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# Rapid Assessment of the Rock Strength in Solid by the Shock Pulse Method

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Abstract

*The expediency of the shock pulse method use for the rock strength assessment directly in place is defined. A method version with the determination of the shock pulse duration is substantiated. The information about a new control device is presented.*

***Key words**: rock strength, nondestructive control, shock pulse method.*

Effective and safe operation of mining requires a certain set of data on the physical and mechanical properties of the solid. The most important is to know the strength characteristics of rocks to assess the competence of courses. The most valid data on the physical and mechanical properties of rocks and ores considering the scale effect of strength are known to be obtained either by the tests of sizeable samples, either by the strength assessment directly in the solid using the methods of nondestructive control. The last are increasingly used due to their efficiency, low labor costs and relatively high accuracy.

Most of the nondestructive control methods are indirect. The determined in place information-bearing parameter is associated with the strength characteristic of correlation dependence. Decrease in the determination accuracy of the strength characteristics in individual control points compared with laboratory tests is compensated by the ability to increase considerably the amount of sampling and decrease significantly the inspection costs.

Nondestructive control of concrete is most elaborated methodologically, what is fixed by the number of normative documents, in particular, the Ukrainian standard DSTU BV.2.7-220:2009 [1]. The facilities, developed specifically for the concrete control are also used in related fields after the appropriate adaptation. In particular, after the occurring of mobile ultra-audible concrete scopy equipment it became possibile to use them in the field conditions, and then in mines. As a result of the investigations the sufficiently close correlation between the strength characteristics of a wide range of rocks and the velocities of elastic waves in the ultra-audible gamut is determined.

However, this method has certain limitations:

- the complexity of the permissibility provision if the equipment in the dust- and gas-hazardous mines is necessary;

- the reduction in the accuracy of the determination of the elastic waves velocities in rocks with a high attenuation of ultra-audible signal;

- the complexity of the contact conditions provision of the "sensor-environment" system.

In our opinion, the shock pulse method [3], the basic provisions of which, as well as the procedure of the obtaining of calibration dependencies for concrete are regulated in the already mentioned DSTU BV.2.7-220:2009, is the most acceptable for the rapid assessment of the rock strength properties in full-scale conditions.

he theoretical analysis of the processes occurring in collision of the hard ram tester, having a contact surface of a sphere with the surface of the rock mass was performed when considering the use of the shock pulse method for the rapid assessment of the rock mass strength characteristics. The analytical form of the shock pulse model (the vibratory acceleration dependence on the time) is of the form

(1)
$$a(t) = a_m \sqrt{(\sin \frac{\pi}{\tau} t)^3},$$

where $a_m$ - amplitude of the vibratory acceleration; $\tau$ - the duration of the shock pulse.

Theoretical studies made it possible to obtain the following expressions for the amplitude and duration of the shock pulse. For the amplitude

(2)
$$a_m = \frac{1{,}285 \sqrt[5]{V_0^6}}{\sqrt[10]{R} \sqrt[5]{(m(\frac{1-\nu_1^2}{E_1} - \frac{1-\nu_2^2}{E_2}))^2}},$$

where $R$ - radius of the contact surface of the ram tester; $m$ - mass of the ram tester; $V_0$ - velocity of the ram tester at the initial interaction with the solid; $E$ - a dynamic modulus of elasticity; $\nu$ - the dynamic Poisson's ratio (the indices "1" and "2" refer to the material of the ram tester and solid, respectively).

Duration of the shock pulse is expressed by

(3)
$$\tau = 2{,}87 \sqrt[5]{\frac{1}{V_0}} \sqrt[5]{\frac{m^2}{R}} \sqrt[5]{(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2})^2}.$$

Mass and radius of the ram tester are constants. Velocity $V_0^*$ of the ram tester at the time of its interaction with the solid is a variate in the process of measurement. The degree of impact of the parameter variation on the relative change of two informative parameters - amplitude and duration of the shock pulse is shown in Fig. 1.

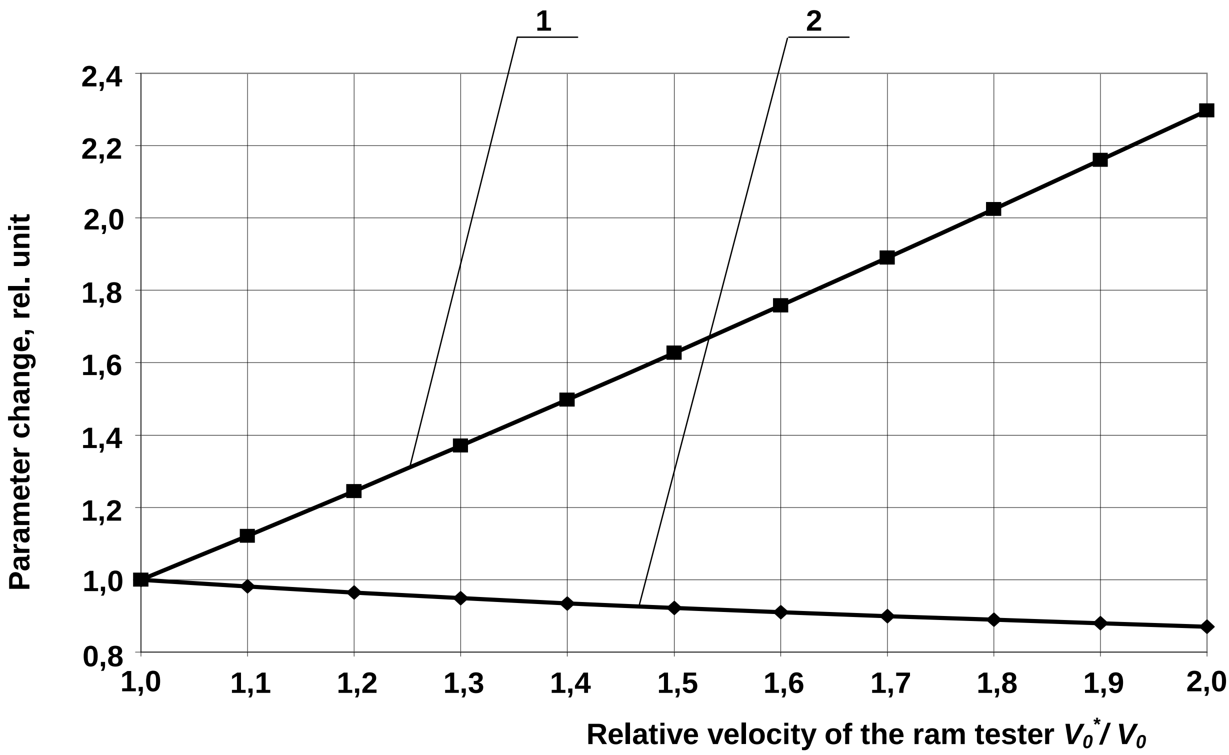

**Fig. 1. Relative change in the parameters of the shock pulse with a relative change of the initial collision velocity:**

1 - change of the amplitude value; 2 - change of duration

The calculations show that the amplitude of the shock pulse increased 2.3 times with 2 times increase of the ram tester initial velocity. Regulation of the impact rate with the spring energy storage unit use is performed for quality control of concrete with registration of amplitude or pulse energy in industrial devices. This solution is not optimal for the mine conditions due to the following reasons:

- the presence of an aggressive mine dust and high humidity, significantly reducing the nonfailure operation time of moving elements of the impact device;

- the necessity to perform measurements at different angles relative to the gravity vector, bringing additional errors to the result.

Fig. 1 shows that the shock pulse duration is reduced only by 0.13 rel. un. at the same variation of the impact rate, therefore the increase of stability of the informative parameter $\tau$ compared to the parameter $a_m$ at the impact variation is one of the factors testifying in favor of its choice. Additional necessary condition is the dependence between the shock pulse duration and one of the strength characteristics. The dependence set for the rock break-down point on the simple compression is of the form

$$\tau \approx 2{,}9 \sqrt[5]{\frac{m^2 A^4}{V_0 \rho_2^{\,2} R(\sigma_{com.} + B)^4}}, \quad (4)$$

where $A$ and $B$ - constants for a certain rocks category, experimentally determined by the ultrasound investigation; $\sigma_{com.}$ – the rock break-down point on compression.

The inverse dependence is of practical interest – $\sigma_{com.} = F(\tau)$. Given some certain simplifying assumptions, it can be represented as an exponential function

$$\sigma_{com.} = A^* \cdot \tau^{-B^*}, \quad (5)$$

where $A^*$ and $B^*$ - new constants, comprehensively including parameters $A$ and $B$, as well as characteristics of stably supported test conditions.

Dynamic testing of samples of various solids with the shock pulse registration on the storage oscilloscope screen is performed on a specially designed shock table. Pulse duration, as well as its amplitude is determined by the computer processing of scope trace images. Destructive testing of samples DSTU GOST 28985:2008 is performed at a later step. Correlation dependences between the shock pulse duration and the break-down point on the simple compression are obtained by experimental bulk processing. It is shown in Table 1.

**Table 1 Regression equations for the description of of the rock strength dependence on the shock pulse duration**

| Investigated geomaterial | Regression equation | Equation certainty |
|---|---|---|
| Hydrous sulphate of lime | $\sigma_{com.} = 3.4404\tau^{-1.3402}$ | 0.8218 |
| Coal | $\sigma_{com.} = 7.7731\tau^{-1.0605}$ | 0.8157 |
| Malmrock | $\sigma_{com.} = 2.614\tau^{-1.3213}$ | 0.8788 |

| | | |
|---|---|---|
| Siltstone | $\sigma_{com.} = 0.0375\tau^{-3.8711}$ | 0.8396 |

Example of the malmrock strength connection with shock pulse duration is graphically shown in Fig. 2.

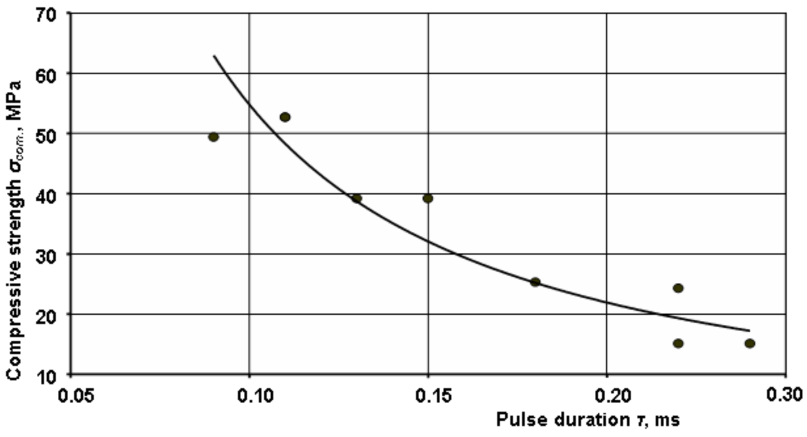


**Figure 1 Malmrock compressive strength connection with shock pulse duration**

Performed theoretical and laboratory experimental studies allowed to demonstrate parameters and develop experimental sample design of the Dicon device specifically designed for operation in the field and mining conditions. Determination of the shock pulse duration is performed in the operating regime "Material control". Block diagram of the device that implements the specified regime is shown in Fig. 3.

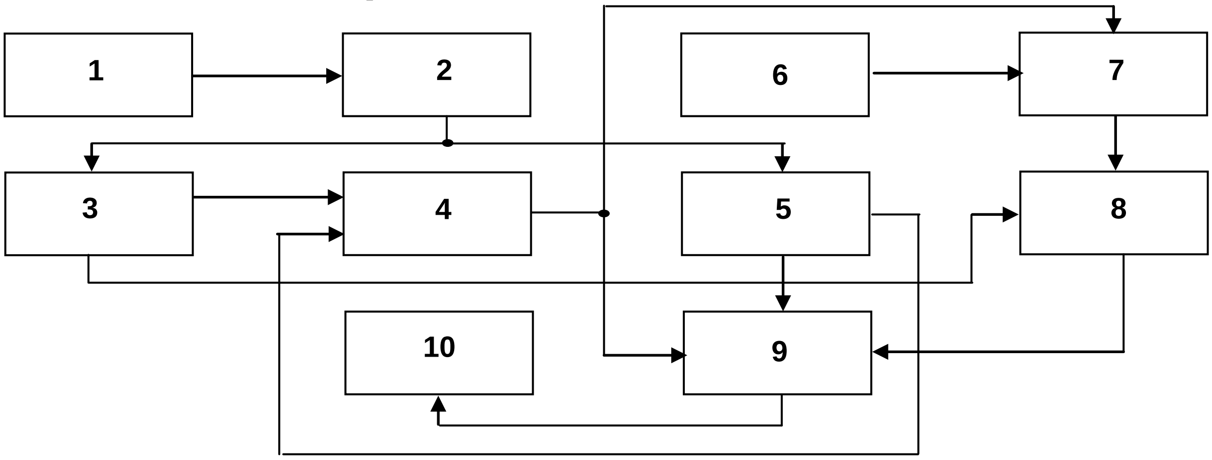


**Figure 3 Block diagram of the Dicon device, that makes measurement of the shock pulse duration:** 1 - primary transducer, 2 - voltage amplifier, 3 - first threshold device, 4 - "time gate" former, 5 - second threshold device, 6 - reference clock, 7 - first electronic switch, 8 - second electronic switch, 9 - pulse counter, 10 - digital data display

The signal magnitude in output of the primary transducer 1 is a few tenths of volt, which is insufficiently for its processing by digital methods. Amplifier 2 is designed to achieve the desired signal level. The first threshold device 3 is used to form pulses of the measured duration $\tau^*$. The generation of the single pulse of constant duration $\tau_u$ occurs synchronously in the pulse "time gate" former 4. The second threshold device 5 also generates the constant duration pulse $\tau_b$ ($\tau_b >> \tau_i$). Reference clock 6 produces continuous sequence of the calibrated against frequency (100 kHz) pulses, which are fed to the switching input the first electronic switch 7. Control input of the switch 7 is connected to the output of the "time gate" former 4 and opens it by the time interval duration of 3 ms. If an input pulse has an amplitude sufficient for the second threshold device operation, at a single potential on its output the former 4 restart will be blocked and, accordingly, the switch 7 will be blocked at the end of the specified 3 ms till the closure of pulse with duration $\tau_b$. Pre-selected in time the comparison pulses pass from the output of the switch 7 to the switching input of the second electronic switch 8, and go through it to the counter 9. The switch 8 opening is performed by pulses of the measured duration $\tau^*$ from the unit 3 output. The shock pulse duration determines the number of the comparison pulses, counted during the interval $\tau^*$. Digital data display 10 shows the status of the counter 10. The counter is set to zero by the trailing edge of the block pulse, as well as at the end of the pulse "time gate" forming with a zero potential at the output of the former 5. The device is then ready to make measurements again.

The most important technical characteristics of the Dicon device relating to the regime of "Material control", are as follows:

range the duration determination, ms - 0-1.99;
reduced error of measurement, % - 1.5;
duration of the indication result, s - 2–5;
voltage supply, V - 6;
power consumption, W - 0.2.

DICON equipment was used in the study of geological disturbance in courses of Artemovsk gypsum mine. The reduction in solid strength outside of the visually observable cave exit is one of the problems when assessing the long-term competence of the courses traversing geological disturbances in the form of cave occurrences. The exact delimitation of boundaries of the cave influence area allows to optimize the composition of engineering measures to ensure the safe operation of course.

Markup at a pitch of 1 m is initially performed in relation to surveying picket on the roadway side. Surface conditioning on the area up to 10 $cm^2$ is performed in each of the control points. In one point, 10 measurements of the shock pulse duration followed by the results averaging are performed.

Fig. 4 shows the results of measurements of the shock pulse duration in the lower part of combine aircourse 19 of the stall of the VII-th block near the barrier, located under the highway "Kharkiv - Rostov". The visible boundaries of cave occurrence are grey.

The measurement results show a smooth decrease in the gypsum strength (high values of the shock pulse duration) as it approaches the geological disturbances. The width of the transition zone is about 4 m in this case.

**Concusions**

1. The implementation of tools and methodology of rapid assessment of the rock strength characteristics directly in place instead of core sampling, samples preparation and testing in the in laboratory conditions is a challenge today. In this regard, the shock pulse method is promising.

2. The existence of a close connection between the shock pulse duration and rock break-down point on the simple compression, analytically expressed by the power dependence is theoretically established and experimentally proved.

3. Experimental prototype of DICON device for the rapid assessment of rock strength in the solid by the magnitude of shock pulse duration was developed and tested in operating conditions.

4. The method can be used in the crude ore occurrences during the obtaining of corresponding correlation dependences between the value of information-bearing parameter and the strength of ores and adjacent strata.

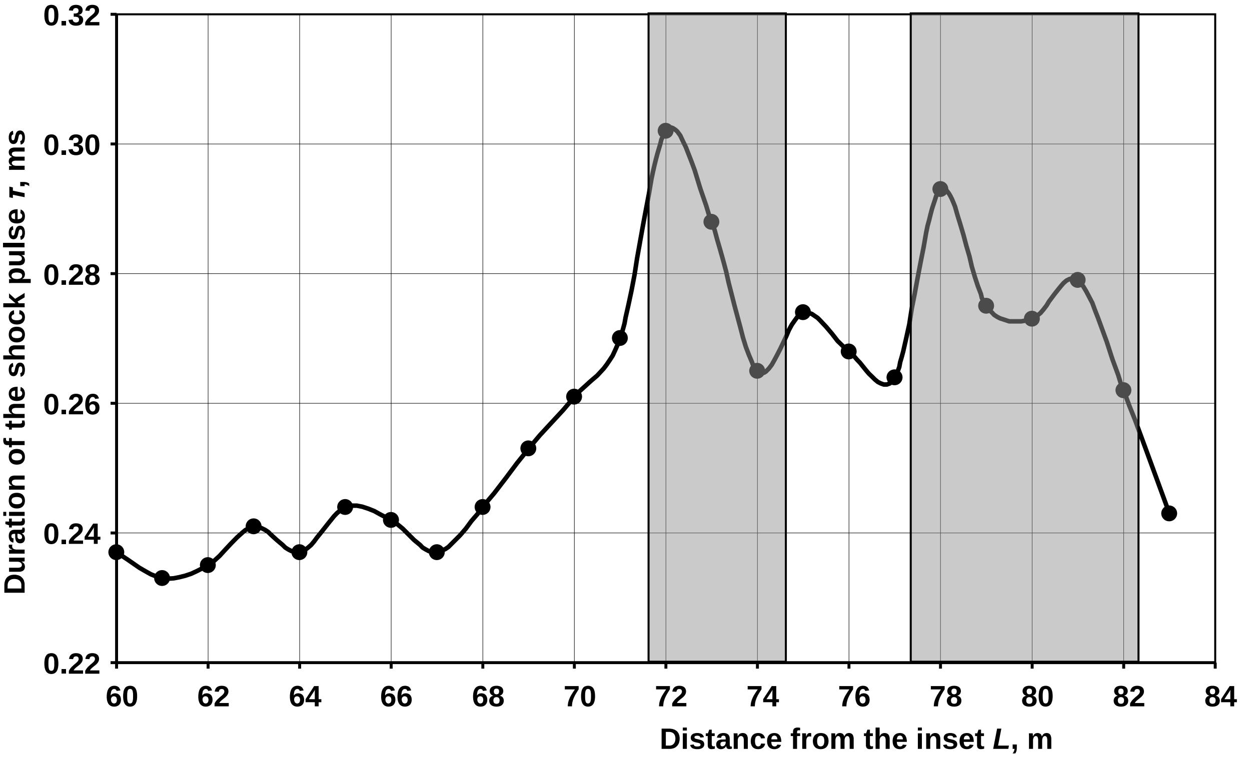


**Figure 4 Change of the shock pulse duration on the surface of gypsum solid near the geological fault**


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