The equation of the oscillatory motion of the blade of the earth-moving machine depending on the properties of the ground and the parameters of the blade

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Abstract. The influence of the design parameters and technological properties of the ground on the nature of the oscillatory movement of the blade of the working body of the earth-moving machine is investigated.

The purpose of the study is to identify the force factors of the interaction of the oscillatory working body of the earth -moving machine with the ground and determine its optimal parameters.

The equation of the oscillatory motion of the blade of the working body of the earth-moving machine depending on its design parameters and technological properties of the ground is obtained.

The results can be used in the development and determination of the optimal design parameters of the working bodies of earth-moving machines.

Keywords: working body, oscillatory motion, knife, ground moving.

1 Introduction

You can increase the productivity of earth-moving machines by increasing the engine power and traction force. Another direction of increasing the productivity of these types of machines is to improve the scheme and design of their working bodies. This will allow, without increasing the power and traction of these types of machines, to increase its productivity by reducing the resistance of the ground to the working body of the earth-moving machine [1-4].

When carrying out earth-moving operations in order to reduce the resistance of the ground to the working bodies of machines, other methods can also be used. For example, based on the use of vibrations or vibrations of the working body of machines (active working bodies), as well as a shock or explosion [5].

Vibration organs include those working bodies on which vibration sources are installed, which inform the working body of vibrations of a certain frequency and in a certain direction. The resulting pulse load destroys the ground, thereby reducing the resistance of the working body, and therefore the machine [6, 7].

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In earth-moving machines with blade and dump working bodies, vibration is usually transmitted to the dump or blade of the working body of the machine.

The disadvantage of vibrating working bodies of earth-moving machines is the complexity of the design, and sometimes a higher total energy consumption [8].

In this regard, the working bodies of machines are relevant, in which the oscillatory movement of the blade or cutting edge occurs due to the heterogeneity of the ground structure. Due to the heterogeneity of the ground structure, the resistance forces to the working body of the machine will also be variable. As a result, when interacting with the ground, there is a self-oscillating movement of the working body. Self-oscillating working bodies, unlike working bodies with an active drive, do not require energy supply, therefore, they have a simpler design and lower energy consumption. At the same time, they have all the advantages of working bodies with an active drive [9-11].

The purpose of the study is to determine the influence of the technological properties of the ground and the design parameters of the blade of the working body of the earth-moving machine on the nature of its oscillatory movement.

2 Methods

The scheme of the proposed self-oscillating working body of the earth-moving machine in the plan is shown in Fig. 1. The angle in the plan between the direction of movement and the line of the cutting edge of the blade when working is γ_0 . The blade has the ability to rotate around the vertical axis OZ , passing through the tip of the blade (hinge A) and perpendicular to the plane of the drawing. Also, the blade 1 is spring-loaded with a spring 3, which also in a special case can be made in the form of a torsion shaft also passing through the OZ axis.

Fig. 1. Diagram of the forces acting on the blade of the working body.

Having considered the process of interaction of the blade of the working body with the ground and determining the influence of its parameters on the parameters of self-oscillatory motion, we can describe the equation of its oscillatory motion.

When obtaining the equation, you can consider two options for attaching a blade that performs an oscillatory movement. The first option – the axis of rotation of the blade passes through the leftmost tip of the cutting edge of the blade, as shown in Fig. 1. The second option – the axis of rotation of the blade is located at some distance from the line of the cutting edge of the blade. In this study, we will consider the first option.

In this paper, the oscillatory motion of the blade of the working body relative to the vertical axis OZ , which also performs translational motion in the ground at a speed of V_e , is theoretically investigated (Fig. 1).

Also, Fig. 1 shows the forces acting on the blade of the working body. The cutting edge 1 is limited from turning by the spring 3 interacting through the lever 2. In Fig. 1, the force R , is the horizontal projection of the main vector of the ground resistance force on the direction of the forward movement of the blade. The moment M_R of the force R is balanced by the moment M_C , the force P_C , acting on the blade lever from the side of the spring 2.

3 Results and discussion

The above diagram of the blade attachment requires the use of a spring 3 with high rigidity to balance the moment M_C . In this case, the self-oscillating system will have a high natural frequency of oscillations, determined by the formula:

$$\omega_0 = \frac{1}{2\pi} \sqrt{\frac{c}{J}} \quad (1)$$

where c is the torsional rigidity of the blade turning system, H m/rad; J is the moment of inertia of the blade with the axis and lever relative to the vertical axis OZ , $\text{kg} \cdot \text{m}^2$.

With the forward movement of the working body, under the action of the constant component of the resistance, the blade will be set at an angle γ_0 , at which the moments M_R and M_C are mutually balanced. When the ground resistance changes, therefore, the value of M_R , the blade 1 performs an oscillatory movement at a certain angle γ relative to the position with an angle γ_0 . The energy of the oscillatory motion decreases due to friction losses. However, the inconstancy of the ground resistance force leads to the constant occurrence of new vibrations with different amplitudes.

In this design, the frequency of natural vibrations of the working body can be adjusted by changing the torsional rigidity of the system. For example, changing the spring stiffness or using springs with different characteristics.

The blade is also affected by the moment M_D from the dissipative forces P_D of the ground, which counteracts the oscillatory movement of the blade. Then the oscillatory motion of the blade of the working body of the machine can be described by the following equation:

$$J\ddot{\gamma} = M_R + M_C + M_D \quad (2)$$

where M_D is the total moment of dissipative forces P_D .

The moment M_R of the force R is determined by the equation (Fig. 1):

$$M_R = R \frac{L}{2} \cos \varepsilon, \quad (3)$$

where L is the length of the cutting edge of the blade; ε is the angle of friction of the ground against the cutting edge of the blade during the translational movement of the working body.

The force R can be expressed by the formula:

$$R = \frac{R_Y}{\sin(\varepsilon + \gamma_0)} \quad (4)$$

where R_Y is the projection of the force R on the direction of movement of the working body; γ_0 is the angle in plan between the direction of translational movement of the working body and the line of the cutting edge of the blade, when M_R and M_C are mutually balanced and are respectively equal to M_R^0 and M_C^0 .

The force of R_Y is written in the following form [12]:

$$R_Y = k_0 B_0 = k_0 L \sin \gamma_0 \quad (5)$$

where k_0 is the specific resistance of the ground in the direction of movement of the working body, per unit width of the blade grip, N/m; B_0 is the width of the blade grip, when the angle between the direction of movement of the working body and the line of the cutting edge of the blade is γ_0 .

Substituting R_Y from equation (5) into (4), we obtain:

$$R = \frac{k_0 L \sin \gamma_0}{\sin(\varepsilon + \gamma_0)} \quad (6)$$

From equations (3) and (6), we obtain the following equation for determining M_R^0 :

$$M_R^0 = \frac{k_0 L^2 \cos \varepsilon \sin \gamma_0}{2 \sin(\varepsilon + \gamma_0)} \quad (7)$$

Given that when the angle between the direction of movement of the working body and the line of the cutting edge of the blade is γ_0 , then $M_R^0 = -M_C^0$, we write:

$$M_C^0 = -\frac{k_0 L^2 \cos \varepsilon \sin \gamma_0}{2 \sin(\varepsilon + \gamma_0)}. \quad (8)$$

When the blade moves forward, it performs a self-oscillatory movement, deviating from the angle γ_0 by a certain angle γ , then the moments M_R and M_C are determined by the equations:

$$M_R = \frac{k_0 L^2 \cos \varepsilon \sin(\gamma_0 + \gamma)}{2 \sin(\varepsilon + \gamma_0 + \gamma)} \quad (9)$$

$$M_C = -\frac{k_0 L^2 \cos \varepsilon \sin \gamma_0}{2 \sin(\varepsilon + \gamma_0)} + c\gamma \quad (10)$$

The energy loss of the oscillatory movement of the blade of the working body in the ground is determined, taking into account the dry, viscous and quadratic component of the friction force. The main moment of the dissipative friction forces is a quadratic dependence on the angular velocity and is directed against the direction of rotation of the blade [13-15]:

$$M_D = (b_1 m_1 \operatorname{sgn} \dot{\gamma} + \dot{\gamma} + b_3 m_3 \dot{\gamma}^2 \operatorname{sgn} \dot{\gamma}), \quad (11)$$

where b_1, b_2, b_3 are coefficients that depend on the properties of the soil and relate to the dry, viscous and quadratic components of the friction force, respectively; m_1, m_2, m_3 are coefficients determined by the design parameters of the working body; δ - the Kronecker function, respectively, having the values -1, 0, 1 at $\dot{\gamma} < 0, \dot{\gamma} = 0, \dot{\gamma} > 0$ [16, 17].

We determine the coefficients m_1, m_2, m_3 included in equation (11), which depend on the design parameters of the working body. The main part of the ground friction force on the working body of the machine acting on the blade, as is known, falls on its cutting edge. A much smaller part of the ground friction force affects the upper surface of the blade [18, 19].

Next, we write the formula (11) in the form:

$$M_D = (M_1 \operatorname{sgn} \dot{\gamma} + M_2 + M_3 \operatorname{sgn} \dot{\gamma}), \quad (12)$$

where M_1, M_2, M_3 are the moments of ground resistance relative to the axis of rotation of the blade, created by the forces of dry, viscous and quadratic friction.

Next, we define the moments M_1, M_2, M_3 in the form of integrals:

$$M_1 = b_1 \int_0^L l dl = b_1 \frac{L^2}{2} \quad (13)$$

$$M_2 = b_2 \int_0^L v_l l dl = b_2 \dot{\gamma} \int_0^L l^2 dl = b_2 \frac{L^3}{3} \dot{\gamma} \quad (14)$$

$$M_3 = b_3 \int_0^L v_l^2 l dl = b_3 \dot{\gamma}^2 \int_0^L l^3 dl = b_3 \frac{L^4}{4} \dot{\gamma}^2 \quad (15)$$

where l is the distance from the axis of rotation of the blade to the segment dl on the cutting edge of the blade; v_l is the speed of the segment of the cutting edge dl during the self-oscillating movement of the knife.

Then m_1, m_2, m_3 are determined by the following formulas:

$$m_1 = \frac{L^2}{2}; \quad m_2 = \frac{L^3}{3}; \quad m_3 = \frac{L^4}{4}. \quad (16)$$

After the transformations, the equation of the self-oscillating motion of the blade of the working body (2) will take the form:

$$J\ddot{\gamma} = \frac{k_0 L^2 \cos \varepsilon}{2} \left[\frac{\sin(\gamma_0 + \gamma)}{\sin(\varepsilon + \gamma_0 + \gamma)} - \frac{\sin \gamma_0}{\sin(\varepsilon + \gamma_0)} \right] + c\gamma - \left(b_1 \frac{L^2}{2} \operatorname{sgn} \dot{\gamma} + b_2 \frac{L^3}{3} \dot{\gamma} + b_3 \frac{L^4}{4} \dot{\gamma}^2 \operatorname{sgn} \dot{\gamma} \right) \quad (17)$$

or, by entering the appropriate notation, we get:

$$\ddot{\gamma} - A_0 \left[\frac{\sin(\gamma_0 + \gamma)}{\sin(\varepsilon + \gamma_0 + \gamma)} - \frac{\sin \gamma_0}{\sin(\varepsilon + \gamma_0)} \right] - A_c \gamma + A_2 \dot{\gamma} + (A_1 + A_3 \dot{\gamma}^2) \operatorname{sgn} \dot{\gamma} = 0 \quad (18)$$

$$\text{where } -A_0 = \frac{k_0 L^2 \cos \varepsilon}{2J}; \quad A_c = \frac{c}{J}; \quad A_1 = \frac{b_1 L^2}{2J}; \quad A_2 = \frac{b_2 L^3}{3J}; \quad A_3 = \frac{b_3 L^4}{4J}.$$

To determine the influence of the parameters of the working body on the nature of oscillations, equation (18) is numerically solved.

To solve these equations, it is necessary to determine the parameters that depend on the properties of the ground. The characteristics of the ground resistance were determined as a result of processing experimentally obtained vibrograms recorded during the movement of the working body with certain parameters in this ground.

The parameters of the working body and the properties of the ground affect such characteristics of the movement of the working body as the frequency and period of vibrations and the attenuation decrement.

The results of the calculations are shown in Figs 2 and 3 in the form of graphs. Fig. 2 shows the calculated vibrogram of the oscillatory motion of the working body having the parameters: $B_0 = 0,25\text{m}$, $\gamma_0 = 45^0$, $J = 0,04\text{kg} \cdot \text{m}^2$, $c = 45\text{H/m/grad}$.

Fig. 2. Vibrogram of the oscillatory movement of the working body.

Fig. 3. Graph of the dependence of the decrement of oscillations on the amplitude.

Fig. 3 shows a graph of the dependence of the decrement of vibrations of the working body on the amplitude of vibrations. As can be seen from the figure, the greater the amplitude of the oscillations, the greater the decrement of the oscillations. This relationship is directly proportional.

4 Conclusions

The equation (18) of motion of the blade of the working body of an earth-moving machine is obtained, depending on the technological properties of the soil and the design parameters of the self-oscillating working body. This equation can be used to determine the optimal parameters of the working bodies of earth-moving machines.

When determining the influence of the parameters of the working body and the ground on the nature of oscillatory movement of the blade, equation (18) is solved numerically.

As the solution of the resulting equation shows, the parameters of the working body and the properties of the soil affect such characteristics of the oscillatory motion as the frequency and period of vibrations, the decay decrement. At the same time, the greater the oscillation amplitude, the greater the attenuation decrement. This dependence is actually directly proportional.

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