Determination of external impacts on the bearing unit of the geokhod

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Abstract. The mathematical model of interaction of the bearing unit of the geokhod with geoenvironment and related systems was developed. The model takes into account the variability of the bearing unit of the geokhod and opens up the possibilities for further determining the inter-actions of the elements of the bearing unit of the geokhod with each other.

1. Introduction
Designing new mining machines is an urgent task [1–6]. When designing new mining machines it is necessary to create mathematical models [7–12]. The geokhod is a tunneling shield that implements movement in the rock mass due to interaction with the system of spiral contour channels formed by it [13]. The geokhod is a new class of mining equipment, as a result a number of difficulties arise in its design and manufacture. Creation of mathematical models of interaction of systems of the geokhod with each other is an actual problem [14–20]. To justify the design parameters of the bearing unit of the geokhod, it is necessary to determine the nature of external influences and internal interactions of the bearing unit of the geokhod.

2. Materials and methods
Considers two variants for the layout of the bearing unit. The shell of the bearing unit can be paired with the head section of the geokhod (figure 1, a) and carry out rotational and translational motion with it. Or it can be paired with a stabilizing section of the geokhod (figure 1, b) and carry with it only the translational motion.
Figure 1. Variants for the layout of the bearing unit of the geokhod: a) the shell of the bearing unit paired with the head section b) the shell of the bearing unit paired with the stabilizing section.

The calculation scheme of external forces acting on the shell of the geokhod was compiled (figure 2). The symbols used in the scheme are shown in table 1.

In the first variant, the friction force of the bearing unit of the geokhod against rock is directed along the line of location of the helical blade of the geokhod. It is named as $T_{FB}$ (var a). In the second variant, the friction force of the bearing unit of the geokhod against rock is directed along a path of movement of geokhod. It is named as $T_{FB}$ (var b).

Figure 2. Calculation scheme of geokhod propel efforts.
### Table 1. Legend to calculation scheme (figure 2).

| Symbol | Unit of measure | Name |
|--------|-----------------|------|
| $F_{PF}$ | [N] | Screw propeller Pulling force |
| $P_{PH}$ | [N] | Normal component of rock pressure on the head section |
| $P_{PS}$ | [N] | Normal component of rock pressure on the stabilizing section |
| $P_{PB}$ | [N] | Normal component of rock pressure on the bearing unit of the geokhod |
| $R_T$ | [N] | Total cutting resistance projection on sections axis of rotation |
| $R_{HB}$ | [N] | Reaction of contour rocks on the helical blade |
| $R_{WBHB}$ | [N] | Reaction of contour rocks on the helical blade working body |
| $R_{WBCTR}$ | [N] | Reaction of contour rocks on the counter-rotation elements working body |
| $T_{HB}$ | [N] | Helical blade friction against rock |
| $T_{CTR}$ | [N] | Total friction force of stabilizing section counter-rotation elements against rock |
| $T_{FH}$ | [N] | Total force of the head section shell friction against rock |
| $T_{FB}$ | [N] | Total force of the bearing unit of the geokhod shell friction against rock |
| $T_{FS}$ | [N] | Total force of the stabilizing section shell friction against rock |
| $M_{WB}$ | [N · m] | Moment of cutting resistance on the main working body |
| $M_{WBHB}$ | [N · m] | Moment of cutting resistance on the helical blade working body |
| $M_{WBCTR}$ | [N · m] | Moment of cutting resistance on the counter-rotation elements working body |
| $M_{BR}$ | [N · m] | Moment of broken rocks shift up from the geokhod bottom |
| $G_{H}$ | [N] | Weight of the head section with executive bodies, loading devices and other equipment |
| $G_{BU}$ | [N] | Weight of the bearing unit of the geokhod with loading devices and other equipment |
| $G_{ST}$ | [N] | Weight of the stabilizing section with loading devices and other equipment |
| $G_{BR}$ | [N] | Weight of broken rock mass inside the unit |
| $G_{TRM}$ | [N] | Weight of transported rock mass inside the unit |
| $r_{H} = r_{ST}$ | [m] | Head and stabilizing sections radiuses |
| $h_{HB}$ | [m] | Helical blade height |
| $h_{CTR}$ | [m] | Counter-rotation elements height |
| $\alpha$ | [degrees] | Mine working gradient angle |
| $\beta$ | [degrees] | Helical blade angle |
| $\omega$ | [sec^{-1}] | Angular rotating velocity of geokhod head section |
The geokhod was considered as a solid body, which under the influence of external forces is in equilibrium. The section method was applied to the compiled calculation scheme. Cross-section of the geokhod on planes $a-a$ and $b-b$ was made. Received three parts of the calculation scheme. They were named: the head part of the calculation scheme (figure 3); the tail part of the calculation scheme (figure 4); the middle part of the calculation scheme (figure 5).

![Figure 3. The head part of the calculation scheme.](image)

3. Results and discussion

On the head part of the calculation scheme (figure 3) introduced a countervailing forces $R_{HX}$, $R_{HY}$, $R_{HZ}$ and countervailing moments of forces $M_{HX}$, $M_{HY}$, $M_{HZ}$.

The following assumptions and limitations were made:

– the force manifestation of the rock pressure is uniformly distributed over the shell of the geokhod;

– shell of geokhod has absolute rigidity;

– geokhod carries out absolutely rectilinear movement with an arbitrary mine working gradient angle. Therefore $R_{HZ}=0$, $M_{HY}=0$, $M_{HZ}=0$.

Was drawn up the system of equations:

\[
\begin{align*}
F_{PF} - R_T - R_{WBHB} \cdot \cos \beta - (G_H + G_{BR}) \cdot \sin \alpha - T_{HB} \cdot \sin \beta - T_{FH} \cdot \sin \beta - R_{HX} &= 0 \\
M_{WB} - M_{WBHB} \cdot \cos \beta - M_{BR} - T_{HB} \cdot \left( r_H + \frac{h_{HB}}{2} \right) \cdot \cos \beta - R_{RA} \cdot \left( r_H + \frac{h_{CTR}}{2} \right) \cdot \sin \beta - T_{FH} \cdot r_H \cdot \cos \beta + M_{HX} &= 0 \\
R_{WBHB} \cdot \sin \beta - T_{HB} \cdot \cos \beta - (G_H + G_{BR}) \cdot \cos \alpha - T_{FH} \cdot \cos \beta - R_{HB} \cdot \sin \beta - R_{HY} &= 0
\end{align*}
\]

(1)

The values $T_{HB}$ и $F_T$ are equal:

\[
T_{HB} = |R_{HB}| \cdot f_{FR}
\]

(2)

\[
F_{PF} = R_{HB} \cdot \cos \beta ,
\]

(3)

where $f_{FR}$ – coefficient of friction of steel against rock.
Then the system of equations (1) took the form:

\[
\begin{align*}
R_{HB} \cdot \cos \beta \cdot (1 - f_{FR} \cdot \tan \beta) &- R_T - R_{WBHB} \cdot \cos \beta - (G_H + G_{BR}) \cdot \sin \alpha - T_{FH} \cdot \sin \beta - R_{HX} = 0 \\
M_{WB} - M_{WBHB} \cdot \cos \beta - M_{BR} - R_{HB} \cdot \left( r_H + \frac{h_{HB}}{2} \right) \cdot \cos \beta \cdot (f_{FR} + \tan \beta) &= -T_{FH} \cdot r_H \cdot \cos \beta + M_{HX} = 0 \\
R_{WBHB} \cdot \sin \beta - R_{HB} \cdot f_{FR} \cdot \cos \beta - (G_H + G_{BR}) \cdot \cos \alpha - T_{FH} \cdot \cos \beta - R_{HB} \cdot \sin \beta - R_{HY} = 0
\end{align*}
\]  

(4)

Values $R_{HX}$, $R_{HY}$, $M_{HX}$ were obtained from equations of system (4):

\[
\begin{align*}
R_{HX} &= R_{HB} \cdot \cos \beta \cdot (f_{FR} \cdot \tan \beta - 1) + R_T + R_{WBHB} \cdot \cos \beta + (G_H + G_{BR}) \cdot \sin \alpha + T_{FH} \cdot \sin \beta \\
R_{HY} &= R_{WBHB} \cdot \sin \beta - R_{HB} \cdot f_{FR} \cdot \cos \beta - (G_H + G_{BR}) \cdot \cos \alpha - T_{FH} \cdot \cos \beta - R_{HB} \cdot \sin \beta \\
M_{HX} &= -M_{WB} + M_{WBHB} \cdot \cos \beta + M_{BR} + R_{HB} \cdot \left( r_H + \frac{h_{HB}}{2} \right) \cdot \cos \beta \cdot (f_{FR} + \tan \beta) + T_{FH} \cdot r_H \cdot \cos \beta
\end{align*}
\]  

In expressions (5–7) unknown is $R_{HB}$. We introduce constants independent of the unknown $R_{HB}$

\[
\begin{align*}
R_1 &= R_T + R_{WBHB} \cdot \cos \beta + (G_H + G_{BR}) \cdot \sin \alpha + T_{FH} \cdot \sin \beta \\
M_1 &= -M_{WB} + M_{WBHB} \cdot \cos \beta + M_{BR} + T_{FH} \cdot r_H \cdot \cos \beta \\
R_2 &= R_{WBHB} \cdot \sin \beta - (G_H + G_{BR}) \cdot \cos \alpha - T_{FH} \cdot \cos \beta
\end{align*}
\]  

Then the expression (5–7) took the form:

\[
R_{HX} = R_{HB} \cdot \cos \beta \cdot (f_{FR} \cdot \tan \beta - 1) + R_1
\]  

(11)

Figure 4. The tail part of the calculation scheme.
On the tail part of the calculation scheme (figure 4) introduced a countervailing forces $R_{TX}, R_{TY}, R_{TZ}$ and countervailing moments of forces $M_{TX}, M_{TY}, M_{TZ}$.

Was drawn up the system of equations:

\[
\begin{align*}
R_{TX} - T_{FS} - (G_{ST} + G_{TRM}) \cdot \sin \alpha - T_{CTR} - R_{WBCTR} &= 0 \\
M_{WBCTR} + R_{CTR} \cdot \left(r_h + \frac{h_{CTR}}{2}\right) - M_{TX} &= 0 \\
R_{TY} - (G_{H} + G_{TRM}) \cdot \cos \alpha &= 0
\end{align*}
\]  

The value $T_{CTR}$ is equal:

\[
T_{CTR} = \frac{M_{ROT}}{r_h + \frac{h_{CTR}}{2}} \cdot f_{FR},
\]

where $M_{ROT}$ – desired torque of the geokhod transmission, [N\cdot m].

Then the system of equations (14) took the form:

\[
\begin{align*}
R_{TX} - T_{FS} - (G_{ST} + G_{TRM}) \cdot \sin \alpha - M_{ROT} \cdot \left(r_h + \frac{h_{CTR}}{2}\right) \cdot f_{FR} - R_{WBCTR} &= 0 \\
M_{WBCTR} + R_{CTR} \cdot \left(r_h + \frac{h_{CTR}}{2}\right) - M_{TX} &= 0 \\
R_{TY} - (G_{H} + G_{TRM}) \cdot \cos \alpha &= 0
\end{align*}
\]  

Values $R_{TX}, R_{TY}, M_{TX}$ were obtained from equations of system (16):

\[
\begin{align*}
R_{TX} &= T_{FS} + (G_{ST} + G_{TRM}) \cdot \sin \alpha + \frac{M_{ROT}}{r_h + \frac{h_{CTR}}{2}} \cdot f_{FR} + R_{WBCTR} \\
R_{TY} &= (G_{H} + G_{TRM}) \cdot \cos \alpha \\
M_{TX} &= M_{WBCTR} + R_{CTR} \cdot \left(r_h + \frac{h_{CTR}}{2}\right)
\end{align*}
\]

In expressions (17–19) unknown are $R_{CTR}$ and $M_{ROT}$. We introduce constants independent of the unknown $R_{CTR}$ and $M_{ROT}$. 

\[
M_{hX} = R_{HB} \cdot \left(r_h + \frac{h_{HB}}{2}\right) \cdot \cos \beta \cdot (f_{FR} + tg\beta) + M_i
\]

\[
R_{HV} = R_2 - R_{HB} \cdot \cos \beta \cdot (f_{FR} - tg\beta)
\]
\[ R_3 = T_{FS} + (G_{ST} + G_{TRM}) \cdot \sin \alpha + R_{WBCTR} \]  
\[ R_4 = r_H + \frac{h_{CTR}}{2} \]  

Then the expression (17, 19) took the form:

\[ R_{TX} = R_3 + \frac{f_{FR}}{R_4} \cdot M_{ROT} \]  
\[ M_{TX} = M_{WBCTR} + R_4 \cdot R_{CTR} \]  

Consider the middle part of the calculation scheme (figure 5).

\[ \begin{align*} 
0 & = -F_{BBUTY} \times H_{HY} - G_{BU} \cdot \sin \alpha - T_{FB} \cdot \sin \beta \\
0 & = -M_{BBUTX} \times H_{HX} - M_{HY} \cdot r_H \cdot \cos \beta \\
0 & = R_{HY} - R_{TX} - G_{BL} \cdot \cos \alpha - T_{FB} \cdot \cos \beta \end{align*} \]  

\[ \text{Taking into account the expressions (11–13, 18, 22, 23), the system of equations (24) took the form:} \]
\[
\begin{align*}
R_{HB} \cdot \cos \beta \cdot (f_{FR} \cdot \tan \beta - 1) + R_i - R_3 - \frac{f_{FR}}{R_4} \cdot M_{ROT} - G_{BU} \cdot \sin \alpha - T_{FB} \cdot \sin \beta &= 0 \\
M_{WCTR} + R_4 \cdot R_{CTR} - R_{HB} \cdot \left( r_H + \frac{h_{HB}}{2} \right) \cdot \cos \beta \cdot (f_{FR} + \tan \beta) - M_1 - T_{FB} \cdot r_H \cdot \cos \beta &= 0 \\
R_2 - R_{HB} \cdot \cos \beta \cdot (f_{FR} - \tan \beta) - \left( G_{HH} + G_{TRM} \right) \cdot \cos \alpha - G_{BU} \cdot \cos \alpha - T_{FB} \cdot \cos \beta &= 0
\end{align*}
\]

We introduce constants independent of the unknown \(R_{HB}, R_{CTR}\) and \(M_{ROT}\):

\[
\begin{align*}
R_i &= R_i - R_3 - G_{BU} \cdot \sin \alpha - T_{FB} \cdot \sin \beta \\
R_6 &= R_2 - \left( G_{HH} + G_{TRM} \right) \cdot \cos \alpha - G_{BU} \cdot \cos \alpha - T_{FB} \cdot \cos \beta \\
M_2 &= M_{WCTR} - M_1 - T_{FB} \cdot r_H \cdot \cos \beta
\end{align*}
\]

Find the unknown \(R_{HB}, R_{CTR}\) and \(M_{ROT}\):

\[
\begin{align*}
R_{HB} &= \frac{R_6}{\cos \beta \cdot (f_{FR} - \tan \beta)} \\
R_{CTR} &= \frac{R_6 \cdot \left( r_H + \frac{h_{HB}}{2} \right) \cdot \left( f_{FR} + \tan \beta \right)}{f_{FR} - \tan \beta} - M_2 \cdot \frac{1}{R_4} \\
M_{ROT} &= \frac{R_6 \cdot \left( f_{FR} \cdot \tan \beta - 1 \right) + R_5}{f_{FR}} \cdot \frac{R_4}{\cos \beta \cdot (f_{FR} - \tan \beta)}
\end{align*}
\]

Consider the second variant of the configuration of the bearing unit of the geokhod. Was drawn up the system of equations:

\[
\begin{align*}
R_{HX} - R_{TX} - G_{BU} \cdot \sin \alpha - T_{FB} &= 0 \\
M_{TX} - M_{HX} &= 0 \\
R_{HY} - R_{TY} - G_{BU} \cdot \cos \alpha &= 0
\end{align*}
\]

The system of equations (32) was solved similarly to the solution of the system (24). Unknown were named \(R'_{HB}, R'_{CTR}\) and \(M'_{ROT}\):

\[
\begin{align*}
R'_{HB} &= \frac{R_6 + T_{FB} \cdot \cos \beta}{\cos \beta \cdot (f_{FR} - \tan \beta)}
\end{align*}
\]
\[
R'_{CTR} = \left[ \frac{(R_c + T_{FB} \cdot \cos \beta) \left( r_H + \frac{h_{HFB}}{2} \right) \cdot (f_{FB} + \tan \beta)}{f_{FB} - \tan \beta} - M_z - T_{FB} \cdot r_H \cdot \cos \beta \right] \cdot \frac{1}{R_z} \tag{34}
\]

\[
M'_{ROT} = \left[ \frac{(R_c + T_{FB} \cdot \cos \beta) \cdot (f_{FB} \cdot \tan \beta - 1)}{f_{FB} - \tan \beta} + R_z + T_{FB} \cdot (\sin \beta - 1) \right] \cdot \frac{R_z}{f_{FR}} \tag{35}
\]

4. Conclusion

The expressions obtained are the mathematical model of the interaction of the bearing unit with the rock mass and another systems of geokhod.

The results obtained will allow:

- to carry out a comparative analysis of different layouts of the bearing unit of the geokhod;
- define internal interactions of the bearing unit of the geokhod.

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