Evaluation of Energy Characteristics of High Voltage Equipment for Electro-Blasting Destruction of Rocks and Concrete

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Abstract. The splitting off concrete monolith via electro-blast technology is described. High-voltage investigations were performed using the electric-discharge blasting unit with charging voltage up to 15 kV and maximum energy of 126 kJ. Several series of experiments of multi-borehole electro-blast with initiation of plasma channel by wire explosion have been carried out. The combined effect of pulse electric discharge and gas generating composition allows to increase the energy of electro-blasting. According to data obtained from experiments the average value of energy for concrete monolith splitting off of 1 m^3 is about 1554 kJ. The energy of electrical discharge pulse is about 95 kJ and gas-generating composition has energy contribution of 3.8 kJ/g. For carrying out of one electric-discharge blasting experiment 6-8 minutes has been spent. Therefore, the efficiency of pulse power system is about (0.85-0.9) m^3/h.

1. Introduction

Electro-blast method of solids destruction is based on the wave dynamics principles due to the rapid electrical energy release into the expanding plasma channel of the capillary electrical discharge in condensed media at impulse current flow through the channel [1].

A high voltage pulsed power electrical discharge through a solid can create a plasma channel with high energy density of about 25-30 kJ/cm^3. Inside the channel the electrical energy is transformed into internal thermodynamic energy which is subsequently used to deform and finally to destruct the surrounding solid. This process is basic for many technological applications where energy of 10-100 J/cm is deposited from a high voltage pulse generator in less than a few μs, leading to the increasing of plasma channel temperature and pressure of up to 10^4 K and 10^9 Pa respectfully [2-6].

The explosive expansion of plasma channel launches the shock-wave disturbances into surrounding solid and causes the stress-strain material state and formation of the mechanical compressive, tensile and shear stresses. Mechanical stresses are in the range of tens to hundreds of MPa and results in the plastoelastic deformations causing the solid destruction. The total effect of these factors leads to the radial crack initiation and propagation and, finally, to the solid media destruction. This method makes it possible to destruct the oversized rocks and concrete blocks, as well as carry out the directional concrete monolith splitting off.

The high energy efficiency of electro-blast method is caused by the impulse mode of loading of the material, providing the material brittle fracture with a predominance of tensile and shear stresses which required values are lower compared to the destruction by compression as in traditional mechanical method. The dynamic character of the loading provides the brittle fracture of solid with the

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minimal energy loss for the plastic deformation. The high degree of energy localization in the discharge channel ensure the crack initiation in solid at relatively low values of the single pulse energy, which is equivalent to grams of trinitrotoluene. The possibility of regulation over a wide range of the mode of plasma channel energy release allows to create the optimal conditions for solid loading and maintaining the propagation of cracks and destruction of the material depending on the nature and size of the destructible solid.

The efficiency of electro-blast method in comparison with the traditional mechanical methods strongly depends on the electrical properties of the destructible material and almost does not depend on its mechanical properties. Therefore, electro-blast method can be applied to the material of different mechanical strength, the greatest technical and economic effect of its application is reached with treatment of hard rocks and materials, and it makes a priority area of its use.

State-of-the-art of research in the field of the fundamentals of electro-blast technologies, despite the numerous and profound study of the discharge in condensed dielectrics [7-10], is characterized by a number of problems. There is still a matter of controversy, not only the role of parameters of electrical energy release in the plasma channel, but also the influence of wave processes on the formation of dynamically changing fields of mechanical stresses and deformations in solid. Electro-blast method of rocks and concrete fracture allows to control the plasma channel energy release and, thus, to affect the mechanical stress and deformation field around it, determining the material fracture pattern. The main goal in raising the efficiency of electro-discharge technologies is therefore matching of energy release rate conditions during the discharge and characteristics of the generated pressure wave causing the deformations in solid. At present the choice of regime parameters is carried out empirically and does not allow, not only to optimize them, but solve the fundamental task of technical and economic efficiency of blast-hole destruction.

The feature of electro-discharge installations is their impulse action on the destructible object. On the one hand, the radial cracks initiation requires the steep current impulse front, on the other hand - the main crack growth efficiency rises with increasing in pulse duration. To realize simultaneously both requirements in one installation is technically difficult. The efficiency of electro-discharge destruction of rocks and concrete depends on efficiency of conversion of stored electrical energy into a shock-wave disturbances and the duration of the energy release during the electro blast [11-12]. In order to increase the time of electro explosive effect on the destructible material walls, the researches have been carried out on the combined effects of the electrical discharge impulse and energy of the gas generating chemical composition.

2. Experimental Setup

An electric-discharge blasting unit was designed and fabricated at the High Voltage and Electro-physics Department of Tomsk Polytechnic University for carrying out the high voltage and high current investigations. The electric-discharge blasting unit is based on the custom high current pulse generator (HCPG) with operating voltage of up to 15 kV, peak current – up to 300 kA and stored energy in the battery of up to 126 kJ. The length of the bundle of 8 high voltage coaxial cables type RK-50-17-17 transmitting energy to borehole is 12 m. Pulse power system was mounted on the rigid metal frame and placed into a container with internal dimensions 275×175×180 cm.

3. Experimental Results of Reinforced Concrete Basement Destruction

The experiments of multi-borehole electric-discharge blasting on reinforced concrete basement were carried out. For splitting off concrete the electro-explosive cartridges (EC) as a working instrument were used. EC is a coaxial system with the thin copper wire which explodes at the moment of commutation of capacitor bank. Wire electro-explosion is the fast process of wire heating and evaporation by the high density current (up to 10^{12} A/m^2) which leads to plasma channel initiation accompanied with the further shock wave generation and its propagation into the surrounding material [1].

For increasing of the energy release duration with the aim of the borehole pressure growing as well as creation of additional mechanical tensile stress, the gas generating composition (GGC) was used. The GGC is a mixture of ammonium nitrate and diesel fuel. Each EC was filled with 18-20 grams of the mixture. The energy contribution of such chemical composition is 3.8 kJ/g. Under the certain conditions one can assume this composition as pyrotechnic mixture, not as explosives. The condition of assured detonation is provided with the minimum critical diameter of the cylindrical explosive when the detonation is possible. Since the critical diameter for such mixture is equal to 50 mm [13], and the diameter of the boreholes in the experiments was 26 mm, it is complies to conditions precluding the possibility of the transition of the combustion reaction to the detonation.

After the plasma channel initiation the GGC burns and generates a lot of gas, which creates additional pressure in the borehole. In order to increase the duration of heightened pressure in borehole, the borehole mouth was tamponed with construction gypsum. An arrangement of boreholes and the results of a series of experiments of multi-borehole electric-discharge blasting with GGC are shown in Fig. 1.

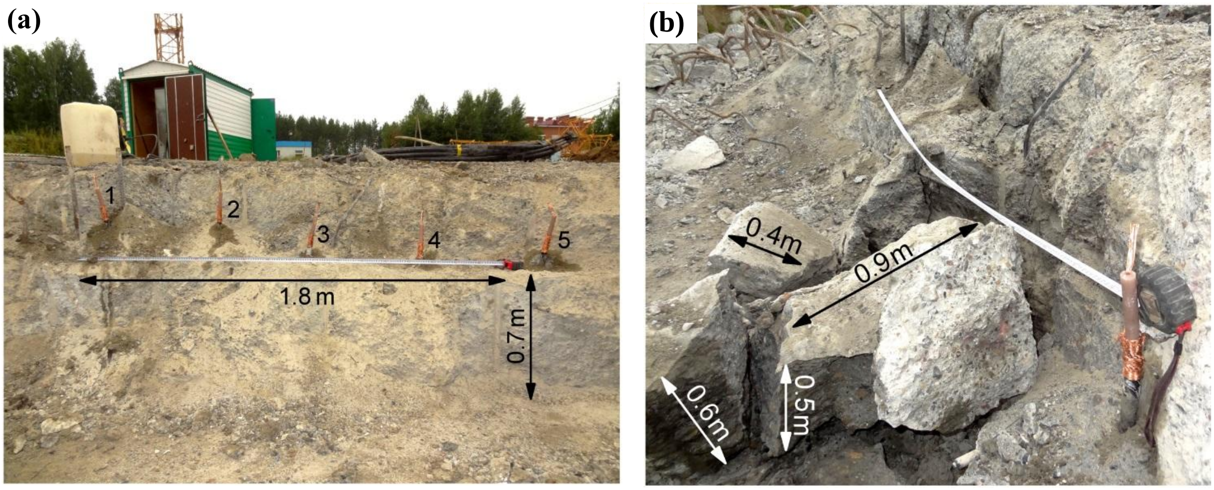

Fig.1. The experiments of multi-borehole electric-discharge blasting of concrete, (a) – an arrangement of boreholes, (b) – results of experiment series of electric-discharge blasting

The distance between the boreholes was 40-50 cm. The distance from the edge of the free surface was 40-45 cm, the depth of boreholes was 60-70 cm. Each electrode was sequentially connected with the coaxial cables and a high-voltage pulse with energy of about 95 kJ was applied. At the experiments four of the five previously prepared electrodes with EC were used for splitting off from the concrete monolith as it shown in Fig. 1 (a).

Table 1. The result of several series of the experiments

#	Quantity of boreholes	Consumed energy, kJ	Splitted off volume, m^3	Specific fracture energy, kJ/m^3
1	4	680	0.42	1619
2	4	680	0.38	1790
3	2	340	0.22	1545
4	2	340	0.25	1360
5	4	680	0.44	1545
6	5	850	0.58	1465

The results of calculations show that up to 30-35 % of stored energy dissipates as resistive losses in active resistance of the capacitors, coaxial cables and buses during the discharge. Only 9-10 % of released in EC energy was spent for material destruction. The rest part of energy was spent for discharge channel initiation, plasma formation and heating. The total energy consumed for splitting off concrete fragment with volume of about 0.42 m^3, considering the energy contribution from GGC, was equal to 680 kJ (Fig. 1 b). According to given technique a several series of experiments with different number of boreholes were carried out. The experiment results are given in Table 1.

4. Discussion

In [14], the specific fracture energy of various technologies of solid materials destruction is presented. The experimental results allow comparing the electric-discharge blasting technique with the other existing methods of materials destruction. Specific energy consumption of electric-discharge blasting technique is much lower while the total efficiency is considerably lower than traditionally used methods of rocks and concrete destruction. The possible reasons of that might be usage of one-time EC, imperfect of technological operations, small part of process automation et al.

As it was previously described, only a tenth of stored energy is allocated into the plasma channel. However, energy allocation for microsecond time period in the small volume leads to the increasing of plasma channel pressure up to GPa. At this moment the power of energy release reaches hundreds of MW, which results in the cracks initiation and propagation in the solid material. The usage of gas generating composition allows compensation of dissipated energy (resistive losses), and improving the electro-blasting method efficiency for solid destruction.

5. Summary

The experimental study of multi-borehole electric-discharge blasting accompanied with the gas generating composition was carried out to develop the approach of concrete splitting off. Combined effect of pulse electric discharge and gas generating composition allows compensation the much resistive energy losses with the small quantity of pyrotechnic mixture. Increasing in the energy release duration due to combustion reaction of GGC leads to the creation of additional mechanical tensile stresses, cracks formation enhancement and improving of the electro-blasting method efficiency.

The productivity of the electric-discharge blasting of solid materials destruction depends on the time of borehole drilling, installation of electrodes into the borehole, its connection to the electrode holder and finally charging of the capacitive energy storage. One can assume from the Table 1 that average energy required for 1 m^3 of lump splitting off from concrete monolith is about of 1554 kJ. It takes 6-8 minutes to complete one electric-discharge blasting. The time of removing split off pieces of concrete is not assumed**.** At the optimum mode of operation for distributing of such quantity of energy the 9-10 boreholes have been required. Therefore, the efficiency of present pulse power system is about (0.85-0.9) m^3/h.

The electric-discharge blasting unit can be applied for rock fragmentation, utilization of strong concrete constructions, dismantling of monolithic structures, tunnels construction or expansion and so on. The application of described technology in industrial scale requires the solution of some problems: the process automation, the usage of long life time operation instrument, the reducing of energy losses and improving of energy transfer efficiency into the discharge channel.

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