Impact of the inclination angle of a blade of the geokhod cutting body on the energy intensity of rock destruction

V V Aksenov¹, A B Efremenkov²,⁶, V Yu Sadovets³, D A Pashkov⁴ and V A Efremenkov⁵,⁶

¹Research Center Siberian NPO Ltd, Sovetsky prospect, 56 650002, Kemerovo, Russia
²Yaroslav-the-Wise Novgorod State University, ul. B. St. Peterburgskaya, 41 173003, Veliky Novgorod, Russia
³T.F. Gorbachev Kuzbass State Technical University, ul. Vesennaja, 28 650000, Kemerovo, Russia
⁴Institute of Coal, Federal Research Center for Coal and Coal Chemistry, Siberian Branch of the Russian Academy of Sciences, Leningradsky prospect, 10 650610, Kemerovo, Russia
⁵Peter the Great St.Petersburg Polytechnic University (SPbPU), Polytechnicheskaya, 29 195251, St.Petersburg, Russia
⁶E-mail: 55vva42@mail.ru
⁷E-mail: abc@novsu.ru

Abstract. The article presents the dependence of the energy intensity of rock destruction on the inclination angle of blade of geokhod cutting body for the destruction of low hardness rocks. To formulate the research tasks, the main provisions of the geokhod technology for making workings are presented; the features of the new class of mining equipment, geokhod, are given. The research relevance is formulated. To determine the energy intensity of the rocks destruction, the method of calculating the power and geometric parameters of the geokhod blade cutting body was chosen. An algorithm has been developed for calculating the energy intensity of rock destruction, on the basis of which a computer program has been developed for determining the power parameters of the geokhod blade cutting body. In addition, the article presents well-founded forms of face, which appear as a result of destruction with the blade cutting body of the geokhod. To determine the influence of the inclination angle of the geokhod blade cutting body on the energy intensity of destruction, the geometrical parameters of the blade cutting body and the parameters of the mining and technical conditions of the mine working were justified. As a result of the study, it was revealed that the energy intensity of rock destruction with the blade cutting body decreases unevenly as the inclination angle of the blade towards the reverse cone increases.

1. Introduction
The formation of a cavity in an underground space at shallow depths is a difficult and time-consuming task. Existing mining systems and technologies of mine workings are poorly adapted, and in most cases are not able to solve problems arising during the development of underground space at small depths [1, 2, 3, 4].
One of the promising approaches to the technology of making workings in small depths is the use of geokhod technology. The main device of the developed technology is a new class of equipment – geokhod. This is a technological apparatus intended for carrying out the excavation of underground workings for various purposes and location in space [4, 5, 6, 7, 8]. One of the variants of the geokhod design is presented in figure 1 [9, 10, 11].

![Figure 1. A prototype of geokhod with a drum cutting body.](image1)

The use of geokhods with drum-type cutting bodies for the destruction of low hardness rocks [12, 13] is not effective from the point of view of safety and complexity of the design of the cutting body itself. A more promising constructive solution of the geokhod cutting body for the destruction of low hardness rocks is the use of blade of the earth-moving machine cutting body [11]. One of the constructive solutions for the geokhod blade cutting body with a diaphragm overlapping the working face is shown in figure 2.

![Figure 2. A constructive solution for the geokhod blade cutting body.](image2)

In the process of developing constructive solutions for devices and elements of the cutting body of a geokhod, it is necessary to take into account the complex movement of the machine towards the working face. Accordingly, when justifying the power parameters of devices and elements of the cutting body of
a geokhod, it is necessary to take into account not only the peculiarities of the interaction of geokhod devices with the external environment, but also the interaction of elements among themselves.

To assess the performance of the executive body of the mining machine, the energy intensity of rock destruction is used [14, 15, 16]. In geokhod technology of cavity formation in underground space, the energy intensity of the destruction of low hardness rocks will be influenced by the geometrical parameters of the geokhod cutting body. Therefore, the research aimed at determining the influence of the geometrical parameters of the geokhod blade cutting body on the energy intensity of the rock destruction is relevant.

2. Research methodology

From the developed methodology for determining the energy intensity of rock destruction by earth-moving machines (p, MJ/m$^3$) proposed by Yu. A. Vetrov, the energy intensity is determined by the expression

$$p = \frac{P}{F_{mid}},$$

(1)

where $P$– blade cutting force, H;

$F_{mid}$ – slot cross section area, mm$^2$.

One of the parameters that affect the energy intensity of destruction is the slot cross section area. The impact of forces of one blade of geokhod cutting body for the destruction of low hardness rocks is presented in figure 3.

![Figure 3](image.png)

**Figure 3.** The areas of action of the components of the cutting force with a sharp blade.

For one blade of the geokhod cutting body, the cross-sectional area of the slot will be determined by the expression

$$F_{mid} = bh + k_{side}^2 h^2 \text{ctg} \gamma,$$

(2)

where $b$ – the blade width, m;

$h$ – depth of cutting, m;

$k_{side}$ – the depth ratio of the expansion part of the slot;

$\gamma$ – angle of inclination of the expansion part of the slot to the horizon, degree.

The second parameter affecting the energy intensity of rock destruction is the power factor. For the geokhod blade cutting body, the main power parameters will be the projection of the total force of the
resistance of the soil to cutting on the axis of rotation of the geokhod $P_0$ and on the plane perpendicular to the axis of rotation of the geokhod $R_{cb}$, as well as the moment of resistance to cutting from this component of $M_{cb}$ [14, 15, 16, 17]. The scheme of action of power factors is presented in figure 4.

![Figure 4](image)

**Figure 4.** Calculation scheme for determining the total force of soil resistance to cutting with a blade cutting body of a geokhod.

To determine the energy intensity of rock destruction with a blade cutting body of a geokhod, the cutting force $P$ in expression (1) will be equal to the projection of the total soil resistance to cutting on the plane perpendicular to the axis of rotation of the geokhod $R_{cb}$. Therefore, expression (1) takes the form

$$p = \frac{R_{cb}}{F_{mid}},$$

(3)

For a geokhod blade cutting body, the total projection of the resistance of the soil to cutting on a plane perpendicular to the axis of rotation is equal to [14–19]

$$R_{cb} = n(R_{cb,cv} + R_{cb,side}),$$

(4)

where $n$— the number of blades of the geokhod body;
$R_{cb,cv}$— projection of the component of the force of soil resistance to cutting, depending on the width of the cut, on the plane perpendicular to the axis of rotation of the geokhod, $H$;
$R_{cb,side}$— projection of the component of the force of soil resistance to cutting, not depending on the width of the cut, on the plane perpendicular to the axis of rotation of the geokhod, $H$.

Projection of the component of the force of soil resistance to cutting, depending on the width of the cut, on the plane perpendicular to the axis of rotation of the geokhod [14–19]

$$R_{cb,cv} = \frac{\omega m h_0^2}{2\pi m \cos \gamma} \left[ \frac{(\sin \beta_2 - \sin \beta_1)}{\sin \beta_2 \cdot \sin \beta_1} + \frac{ctg(\delta + \varphi_f)ln\left[\frac{tg \beta_2}{2}\right]}{\frac{tg \beta_2}{2}} \right].$$

(5)

Projection of the component of the force of soil resistance to cutting, not depending on the width of the cut, on the plane perpendicular to the axis of rotation of the geokhod [18–23]
\[ R_{cb,cv} = \frac{h_B}{n} \left( m_{side} \frac{h_B}{n} + m_{side,mid} \right) \frac{\sin(\delta + \varphi_f + \beta_1) + \sin(\delta + \varphi_f + \beta_2)}{\sin(\delta + \varphi_f)} \].

(6)

Figure 5 shows the scheme of the geokhod blade cutting body, on which its main geometrical parameters are indicated. One of them is the inclination angle of the blade to the plane perpendicular to the axis of rotation of the geokhod – \( \gamma \), the change of which affects the shape of the face. At \( \gamma = 0^\circ \), a flat face shape is formed (figure 6, a), and at \( \gamma > 0^\circ \) a conic face shape appears (figure 6, b).

Figure 5. Scheme of a blade cutting body.

Taking into account the inclination angle of blade to the plane perpendicular to the axis of rotation of the geokhod (\( \gamma \)), the expression (2) takes the form

\[ F_{mid} = \frac{bh}{\cos \gamma} + k_{side} h^2 c t g \gamma_{pr}, \]

(7)

Figure 6. Scheme of a blade cutting body.
3. Results

To determine the influence of the inclination angle of the blade to the plane perpendicular to the axis of rotation of the geokhod on the energy intensity of rock destruction, we justified the parameters of mining technical conditions of making workings with geokhods, as well as the geometric parameters of the blade cutting body. The values of these parameters are presented in Table 1.

Table 1. Mining technical conditions of making a working with a geokhod and the geometrical parameters of the geokhod blade cutting body.

| Name                                           | Symbol | Unit of measurement | Value  |
|------------------------------------------------|--------|---------------------|--------|
| Geokhod radius                                 | \(R_g\) | m                   | 0.3    |
| Central nozzle radius                          | \(r_o\) | m                   | 0.025  |
| External propulsion step                       | \(h_B\) | m                   | 0.3    |
| Coefficient taking into account the influence of the cutting angle | \(\varphi\) |                  | 0.59   |
| Specific cutting force in the frontal part of the slot at a cutting angle of 45° | \(M_{cv}\) | H/m²             | 97000  |
| Strength of the destruction of the soil in the side parts of the slot | \(M_{side}\) | H/m²             | 36000  |
| Specific cutting force of one of the side edges of the blade | \(M_{side,mid}\) | H/m             | 8490   |
| Number of blades on a cutting body             | \(n\)  | pcs                 | 1      |
| Angle of inclination of the radial blade to the plane perpendicular to the axis of rotation of the geokhod | \(\gamma\) | deg             | 0      |
| Cutting angle                                  | \(\delta\) | deg              | 25     |
| Friction angle                                 | \(\varphi_f\) | deg          | 31.4   |
| Depth ratio of the expansion part of the slot  | \(K_{side}\) |                 | 0.9    |
| Angle of inclination of the expansion part of the slot to the horizon | \(G_{pr}\) | deg            | 30     |

According to expression (3), the dependence of the energy intensity of rock destruction with the blade of the geokhod cutting body on the inclination angle of the blades of the geokhod cutting body is determined.

The procedure for calculating the geokhod blade cutting body is shown in Figure 7. The developed algorithm was applied when designing a computer program for determining the energy intensity of the rock destruction with the geokhod blade cutting body.
Figure 7. Algorithm for calculating the energy intensity of the rock destruction with the geokhod blade cutting body.

On the basis of the obtained values, we plotted a graph (figure 8) of the changes in the energy intensity of the rock destruction with the blade cutting body of the geokhod if the inclination angle of blades is changed.

The ordinate axis of the presented dependence shows the value of the energy intensity of the rock destruction with the blade cutting body of the geokhod (MJ/m³), and the abscissa axis shows the change of inclination angle of blades of the geokhod cutting body (deg.).

Figure 8. Dependence of the energy intensity of the rock destruction with the geokhod blade cutting body on the inclination angle of blade.

From the graph presented in figure 8, it follows that:
– the value of the energy intensity of the rock destruction with the geokhod blade cutting body changes nonlinearly downwards with an increase in the inclination angle of blades of geokhod cutting body;
– the energy intensity of the rock destruction decreases as a result of the relative increase in the area of the cut;
– from the point of view of the energy intensity of the rock destruction with the geokhod blade cutting body, the conic shape of the face is preferable, as shown in figure 6, b.

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