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***V. I. BOLOBOV*[1]**, *Professor, Senior Researcher, Doctor of Engineering Sciences*
***S. A. CHUPIN*[1]**, *Associate Professor, Candidate of Engineering Sciences, chupin_sa@pers.spmi.ru*
***B. LE-THANH*[2]**, *Senior Researcher*

[1]Saint Petersburg Mining University, Saint Petersburg, Russia
[2]Vinacomin–Institute of Energy & Mining Mechanical Engineering (IEMM), Hanoi, Vietnam

INFLUENCE OF PICK BLUNTING ON HYDRAULIC BREAKER CAPACITY IN FRACTURE OF GRANITE BLOCKS

The necessary condition for the operation of crushers in the production of crushed granite is feeding of the crushers with granite fragments of a certain size. At the same time, granite fragmentation after blasting does not always meet the required size for the crushers and needs additional destruction by blasting or disintegration directly on site. Hydraulic breakers are most often used in disintegration of oversizes. For example, in quarries in Vietnam, JCB HM380 hydraulic breakers with a fracture energy of up to 2.5 kJ are widely used. The working tools of the hydraulic breakers are steel picks of various diameters and shapes. The operation of this tool is accompanied by its intensive wear due to the impact-abrasive action of rocks; the pointed part of the tool gets gradually blunted, which affects the rate of penetration of the pick in rock. In this regard, it is relevant to determine the influence exerted by the degree of wear of the pick on the performance of the hydraulic breaker, and to find out whether replacement or re-sharpening of the pick is expedient.

In this paper, based on the previously determined crack propagation velocity in granite and the impact time, the length of the fracture is calculated. The dimensions of a crack in a granite block are calculated depending on the degree of blunting of the pick at a certain number of blows per cycle. At the same time, the limiting value of a crack that causes chipping of a piece from rock mass was considered as the fracture length to free surface at different degrees of pick blunting. Based on these calculations, the average productivity and energy input of disintegration process were determined.

It is shown that for a tool with a completely worn tip, the decrease in the productivity and the increase in the energy input of fracture reach two times compared with a sharpened pick. In this regard, from the point of view of increasing the hydraulic breaker capacity, it is advisable to replace or re-sharpen the pick after complete wear of its tip.

Keywords: *hydraulic breaker pick, degree of blunting, capacity, granite, oversize crushing*
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Introduction

A considerable amount of a state budget comes from the mineral mining sector. For instance, according to [1], in the period between 2005 and 2018, the Vietnamese mining industry replenished the amount of the state treasury by 9.39% of GDP. To achieve gains, the mineral production needs advanced technologies, including high-performance machines and equipment [2–8], environmental mitigation [9–12], as well as process automation and digitalization [13, 14]. One of the fields that demands much mineral resources is construction, and the main construction material is crushed granite. Granite enjoys wide application in concrete manufacturing, in construction of roads, buildings and structures, etc. By estimates, granite reserves in quarries in Vietnam average 30 Bm^3.

One of the common methods of mineral mining remains drilling and blasting, and its efficiency largely depends on the drilling equipment and tools in operation [4, 15]. Yet, some operations require only the hammer blow (breaking of oversizes, chipping, etc.). The oversize breaking tool is prone to fast wear, which brings a big drop in productivity and a jump in expenses connected with new tool purchase. The service life extension of a tool is a relevant research issue which includes the tool re-designing, the use of new materials and their manufacturing techniques [16–25].

Granite quarries in Vietnam have a low capacity—around 300 thousand tons per year. Such poor performance is due to inaccessible transportation and low-productive crushing-and-screening plants. The maximum allowable size of material to be broken should never exceed 480 mm. In fragmentation by blasting, approximately 10–12% of fragments exceed the maximum allowable size, which calls for additional on-site breaking of oversizes by blasting or disintegration. As per the research [26], more than 600 types of hydraulic breakers of different design, parameters and characteristics are produced at the present time. Granite quarrying most often uses hydraulic breakers having a blow energy up to 2.5 kJ (JCB, Furukawa Daemo, Soosan), and the breaking tool is the picks with the blunted acting face. The general information on the designs of the listed and other-type hydraulic breakers, as well as on their manufacturers is given in the work [26].

An oversize is brought down to a permissible size by means of chipping. Chipping involves a series of blows directly at the rock face. A pick penetrates the rock and generates tensile and shearing stresses in it, which leads to separation of pieces from the oversize.

During operation, pointed end of a pick wears off gradually, with the displacement of the blunting to the cylindrical portion of the pick. The main cause of the phenomenon is the impact abrasive wear. In this case, as a consequence of the growth of the contact area, the pick penetration rate drops, and it is required to re-sharpen or replace the tool. On the other hand, the operating practice of hydraulic breakers in granite quarries in Vietnam shows that a hydraulic breaker is capable to operate after run-out of the pointed end of the pick and up to the moment of the total wear of the pick body. In this connection, the question is how the degree of wear of a pick affects the hydraulic breaker capability and when it is necessary to replace or re-sharpen the pick. Since literature insufficiently exposes the issue, this paper attempts to answer the question above.

Hydraulic breaker performance factors

Impact fracture of rocks is investigated by many researchers such as L. S. Ushakov [27], Yu. A. Lagunova [28], V. G. Zedgenizov [29, 30], I. V. Chuprov [31], I. Grantmyre and I. Hawkes [32, 33], A. Mahhyera et al [34], A. Afrouz et al [35], N. Bilgin et al [36–38], A. A. Khoreshok et al [39], W. R. Wayment [33], Aksoy [40–42] and by many others. These scientists and the followers [27–44] developed a mathematical description of the process of impact tool penetration in rocks, estimated the energy intake of the fracture process and the capacity of percussive machines. At the same time, the influence of the degree of the impact tool blunting on the blow parameters during the tool operation lacks proper consideration. The first theoretical investigation of hydraulic breaker operation was undertaken by Evans [45]. The researcher indicated that the susceptibility of rocks to the impact fracture depends on both the compressive and tensile strength. The broken rock volume per one blow defines efficiency of hydraulic breakers. In the meanwhile, the broken rock volume depends not only on the rock strength but also on the rock lamination, jointing, inclusions, etc.

It is shown in [33] that the specific energy defined as the crushing energy of unit rock volume is inversely proportional to the impact energy:

$$SE = k \big/ \sqrt{E_i}\ ; \tag{1}$$

$$E_i = MV^2 \big/ 2\ , \tag{2}$$

where SE is the specific energy; E_i is the impact energy; M is the tool mass; V is the tool penetration velocity; k is a constant.

Many researchers addressed the issue of rock fracture during penetration of a tool [35–38, 46, 47]. All studies based on the fracture process observations and data collection.

Bilgin [36, 37] has for many years accumulated data on the Istanbul Metro construction and deduced an empirical relation as a result:

$$IBR = 4{,}24P\left(RMCI\right)^{-0{,}567}\ ; \tag{3}$$

$$RMCI = \sigma_c\left(RQD / 100\right)^{2/3}\ , \tag{4}$$

where IBR is the instantaneous or net breaking rate, m^3/h; P is the cutting power, HP; $RMCI$ is the rock mass cuttability index, MPa; σ_c is the uniaxial compressive strength, MPa; RQD is the rock quality designation, %.

Aksoy [40, 41] proposes to add the calculation of the hydraulic breaker capacity with the block perforation index BPI and geological strength index GSI:

$$NBR = 15{,}423P^{0{,}057}WRBI^{-0{,}229}\ ; \tag{5}$$

$$WRBI = \frac{256BPI^{0{,}25}GSI^{0{,}2}}{20}\ , \tag{6}$$

where NBR is the net breaking rate, m^3/h; P is the destructive power of hydraulic breaker, HP; $WRBI$ is the weak rock brittleness index, MPa; BPI is the block perforation index, MPa; GSI is the geological strength index, MPa.

Aksoy [42] generalized the authorial relations for different kinds of mining operations:

Open cutting:

$$NBR = 289{,}28P^{0{,}036}GSI^{-0{,}73}BPI^{-0{,}17}\ ; \tag{7}$$

Underground mining:

$$NBR = 1596{,}71P^{-0{,}25}GSI^{-1{,}025}BPI^{-0{,}11}\ ; \tag{8}$$

All other mining operations:

$$NBR = 406{,}87P^{0{,}064}GSI^{-0{,}76}BPI^{-0{,}15}\ . \tag{9}$$

Based on the studies performed by Professor Sokolinsky [48], the present paper authors propose a mathematical model of impact fracture of rocks by hydraulic breaker pick with regard to the blunting degree of the tool. The case-study of JCB HM380 hydraulic breaker shows that blunting of the pick causes a monotonous increase in penetration resistance in rocks (up to 2 times) both in single and multiple blows, which results in a decrease in penetration and in blow time as compared with the initial condition of the tool by 28 and 20%, respectively.

Effect of blunting ratio of pick on blow time and crack length

The research was based on the studies by Professor Sokolinsky [48]. According to his theory, a piece of rock is separated from rock mass by an impact given the induced crack reaches free surface. The required crack length h_c^* to free surface can be achieved in one blow and in a series of blows. In the latter case, the total crack length is a sum of the crack lengths h_{c_i} per each blow:

$$h_c^* = \sum h_{c_i}\ . \tag{10}$$

The operation of JCB HM380 hydraulic breaker in a granite quarry demonstrated that splitting-off occurred after a series of 30 blows at the same point. Therefore, it was assumed that this number of blows n made one cycle N.

The size of a granite fragment separated from rock mass was found as function of the summed lengths $\sum h_{c_i}$ of cracks generated in rock mass after a cycle of blows by a pick set at an angle of 90° relative to rock mass at different degrees of the pick blunting. The total crack length $\sum h_{c_i}$ was calculated on the basis of the total origin time of cracks and their growth rate:

$$\sum h_{c_i} = \sum t_{c_i} R_c\ . \tag{11}$$

As per [8], the crack origin time t_{c_i} per one blow in a cycle and the total origin time $\sum t_{c_i}$ of all cracks per the whole cycle were assumed as the blow times t_{max_i} and $\sum t_{max_i}$, respectively. The time values decrease with each blow and with the increase in the degree of the pick blunting (**Figs. 1** and **2**).

The crack growth rate R_c in granite fracture is approximately 11 m/s according to [49].

The fracture length per a cycle of blows in granite was calculated with regard to the crack growth rate R_c and the total crack growth time $\sum t_{c_i} = f\left(S_p\right)$, from Eq. (11), at different degrees of the pick blunting (see fig. 1).

The crack length $\sum h_{ci}$ reduces by 20% in passing from the initial condition (S_{p0} = 0.34) to the final condition (S_{pf} = 1.0) of the pick.

Effect of pick blunting on fracture efficiency and energy input

The hydraulic breaker capacity was studied using a granite block 700×700×700 mm. This size conforms with the average oversize in rock blasting. The certain size of the crushing equipment (jaw crusher with an inlet size of 600 mm) requires the rock fragment size not larger than

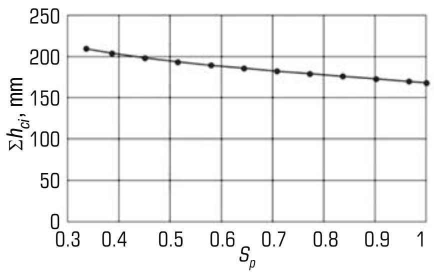

Fig. 1. Crack length $\sum h_{ci}$ as function of pick blunting S_p

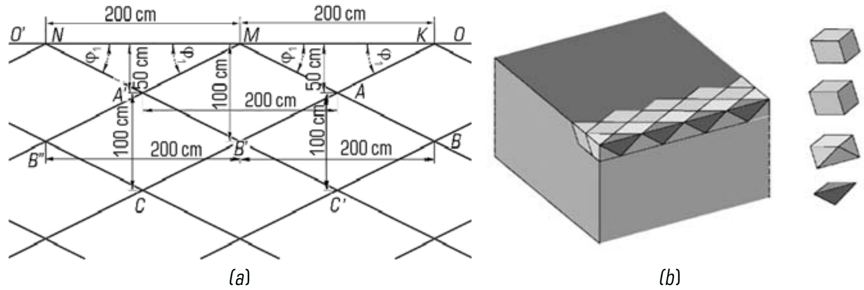

Fig. 2. Zelenin's mode of blowing (*OO'*, *BB'*—the first and second lines of blowing, respectively; *A*, *A'*, *B*, *B'*, *C*, *C'*—points of impact) (*a*) and lines of blowing by hydraulic breaker pick and shapes of fragments in each blowing line (*b*)

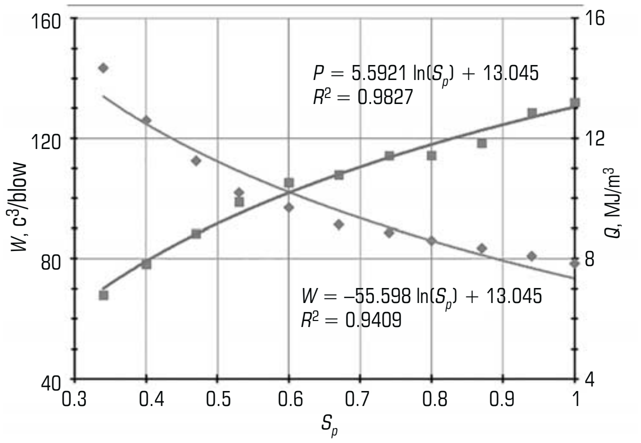

Fig. 3. Average hydraulic breaker capacity *Q* and fracture energy input *W* versus pick blunting S_p

480×480×480 mm. The blowing mode was in accordance with Zelenin's scheme [50]. In this case, the point of impacts is calculated from the condition that a cycle of 30 blows results in a fracture which reaches free surface at the pick setting at an angle of 90° to horizontal surface (see fig. 2).

Each fragment volume V_i, was calculated per each line of blowing. For instance, for OO' (Fig. 2*a*), $V_i = \frac{1}{6}\sin\gamma \sin 2\gamma (\sum h_{c_i})^3$, and the angle γ is approximately 60°.

The number ΣN^* of impact cycles required to cut an oversize down to a designed size was found from the initial oversize volume *V*, its final volume V_0, fragment volume V_i in a blowing line and the number of fragments in this line. The calculations were performed per each degree of the pick blunting S_p. The average capacity of hydraulic breaker in fracturing of an oversize was assumed as $Q = (V - V_0)/ \Sigma N^* n$, cm³/blow.

Figure 3 depicts the hydraulic breaker capacity *Q* and the fracture energy input *W* versus the pick blunting S_p.

The increasing pick blunting (Fig. 3) results in the decreasing capacity *Q* and in increasing fracture energy input *W*. The pick in the initial condition ($S_{p0} = 0.34$) has *Q* round 135 cm³/blow, the totally blunt pick ($S_{lim} = 1$) has a capacity of 75 cm³/blow, i.e. 2 times lower, at the agreeable increase in the energy input *W* from 6.8 to 13.2 MJ/m³. In the further operation of the pick with the totally worn point, the values of *Q* and *W*, agreeable with S_{lim}, remain in wear of the whole cylindrical projection of the pick from the body of the hydraulic breaker. Periodic sharpening of the pick with the worn point can enable increasing the hydraulic breaker capacity to a value conformable with the initial condition of the pick. In case of the test pick with the sharpened and projected parts 100 and 400 mm long, respectively, re-sharpening can be performed 2 times. As the calculations show, re-sharpening can increase the average capacity of a hydraulic breaker by 30% per the whole service life of the tool. The expediency of re-sharpening is determined from the comparison of the cost of the product and the expenses connected with the re-sharpening.

The calculated energy inputs (6.8–13.2 MJ/m³) agree with the values obtained in [51–53]: ~ 12.6, 10.4 and 12.1 MJ/m³.

Conclusions

The accomplished research has found that blunting of picks during operation essentially decreases capacity of hydraulic breakers in cutting of granite oversizes and increase the fracture energy input. For a pick with a totally worn point, the capacity decrease and the energy input increase reach two times as compared with the sharpened pick. In this respect, for enhancing capacity of hydraulic breakers, it is advisable to perform re-sharpening of picks after their total blunting.

This proposed procedure is applicable in fracturing of other type rocks after adjustment of the experimental data such as the crack growth rate and the number of blows required to separate a unit fragment of rock.

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