Improvement of rock crushing quality based on the load specifications set for electrically-driven hydraulic drilling rigs

D V Antonenkov[1], V Z Manusov[1], R Yu Tsarev[2]

[1] Novosibirsk State Technical University, 20, Karl Markx ave., Novosibirsk, 630073, Russia
[2] Siberian Federal University, 79, Svobodny pr., Krasnoyarsk, 660041, Russia

E-mail: Antonenkovdv@mail.ru

Abstract. The analysis was completed on the main production factors which determine energy characteristics of an electrically-driven hydraulic roller-bit drilling rig at drilling operations under the condition of the Far North deposit. In addition, the correlation ratio between the parameters and electric energy consumption was analyzed for the DM-H drilling rig. The equations expressing the relation of the drilling rig load to the drilling speed have been identified. In order to improve the quality of rock crushing, we have modified the method of determining the properties and condition of the rock mass in order to correct the connection layout of the blasting circuit, the activation system, the change in the type of an explosive agent, as well as the composition and weight of the blasthole charge. The proposed approach allows reducing the cost of drilling and blasting operations by 6 % through the improvement in the accuracy of the designed physical and mechanical properties in terms of both the stratum depth and the strike of the mining block.

1. Introduction

Up to the present time, companies engaged into the open mining of mineral resources have operated under the insufficient data on the processing properties of rocks. The lack of reliable information on the rocks drillability prevents to perform with the sufficient accuracy the rating and planning of power consumption [1], labor and material resources, estimating the equipment and overhaul and reconstruction park, and developing the energy saving activities.

One of the ways to improve the methods of rating and planning is to identify the main processing factors that determine the power consumption and to specify principles of their connection with power consumption indicators. The quantitative evaluation of the degree of influence of processing factors enables not only to specify the key determining factors but also creates a common basis for determining the dependencies of power consumption and designing output performance of mining industry mechanisms [2].

The development of permafrost rock complicates the drilling and blasting operations mainly due to the increased resistance of frozen rock to drilling and blasting, which related to the rock structural viscosity and high mechanical strength owing to the cementing effect of ice.

The key factor of achieving high-quality blast-induced crushing of rock masses is compliance of the parameters of explosive loading with the physical and mechanical properties of rocks. The parameters of explosive loading can be adjusted by changing the type of explosive agent, composition of the blasthole charge, etc., while the physical and mechanical properties of rocks are a given value which does not depend on us: we can only determine them. Therefore, to control the drilling and blasting operations means to provide for the correct choice of blasthole charges parameters (diameter and composition of the blasthole charge, type of the explosive agent, multirow short-delay blasting patterns, etc.) for rocks with certain physical and mechanical properties and to timely change these parameters as the rocks properties change.

The systematic approach to solving geotechnical problems, which is based on the creation of images of objects by using their generalized (fundamental) elements and after their manifestation, enables to solve the inverse task: to identify the object and its properties by the set of determined elements [3]. Thus, a combined geological and geophysical approach which ensures the study of all calculated layer intersections can be considered as an effective addition to geophysical sampling. The latter allows increasing the reliability in determining the composition of layers [4, 5].

2. Case study

The description of the main circuit of the DM-H electrically-driven hydraulic roller-bit drilling rig used in the Far North deposits.

The power voltage of 6 kV is supplied to the drilling rig through the rotary collector ring. It is further fed to a high voltage circuit-breaker. Then the circuit splits:

- through fuses to the transformer T 6000/380/220/110V;
- through the circuit-breaker and fuses to the main motor contactor MTR.

The transformer is designed with four low-voltage windings with a common neutral conductor. Three windings form a three-phase star connection (~380V). The neutral conductor is designed for the voltage of ~ 220V. The fourth winding generates single-phase voltage of ~110V. The MTR main motor which drives the hydraulic pumps and the air compressor is supplied with the power voltage of 6 kV via the high voltage circuit-breaker, fuses, and contactor. Hydraulic motors are used as main drive motors. The hydraulic system is controlled with balanced drives of the main pumps and valves with the help of controllers. During drilling, the controllers of the main pumps send a maximum task to the proportional drives of these pumps. The rotary speed controller sends the task to the proportional drive of the main rotation valve. In order to change the rotation speed of the drilling rig, it is required to change the task sent by the controller [6].

The studies completed by the authors [7, 8] for various types of roller-bit drilling rigs found that the electric energy consumption during drilling operations is a random value that depends on the combination of drilling modes parameters. To apply the methods of the probability theory to determine the patterns of energy consumption, it is necessary to identify the factor that most comprehensively accounts for the change in the mode of the rig operation.

The identification of a factor that gives the most comprehensive characteristics to the drilling rig operation, and consequently, its electric energy consumption, can be made on the basis of the studies performed to determine the dependencies between the operating parameters of drilling [8].

According to the work [9], the variability of rock properties within an interval of up to 1 m in some cases can be commensurable to the variability of the entire block under consideration. Thus, the indices of the rock properties which have a significant impact on the quality of rock crushing during blasting vary within a sufficiently great range even in the interval of up to 1 m, while the traditional methods and techniques of drilling and blasting operations do not take that fact into account, and that undoubtedly has an adverse affect on the blasting efficiency.

Performing drilling with roller-bit rigs is ensured by the simultaneous operation of several mechanisms (rotator, compressors of the hydraulic system pumps, fans, etc.), therefore, it is extremely difficult to analytically express the dependence of the consumed power on the drilling speed.

Below are the results of the study and specifications of the energy parameters for the main roller-bit drilling rig of type DM-H used in the Far North deposits.

According to the experimental data obtained for the DM-H drilling rig operating under the production conditions of the Far North, we have built a correlation field of points together with an empirical curve (see Figure 1). $P = f(\upsilon_{drilling})$ The run of the influence curve shows that the drilling speed increased from 0.1 to 0.7 m/min causes the power consumption growth, however, with the further increase in drilling speed (from 0.7 to 1.3 m/min) the consumption goes down. This can be explained by the fact that a high speed corresponds to low-duty conditions of drilling that are observed within the first meters of the borehole in the layer previously loosened by blasting and operation of the excavator on the bench. The power change in the range from 268 kW at $\nu_{drilling,} = 0.5$ m/min to 270 kW at $\nu_{drilling,} = 0.9$ m/min is insignificant. If we consider power as a constant value at this point this will cause a mean square error in determining the specific power consumption as a function of drilling speed. With the view to the above, a more accurate analytical dependence was developed.

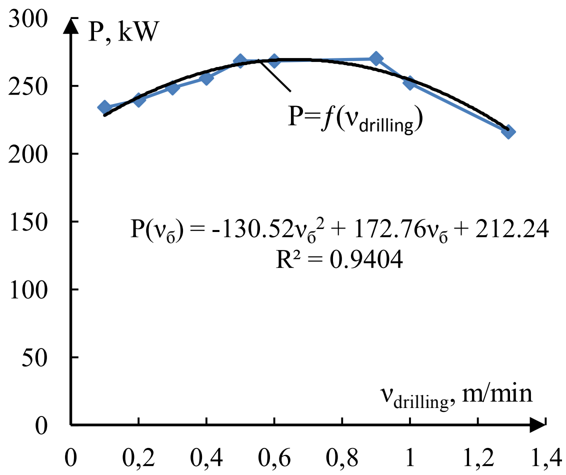

Figure 1. Empirical relation $P=f(\nu_{drilling})$ for DM-H drilling rig

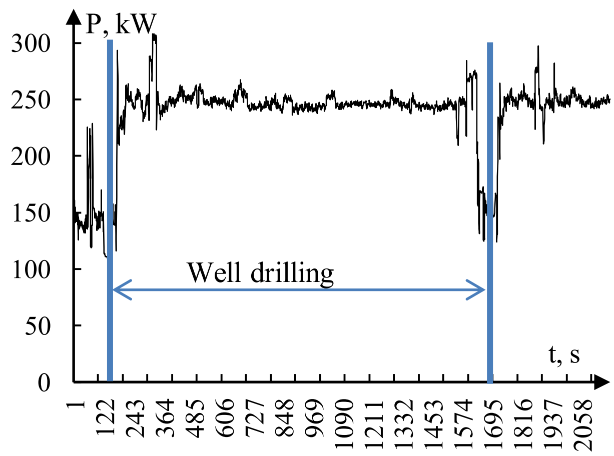

Figure 2: Relation diagram $P=f(t)$ for DM-H drilling rig

According to the empirical curve shape, the most suitable relation can be expressed by the second order polynom. Thus, the equation of power consumed by the drilling rig can be expressed as follows:

$$P(\nu_{drilling}) = -130.52\nu_{б}^{2} + 172.76\nu_{б} + 212.24 \quad (1)$$

Rotary drilling rigs are primarily used in open pit mining projects. Studies on determination of the specific power consumption were carried out by using power circuit quality analyzer for recording power parameters (see Figure 2) of the DM-H drilling rig by taking into account performance of the machines and drillability of rocks.

The specific power consumption of roller-bit drilling rigs during drilling operations depends on many factors: rock strength (rock category in terms of drillability), operating mode of the drilling rig (rotation speed of the unit, axial pressure), type and bluntness of the drill bit, etc. However, the main factor is the rock type in terms of drillability.

As stated above, the essential part of geological prospecting works is the study of physical and mechanical properties of deposit rocks. The results obtained enabled to define the standard explosive ratio for various lithotypes of rocks.

The unified assessment and classification of rocks by blastability is based on the estimated (standard) explosive ratio, i.e. explosive ratio (in grams) of the reference explosive substance (ammonite 6ZhV (mixture of water-resistant ammonium nitrate and trotyl)) necessary for crushing of one cubic meter of solid rock that has six free surfaces (free hanging state) with face sizes from 1 m to lumps with a linear size of 0.25 m when placing the blasthole charge in the cube center.

The designed explosive ratio defines blastability of the rock which is considered as a physical object and is valid for the calculation of a single charge. However, it does not take into account the technical and organizational conditions of the industrial blasting works in open pits: location of boreholes with respect to the free surfaces, shape and size of the boreholes spacing, the sequence of blasting of the boreholes group, extent of the blast damaged zone, set granulometric composition of the blasted rock, etc. These factors are taken into account to determine an estimated explosive ratio for each blast.

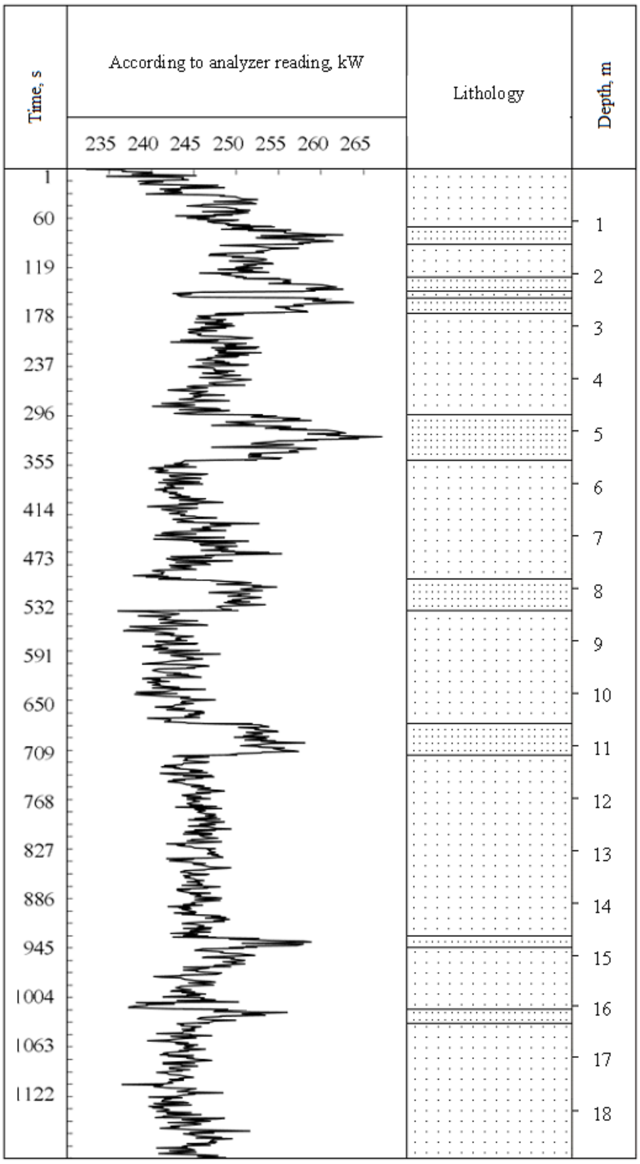

Figure 3. Loading of the DM-H 204 drilling rig to drill 19 m deep borehole

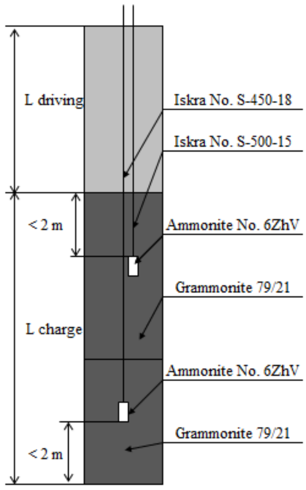

Figure 4. Standard composition of the blasthole charge for hard blasted rocks ("Iskra" No. S-450-18 — 1 unit, "Iskra" No. S-500-15 — 1 unit, Ammonite No. 6ZhV — 6 kg, cartridge of 2.85 kg, Grammonite 79/21 — 864 kg)

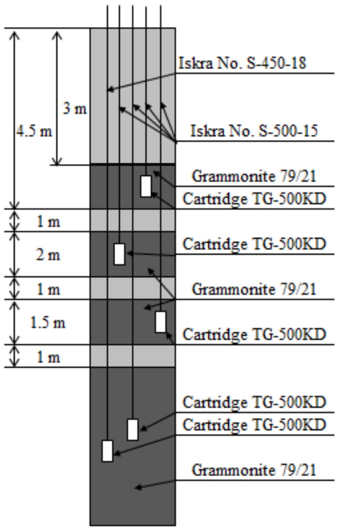

Figure 5. Combined (dispersed) composition of the blasthole charge for hard blasted rocks (based on measurements of the load) ("Iskra" No. S-450-18 — 1 unit, "Iskra" No. S-500-15 — 4 units, Ammonite No. 6ZhV — 24 kg, cartridge of 2.85 kg, Grammonite 79/21 — 760 kg)

Thus, the minimum standard explosive ratio for schistous siltstone is 0.26 kg/m^3, and the maximum explosive ratio for fine sandstone in silica cement is 0.78 kg/m^3. However, due to the fact that strength properties of rocks vary to the large extent, the existing mathematical methods do not ensure an accurate design of physical and mechanical properties of rocks in interwell space based on geological exploration grid which is 100x100 m or bigger. Consequently, it is not possible to determine the spatial variability of strength properties based on the formation depth inside the blasting block on the basis of geological exploration works. This is the reason why design engineers have to deliberately overestimate the standard explosive ratio when designing drilling and blasting works. The actual explosive ratio is quotient from division of the consumed amount of explosives for the amount of the blasted rock and is set based on a number of industrial explosions performed at this site in order to select the best technical and economic indicators for blasting operations [10].

In order to determine the types of host rocks during drilling and blasting operations, the dependence of the drilling rig load is to be accounted for. Figure 3 shows load diagram for drilling of one 19 m deep borehole.

The load factor allowed to determine what kind of rock was drilled by the rig. Combined explosives can be used if the data are available on what rock formation is at specific depth (see Figure 5). Specifically, certain type of borehole prescribes applying to the standard composition of a blasthole charge for hard blasted rocks in the pit (see Figure 4).

3. Conclusion

The method proposed in this work enables to quickly determine the rock properties and conditions, correct the connection layout of the blasting circuit and activation system and change the type of explosive agent, as well as the composition and weight of the blasthole charge, which can reduce the cost of drilling and blasting works by 6 %. In the course of the work, we have analyzed the energy consumption of drilling rigs used in the Far North deposit. Thus, the proposed method allows improving the accuracy of designing the variability in the physical and mechanical properties in terms of both the stratum depth and the strike of the mining block, as well as reducing the explosive ratio.

References

[1] Antonenkov D.V., Solovev D.B. Mathematic simulation of mining company’s power demand forecast (by example of “Neryungri” coal strip mine) IPDME 2017 IOP Publishing IOP Conf. Series: Earth and Environmental Science 87 pp. 1-6 (2017) 032003 doi :10.1088/1755-1315/87/3/032003

[2] Rogalski B.S., Voytyuk J.P. (2009) Kontrol' elektrospozhivannya girnichih mashin i tekhnologichnih vlastivostej girs'kih porid [Control of the power consumption of mining machines and technological rocks],Vinnitsa: UNIVERSUM-Vinnitsa, pp. 79.

[3] Grib N.N., Kuznecov P.Yu., Siasko A.A. & Kachaev A.V. Izuchenie pokazatelej kachestva ugleporodnogo massiva geofizicheskimi metodami na primere izucheniya zol’nosti ugol’nyh plastov [Coal mass quality indicators study by geophysical methods with reference to coal beds ash content analysis]. Sovremennye problemy nauki i obrazovaniya – Modern Problems of Science and Education, 2013, no. 2. Available at: http://www.science-education.ru/ru/article/view?id=8868 (accessed 15.11.2017).

[4] Yan T., Liu Z., Xing L., Luo Y., Bai Y. & Huang S. Evaluation of the gas content of coal reservoirs with geophysical logging in Weibei coalbed methane field, southeastern Ordos basin, China. Resources and Sustainable Development, 2013, Pts 1-4, Vol. 734-737, pp. 331-334. dol: 10.4028/www.scientific.net/AMR.734-737.331.

[5] Asmina A., Sutriyono E. & Hastuti E. Gas Content Appraisal of Shallow Coal Seams in the South Palembang Basin of South Sumatra. International Journal of Geomate, 2017, Vol. 12, issue 33, pp. 45-52.

[6] Aquila Mining System Ltd.: The manual system of DM-1/3/5 for drilling machines “Ingersoll – Rand” DM-M3 и DM-H., 340101, t. 1.0, 1996.

[7] Olejnikov V.K. (1983) Analiz i planirovanie ehlektropotrebleniya na gornyh predpriyatiyah [Analysis and planning of power consumption at mining enterprises], Moscow: Nedra, pp. 192.
[8] Belyh B.P., Sverdel' I.S., Olejnikov V.K. (1971) Ehlektricheskie nagruzki i ehlektropotreblenie na gornorudnyh predpriyatiyah [Electrical loads and power consumption in mining enterprises], Moscow: Nedra, pp. 247.
[9] Antonenkov D.V., Solovev D.B., Manusov V.Z. Estimation of Energy Consumption of DM-H Drill Rig Main Drive in Far North Conditions / 2018 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon) (2018) pp. 1-5 IEEE doi: 10.1109/FarEastCon.2018.8602484
[10] Kutuzov B.N. (1974) Vzryvnye raboty [Blasting operations], Moscow: Nedra, pp. 368.