Substantiation of characteristic bending points of the blade operating body of the geokhod

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Abstract. The article substantiates the characteristic bending points of blade operating body of the geokhod. The urgency of the research is considered. The information on the work peculiarities of the operating body of the geokhod is given. The method of calculation of the blade operating body of the geokhod is described, in particular, the entire force of the blocked cutting by a single radial blade of the IO of the geokhod is shown, and this force is also represented as a sum of three constituent forces. To establish the purpose and objectives of the study, it is justified to choose the force to overcome the soil resistance by the front face of the blade P_{cv}, which is proportional to the cross-sectional area of the slot before the front edge of the knife and which depends on the angle and strength of the soil. The limits of integration of the projection of the component of the soil resistance force into the cutting, depending on the width of the cut, on the axis of rotation of the geokhod $P_{0.cv}$ and on the plane perpendicular to the axis of rotation of the $R_{IO.CV}$. Based on the study, the tasks for further research have been determined.

Introduction

Today, new technologies in the field of robotics are being implemented at a rapid pace. However, the less developed area is the creation of devices that can move underground [1, 2]. In this connection, the tasks are to develop new approaches, technology, and machines that allow all processes to be robotically performed to form a cavity in an underground space [3]. One of the directions that allows an underground robot to move underground is the application of geovinchester technology, the basic element of which is the geokhod.

At the current stage of the development of elements of geovinchester technology, there is an urgent need to develop constructive and technical solutions for executive bodies capable of producing cavities in the underground space along rocks with a strength of up to 1 on the scale of M.M.

Protodyakonov [4]. Therefore, the work aimed at justifying the parameters of the executive bodies of geoopds to destroy rocks with a strength of up to 1 is relevant.

Features of the operating body of the geokhod

The peculiar nature of the movement of the geokhod on the face causes the formation of a complex surface shape not only of the bottom face itself, but also of the executive body (IO). The surface of the face, when its IG is destroyed, has the appearance of several helicoidal surfaces with ledges.

Point A (figure 1), located on the periphery of the knife, at the given step of the helical blade h_B of the external propeller, passing for one complete revolution along the circumference of the path $2\pi R_g$, moves to the face at an angle β_1 to the plane perpendicular to the axis of rotation of the geokhod [5, 6, 7], and

$$\beta_1 = arctg \frac{h_B}{2\pi R_g}, \tag{1}$$

where R_g – radius of the head section of the geokhod.

Any point of the knife located at a distance x (Figure 1) from the axis of rotation of the geokhod, moves to the face at an angle [5,6]:

$$\beta_x = arctg \frac{h_B}{2\pi x} \tag{2}$$

The points of the knife, which are closer to the axis of rotation of the geokhod, move to the face at a greater angle than the points on the periphery of the knife. Thus, with the helical movement of the knife IO of the geokhod to the face, the points of the knife form a helicoidal (helical) surface. Consequently, the section of the face in the sector between adjacent knives after their passage takes the form of a screw surface.

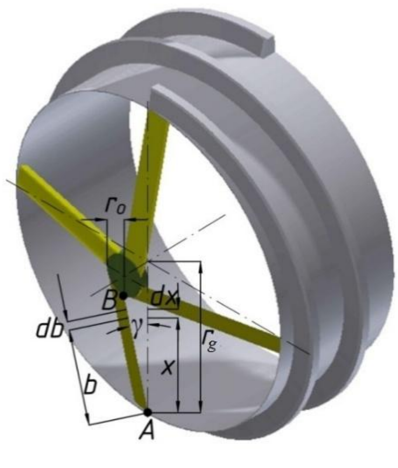

Figure 1. Scheme of the knife executive body.

Each point of the knife in one turnover of the geokhod must be moved to the production face by an amount equal to the step of the external drive of the geokhod generator $h_в$. In this case, the path length for each point in the process of moving will depend on the radius of the location on the knife of the IO of the geokhod. The knife points that are closer to the axis of rotation of the geokhod are moved to the corner at a large angle (point B at an angle β_B) than the points located at the periphery of the knife (point A at an angle β_A) (Figure 2). The value of the cut-off layer for each point of the IO knife of the geokhod will depend on the angle of displacement of the point on the face of the mine.

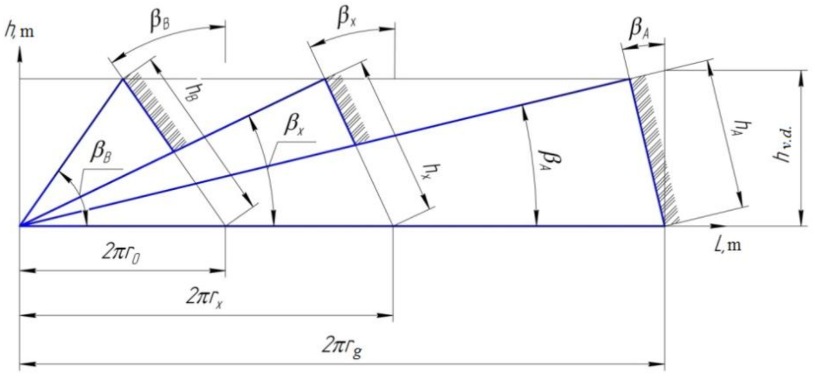

Figure 2. Direction of motion of the knife points IO, depending on the location on the knife along the radius of the geokhod

Thus, the height of the formed shoulder *h* depends on the pitch of the helical blade, the number of radial blades and the angle of movement of the knife point IO of the geokhod to the workhole [5,6]:

$$h = \frac{h_B}{n}, \tag{3}$$

where *n* is the number of knives on IO.

Method of calculation of the knife executive body of the geokhod

When cutting a single radial knife for a geokhod engine, the entire force of the blocked cutting can be represented as a sum of three component forces (Figure 3) [8,9,10]:

- force to overcome the resistance of the soil with the front face of the knife P_{cv}, which is proportional to the cross-sectional area of the slot in front of the front edge of the knife and which depends on the angle and strength of the soil;

- forces to overcome the resistance of the ground to the destruction in the lateral extensions of the groove P_{side}, which is proportional to the area of these parts of the slot, which depends on the strength of the soil and which does not depend on the cutting angle and the width of the cut;

- forces to overcome the resistance of the ground to the cut by the lateral edges of the knife at the bottom of the slot of the $P_{side\ mid}$, 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.

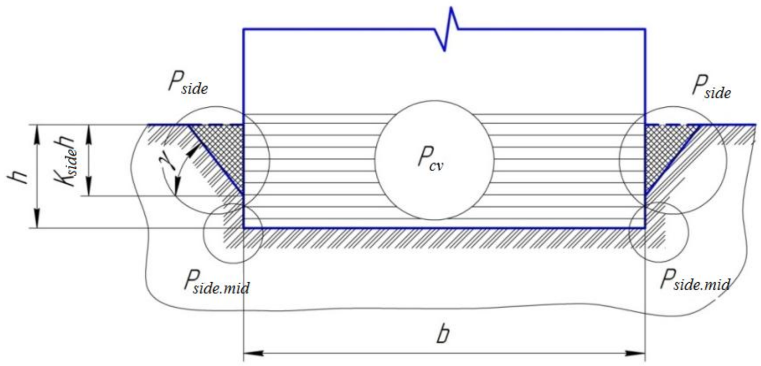

Figure 3. Areas of action of the component sharp knife cutting force.

All force of the blocked cutting by a simple sharp knife [11]:

$$P_{cr} = \varphi m_{cv} bh + 2m_{side} h^2 + 2m_{side.mid} h \quad (4)$$

where $\varphi\ m_{cv} bh$ - the strength of overcoming the frontal resistance of the knife (on Figure 3 $P_{св}$), H;

$2m_{side} h^2$ - the entire force of soil destruction in the lateral extensions of the slot (P_{side} on Figure 3), H;

$2m_{side.mid} h$ - lateral force ($P_{side.mid}$ on Figure 3), H;

φ - coefficient that takes into account the influence of the cutting angle;

m_{cv} - specific cutting force to overcome the resistance of the ground with the front face at a cutting angle of 45^0, Pa;

b - width of knife, m;

h - depth of cut, 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 shearing force of one of the lateral edges of the knife, H/m.

We divide the force of the blocked cutting into two components, one of which depends on the width of the cut (knife) *b*, and the other is not. The first component is denoted P_{cv}, the second is P_{side}. Then, on the basis of expression (4)

$$P_{cv} = \varphi m_{cv} hb; \quad (5)$$

$$P_{side} = 2h\left(m_{side} h + m_{side.mid}\right). \quad (6)$$

The component of the cutting force, depending on the width of the cut, for the elementary section of the knife IO (*db* on Figure 1) is determined by the expression

$$dP_{cv} = \varphi m_{cv} h db. \quad (7)$$

An additional cutting force that must be applied to the *db* knife's elementary section with a wear pad or blunted

$$dP_{p.wear} = P_{wear} db; \quad (8)$$

$$P_{изн} = p_o + p_{condit} \frac{h}{\left(h + h_{condit}\right)}, \quad (9)$$

where p_o, p_{condit}, h_{condit} - parameters characterizing the resistance to elastoplastic compression. With considering $db = \frac{dx}{\cos\gamma}$ we get

$$dP_{cv} = \frac{\varphi m_{cv} h dx}{\cos\gamma}. \quad (10)$$

$$dP_{cv}^{w} = dP_{cv} - dP_{p.wear}; \quad (11)$$

With blunt knives, the normal component of the cutting force

$$dN_{cv}^{w} = ctg\left(\delta + \varphi_{fr}\right) \frac{\varphi m_{cv} h}{\cos\gamma} dx - \frac{ctg\left(\delta + \varphi_{fr}\right)}{\cos\gamma} P_{wear} dx. \quad (12)$$

Figure 4 shows the projections of the total ground resistance force to the cutting on the axis of rotation of the geokhod (P_0) and the plane perpendicular to the axis of rotation of the geokhod (R_{io}).

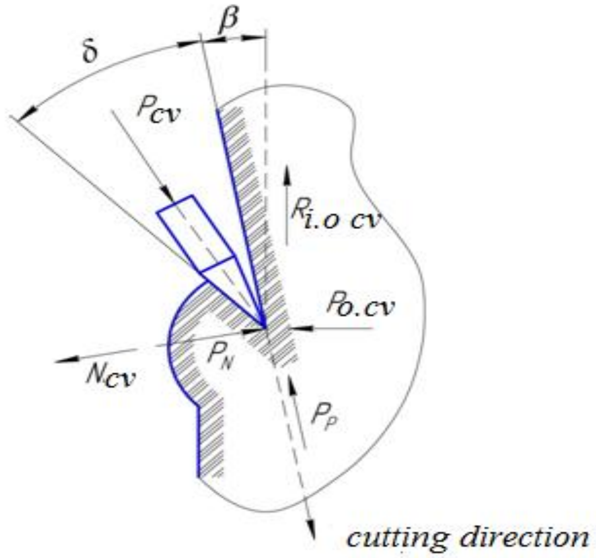

Figure 4. Calculation scheme for determining the resistance force of the soil with the front face of the knife.

Projections of the component of the ground resistance force of cutting, depending on the width of the cut, on the axis of rotation and the plane perpendicular to the axis of rotation of the geodatabase, as well as the moment of resistance to cutting from this component for blades with a wear pad.

$$dP_{o.cv} = \sin\beta_x dP_{cv} - \cos\beta_x dN_{cv}\,; \tag{13}$$

$$dR_{i.o.sv} = \cos\beta_x dP_{cv} + \sin\beta_x dN_{cv}\,; \tag{14}$$

After substituting and solving the integrals, we finally have

$$P_{o.cv} = \frac{\varphi m_{cv} h_в^2 + h_в n P_{wear}}{2\pi n \cos\gamma} \cdot \left(\ln \frac{tg\left|\frac{\beta_2}{2}\right|}{tg\left|\frac{\beta_1}{2}\right|} \right) - \\ - \frac{h_в}{2\pi}\left(\varphi m_{cv} \frac{h_в}{n} \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} - \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} P_{wear} \right) \frac{\sin\beta_2 - \sin\beta_1}{\sin\beta_1 \sin\beta_2} \tag{15}$$

$$R_{i.o.cv} = \frac{\varphi m_{cv} h_в^2 + h_в n P_{wear}}{2\pi n \cos\gamma} \cdot \frac{\sin\beta_2 - \sin\beta_1}{\sin\beta_1 \sin\beta_2} + \\ + \frac{h_в}{2\pi}\left(\varphi m_{cv} \frac{h_в}{n} \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} - \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} P_{wear} \right) \cdot \left(\ln \frac{tg\left|\frac{\beta_2}{2}\right|}{tg\left|\frac{\beta_1}{2}\right|} \right); \tag{16}$$

Projections of the component of the ground resistance force of cutting, independent of the width of the cut, on the axis of rotation of the geodatabase and the plane perpendicular to the axis of rotation, as well as the moment of resistance to cutting from this component [12]

$$P_{o.side} = \frac{h_B}{n}\left(m_{side} \frac{h_B}{n} + m_{side.mid} \right)\left[-\frac{\cos(\delta + \varphi_{fr} + \beta_1) + \cos(\delta + \varphi_{fr} + \beta_2)}{\sin(\delta + \varphi_{fr})} \right]; \tag{17}$$

$$R_{i.o.side} = \frac{h_B}{n}\left(m_{side}\frac{h_B}{n} + m_{side.mid}\right)\left[\frac{\sin(\delta+\varphi_{fr}+\beta_1)+\sin(\delta+\varphi_{fr}+\beta_2)}{\sin(\delta+\varphi_{fr})}\right]; \quad (18)$$

Methods of research

To find the characteristic points from the bending of the knife IO, we use a force that depends on the width of the cut, i.e. force to overcome the resistance of the ground with the front face of the knife $P_{cv.}$ Figure 4 shows the projections of the component of the ground resistance force of the cutting, depending on the width of the cut, on the axis of rotation of the geokhod ($P_{0.CV}$) and on a plane perpendicular to the axis of rotation of the geodatabase ($R_{IO.CV}$). Based on these projections, four characteristic points can be distinguished:

1) At what *x*, the projection of the component of the soil resistance force to the cutting, depending on the width of the cut, on the axis of rotation of the geokhod ($P_{0.CV}$) in the range from 0 to *x*, will be equal to the projection of the component of the soil resistance force of cutting, depending on the width of the cut, on the plane perpendicular to the axis of rotation of the boat ($R_{IO.CV}$) in the range from *x* to R_g, i.e.

$$\int_0^x P_{o.cv}dx = \int_x^{R_g} R_{i.o.cv}dx \; ; \quad (19)$$

2) At what *x*, the projection of the component of the soil resistance force to the cutting, depending on the width of the cut, on the axis of rotation of the geokhod ($P_{0.CV}$) in the range from 0 to *x*, will be equal to the projection of the component of the soil resistance force of cutting, on the axis of rotation of the geodatabase ($P_{0.CV}$) in the range from *x* to R_g, i.e.

$$\int_0^x P_{o.cv}dx = \int_x^{R_g} P_{o.cv}dx \; ; \quad (20)$$

3) At what *x* the projection of the component of the soil resistance force of cutting, depending on the width of the cut, on the plane perpendicular to the axis of rotation of the geodatabase ($P_{0.CV}$) in the range from 0 to *x*, will be equal to the projection of the component of the soil resistance force of cutting, in the plane perpendicular to the axis of rotation of the geodatabase ($R_{IO.CV}$) in the range from *x* to R_g, i.e.

$$\int_0^x R_{i.o.cv}dx = \int_x^{R_g} R_{i.o.cv}dx \; ; \quad (21)$$

4) At what *x*, the resultant force of the projection of the component of the co-resistivity of the cutting force, depending on the width of the cut, on the axis of rotation of the geokhod ($P_{0.CV}$) and the projection of the component of the ground resistance force of cutting, depending on the width of the cut, on a plane perpendicular to the axis of rotation ($R_{IO.CV}$) in the range from 0 to *x*, will be equal to the equal-acting force of the component of the soil resistance force of cutting, depending on the width of the cut, on the axis of rotation of the geodatabase ($P_{0.CV}$) and the projection of the component of the soil resistance force to cutting, depending on breadth s slice, on a plane perpendicular to the axis of rotation of the geokhod ($R_{IO.CV}$) in the range from *x* to R_g, i.e.

$$\int_0^x R_{cv}dx = \int_x^{R_g} R_{cv}dx \; ; \quad (22)$$

Results

The projection of the component of the soil resistance force to cutting, depending on the width of the cut, on the axis of rotation of the geodatabase ($P_{0.CV}$) in the range from 0 to *x*

$$P_{o.cv} = \frac{\varphi m_{cv} h_в^2 + h_в n P_{wear}}{2\pi n \cos\gamma} \cdot \left(\ln \frac{tg\left|\frac{\beta_x}{2}\right|}{tg\left|\frac{\beta_1}{2}\right|} \right) - \tag{24}$$

$$- \frac{h_в}{2\pi} \left(\varphi m_{cv} \frac{h_в}{n} \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} - \frac{ctg(\delta_1 + \varphi_{fr})}{\cos\gamma} P_{wear} \right) \frac{\sin\beta_2 - \sin\beta_x}{\sin\beta_x \sin\beta_2}$$

The projection of the component of the soil resistance force to cutting, depending on the width of the cut, on a plane perpendicular to the axis of rotation of the boat ($R_{IO.CV}$) in the range from 0 to x

$$R_{i.o.cv} = \frac{\varphi m_{cv} h_в^2 + h_в n P_{wear}}{2\pi n \cos\gamma} \cdot \frac{1 - \sin\beta_x}{\sin\beta_x} +$$

$$+ \frac{h_в}{2\pi} \left(\varphi m_{cv} \frac{h_в}{n} \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} - \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} P_{wear} \right) \cdot \left(\ln \frac{1}{tg\left|\frac{\beta_x}{2}\right|} \right) \tag{25}$$

The projection of the component of the ground resistance force to cutting, depending on the width of the cut, on a plane perpendicular to the axis of rotation of the boat ($R_{IO.CV}$) in the range from x to R_g

$$R_{i.o.cv} = \frac{\varphi m_{cv} h_в^2 + h_в n P_{wear}}{2\pi n \cos\gamma} \cdot \frac{\sin\beta_x - \sin\beta_1}{\sin\beta_1 \sin\beta_x} +$$

$$+ \frac{h_в}{2\pi} \left(\varphi m_{cv} \frac{h_в}{n} \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} - \frac{ctg(\delta + \varphi_{fr})}{\cos\gamma} P_{wear} \right) \cdot \left(\ln \frac{tg\left|\frac{\beta_x}{2}\right|}{tg\left|\frac{\beta_1}{2}\right|} \right) \tag{26}$$

Conclusion

For further research it is necessary:

- to determine the meaning of the characteristic bending points of the blade operating body of the geokhod;
- to determine the influence of soil properties on the characteristic points of bending;
- to determine the effect of the parameters of the geokhod on the characteristic points of bending.

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