Modern Methods and Tools for Determining Drillability and Blastability of Rocks

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Abstract. Often in practice, the coefficients of Protodyakonov scale of hardness \( f \) are not established based on objective measurements that are very laborious, but by visual degree and rock family type, which naturally significantly reduces the accuracy of calculations. In this regard, it is proposed to obtain information on the physical-mechanical properties of rocks directly from rigs during drilling, based on the energy characteristics of this process; its main characteristic is the specific drilling energy, i.e., the energy required to destroy a unit of rock during drilling.

For a quantitative assessment of the rock strength as resistance to mining - technological destruction - prof. M.M. Protodyakonov [2] proposed the coefficient of hardness \( f \), in the first approximation, it is proportional to the rock break-down point under compressive load. The scale of hardness was developed, according to which all rocks are divided into ten categories. Many post-Soviet engineers use this coefficient. Since the coefficient of hardness mainly reflects only fracturing under compressive loads, and in real conditions tensile and shearing forces are often used, it becomes necessary to introduce other indicators to assess the properties of rocks.

1. Introduction

The high profitability of the mining enterprise in market conditions is impossible without the effective use of the most reliable data on the rock mass. These data are determined in the process of geological exploration and refined during the development of the field deposit [15]. The technological effectiveness of mining operations is primarily determined by the mechanical and strength properties of the rock mass. At the mining enterprises conducting drilling and blasting operations, they use such indicators as the drillability and blastability of the rock. It is proposed to determine these indicators during technological drilling, without conducting additional research.

The most common indicator of the mechanical properties of rocks is a strength, i.e., rupture resistance. Ultimately, the strength is determined by the ratio of the work required for fracturing to the resulting condition.

Since the coefficient of hardness mainly reflects the rock fracturing under compressive loads, and in real conditions tensile and shearing forces are often present, it becomes necessary to introduce other indicators to assess the properties of rocks. All of them can be summarized in the following main groups [2]:

1. Strength of rocks or rupture resistance to elementary stresses (compression, tension, shear).
2. Deformability of rocks or resistance to changes in their shape or volume.
3. Hardness of rocks or resistance to their local destruction (when pressed or scratched).
4. Crushability of rocks or resistance to grinding.
5. Workability of rocks or resistance to destruction in various industrial processes (breaking, beating, drillability, blastability, etc.).
6. Resistance of rocks to destruction under various technological processes (shaping, drilling) carried out by single tools of special devices reproducing real mining processes under certain idealized standard conditions.
7. Abrasiveness of rocks or ability to wear out working tools of mining machines.

   If we determine all these indicators, we can get objective mechanical properties of rocks; however, more often, in production, there is no real need for such accuracy. As numerous studies have shown, when breaking rocks by drilling to determine the mechanical properties of rocks it is enough to use three basic indicators of the mechanical properties of rocks: plasticity (deformability), hardness, and abrasiveness [3,4].

   However, using these three indicators at once is far from easy, so only two of them can be used for an approximate assessment of the mechanical properties of rocks when drilling. During impact drilling, the key indicator is hardness and plasticity, and during rotary drilling and cutting, we need hardness and abrasiveness values. At the same time, of course, the accuracy of the description of rock properties will decrease.

   In practice, we often use approximate simple measurement methods suitable for conducting mass experiments.

   The various classifications of rocks by drillability are based on the speed of drilling. Drillability is usually estimated by the depth of the hole or well drilled in the rock for 1 min of the net drilling time under standard conditions or, on the contrary, by the amount of the net drilling time of 1 m hole or well under the same conditions. Besides rock properties, drillability also depends on the design features of drilling equipment and its mode of operation.

   Blasting is currently the most common method of rock breaking. The destruction of rocks during an explosion occurs as a result of the cumulative effect of expanding explosion products (gases), detonation, shock waves, and unloading waves. In the calculations of blasting, the main physical-technical characteristic of rocks is the specific consumption of explosives - $q$. Therefore, the correct calculation of $q$ for rocks, considering the entire complex of physical parameters that determine its value, is of great importance. The specific consumption of explosives as applied to certain types of rocks is identified by different scales and rock classifications by blastability. The reference specific consumption of explosives $q_r$ for most rocks varies from 0.05 to 0.8 kg/m³, in case of uncategorized rocks it reaches 0.9-1.4 kg/m³ [6].

   Rocks of the same family, depending on their granularity, heterogeneity, weathering, fracturing, etc., can have dramatically different mechanical properties. Therefore, putting the rock under a certain category by mechanical properties based solely on its family will be extremely approximate and subjective. Rocks are often heterogeneous in their composition and structure. Their mechanical properties in the same face can vary greatly. Therefore, it makes no sense to use overly accurate and complex measurement methods for determining indicators of mechanical properties of rocks, since their accuracy cannot be used anyway. To date, there are many ways to obtain the latest information on the strength of rocks from the face. For example, they are determining the change in the strength of an average piece in the rock mass after blasting is described in [7, 8, 14, 16, 18]. However, all these assessment methods are very laborious.

2. Methods and materials

In this regard, it is proposed to obtain information on the physical-mechanical properties of rocks directly from the rigs during drilling, based on the energy characteristics of this process. The simplest and at the same time quite effective way to interpret the results of drilling is to calculate the energy indicators of the drilling process. One of the successful energy indicators is the specific drilling energy proposed by R. Teale [9]. The specific energy is defined as the work expended in mining a volumetric...
unit of rock. The amount of energy required to extract a given volume should depend entirely on the properties of the rock. The difference between this theoretical and actual amount of energy can be explained by regrinding losses, friction and mechanical losses not directly related to drilling. For rotary drilling, the specific energy can be described by the formula:

\[ e = \frac{F}{S} + \frac{2NT}{SV} \]  

where \( e \) – specific drilling energy, kJ/m³; \( F \) – load on the drilling bit, kN; \( S \) – borehole cross-section, m²; \( N \) – drilling bit rotation speed, r/s; \( T \) – bit torque, kN·m; \( V \) – drilling rate, m/s.

For hydraulically driven drilling rigs, the expression is transformed into:

\[ e = \frac{F}{S} + \frac{2kPT}{SV} \]  

where \( k \) – structural parameter of the drilling rig rotator, m³; \( P \) – rotator inlet pressure, kN/m².

For electric rotary driven drilling rigs, the expression for the specific drilling energy will be as follows:

\[ e = \frac{F}{S} + \frac{UI}{SV} \]  

where \( U \) - bit rotator motor operating voltage, kW; \( I \) - bit rotator motor operating current, A.

From the specific energy values, we can switch to rock hardness. Currently, most mining enterprises, use the strength factor as a hardness coefficient \( f \). Depending on this value, rock strengths are classified according to different categories [10]. Table 1 shows experimental data on the correspondence of the hardness coefficient according to M. M. Protodyakonov to the specific drilling energy and the specific blasting energy [11, 12, 13].

Table 1. Correlation between hardness coefficient, specific drilling energy, and specific blasting energy.

| #   | Hardness coefficient according to M. M. Protodyakonov | Minimum specific drilling energy, MJ/m³ | Maximum specific drilling energy, MJ/m³ | Specific blasting energy, MJ/m³ |
|-----|-------------------------------------------------------|---------------------------------------|---------------------------------------|-------------------------------|
| 1   | 6                                                     | 30.48                                 | 42.68                                 | 2.62                          |
| 2   | 7                                                     | 42.68                                 | 54.87                                 | 2.89                          |
| 3   | 8                                                     | 54.87                                 | 67.06                                 | 3.16                          |
| 4   | 9                                                     | 67.06                                 | 79.26                                 | 3.38                          |
| 5   | 10                                                    | 79.26                                 | 91.45                                 | 3.59                          |
| 6   | 11                                                    | 91.45                                 | 109.74                                | 3.8                           |
| 7   | 12                                                    | 109.74                                | 128.03                                | 3.98                          |
| 8   | 13                                                    | 128.03                                | 152.42                                | 4.11                          |
| 9   | 14                                                    | 152.42                                | 176.8                                 | 4.23                          |
| 10  | 15                                                    | 176.8                                 | 213.38                                | 4.36                          |
| 11  | 16                                                    | 213.38                                | 256.06                                | 4.52                          |
| 12  | 17                                                    | 256.06                                | 304.83                                | 4.67                          |
| 13  | 18                                                    | 304.83                                | 359.7                                 | 4.8                           |
| 14  | 19                                                    | 359.7                                 | 420.67                                | 5                             |
| 15  | 20                                                    | 420.67                                | 493.83                                | 5.09                          |

Figure 1 shows a graph of the relationship between the minimum specific drilling energy and the hardness coefficient according to Protodyakonov. From the graph, one can see an unambiguous relationship between these parameters.
The dependence can be interpolated by the following power function \( R^2 = 0.93 \):

\[
K_{pr} = 1.07E_d^{0.49}
\]  

(4)

where \( K_{pr} \) – hardness coefficient according to M.M. Protodyakonov, \( E_d \) – minimum specific drilling energy.

There is an unequivocal relationship between the specific drilling energy and the specific blasting energy. The dependency graph is shown in Fig. 2.

**Figure 1.** Relationship between the minimum specific drilling energy and the hardness coefficient.

The dependence can be approximately represented by the following power function \( R^2 = 0.97 \):

\[
E_{bl} = 1.17E_d^{0.25}
\]  

(5)

where \( E_{bl} \) – specific blasting energy, MJ/m\(^3\); \( E_d \) – minimum specific drilling energy, MJ/m\(^3\).
3. Conclusion

Thus, with the automated design of drilling and blasting operations, the transition from the hardness coefficient according to Protodyakonov to the specific drilling energy and further to the specific blasting energy is fully justified. The advantage of this approach lies in the possibility of measuring the specific drilling energy directly in the process of drilling blast holes and determining, on this basis, the hardness coefficient and the specific blasting energy. Based on the data obtained from the face, it is possible to make an exact calculation of the parameters of drilling and blasting operations, considering geological conditions, and to select the parameters of blasting operation according to the fracturing energy intensity.

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