THE ANALITICAL RESEARCH OF THE PROCESS OF FORMING THE MOTOR-GRADER MOTION PATH AT IMPLEMENTATION OF WORKING OPERATIONS

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Abstract: *Based on the analysis of the mathematical model of the motor grader movement in the process of implementation of working operations, the factors that have the greatest influence on formation of the machine's motion path are identified. It is proved that some of the factors characterizing the parameters of the machine and technological process have a destabilizing impact on the formation of the grader motion path, while the rest of them have a stabilizing impact. The analytical research enables developing practical recommendations to ensure the movement of the machine along a predetermined path without deviations.*

Keywords: ROAD-HOLDING ABILITY, PROCESS OF MOVEMENT, MOTOR-GRADER, MATHEMATICAL MODEL

1. Introduction

As a rule, motor-graders perform working operations in the process of which the main blade is positioned at the working angle different from 90 and with he tilt in the vertical plane. In this case at cutting the developed medium the formation of a cut layer of a triangular shape with the simultaneous dumping of the material to the side takes place. The main peculiarity of such operations is the displacement of the coordinate of application of the resultant resistance vector on the blade, which leads to an asymmetric loading of the machine [1]. The force action of this type can lead to the deviation of the machine form the predetermined motion path, which results in the deterioration of indicators of quality of the implemented working operations, a drop in the productivity of the machine, etc.

2. Analysis of publications

The asymmetric application of external loads to the working body, the action of lateral forces on the working attachment and undercarriage can lead to the deviation of the machine from the planned path of motion, interpreted as the loss of road-holing ability.

The lateral displacement is at a large degree is characteristic for machines with unevenly distributed load affecting the working attachment of agricultural machinery, earth-moving machines (EMM), etc.

Most of developments in this field are dedicated to the problem of the vehicle movement across the slope with its differential unlocked. The resulting redistribution of the vertical reactions onto its wheels causes the emergence of destabilizing moments along with other moments that cause the deviation of the tractor from the predetermined direction. By means of the technology [2, 3] that implies movement of an additional load in the lateral direction in the form of a flat plate to cause a lateral displacement of the center of gravity, the emergence of stabilizing moments proportional to the slip moments acting on the respective axles of the tractor is provoked. This results in the increase of the vehicle's road-holding ability and it keeps moving within the predetermined motion corridor.

There are many designs of the front axle with the control of the tilt of its propelling devices in the vertical plane in order to maintain a straight-line motion on the slope [4].

Some of the inventions concerning the problem of the road-holding ability solve this task by means of an additional wheel, mounting it along the longitudinal axis of the vehicle either in front of or behind it. This can be a disk, wheel or ripper able to keep the machine on the chosen trajectory of motion [5].

The purpose and objectives

The purpose of the article is to reveal the relationship between the factors stabilizing and destabilizing the parameters of the road-holding ability of the motor-grader in an analytical form.

3. The solving of the set purpose

The carried out field researches have allowed to identify features of the process of loosing the road-holding ability by a motor-grader [1]. In particular, at the initial stage of work, despite the asymmetric application of external resistance forces $\sum W$ (Fig.1), the machine moves along the straight-line trajectory. Then as the material accumulates in front of the blade, there comes a moment when the motor-grader spontaneously turns around with respect to the point corresponding to the coordinate of application of the resultant vector of external resistance forces (point O), after which the machine again continues its straight-line motion. The actual trajectory of the machine motion consists of linear segments and zones of unintentional turning in the points of their joining.

At approaching the zone of unintentional turning, the actual linear speed of the motor grader decreases almost to zero, but due to the considerable engine power there takes place an obvious slippage of the driving wheels. The experiments show that in this case the theoretical speed of the machine determined by the angular velocity of rotation of the crankshaft is reduced by no more than 4 %. This effect is possible when the total resistance forces at movement of the machine $\sum W + W_f$ are equal to the maximum traction force under conditions of adhesion of the driving propelling devices with the support surface:

$$T_\varphi = \sum W + W_f , \tag{1}$$

where W_f — resistance to the machine rolling.

It should also be noted that at the stage of straight-line motion the dynamic model of this process is described by the following basic equation of dynamics

$$m\ddot{x} = \sum T - (\sum W + W_f);$$

where x - coordinate of the horizontal displacement of the machine; $\sum T$ - total tractive effort developed by the machine; m - mass of the motor grader

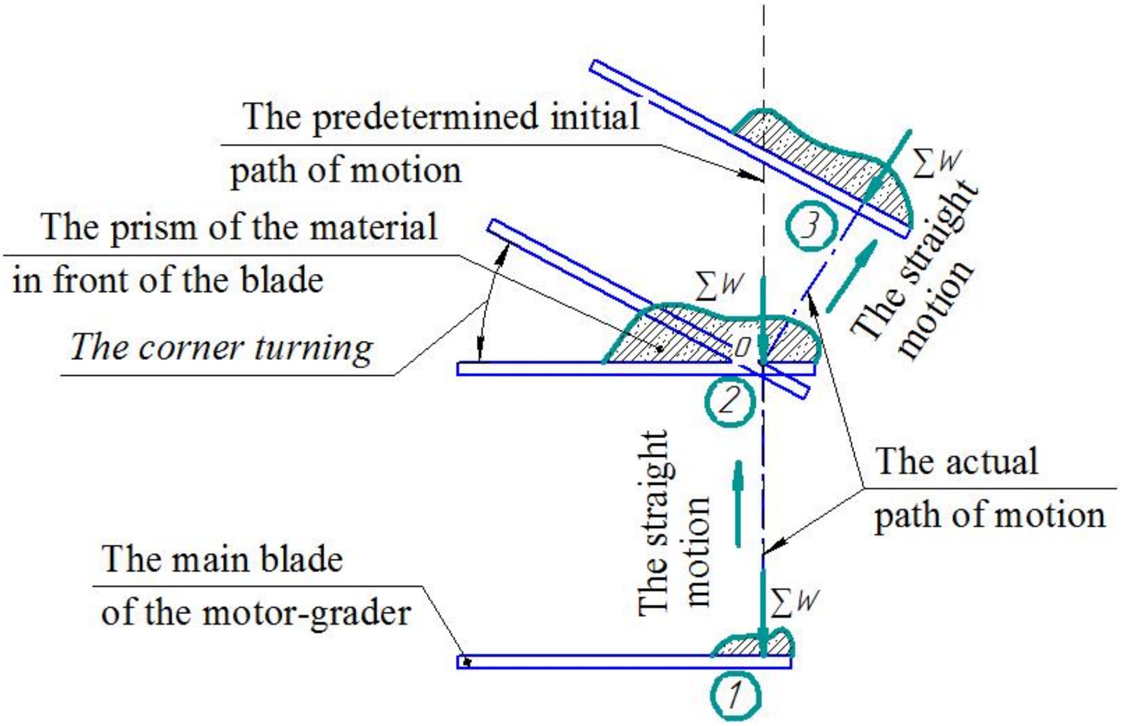


Fig.1 The process of forming the actual motion path of the motor-grader at asymmetric application of external resistance forces to the blade

However, at the moment of the unintentional turning the dynamic model changes and can be presented as follows (Fig. 2)

$$I\ddot{\alpha} = M(T) - M(\sum W, W_f, P_б),$$

where $\ddot{\alpha}$ - coordinate of the angular displacement of the machine; I - moment of inertia of the machine with respect to the center of turning; $M(T)$ - torque developed by tractive efforts; $M(\sum W, W_f, P_б)$ - torque developed by resistance forces.

The analysis of the application of external forces (Fig. 2) made it possible to determine the conditions for the transition from the straight-line motion of the machine to its unintentional turning:

$$\begin{cases} T_2 + T_3 = \sum W + W_f \\ M(T) \rangle M(\sum W, W_f, P_б). \end{cases} \tag{2}$$

Figure 2 shows: $P_{бi}$ - forces of resistance to lateral displacement of the wheels; W_{np} - resistance to moving the prism of soil in front of the blade; W_p - resistance of soil to cutting; W_c - resistance to moving the cut layer of soil up the blade. The resultant vector of resistances acting on the blade is equal to

$$\sum W = W_p + W_c + W_{np}$$

The center of turning of the machine is in the zone of the blade jamming in the soil. The torque turning the machine clockwise is calculated by the equation:

$$M(T) = T_2 \cdot l_1 + T_3 \cdot \left(l + l_1\right).$$

The moment of resistance forces preventing the machine from turning,

$$M(\sum W, W_{fi}, P_{бi}) = W_{f1} \cdot (\frac{l}{2} + l_1) + W_{f2} \cdot l_1 + W_{f3} \cdot (l + l_1) +$$
$$+ P_{б1} \cdot l_2 + (P_{б2} + P_{б3}) \cdot l_3 + W_{np} \cdot l_5 + (W_p + W_c) \cdot l_4.$$

Tractive efforts $\left(T_i\right)$, forces of resistance to lateral displacement $\left(P_{бi}\right)$ and forces of resistance to rolling $\left(W_{fi}\right)$ are determined by certain common equations and depend on the value of the support reaction on the undercarriage [6].

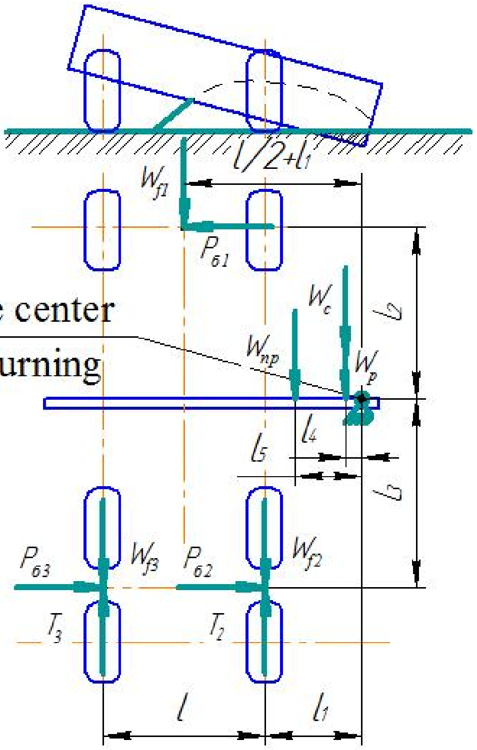


Fig.2 The scheme of the application of forces to the motor-grader in the horizontal plane at the unintentional turning of the motor-grader

The components of the resultant vector of resistance also can be determined by means of widely-known equations [7, 8].

$$W_p = k \cdot F;$$

$$W_{np} = V_{np} \cdot \frac{\delta_{гр}}{k_p} \cdot g \cdot \mu_1;$$

$$W_c = V_{np} \cdot \frac{\delta_{гр}}{k_p} \cdot g \cdot \mu_2 \cdot \cos^2 \delta.$$

In the presented dependences k - specific resistance of the developed material to cutting; F - area of the cut layer; V_{np} - volume of the prism of the moved material; $\delta_{гр}$ - density of the material in the natural state; k_p - coefficient of loosening of the developed material; g - acceleration of gravity; μ_1 - coefficient of internal friction of the material; μ_2 - coefficient of external friction of the material against steel; δ - cutting angle.

The tuning of the machine under condition (2) will last until the moment when the dependence (1) changes as follows:

$$T_2 + T_3 \rangle \sum W + W_f,$$

after which the movement of the motor-grader along the straight-line trajectory continues.

The considered mathematical model allows to explain the character of the motor-grader motion depending on the application of forces at its loading. Along with this, the field researches conducted with the real motor-grader ДЗк – 251 on the Testing ground of Kharkiv National Automobile and Highway University allowed to identify a number of additional factors that also influence the parameters of the motor-grader road-holding ability at performing working operations [1, 9]. To such parameters, first of all, there can be attributed the turning angle of the driven wheels in the horizontal plane (γ), the tilt angle of the front wheels in the vertical plane (ρ), the angle of the transverse gradient of the support surface (φ) and the coefficient of adhesion of the driving propelling devices with the support surface ($\varphi_{сц}$).

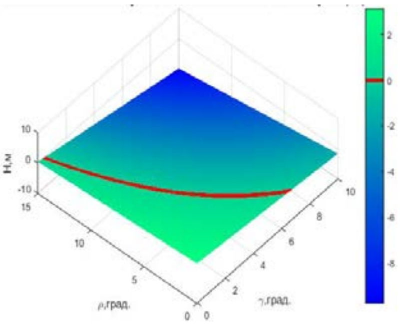
On the basis of the factorial experiment, a regression equation was obtained, which allows to determine the lateral displacement of the motor grader H depending on the above mentioned factors for the same conditions of external loading:

$$\begin{aligned} H(\varphi,\varphi_{сц},\gamma,\rho) &= 2{,}6589 - 0{,}1538\varphi + 0{,}7015\varphi_{сц} - 0{,}80095\gamma + \\ &+ 0{,}1441\rho - 0{,}4219\varphi\varphi_{сц} + 0{,}0208\varphi\gamma - 0{,}0343\varphi\rho + 0{,}505\varphi_{сц}\gamma - \\ &- 0{,}4967\varphi_{сц}\rho - 0{,}0343\gamma\rho + 0{,}035\varphi\varphi_{сц}\gamma + 0{,}0948\varphi\varphi_{сц}\rho + \\ &+ 0{,}0064\varphi\gamma\rho - 0{,}0033\varphi_{сц}\gamma\rho - 0{,}0124\varphi\varphi_{сц}\gamma\rho. \end{aligned} \quad (3)$$

In the course of the experiments it was revealed that some of factors have a destabilizing effect on the parameters of road-holding ability, and some, on the contrary, allow the machine to be kept on the planned trajectory. In particular, the turning of the driven wheels in the direction opposite to that of the unintentional turning of the motor-grader and the tilt of the same wheels in the same direction provide for eliminating the displacement of the motor-grader in the lateral direction even with significant torque acting on the machine in the horizontal plane. Unfortunately, currently there are no recommendations for choosing the angles γ and ρ.

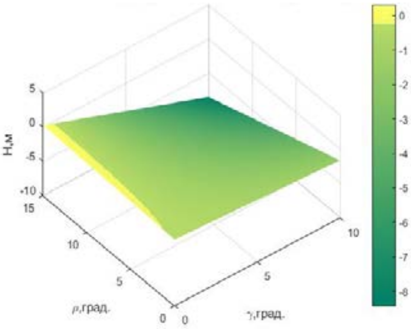
However the equation (3) made it possible to determine the dependence between the angles enabling to keep the machine on the straight-line course under the given conditions off asymmetric loading of the motor-grader.

Figures 3 and 4 present graphics of dependence of the lateral displacement of the motor grader on the angles γ and ρ of the position of the driven wheels. The tables give rational dependence of the angles allowing to keep the machine on a straight-line trajectory of movement for the loading conditions realized in the experiment.



The dependence of the angles of tilt and turning of the motor-garder front wheels	
ρ, deg.	γ, deg.
0 □	-0.605□
3 □	1.284□
6 □	1.51□
9 □	1.624□
12 □	1.695□

Fig.3 The dependence of the lateral displacement of the motor-grader from the angle of the front wheels tilt in the vertical plane (ρ) and the angle of their turning in the horizontal plane (γ).



The dependence of the angles of tilt and turning of the motor-garder front wheels	
ρ, deg.	γ, deg.
0 □	1.37□
3 □	0.97□
6 □	1.018□
9 □	1.0317□
12 □	1.038□

Fig.4 The dependence of the lateral displacement of the motor-grader from the angle of the front wheels tilt in the vertical plane (ρ) and the angle of their turning in the horizontal plane (γ). The working operations are performed on the site with transverse gradient of φ=8□.

Conclusions

The conducted analysis of the power asymmetric loading of the motor-grader in the process of performing working operations made it possible to determine the boundary conditions that change the nature of the vehicle motion and determine the form of its actual trajectory.

The field research made it possible to reveal the influence of additional factors on the formation of parameters of the road-holding ability. The proposed method allows to calculate the values of such parameters as the angle of rotation of the front wheels in the horizontal plane and the angle of their tilt in the vertical plane, allowing to keep the motor-grader on a straight trajectory of motion even with an asymmetric application of external loads. The obtained data can become a basis for the development of automatic systems ensuring the stability of the trajectory of the motor-grader.

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