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# Design of a device for rocks strength properties determining to solve the tasks of rock rock-cutting machines design

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**Abstract.** The article presents methods for rocks strength properties determining in mining machines engineering in Russia, CIS countries and Europe. It is shown that general drawback of methods considered is lack of possibility of carrying out instant tests at various points in rock massif. Criteria are given for the method of rocks strength properties determining as applied to mining engineering tasks. Based on established criteria, the fundamentally new method has been developed. Technical devices are proposed for the method implementation in testing individual samples and rock massif. Construction of the laboratory stand estimating energy intensity of rock destruction is presented. Relationship between its value, coefficient of strength according to the M.M. scale of Protodyakonov and average particle size of the destroyed rock is shown.

The mining industry is the largest consumer of electric energy in the country. According to the data of the Uskovskaya coal mine of the Yuzhkuzbassugol United Coal Company, only one mining face of underground mine consumes about 650 thousand kWh of energy per month during its operation. Reducing energy consumption in mining by even a few percent can result in a significant economic effect across the country.

One of the main processes carried out during mining operation is destruction of rocks, provided by various technological machines (tunneling and mining combines, drilling rigs, crushers, etc.). The main point of this process is multistage transformation of electrical energy into mechanical one with its further transfer to destroyed rocks. Implementation of more rational design solutions in mining machines design and reasonable choice of engine power can significantly improve the process efficiency, which in turn will lead to reduction in energy consumption.

The main parameter used in the design and optimization of rock destruction machines is rocks strength properties data. In Russian practice and in the CIS countries as well the strength coefficient according to the scale of M.M. Protodjakonov is the most widespread for these purposes, it is defined by crushing cores or testing rock samples of irregular shape by dropping the load (Figure 1-a) [1].

In Europe, rocks strength properties are tested by method of point load testing, when point load is applied to the samples by coaxial punches (Point load test). The R&D

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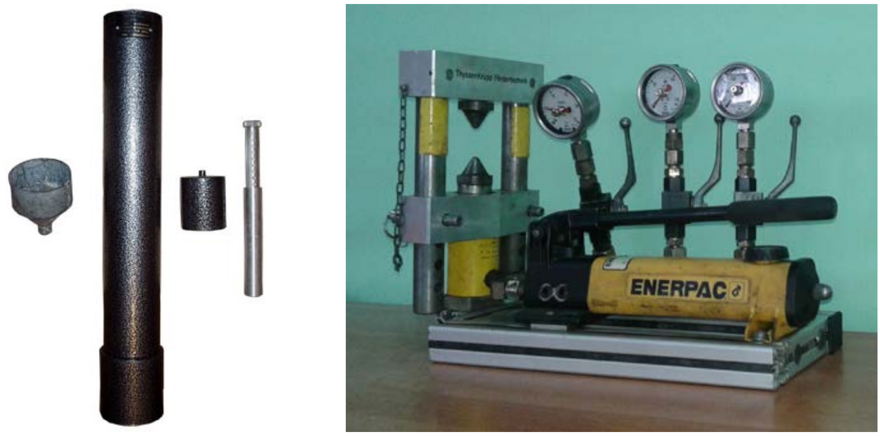
department of ThyssenKrupp Fördertechnik engineering company, Germany, has developed a unique device (Figure 1-b), providing implementation of this method in industrial conditions, and software for test results processing. Based on the set of data obtained, including rock strength index, regression line slope, tensile strength parameter, and the average and maximum compressive strength and tensile strength of rocks, the company engineers design and select the required mining equipment [2,3].




a b

**Fig. 1.** Devices for rocks strength properties testing: a) by means of dropping the load, b) by means of point load test, modified by ThyssenKrupp Fördertechnik

The methods of rocks strength properties determining mentioned above implemented in mining machinery engineering, have a significant drawback, both of them do not provide a possibility of carrying out instant testing at various points in the array, since in this case it is required to drill a well with core extraction, which is long enough and time-consuming. Taking into account this fact, the authors of the article have completed research in order to develop express method for rocks strength properties determining and technical devices for its implementation.

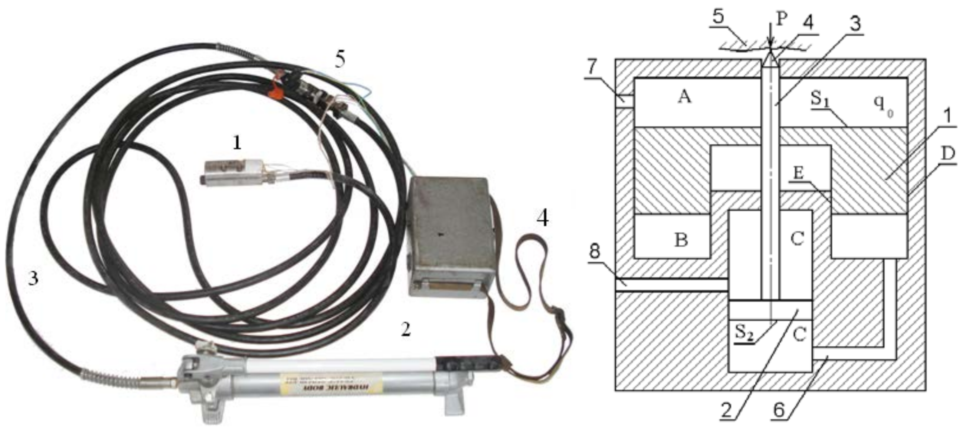
Based on the requirements to the process of mining machines design, the developed method shall meet the following criteria: test properties of rocks through mechanical destruction; ensure possibility of instant testing of rock samples in its natural occurrence; provide accuracy and reproducibility for the same petrographic objects with a coefficient of variation not exceeding 15-20%.

Implementation of rocks mechanical destruction mechanism in conditions of rocks natural occurrence providing instant determination of its properties can be achieved by indenter impacting the walls or the face of the well drilled in the rock massif. Introduction of an indenter into the face of the well is less desirable, as it requires periodic deepening of the well with extraction of set of drills during testing procedure at various distances from the wellhead.

Thus, a method that satisfies the above requirements should be based on introduction of an indenter with a special device into the well wall or a rock sample with fixation of the stress-strain diagram and further determination of strength properties of rocks on its ground.

Figure 2-a shows the device named "PSSh-1" hardness testing unit [4,5], developed by the authors, which allows to fix the diagram of hardness indentation in the wall of a well. "PSSh-1" consists of a hydraulic cylinder 1, a pump 2, a high-pressure hose 3, a measuring unit, and a pressure sensor 5. The piston rod of the hydraulic cylinder is equipped with an indenter interacting with rock during operation of the device.

Advantage of the device is possibility of using indenters of various shapes, as well as ability to perform measurements in particularly strong rocks due to original design of hydraulic cylinder (Figure 2-b). The hydraulic cylinder of the device is a system with three concentric chambers: the input one - A, the ring one - B and the discharge one - C. Rodless piston 1 with its cylindrical surfaces D and E interacts with the surface of the input A and the ring B chambers respectively. In the discharge chamber C load piston 2 is placed with the rod 3, equipped with the indenter 4 which is impacting the rock 5. The ring chamber B has a hydraulic connection with the discharge chamber C through the channel 6. The channels 7 and 8 are intended for the working fluid supply into the input chamber A of the hydraulic cylinder and into the rod space of the discharge camber C.




a b

**Fig. 2.** "PSSh-1" hardness testing unit

The principle of amplification introduced in the proposed system is expressed by the following relationship:

$$P = \frac{q_0 \cdot S_1}{S_1 - S_2} \cdot S_2 , \qquad (1)$$

where $P$ is the force on the indenter; $q_0$ is fluid pressure in chamber A; $S_1$, $S_2$ are the section areas of the rodless piston 1 and the load piston 2, respectively.

The data collection system of the device allows recording of the indenter movements and the pressure in hydraulic system of the device, thereby enabling construction of a stress-strain diagram. Based on it, strength properties of rocks are determined with the help of specially developed software pack.

The "PSSh-1" hardness testing unit was tested through determining the strength properties of a marble sample with linear dimensions of 500x150x200 mm, in which 2 wells of 58mm in diameter were drilled. The hardness indentation diagram obtained from the device memory card is shown in Figure 3.

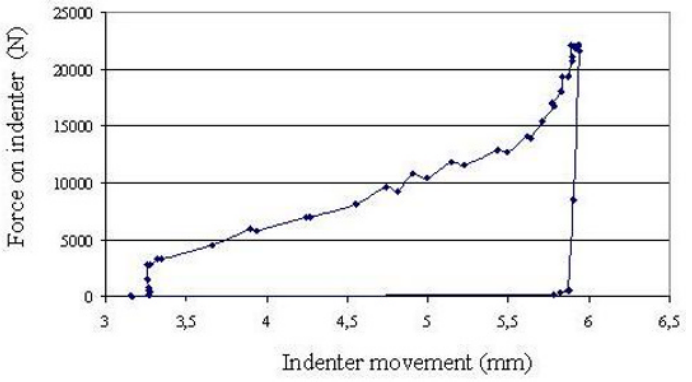



**Fig. 3.** Hardness indentation diagram obtained during marble block testing by the "PSSh-1" hardness testing unit

To carry out tests of rock samples, it is proposed to use a device based on a hand hydraulic press, with the indenter located in the upper part of the frame (Figure 4).

**Fig. 4.** Device for determining properties of samples of rocks using the developed express method

Specific feature of the method being developed distinguishing it from the other ones, based on indentation of various indenters, is in using indenter in form of straight circular cylinder with diameter equal to its length. Interaction of the indenter with the rock is performed along the generatrix of the cylinder.

Performance of transmission of the destructive impact to the rock allows the indenter to be introduced with less effort than applying indenters with a plane contact surface (in L.A. Schreiner's method, L.I. Baron and L.B. Glatman's method) [6]. In addition, interaction of indenter with the rock along the generatrix of cylinder makes it possible to apply the method for testing rocks both in wells and in samples. In this case, indenter at the initial moment of destruction covers larger set of grains composing the rock, in contrast to spherical and pointed indenters, thereby increasing accuracy in testing resistance of the rock to brittle fracture.

The core of any method of reasonable selecting of drive power of mining machine is algorithm of transition from strength indices to characteristics of rock destruction specific energy costs by one method or another. There are a significant number of methods for determining energy intensity of rock destruction. The most suitable for mining engineering task is the method stated in the patent [7]. The method provides possibility to determine the minimum energy costs for destruction of rocks, taken as the reference ones and used in further design work when choosing the drive power.

In accordance with this method, the rock samples of irregular shape are crushed to predetermined degree of fracturing with preliminary measurement of their volume. At the same time, in order to exclude re-destruction of rock samples, the particles that have reached the predetermined dimensions are removed from the fracture zone. During destruction of rocks, the force on the punch and its movement are registered, as a result the compression diagram is recorded. The work spent on destruction of rocks is defined as the area under diagram, and energy intensity is stated as specific work per a unit of volume of the initial sample.

Advantages of this method, distinguishing it from others, are as follows: ability to control the size of products of rock destruction, simple implementation in mining, use of samples of irregular shape, and their destruction in the simplest way - crushing between two punches.

Relationship between the energy intensity of rock destruction and coefficient of strength according to the scale of Professor M.M. Protodyakonov as revealed by the authors of the method is as follows [8]:

$$W = 4{,}5 + 0{,}29f - 0{,}35d_{as} - 0{,}16d_{as}f + 0{,}003f^2d_{as} - 0{,}006fd_{as}^2 + 0{,}04f^2 + 16d_{as}^2, \qquad (2)$$

where $W$ is energy intensity of rock destruction of J/cm$^3$; $f$ is coefficient of strength according to the scale of M.M. Protodyakonov; $d_{as}$ is average size of the products of destruction, mm.

To revise this dependence, the authors of the article have developed and built the laboratory stand. Structurally, the laboratory stand (Figure 5) consists of a frame 1, a perforated cup 2, in which test specimens of rock are placed, punch 3, driven by a load hydraulic cylinder 4 with the help of a hand pump 5. The perforated cup 2 is placed on the frame 1 with the support 6, in which thrust and radial bearing is placed, which rotates the perforated cup 2 with a handle removing the crushed rock 7. Perforated cup 2 is produced with holes defining the required dimensions of the products of rock destruction.

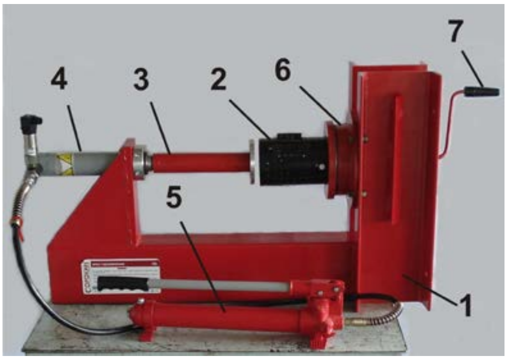



**Fig. 5.** Laboratory stand for determining the minimum energy intensity of rock destruction.

As a result of this work, the method for determining resistance of rocks to brittle fracture is developed, technical equipment for its implementation is constructed, and the algorithm for transitioning from fracturing value to the value of the minimum energy costs for rock destruction is stated.

The obtained results allow reasonable selection of the drive power of mining machines, evaluation of efficiency of their construction and selection of rock destruction method based on information on the strength properties obtained by means of the developed express method.

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