

External loading of the motor grader during the operation of the cutting operation and moving the processed surroundings

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Abstract: The main feature of modern earthmoving machines is the execution of a wide range of different operations. At the same time, the loading mode changes and it is characterized by coordinates, values of the applied forces acting on the machine and the regularities of their change in time. In order for the machine to be able to adapt to the listed variables, it must be equipped with the appropriate systems. Existing calculation methods do not allow taking into account the entire range of these effects. In the proposed work, adaptation approaches of earthmoving and transport vehicles to variable operating conditions are analyzed.

Keywords: EARTH-MOVING MACHINES (EMM), MOTOR GRADER, ROAD-HOLDING ABILITY, DYNAMIC LOADING.

Topicality

A promising area for improving earth-moving equipment, in particular motor graders, is the adaptation of a motor grader to external loading conditions, when performing a cutting operation and moving the processed medium.

For excavating and earth-moving machines, characteristics of the road-holding ability are influenced, apart from the abovementioned parameters, by certain additional destabilizing factors. Firstly, a number of machines is equipped with active implements, which, during the excavation of soil move relative to the base machine leading to occurrence of additional inertia forces in the horizontal plane. Secondly, the main vector of the external resistance forces acting on the blade- and bucket-type implement can be considerably displaced in relation to the longitudinal axis of the base machine, which has randomly changed its position in the process of soil digging. This causes not only occurrence of additional torques in the horizontal plane but also additional lateral loads on the implement [1, 2].

Since for performing a technological operation by a motor grader, the main blade is installed with a grip angle different from 90° and with a skew angle in the vertical plane up to $25-30^\circ$, the additional lateral forces will act on the motor grader during operation, as well as the moments in the horizontal plane that contribute to leaving the planned trajectory of movement.

Review

In accordance with the suggested methodology, at the initial stage, it was proposed to use the indicator of roadholding stability of a motor grader as an adaptation criterion. A review of scientific and technical information showed that, as a criterion for directional stability, the researchers use the coefficients, the levels of the ratio of the total force factor, which contributes to keeping the car on the planned trajectory of movement, to the total force factor, which contributes to the displacement of the car from this trajectory [3]

$$k_y = \frac{P_{y0}}{P_{oecm}} \quad (1)$$

where P_{y0} is the total force factor that keeps the car on the planned trajectory of movement; P_{oecm} is the total power destabilizing factor, which contributes to the deviation of the machine from the planned trajectory of movement.

This approach does not fully correspond to the technological operations that a motor grader performs. To substantiate the criterion of road-holding stability and the structure of the dynamic model of the car movement, the exploratory experimental studies were carried out at the educational and scientific base of Kharkiv National Automobile and Highway University (ESB KhNAHU), in which the trajectory of the motor grader was recorded in the process of performing various technological operations. The experiments were carried out in summer on the soil of the II category. As a base

machine, the DZK-251 motor grader of the Kryukov Railway Car Building Works was used.

The experimental studies have shown that the trajectory of the motor grader movement was formed in different ways: the linear trajectory of the motor grader movement is formed in cases where the working resistance on the blade is relatively small. In this situation, deviations of the real trajectory of the motor grader from the planned one are not registered. In situations where the coefficient of adhesion of the propelling units to the supporting surface is insignificant, the movement of the motor grader was recorded when performing technological operations along a curved trajectory; when cutting the soil, a piecewise linear trajectory of the motor grader was also observed. At this, at the initial stage, the machine moves along the straight line, then, as the external resistance increases, it slows down, turns around the blade blocking point and then continues its straight movement.

Goal

The goal of the publication is to analyze the possibility of adapting the motor grader to the conditions of external loading, whose implementation will help increase the efficiency of machines.

Solution to the problem

In situations when the road-holding stability is lost, it should be noted that the lateral displacement of the machine occurs gradually at the distance of movement (grip). Since it is recommended to carry out most of the technological operations performed by a motor grader with overlapping passes, as a first approximation, we can take the overlap factor k_n or the corresponding lateral displacement of the blade (machine) edge ε_l as a criterion of road-holding stability.

In this case, the criterion $y_p(x)$ of directional stability for grips of length l needs the following condition:

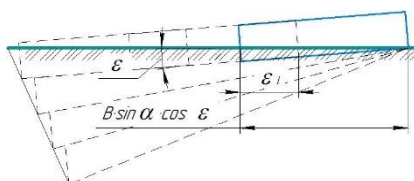
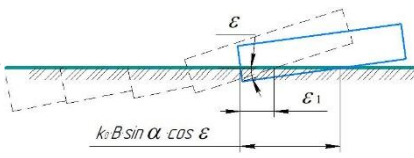
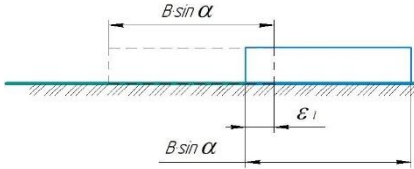
$$y_p(x) \leq y_n(x) \pm \varepsilon_l \quad (2)$$

where y_p is the lateral displacement of the machine while driving along the real trajectory of movement; y_n is the lateral displacement of the machine while driving along the planned trajectory of movement.

The values of ε_l can be determined based on the information given in the reference literature [4, 5], Table 1.

The coefficient k_0 depends on the depth of soil cutting and the value of the skew angle of the blade in the vertical plane, which are determined by the type of technological operation performed. According to previous estimates, the value of this coefficient ranges from 0.2 to 0.65.

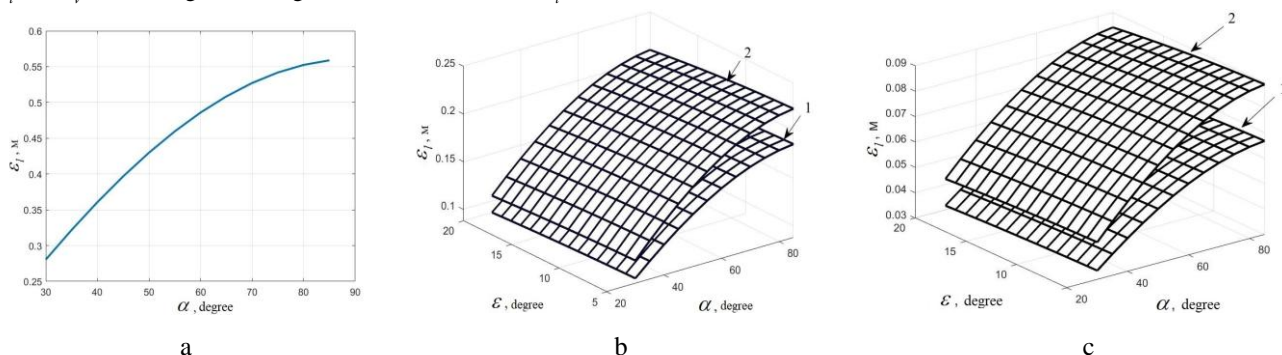
Table 1. Recommended values of admissible displacement of the motor grader blade edge during technological operations

Type of technological operation	Calculation scheme	Value of k_n	Value of ε_l
Cutting, beam development pattern		Loosened soil 1.15–1.3	$(k_n - 1) \cdot B \cdot k_v \cdot \sin \alpha \cdot \cos \varepsilon$ (3)
		Unbroken soil 1.25-1.6	
Cutting, layer-by-layer development pattern		Loosened soil 1.45-1.7	$(k_n - 1) \cdot k_0 \cdot B \cdot k_v \times \sin \alpha \cdot \cos \varepsilon$ (4)
		Unbroken soil up to 2	
Soil displacement		1.1-1.15	$B \cdot k_v \cdot \sin \alpha \cdot (k_n - 1)$ (5)

The coefficient of variation k_v is determined by the normative requirements for the quality of the work performed and the technical and economic indicators that characterize the motor grader operation. These include productivity and unit cost. Previous calculations have shown that the value of this coefficient varies within the range from 0.05 to 0.25 (Fig. 1 a).

The calculation results for the admissible displacement values of ε_l for $k_v = 0.1$ are given in Figure 1 b-c. The value of ε_l varies

within a wide range from 0.033 m to 0.186 m. The range of admissible values of ε_l depends not only on the type of technological operation performed, but also on the physical and mechanical characteristics of the developed soil. Increasing the dragging angle from 40 to 60 results in ε_l increase from 34% to 36%. Increasing the skew angle in the vertical plane from 5 to 20 reduces the values ε_l by 5%– 8%.



1 – loosened soil ($k_n = 1.6$); 2 – unbroken soil ($k_n = 1.8$)

Fig.1 Graph of the dependence of the admissible lateral displacement of on the angle of grip α during the operation: a – displacement of the soil ε ; b – cutting the soil using the beam pattern; c – cutting the soil using the layer-by-layer pattern

Taking into account the assessment of the criterion of road-holding stability, it is necessary to calculate the deviation of the real trajectory of the motor grader blade edge relative to the planned trajectory at a given distance, which corresponds to the length of the face or the grip.

The second stage of the methodology, assuming the technological adaptation of the machine, in our case, was provided by the installation of the main blade of the motor grader with the angle of grip and the angle of skew in the vertical plane in accordance with the normative recommendations. Our studies have shown that due to the variation in the properties of the surroundings being developed and the specifics of the technological operation performed, it is possible to change the recommended geometric characteristics of the installation of the main dump. Their refined values can be determined by solving the problem of optimizing the process of developing the surroundings. Here, the performance

criterion for a given specific technological operation is used as an objective function.

At the third stage of the motor grader adaptation methodology, recommendations should be developed to keep the machine on the planned trajectory within the assigned value of the adaptation criterion. There are two ways to achieve this:

- by the effect of theoretical research based on the development of a mathematical model of the motor grader movement process and subsequent analysis of the formed trajectory;
- by the effect of the analysis of experimental data.

The proposed study takes into account the results of a multifactorial experiment carried out by the authors in the conditions of the KhNAHU test site on the DZk-250 motor grader. With unchanged geometric characteristics of the blade installation

during the experiment, the most significant pre-determined factors were varied: the angle of the cross slope of the supporting surface, the coefficient of adhesion of the motor grader wheels to the supporting surface, the angle of rotation of the front wheels in the horizontal plane and the angle of their skew in the vertical plane. The analysis of the results obtained showed that the cross slope angle and the coefficient of adhesion are destabilizing factors, while the variation of the front wheel alignment angles allows the motor grader to be kept on the planned trajectory.

Thus, the choice of rational values of these angles allows to adapt the motor grader to varying operating conditions and to provide its trajectory within the specified adaptation criterion.

On the basis of the experimental study, regression equations were obtained connecting all four of the variable parameters [6].

The obtained regression equations allow in graphic and numerical form to establish the effect of simultaneous changes in several factors on the indicators of road-holding stability, in particular, on the deviation of the motor grader from the planned trajectory.

The graphs of the dependence of the lateral displacement H of the motor grader on the angle of rotation of the front wheels in the horizontal plane γ and the angle of skew in the vertical plane ρ for different cross slopes of the supporting surface are shown in Figure 2.

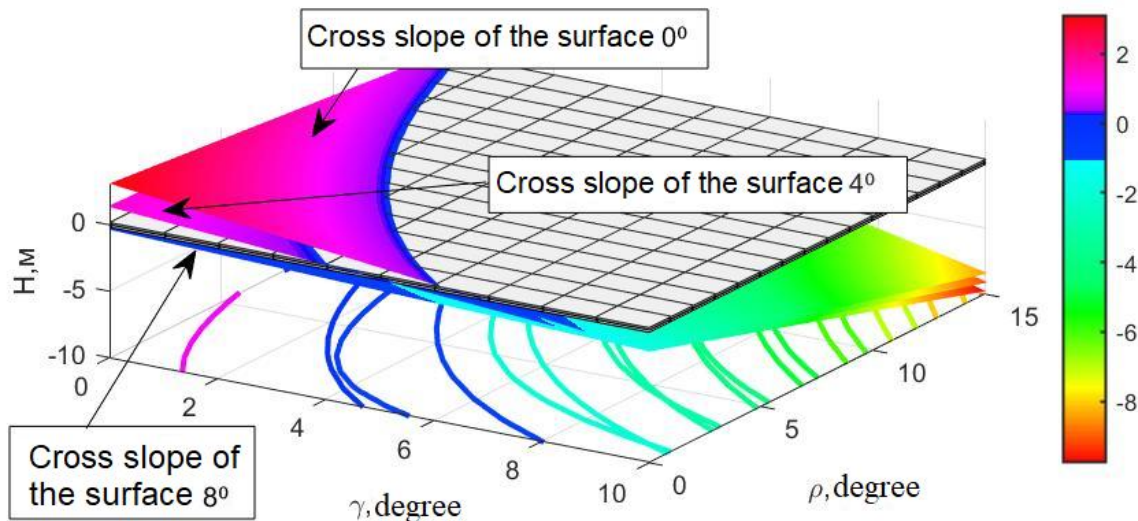


Fig. 2. Graph of the dependence of the lateral displacement of the motor grader on the angles of rotation in the horizontal and skew in the vertical plane of the front wheels for different values of the cross slope of the supporting surface

Similar graphs, but for different adhesion coefficients, are shown in Figure 3. All constructed surfaces are nonlinear. The greatest deviations of the motor grader from the planned trajectory were recorded at $\gamma = 10^\circ$ and $\rho = 10^\circ$ and are $-8.4 \dots -9.7$ m on the grip length of 20 m. In situations when $\gamma = 0^\circ$ and $\rho = 0^\circ$ the deviations are $1.4 \dots 3.2$ m.

The analysis of the regression equations shows that for the given values of the cross slope and the coefficient of adhesion it is possible to determine the relationship between the angles γ and ρ according to which the criterion of road-holding stability is satisfied. Graphically, the range of these values is located in the zone of intersection of the constructed surfaces by two parallel planes, which are located at distance $\pm \varepsilon_i$ relative to the zero offset. In the graphs shown in Figure 4, the range of admissible values of angles γ and ρ is located between the two curves.

The results of such calculations for variable values of the coefficient of adhesion are shown in Figure 5.

Thus, the adaptation of a motor grader according to the criterion of road-holding stability for different angles of the cross slope of the supporting surface and adhesion coefficients is reduced to the choice of wheel alignment angles simultaneously in the horizontal and vertical planes from among the recommended.

Conclusion

The conducted research has proved that the proposed method of adaptation of EMM to variable operating conditions makes it possible to synthesize an adaptation system that meets the selected criteria.

For motor graders of classical design, the adaptation system is reduced to choosing the angle of rotation of the front wheels in the horizontal plane and the corresponding angle of skew in the vertical plane in accordance with the given graphical dependencies.

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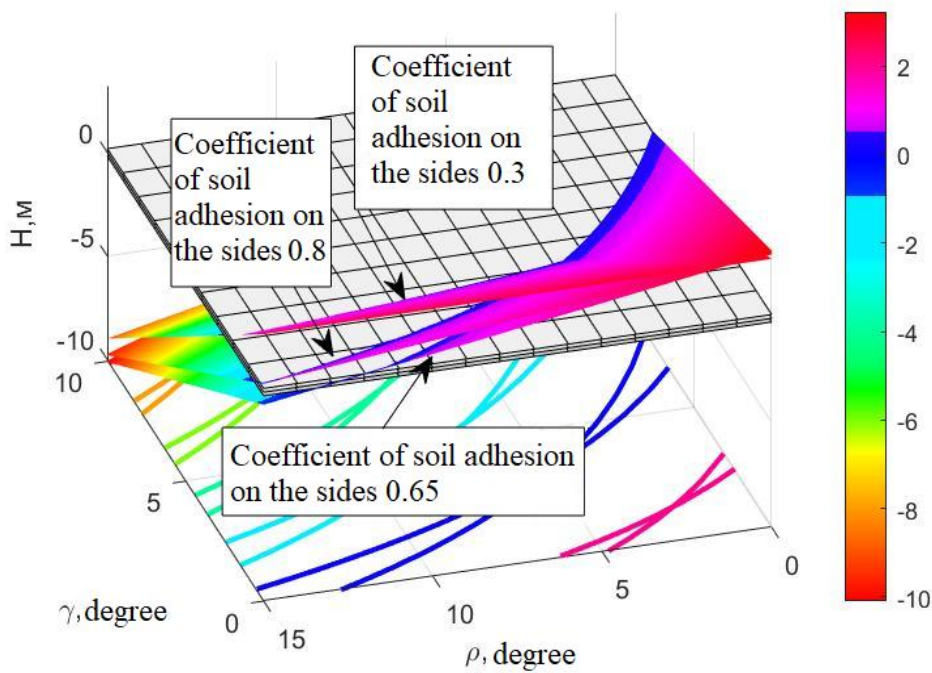


Fig. 3. Graph of the dependence of the lateral displacement of the motor grader on the angles of rotation in the horizontal and skew in the vertical plane of the front wheels for different coefficients of adhesion

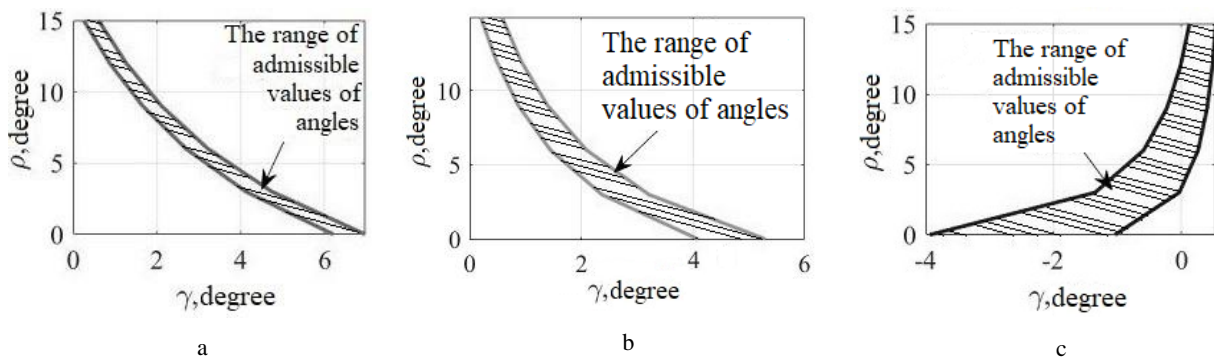


Fig. 4. Graphical dependencies that allow you to determine the ratio of the angles that provide the admissible lateral displacement of the motor grader within $\varepsilon_l = \pm 0.18$ m: a – the cross slope of the supporting surface is 0°; b – the cross slope of the supporting surface is 4°; c – the cross slope of the supporting surface is 8°

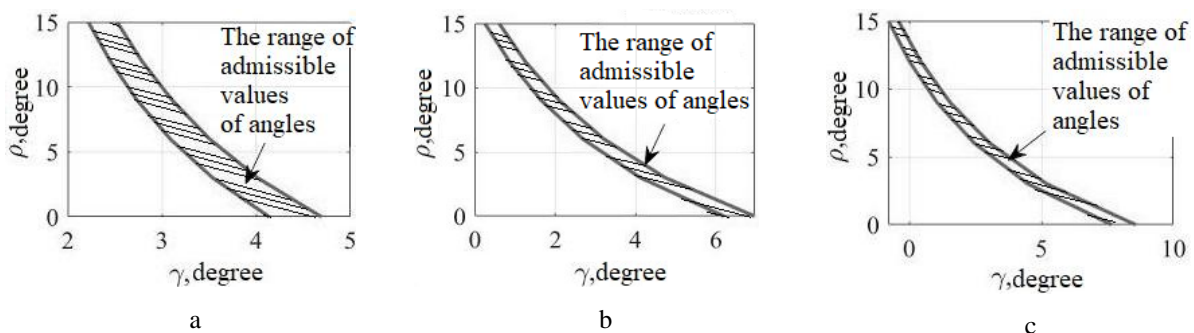


Fig. 5. Graphical dependencies that make it possible to determine the ratio of the angles that provide the admissible lateral displacement of the motor grader within $\varepsilon_l = \pm 0.18$ m: a – the coefficient of adhesion is 0.3; b – the coefficient of adhesion is 0.65; c – the coefficient of adhesion is 0.8