Influence of the knife shape on the operating body cutting force

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Abstract. The basic part of any mining machine is the operating body used for mine working. The parameters of the mining machine are particularly affected by the geometric and force parameters of their operating bodies. The knife shape is one of the geometric indicators of the mining machine cutting part. The existing methodology for calculating a geokhod cutting body does not take this indicator into account. The purpose of the work is to determine the influence of operating body knife shape on the strength of the blocked cutting. The research shows that the knife shape affects only the forces for overcoming the frontal resistance of the soil by the front edge of the knife. It is possible to determine the influence of the cutting edge shape of the operating body on the force of blocked cutting. As a result of the study, it was revealed that when the knife is deepened to the entire cutting depth and when it destroys the face corresponding to its shape, the knife shape does not influence the strength of the blocked cutting.

1. Introduction
The growth in the volume and scale of the effective development of the underground urban space is observed today throughout the world. It is associated with the ever-increasing concentration of the urban population and the continuous increase in the number of vehicles that give rise to almost all of the most acute contemporary urban problems – territorial, transport, environmental, and energy. As noted in research, the depth of development of the underground space is 20–50 m [1–5].

Kuzbass at a depth of 20–50 m is characterized by such soils as loams and clays. The depth of their occurrence ranges up to 95 m [6]. These soils belong to soft rocks according to the scale of M. Protodyakonov [7–9].
A promising trend for solving these issues is the use of geokhod technology for the cavity formation in the underground space, where the geokhod is the basic element [10–15].

The basic part of any mining machine is the operating body used for mine working. The parameters of the mining machine are particularly influenced by the geometric and force parameters of their operating bodies [16–18].

Therefore, the research aimed at substantiating the parameters of the geokhod operating body for the destruction of soft rocks is relevant.

The research purpose is to determine the influence of the knife shape of operating body on the force of blocked cutting.

2. Research Methods
Taking into account the structural possibility of changing the knife geometry, it becomes possible to obtain a number of options for schematic solutions of geokhod cutting bodies used for the destruction of soft rocks, some of which are presented in figure 1.

![Figure 1](image-url)

**Figure 1.** Schematic versions of a four-beam knife of geokhod operating body with different knife geometry: a) a flat shape; b) an inverse cone shape; c) convex cone shape; d) a convex ball shape.

The methodology for determining the force parameters of the geokhod knife operating body is based on the methodology for determining the cutting forces proposed by Yu.A. Vetrov [19–21]. The methods
of Yu. A. Vetrov are based on the laws of the process of cutting soil with simple knives that separate the chips. Under a simple knife, a rectangular-shaped knife is understood (figure 2).

Figure 2. A rectangular-shaped knife.

When cutting with one straight knife of the geokhod operating body, all the power of blocked cutting can be represented as the sum of the three constituent forces (figure 3).

1. Forces to overcome the frontal resistance of the soil with the front edge of the knife $P_{sv}$, proportional to the cross-sectional area of the slot in front of the front edge of the knife and depending on the cutting angle and soil strength;

2. Forces to overcome the resistance of the soil to fracture in the lateral extensions of the $P_{side}$ slot, proportional to the area of these parts of the slot, depending on the strength of the soil and not depending on the cutting angle and width of the cut;

3. Forces to overcome the resistance of the soil to the cut side edges of the knife at the bottom of the slot $P_{side mid}$ proportional to the thickness of the cut, depending on the strength of the soil and not depending on the width of the cut and the angle of cutting.

Figure 3. The action areas of a sharp straight knife cutting force constituents.

To determine the influence of the shape of the knife of the cutting body on the force of blocked cutting, we assume that the recess of the knife occurs throughout the depth of cutting and the knife destroys the face corresponding to its shape.

When cutting with a spherical shape knife of the geokhod operating body, all the power of blocked cutting can be represented as the sum of the three constituent forces (figure 4).
Figure 4. The action areas of a sharp spherical knife cutting force constituents.

Figures 3 and 4 show that the shape of the knife only affects the forces to overcome the frontal resistance of the knife (in figure 3 and 4 indicated as $P_{sv}$).

The entire force of blocked cutting with a straight sharp knife [19–21]:

$$P_{mid} = \varphi m_{cv}bh + 2m_{side}h^2 + 2m_{side,mid}h,$$

where

- $\varphi m_{cv}bh$ - forces to overcome frontal resistance to the knife (in figure 3 indicated as $P_{cv}$), N;
- $2m_{side}h^2$ – soil fracture force in lateral slit extensions ($P_{side}$ in figure 3), N;
- $2m_{side,mid}h$ – side shear forces ($P_{side,mid}$ in figure 3), N;
- $\varphi$ – coefficient taking into account the influence of the cutting angle;
- $m_{cv}$ – specific cutting force to overcome ground resistance with the front face at a cutting angle of 45°, Pa;
- $b$ – knife width, m;
- $h$ – cutting depth, m;
- $m_{side}$ – coefficient characterizing the strength of soil destruction in the lateral parts of the slot, Pa;
- $m_{side,mid}$ – coefficient characterizing the specific shear strength of one of the side ribs of the knife, N/m.

Since $\varphi m_{cv}bh$ environmental parameters multiplied by the cut area ($S$) in the forehead of the knife (figure 3), then with the spherical shape of the knife, it is necessary to determine the cut area ($S_{sp,sh}$) in the forehead of the knife shown in figure 4.

As seen from figure 4, the figure has a complex spherical shape; to find the area, it is necessary to divide the figure into elementary figures (figure 5).

Figure 5. Elementary figures forming a cut with a spherical shape knife.
From figure 5, figures 1 and 3 are circular segments, figures 2 and 3 jointly form a rectangle with sides \(b\) and \(h\). Figures 1 and 3 are the same and have the same area, since figure 3 is figure 1 in the previous cut.

In view of the foregoing, the cut area in the forehead of spherical shape knife will be equal to

\[
S_{sp.sh} = bh, \tag{2}
\]

where \(b\) – cut width, m;

\(h\) – cutting depth, m.

Since the knife width and the cut width are equal, the forces to overcome the frontal resistance to the knife \(P_{cv}\) will be the same for both a straight knife and a spherical knife with equal values of \(b\) and \(h\).

Therefore, the entire force of blocked cutting will not depend on the spherical shape of the knife.

When cutting with one knife when the knife is tilted at an angle \(\gamma_{ob}\), the entire force of the blocked cutting can also be represented as the sum of the three constituent forces (figure 6).

\[
S_{\text{tilt}} = bh, \tag{3}
\]

where \(b\) – parallelogram height or cut width, m;

\(h\) – a parallelogram side or cutting depth, m.

Hence, the forces to overcome the frontal resistance to the knife will be the same for a straight-shaped knife, as well as for a knife inclined at an angle \(\gamma_{ob}\) with equal values of \(b\) and \(h\).

Therefore, the force of blocked cutting will not depend on the shape of the knife.

3. Conclusion

1. The influence of the shape of the knife of the knife operating body on the strength of the blocked cutting is determined.
2. When the knife is deepened to the entire depth of cutting and destroys the face corresponding to its shape, the shape of the knife does not affect the strength of the blocked cutting. It is necessary to determine the influence of the shape of the knife of the knife operating body on the blocked cutting force when the shape of the knife and the shape of the face do not match, in the notching situation.

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