Kinematic parameters of the device for cleaning the excavator bucket

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Abstract. This article discusses the use of a mechanical method of combating soil adhesion to an excavator bucket. Experience in the operation of earthmoving machines shows that when developing wet soils (especially at freezing temperatures), freezing and sticking of soil to working bodies significantly reduces machine performance. The analysis of devices designed for mechanical cleaning of the excavator bucket was carried out, the most effective equipment design was also selected hydraulic excavator, eliminating the disadvantages of other models. According to the technical task, the working body in Compass-3D was designed, angles, speed of movement of the hydraulic cylinder relative to the handle of the excavator and the force on the cutting edge of the bucket were calculated.

1. Introduction
Analysis and generalization of domestic and foreign practice of conducting massive earthworks and open cast mining have shown that the currently used and proposed tools for combating adhesion and freezing of soil to earthmoving equipment buckets can be divided into preventive measures by the nature and principle of action (prevention of adhesion) and bucket cleaning products (restoration of soil evacuation ability) [1-7].

2. Formulation of the problem and method of solution
One of the methods to combat soil adhesion is the mechanical method. Currently, a number of technical solutions are known for cleaning the excavator bucket from adhering and frozen soil.

In the process of patent search and subsequent analysis of the working bodies intended for cleaning the excavator bucket, the most optimal design of the hydraulic excavator equipment [3] was found, which allows cleaning the excavator bucket.
Figure 1. The working body of the excavator in Compass-3D.

In the Compass-3D environment, working equipment was designed (figure 1). The angles, speeds of movement of the hydraulic cylinder relative to the handle of the excavator and the force on the cutting edge of the bucket according to the scheme shown in figure 2 according to the methodology [8] are also calculated.

3. Results and discussion

Initially should be asked $\angle A_3A_4C_4$, presenting the relationship of variable parameters $[l_3 + (l_0 + z) - l_6]_3$ and $S_1$ (figure 2.2), for example, the formula:

$$S_1 = \sqrt{a_3^2 + b_5^2 + \frac{a_5}{a_6}[a_6^2 + b_5^2 - a_5^2 - b_4^2 + 2a_{34}b_4 \cos(\angle A_3A_4C_4)],} \quad (1)$$

derived from a joint consideration of triangles $\triangle A_3A_4C_4$, $\triangle D_3A_3C_4$ and $\triangle S_3A_3C_3$ with a straight link $C_3D_3C_4$.

The angle $\angle B_3A_3C_3$ is determined from triangles $\triangle A_3A_4C_4$, $\triangle D_3A_3C_4$, $\triangle C_3A_3D_3$, and $\triangle B_3A_3C_3$

$$\angle B_3A_3C_3 = (\pi - \phi_6 - \angle A_4A_3D_3) - \arccos\left(\frac{S_2^2 + b_5^2 - a_6^2}{2S_2b_5}\right) \quad (2)$$

Angle in last expression $\angle A_4A_3D_3$ lever rotation 3 (figure 2.1) regarding p.A3 found by the formula

$$\angle A_4A_3D_3 = \arccos\left(\frac{S_2^2 + a_{34}^2 - b_5^2}{2S_2a_{34}}\right) + \arccos\left(\frac{S_2^2 + b_5^2 - a_6^2}{2S_2b_5}\right) \quad (3)$$

Where is the geometric characteristic $S_2$(figure 2) determined by

$$S_2 = \sqrt{a_{34}^2 + b_4^2 - 2a_{34}b_4 \cos(\angle A_3A_4C_4)} \quad (4)$$
Figure 3 shows the change in angle $<A_3A_4C_4$ and $<A_4A_3D_3$ when moving the rod of the hydraulic cylinder.

Having obtained the necessary relationships, we will finally describe the kinematics of the drive under study.

The friction angles $<A_3B_3C_3$ and $<A_3C_3B_3$ in the bearings of the housing and the rod of the hydraulic cylinder are determined respectively from the expressions:

\[
< A_3B_3C_3 = \arccos \left( \frac{[l_3+(l_0+z)-l_6]^2-S_3^2+C_3^2}{2S_3[1+(l_0+z)-l_6]} \right) \\
< A_3C_3B_3 = \arccos \left( \frac{[S_3^2+l_3+(l_0+z)-l_6]^2-C_3^2}{2S_3[1+(l_0+z)-l_6]} \right)
\]

(5) (6)

Figure 3. The graph of angle change $<A_3A_4C_4$ and $<A_4A_3D_3$ when moving the rod of the hydraulic cylinder.

The friction angle $<B_3A_3C_3$ in a simplified form, in addition to expression (2), can be found by the formula

\[
< B_3A_3C_3 = \arccos \left( \frac{S_3^2+C_3^2-[l_3+(l_0+z)-l_6]^2}{2S_3C_3} \right) = \pi-< A_3B_3C_3-< A_3C_3B_3
\]

(7)

The hydraulic cylinder turning speeds relative to its mounting supports are found for instantaneous $z = \text{const}$ from the equalities:

\[
\frac{d}{dt} (\angle A_3B_3C_3) = -z \frac{S_3}{C_3[1+(l_0+z)-l_6]} \sin(\angle A_3B_3C_3)
\]

(8)

\[
\frac{d}{dt} (\angle A_3C_3B_3+\angle A_3C_3D_3) = \frac{d}{dt} (\angle A_3C_3B_3) + \frac{d}{dt} (\angle A_3C_3D_3) = -z \frac{C_3}{[1+(l_0+z)-l_6]} \sin(\angle A_3B_3C_3) - \frac{1}{\sin(\angle A_3C_3D_3)}
\]

(9)

Friction speeds in p.A3 and p.D3 can be described as follows:

\[
\frac{d}{dt} (\angle B_3A_3D_3) = \frac{d}{dt} (\angle B_3A_3C_3+\angle C_3A_3D_3) = \frac{d}{dt} (\angle B_3A_3C_3) + \frac{d}{dt} (\angle C_3A_3D_3) = \frac{z}{S_3C_4} (\sin(\angle B_3A_3C_3+\angle C_3A_3D_3)) \times \frac{[l_3+(l_0+z)-l_6]^2-S_3^2+C_3^2-2S_3[1+(l_0+z)-l_6]C_3 \sin(\angle A_3B_3C_3)+a_3^2+b_3^2]}{2S_3[1+(l_0+z)-l_6]^2+C_3^2-2S_3[1+(l_0+z)-l_6] \sin(\angle A_3B_3C_3)}
\]

(10)

\[
\frac{d}{dt} (\angle A_3D_3C_3) = \frac{z}{a_3b_3} \sin(\angle A_3D_3C_3)
\]

(11)
Missing angles included in the equations (9), (10) and (11) are defined as follows:

\[
< A_3 C_3 D_3 = \arccos \left\{ \frac{S_2^2 + a_5^2 - b_5^2}{2S_1a_5} \right\}; \quad (12)
\]

\[
< A_3 D_3 C_3 = \arccos \left\{ \frac{a_5^2 + b_5^2 - S_1^2}{2ab_5} \right\}; \quad (13)
\]

\[
< C_3 A_3 D_3 = \arccos \left\{ \frac{S_2^2 + b_5^2 - a_5^2}{2S_1b_5} \right\}; \quad (14)
\]

Finally, the speed of rotation of the bucket of an unconventional drive is advisable to write:

\[
\frac{d}{dt}(< A_3 A_4 C_4 + < A_3 C_3 D_3) = \frac{d}{dt}(< B_3 A_3 D_3) \times \left\{ \begin{array}{l}
\frac{b_5 \sin (\pi - (\phi_6 + < C_3 A_3 D_3 + < B_3 A_3 C_3)) - \arccos \left\{ \frac{a_6^2 - b_4^2 + a_3^2 b_4^2 + 2a_3 b_4 \cos(\phi_6 + < C_3 A_3 D_3 + < B_3 A_3 C_3)}{2a_6 a_3^2 + b_4^2 + 2a_3 b_4 \cos(\phi_6 + < C_3 A_3 D_3 + < B_3 A_3 C_3)} \right\} - \arctg \left\{ \frac{-b_5 \sin(\phi_6 + < C_3 A_3 D_3 + < B_3 A_3 C_3)}{b_5 \cos(\phi_6 + < C_3 A_3 D_3 + < B_3 A_3 C_3)} \right\}} \right.
\end{array} \right. \times \left( \begin{array}{l}
\frac{b_4 \sin(\arccos \left\{ \frac{a_6^2 - b_4^2 - a_3^2 - b_4^2 - 2a_3 b_4 \cos(\phi_6 + < C_3 A_3 D_3 + < B_3 A_3 C_3)}{2a_6 a_3^2 + b_4^2 + 2a_3 b_4 \cos(\phi_6 + < C_3 A_3 D_3 + < B_3 A_3 C_3)} \right\})}{-1}
\end{array} \right) \quad (15)
\]

Figure 4. The graph of the speed of movement of the hydraulic cylinder relative to the handle of the excavator.

Figure 4 shows the speed of movement of the hydraulic cylinder relative to the handle of the excavator, which must be paid attention to when determining dynamic loads.

\[
P_3 = -\frac{\pi}{4} [D_1^2 p_1 - (D_1^2 - D_2^2) p_2] K_K \times \frac{b_5}{C_5} \cos(< B_3 C_3 D_3) \sin(< A_4 C_4 D_3) \quad (16)
\]
where: $D_1:D_2$ – respectively, the diameter of the piston and rod of the hydraulic cylinder; $p_1: p_2$ – accordingly, the pressure of the working fluid in its piston and rod cavities; $K_e$ – mechanical efficiency hydraulic cylinder

The angles included in equality (16) are defined as follows:

$$< B_3C_3D_3 =< A_3C_3B_3 + A_3C_3D_3;$$

(17)

$$< A_4C_4D_3 = \arccos \left[ \frac{a_6^2+b_4^2-a_3^2-b_5^2-2a_3b_5 \cos (\phi_6+<C_3A_3D_3+<B_3A_3C_3)}{2a_4b_4} \right]$$

(18)

Figure 5 shows a graph of the force on the cutting edge of the bucket, figure 6 shows a graph of the change in the angle of friction in the rod support and the cylinder body.

Figure 5. The graph of force on the working edge of the bucket.

Figure 6. Friction angle in the rod support and hydraulic cylinder housing.
4. Conclusion
A kinematic analysis of the most effective design of the device intended for mechanical cleaning of the excavator bucket was carried out. According to the proposed technical solution, the working body in Compass-3D was designed, and the angles, the speeds of the hydraulic cylinder relative to the handle of the excavator and the force on the cutting edge of the bucket were calculated.

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