The development of open-cut mining, in its present stage, particularly now, involves increases in the depth of working and in the proportion of hard rocks worked in the overburden and minerals. Under these conditions it is important to develop schemes of continuous operation and techniques which can raise the efficiency of open-cut mines.

In many cases, continuously operated schemes of working hard rocks with conveyerized transport are complicated by the presence of untransportable fractions in the blasted rock, making secondary crushing necessary.

In ore dressing practice, wide use is made of the mechanical method of breaking rock in various types of crushers; however, present types of crushers are not completely adequate for the requirements of continuous operation. Their chief drawback is the transmission of the percussive impulses to the bed, making it necessary to install substantial foundations.

A distinguishing feature of a new type of improved crushers — vibropercussive ones — is the dynamic balance of the design and the high frequency of vibration of the crusher jaws (up to 3000 min\(^{-1}\)). Figure 1 shows a diagram of a vibropercussive jaw breaker of the balanced type. Under the influence of the disturbing force \(F \cdot \sin \omega t\) of vibrator 5, crusher jaws 1 with equal masses \(m_1 = m_2\) execute synchronous antiphase vibrations with amplitude \(A\), which in the designs in question does not exceed 5-6 mm. Support frame 4 is joined to the crusher jaws by elastic rubber elements 3. On collision with a fragment, each jaw communicates to it a force \(P\). The angle between the jaws should exclude the possibility that the fragment can slide upward.

In view of the complexity of the process of rock breaking by double impact and our lack of knowledge of this process, which occurs in vibropercussive crushers, we carried out our investigation in two stages: on laboratory models, and on pilot models, with jaw capacities of 150 x 300 and 600 x 900 mm, respectively.

In the laboratory model we crushed rocks with hardnesses of \(f = 4-19\) on the Protod'yakonov scale (sandstones, limestones, granites, and iron ores); in the pilot model we crushed rocks with \(f = 7-9\) (sandstones and shales).

To make a visual study of single events of rock crushing, we recorded the process by high-speed cinematography at 1500 frames/sec. We tried to establish the influence of various factors on the rate of crushing of rocks in the vibropercussive jaw breakers. The criterion of the rate of crushing was taken to be the throughput of the crusher. We found that the main factors influencing the rate of crushing of the rocks are the mechanical properties of the rocks, the fragment size of the material to be crushed, and the adjustment of the crusher (the ratio between the natural and forced frequencies of nonpercussive vibrations).

The time of residence of the fragment in the crushing cavity between two successive jaw impacts can be divided into three periods: the fragment makes contact with one jaw and moves with it until it meets the other jaw; the moving jaws make contact with the fragment which plays the part of a stop, and all or part of the kinetic energy of the jaws is communicated to the fragment; and the jaws recoil from the fragment.

It is easy to see that, for one particular machine, the kinetic energy communicated to the rock fragment is governed by the impact velocity of the jaws at the moment when they meet the rock.

Experimentally it was found that the optimum rock crushing conditions occur when the adjustment coefficient \(z\) is close to 0.5; therefore the impact velocities were set in the range \(z = 0.4-0.6\).
Fig. 1. Schematic diagram of vibropercussive jaw breaker: 1) Jaw; 2) crusher plate; 3) rubber element; 4) support frame; 5) vibrator; 6) Cardan shaft; 7) synchronizer gear; 8) motor; 9) base frame; 10) carriage; 11) rails; 12) shock absorber.

Graphs of the impact velocities vs the gap and coefficient of restitution of the impact velocity are shown in Fig. 2; here I and II are respectively the upper and lower boundaries of the region within which vibrations are possible with any value of the coefficient of restitution of impact velocity $R$.

To determine $R$ we used the equation of Rusakov and Kharkevich [1], derived for a one-mass system with a fixed boundary. Owing to the synchronism and antiphase motion of the jaws and the symmetry of the vibrocrusher, this formula applies in this case also.

$$V = \Phi \omega x_1,$$

where $V$ is the impact velocity in m/sec, $\Phi$ is the relative impact velocity, $\omega$ is the vibration frequency of the jaws (the angular frequency of rotation of the unbalanced rotors) in 1/sec, $x_1$ is the amplitude of idling without impact in the absence of stiffness, in millimeters,

$$\Phi = \frac{2}{1 - R} \cdot \frac{\lambda f \pm \sqrt{\frac{1 + f^2}{(1 - z)^2} - \lambda^2}}{1 + f^2},$$

where we are using the abbreviations

$$x_1 = \frac{F_m}{\omega^2 m}, \quad \lambda = -\frac{x_0}{x_1}, \quad f = \frac{1 + R}{1 - R}, \quad \text{cig} \pi z, \quad z = \frac{\omega_0}{\omega}$$

and the following notation: $R$ is the coefficient of restitution of the impact velocity; $\lambda$ is the relative gap; $z$ is the coefficient of adjustment of the crusher; $F_m$ is the perturbing force of the unbalanced rotors on one jaw; $x_0$ is the impact gap; and $\omega_0$ is the natural vibration frequency of the crusher without impacts.

Note that (2) is given for a mechanism with a constant forced vibration frequency, whereas in our case the forced frequency is a variable.

To obtain a true picture of the impact velocities, the quantities found from Eq. (2) must be divided by the adjustment coefficient $z$.

Representing the vibrocrusher in an approximate model as a striker-stop, we assume that up to $\lambda = 0$ the blows are inflicted on the crushed fragment in the gap zone, but after further descent, in the jamming zone.