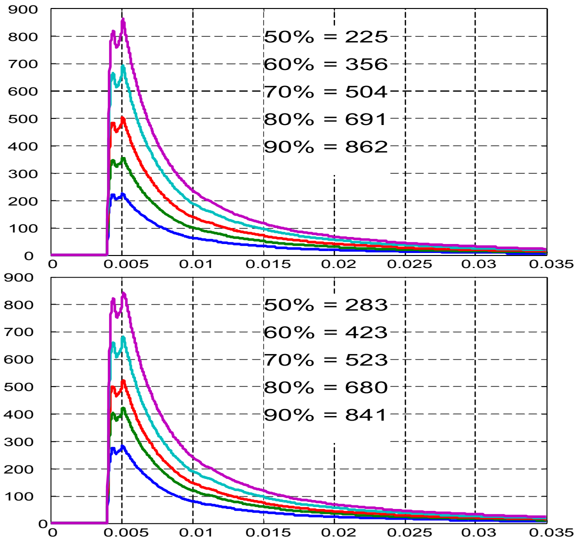

Figure 2. Normalized in time energy of sound pressure signals for various amounts of gas mixture (barrel filling coefficients) with and without powder

As a result of processing the obtained data, power values were determined at points that correspond to fixed amounts of gas mixture with and without powder in accordance with procedure (1) - (6). The data obtained are presented in the form of dependencies in Figure 3.

The dependence of sound signal specific energy on the amount of gas mixture has increasing nature. Each value of barrel filling ratio has single corresponding value of specific sound energy. Thus, in fact, by measured values of sound signal parameters, the amount and quality of detonating gas mixture can be determined.

In the range of gas mixture mass between 120 mg (50% barrel filling) and 185 mg (75% barrel filling), the curve of the sound intensity during shots without powder is higher than the sound intensity during shots with the powder. Starting with the 75% barrel filling coefficient cycle, the nature of sound intensity dependencies changes. Line of sound intensity in case of shooting without powder gets below the line that corresponds to shooting with powder. Presumably, this effect may be related to features of particulate material injection that changes detonation mode of gas in case of barrel filling factors greater than 50%, with more intense excitation of secondary acoustic waves generated by the flow of heated particulate material.

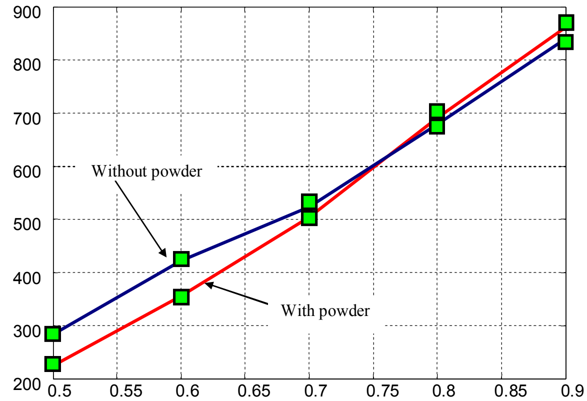

Figure 3. Dependence of sound power on the amount of gas mixture (barrel filling ratio)

Conclusion

The performed experimental research provides a basis for development of information-measuring systems for quality control in the process of detonation spraying, since clear correspondence is determined between sound power recorded at a distance from the barrel of a detonation machine and the amount and quality of the gas mixture, as well as presence and absence of powder material in the flow of detonation products.

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