Design and experimental study of automatic source of P-waves in rock mass

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Abstract. The paper describes application of vacuum impact machines in underground mineral mining. The main parameters are determined experimentally for the automatic control of operation of such machines, and the key area of further improvement is identified.

1. Introduction
Compression–vacuum impact machines designed at the Institute of Mining, SB RAS meant for mineral exploration and underground mining are intended for impact treatment of ground surface at calibrated energy in order to generate underground P-waves for the purposes of exploration seismology. Furthermore, the machines can create weak impacts in underground mines in order to change the stress–strain behavior in rocks, with stress reduction in the zone of actual mining, or for redistribution of stresses into the depth of rock mass [1–6]. Currently, important R&D results have been obtained, and technological innovations are trialed.

At the present time, both in Russia and abroad, the shallow seismology P-waves are generated using manually driven sources (hammers, weight dropper, crow-bars, etc.). Such P-wave sources are efficient for a depth of 100–150 m. In the depth interval of 150–500 m and deeper, a higher impact effect is required. The recently available instrumentation capable to record signals of multiple impacts produced by comparatively light-weight hammering devices are serviceable at a depth to 1500 m. Thus, the manual sources of P-waves for shallow seismology are deficient in creation of long-term impact in deep-level underground mining.

The aim of the R&D described in this paper is to engineer and validate an automatic control system for operation of compression–vacuum impact machines in generation of P-waves in rock mass, to analyze the lab-scale and full-scale tests data of such system and to find application ranges of the machines.

2. Vacuum impact machine parameters and test results
The simplest and the most reliable approach in this respect is creation of automatic impact sources based on mechanical switching interaction between their structural components [7]. At first, thanks to such sources, it is possible to avoid complex electronics and special power supply of transducers and control module. Thus, an automatic vertical-drop machine with a vacuum drive has been designed—vacuum impact machine model VMUD-1.

The long-term weak impact tests were carried out on the East Site of Tashtagol deposit, on level -350 m, in crosscut 8 at a depth of 800 below ground surface.

The impact source meant to create P-waves in rock mass was VMUD-1 (Figure 1).
Figure 1. Vacuum impact machine VMUD-1: 1—general view; 2—impact driver; 3—piston; 4—inertia–friction valve with telescopic tube.

Figure 2. VMUD-1 operation scheme: (a) initial position; (b) upward travel of hammering piston; (c) top position of hammering piston; 1—body; 2—hammering piston; 3—bottom chamber connected to atmosphere via channel 7; 4—top chamber continuously connected with vacuum–compressor 5 and periodically connected to atmosphere via channel 14; 6—bit; 8—inertia–friction valve; 9—gate valve; 10—spring; 11—seat bushing; 12—telescopic tube; 13—gravity switch.

Initially (Figure 2a), valve 8 of the machine is open, and top chamber 4 is connected to atmosphere via channel 14. Hammering piston 2 lies on bit 6. Switch 13 hangs on telescopic tube element 12 connected to gate valve 9 of valve 8. After actuation of vacuum–compressor 5, an operator manually presses valve 8 downward as far as it goes with overcome of resistance of spring 10. Friction seat bushing 11 of gate valve 9 shuts channel 14. Top chamber 4 becomes disconnected from atmosphere. Owing to operation of vacuum–compressor 5, vacuum created in top chamber 4 lifts hammering piston 2 upward (Figure 2b). At a preset height, piston 2 catches switch 13 and moves upward with it and compresses telescopic element 12. At the top position, piston 2 interacts with gate valve 9 via switch 13 and element 12 (Figure 2c). Valve 8 goes up. Cannel 14 opens and connects top chamber 4 to atmosphere. Piston 2 falls down with switch 13 under gravity. At a preset height, element 12 extends totally, and movement of switch 13 is stopped. Gate valve 9 of valve 8 connected
with switch 13 by means of telescopic element 12 moves downward, and friction seat bushing 11 disconnects channel 14 from atmosphere. Vacuum is generated in top chamber 4. Piston 2 continues moving downward and hits bit 6. No another blow is inflicted as piston 2 is caught and moved upward by vacuum in top chamber 4. The cycle is repeated automatically until disengagement of vacuum-compressor 5, or mechanical stoppage of valve 8 in its top position. The flow chart of VMUD-1 machine is protected by the patent of the Russian Federation [8].

Operation of VMUD-1 in underground mine proved the efficiency and reliability of the machine application as a non-explosive source of elastic waves. However, some technical deficiency of the machine was also exposed in the full-scale tests.

Aimed to improve capabilities and reliability of VMUD-1 and to prevent the hammering piston recoil, additional lab-scale tests were performed to study and adjust operating parameters of the inertia–friction valve. These tests show that premature feed of actuation medium (vacuum) in the top chamber lowers the unit impact energy and decelerates the hammering piston before impact. For another thing, the shape and weight of gravity switch 13 are also of importance. The switch should ensure the maximal power stroke of the piston, i.e. to have the least height \( b \), and to be able to move freely in the top chamber of the machine body, i.e., the diameter of the switch should eliminate its possible jam in body 1. At the same time, the weight of switch 13 should never be more than the force of spring 10 in the initial position of VMUID-1 as this can result in shutting of channel 14 and, as a consequence, in destabilization of the whole operating cycle. The inertia mass of the switch should be sufficient to shut channel 14 by friction seat bushing 11 to ensure back run of the piston. In the full-scale tests in Tashtagol, the telescopic tube element length \( L_{tt} \) of machine VMUD-1 for the highest energy of unit impact was \( 0.8L_{ps} \) (\( L_{ps} \)—length of the power stroke of the hammering piston) since the secondary impact (recoil) had no adverse effect on the operation objective—creation of weak impacts in mine field.

Regarding the mine seismology objective, the secondary impact is unwanted for it impairs seismic records, lowers their quality and deteriorates the seismic studies. So, we have quite opposite tasks. First, we have to ensure the highest impact energy in order that elastic P-waves penetrate deeper into rock mass. Second, we need to prevent the secondary impact, i.e. ‘pickup’ of the piston in recoil by the vacuum generated in the top chamber in a certain time before the impact and, as a consequence, pre-blow deceleration of the piston. These objected are met through experimental determination of the efficient length of the telescopic element to ensure implementation of a ‘compromise solution’.

The experimental tests allowed finding and validating the main parameters of the automatic control system for VMUD-1: switch mass \( m = 0.3 \) kg, switch diameter \( d = 75 \) mm, switch height \( b = 15 \) mm, coefficient of restitution of spring \( 10 k = 125 \) N/m, friction bushing length \( l = 85 \) mm, telescopic tube element length \( L_u = 2/3L_{ps} \). Specifications of the modified machine VMUD-1 are given in Table 1:

| Table 1. Experiment and calculation data on growth of axially symmetric and flat induced fractures |
|------------------------------------------|
| Impact driver:                          | Electric |
| capacity, kW                            | 2        |
| weight, kg                              | 4        |
| Number of working chambers              | 1        |
| Body material                           | Ethylene polymer |
| Piston power stroke length, mm          | 900      |
| Inner body diameter, mm                 | 200      |
| Piston weight, kg                       | 40       |
| Unit impact energy, kJ                  | 320      |
| Impact frequency, Hz                    | 0.5–0.3  |
In this manner, the experimental study into the automatic control of VMUD-1 operation has made it possible to increase the impact energy by 15–20%, to reduce the operating cycle time by 1 s, to decrease the total weight of the machine and to eliminate the secondary impact (recoil) during seismic surveys. The impact generation control system for non-explosive source of P-waves in underground seismology has been adjusted and has passed the lab- and full-scale tests with seismic sources with other sizes:

— hammering piston weight 12.5 kg, machine body diameter 160 mm, body length 1500 mm, unit impact energy 150 J;
— hammering piston weight 6 kg, machine body diameter 110 mm, body length 1200 mm, unit impact energy 60–70 J.

The major shortage of VMUD-1 consists in only vertical direction of impacts it generates, which largely diminishes the range of its application. Machine VMUD-1 is applicable in generation of P-waves in shallow seismology, in demolition of old foundation in reconstruction and in breakage of solid blocks. However, in construction seismology, in laying of underground pipelines, or in mining, in creation of impacts in rocks in order to change its stress–strain behavior or for other purposes, its naturally required to generate impacts in any direction of a 3D space, which calls for engineering an appropriate machine and its performance control system.

An advance in engineering of automatic controllable impact machines for the purposes of seismology, underground and sea construction, mineral mining and other anthropogenic activities at super depths in geological media is connected with the electronic intelligent control elements.

3. Conclusions

The R&D has experimentally determined and justified efficient parameters for the mechanical system of automated control of the vacuum impact machine model VMUD-1 intended for the seismology purposes. As a result, the operating cycle of the machine is reduces, the total weight of the machine is diminished, and the unwanted secondary impact is eliminated. The automatic control system for impact generation in non-explosive source of P-waves in seismology has been adapted to different sizes of seismic sources, which allows a wider range of seismic studies to be implemented.

The layouts of intelligent electronic control are developed for P-wave sources in seismology and for various-purpose impact machines. The areas of the further advance of such class compression–vacuum machines are identified.

References

[1] Shneerson MB 1998 *Theory and Practice of Non-Explosive Land Seismic Exploration* Moscow: Nedra (in Russian)
[2] Hill IF 1992 Field techniques and instrumentation in shallow reflection *Quarterly Journal Engineering Geology* No 25 pp 183–190
[3] Palagin VV, Popov AYa and Dick PI 1989 *Shallow Seismic Exploration* Moscow: Nedra (in Russian)
[4] Sheriff R and Geldart L 1995 *Exploration Seismology* Cambridge University Press
[5] Repin AA, Tkachuk AK, Karpov VN, Beloborodov VN, Yaroslavtsev AG and Zhikin AA 2016 Engineering and analysis of independent movable compression–vacuum percussion source of P-waves in seismic survey *Journal of Mining Science* Vol 52 No 1 pp 146–152
[6] Eremenko AA, Timonin VV, Bespalko AA, Karpov VN and Shirts VA 2017 Effect of vibro-impact exposure on intensity of geodynamic events in rock mass *J. Fundament. Appl. Min. Sci.* Vol 4 pp 42–46
[7] Primychkin AYu, Kondratenko AS and Timonin VV 2017 Determination of variables for air distribution system with elastic valve for down-the-hole pneumatic hammer *IOP Conference Series: Earth and Environmental Science* 012025
[8] Tkachuk AK, Karpov VN and Zabolotskaya NN RF Patent No 161441 Vacuum Impact Machine *Byull. Izobret.* 2016 No 1