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An adaptive approach to the processes of execution of technological operations by earth-moving and loading machines

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Abstract. Problem. *Since most often when designing a machine, its operation with the basic type of working equipment is considered, a change in working bodies with a simultaneous change in the loading mode can lead to a decrease in efficiency. One of the possible solutions is the adaptation of machines to changing operating conditions.* ***Methodology.*** *The synthesized adaptation system is based on structural and parametric approaches. The evolutionary changes in the structure of the object are considered by means of transition from one alternative model to another. The synthesis of corrective structural adaptive actions is taken through a heuristic search. The proposed methodology was tested experimentally on a motor grader when cutting and moving the processed surroundings.* ***Results.*** *The detailed experimental studies have shown the main stages of the formation of the movement trajectory, depending on the resistance arising on the blade of the motor grader. The analysis of the obtained results showed that the angle of the lateral tilt and the grip coefficient are destabilizing factors, and the variation of the angles of the front wheels allows keeping the motor grader on the planned trajectory of movement.* ***Originality.*** *The originality of the research lies in the development of a synthesized adaptation system for a motor grader, which, unlike traditional static models, is based on a combination of structural and parametric approaches. This is achieved by considering evolutionary changes in the object's structure through a transition between alternative models and the synthesis of corrective adaptive actions using heuristic search methods. The originality is further confirmed by identifying the synergistic influence of the lateral tilt angle and the grip coefficient as key destabilizing factors, and by establishing regression dependencies that allow for real-time adjustment of front wheel angles to maintain the planned motion trajectory under changing operating conditions.* ***Practical value.*** *The obtained regression dependencies allow for assessing the simultaneous influence of multiple factors on the motion stability indicators in graphical and numerical form and, consequently, adapting the machine parameters to changing operating conditions. Based on the research, the system of automatic wheel load adjustment for a motor grader was developed and patented.*

Keywords: *earth-moving and loading machines, execution of technological operations, adaptation machines, formation of the movement trajectory, trajectory of movement, method of adaptation, variable operating conditions.*

Introduction and Analysis of publications

A promising avenue for enhancing earth-moving machinery, especially earth-moving machines (EMM) and loading machines (LM), is increasing their versatility through the use of a wide range of additional replaceable working equipment. This approach makes it possible to extend the list of performed technological operations and the area of machines utilization and simultaneously increase the total annual productivity. Along with this, a change in the type of the used working body triggers a change in the characteristics of the loading mode of LM and EMM. Since most often when designing a machine, the design situations of its operation with the main (basic) type of working equipment are considered, a change in working bodies or a change in their geometric characteristics with a simultane-

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ous change in the loading mode (which is not taken into account in the design) can lead to a drop in efficiency indicators: indicators of productivity, reliability, quality of the work performed, etc. One of the possible ways out of this situation is the adaptation of the EMM and LM to changing operating conditions.

Purpose and Tasks

The purpose of the publication is to develop the basic provisions of the methodology for adapting EMM and LM to varying operating conditions, implementing this approach will contribute to improving the efficiency of machinery.

Materials And Methods

Analysis of a significant number of definitions given in [1] allows us to interpret adaptation as the ability of natural and artificial systems to adapt to changing external and internal conditions.

Technical objects have a certain specificity in comparison with natural ones. With regard to the complex objects, for example EMM and LM, L. A. Rastrigin proposes to interpret the term “adaptation” as a process of purposeful change in the parameters and structure of a machine, which consists in determining the criteria for its functioning and meeting these criteria [2].

A technical object (EMM, LM), which has the properties of adaptability – the ability to change its parameters due to the changes in itself or depending on its application in order to increase efficiency, can adapt to variable conditions of functioning. An adaptive technical object (EMM, LM) is able to maintain operability in the event of unforeseen changes in the properties of the object itself, control goals or characteristics of surroundings by changing its parameters, the algorithm of functioning or the search for optimal states [3]. The issues of adaptation of technical objects are most fully considered in the theory of automatic control [4-8].

In the systems where the adaptation of a technical object is based on the identification of one or more controlled parameters based on direct or indirect measurements, the structural diagrams similar to that shown in Fig. (**1**) are the most widespread [2, 9-14].

The tasks of synthesizing such systems are reduced to the following sequential actions:

1) developing a set of adaptation criteria that characterize the efficiency of functioning of a technical object (EMM, LM);

2) technical support for obtaining a sufficient amount of information about the current performance indicators of a technical object (EMM, LM);

3) working out and selecting an adaptation algorithm;

4) elaborating an executive system that allows to implement an adaptive impact on a technical object

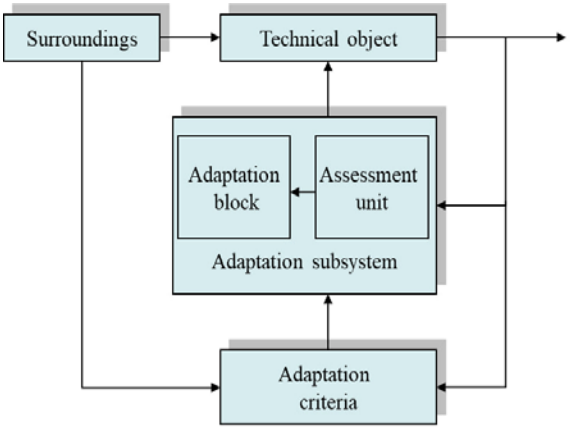


Fig. 1. Structural diagram of the adaptation system of a technical object (EMM, LM) based on the identification of one or more controlled parameters.

In cases where a technical object is a complex combination of individual systems and elements, it is advisable to use an adaptation model based on comparing the reference model of the parameters of a technical object (EMM, LM) functioning and its current functioning model, whose parameters are determined by the influence of the surroundings, as shown in Fig. (2) [2, 9-14].

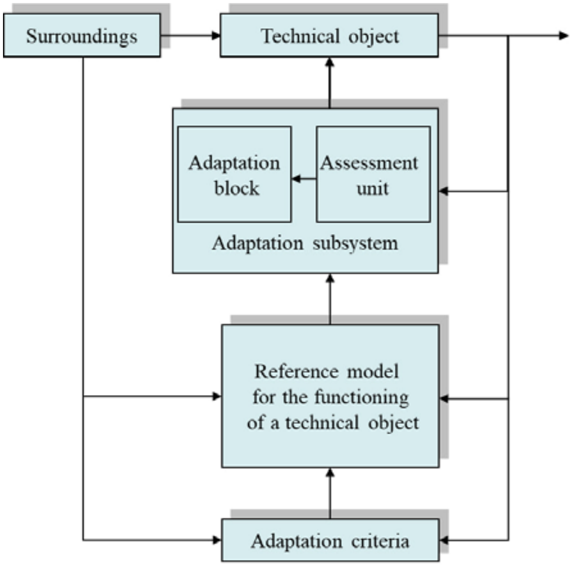


Fig. 2. Adaptation system of a technical object (EMM, LM) based on comparison of the parameters of the current functioning model and the reference model.

The tasks of the synthesis of such an adaptation system differ from those considered above and include:

1) developing a set of adaptation criteria;
2) creating a reference model for functioning of a technical object, based on adaptation criteria;
3) technical support for obtaining information on the current performance of a technical object;
4) developing the current model of functioning of a technical object;
5) developing a methodology for comparing the reference and current models of functioning of a technical object;
6) working out an adaptation algorithm;
7) elaborating an executive system that makes possible to implement an adaptation impact.

Theoretically, any technical object (EMM, LM) can be described by the equations [6]

$$\dot{x} = f(x,u,\xi,t), \quad y = h(x,u,t), \tag{1}$$

where x is a vector of parameters characterizing the state of a technical object; u is the vector of control parameters; ξ is the vector of unknown parameters; y is the output.

The goal of adaptation is to achieve an adaptation criterion (functional) of a certain level [6]

$$Q(x,u,\theta,t) \le \Delta \tag{2}$$

or a limit value

$$Q(x,u,\theta,t) \to \min \quad at \quad t \to \infty. \tag{3}$$

In the given dependencies $Q(x,u,\theta,t)$ is the adaptation criterion (functional); θ is the vector of variable parameters of the control adaptation system (controller).

Despite the fact that the theory of automatic control of technical objects is quite fully developed, the use of adaptation systems at the EMM and LM requires additional research to take into account the peculiarities of the operation of these machines.

The objective of this publication is to comprehensively develop a methodology for adapting EMM and LM to accommodate diverse operational conditions. By establishing these fundamental principles, the aim is to facilitate the implementation of strategies that will enhance the overall efficiency and performance of these machines in different working environments.

One of the features of using EMM and LM is that the operator is preliminary aware of the type of work operations that the machine must perform. The analysis of the operating experience of the EMM and LM shows that the machine adaptation method should include at least three stages displayed in Fig. (**3**):

the stage of justification and development of adaptation criteria;

the stage of technological adaptation;

the stage of adaptation to the existing power factors.

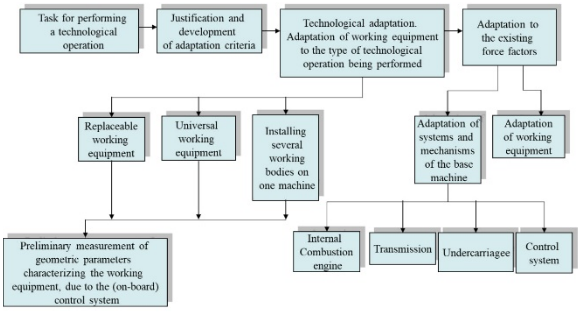


Fig. 3. Methods of adaptation of EMM and LM

At the first stage, based on the technical requirements for the technological operation to be performed, it is necessary to justify and develop adaptation criteria. As a rule, one or several performance indicators are used as adaptation criteria, and they must be maximized, minimized, or kept at a given level.

At the second stage, the machine must be preliminarily adapted to the technological operation. This is done in two steps: a working body, which is necessary to perform the planned technological operation, is installed on the machine, then, using the standard (on-board) controls installed on the machine, the geometric parameters of the working body are preliminarily changed in accordance with the expected background of external resistance and the previously developed adaptation criteria, as shown in Fig. (3). Technically, this problem is solved by installing replaceable working equipment on the EMM or LM, or by using universal working equipment that can be constructively modified into several types of working bodies, or by placing several working bodies on the machine, either of which is used as needed.

A change in the type of the technological operation performed and the type of the working equipment used inevitably leads to a change in the loading parameters of the EMM and LM, which can negatively affect the values of the adaptation criteria. The situation is further complicated by the fact that the loads acting on the working body of the EMM and LM from the processed surroundings are most often random. The proposed methodology suggests the adaptation of the machine to the acting force factors at the third stage. Due to the fact that EMM and LM are complex nonlinear dynamic systems, in order to ensure the specified levels of adaptation criteria, it may be necessary to simultaneously adapt both the systems and mechanisms of the base machine and the working equipment, which puts the adaptation system into the category of multi-dimensional and multi-criteria.

As an algorithm for the synthesis of the system of EMM and LM adaptation we propose to use the revised hierarchical algorithm shown in Fig. (4) suggested by A.A. Rastrigin [2].

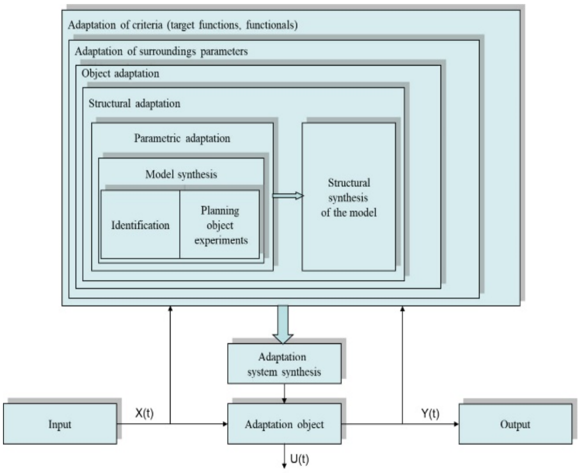


Fig. 4. Hierarchical algorithm for the synthesis of the adaptation system

The adaptation process is based on the structural and parametric synthesis of the object model. The structure is understood as the type and the nature of dependence F of the state of object Y on its controlled X and uncontrolled U of inputs. With regard to technical objects, the structure of the object model is determined by a finite complex of mathematical expressions that uniquely describe the state of the object at any time. Parametric synthesis involves determination of the parameters of the model, which are included in the model operator F. Identification of the parameters of model F of the object is reduced to estimation of the numerical values of the required parameters in the normal functioning of the object [2]. The planning of the experiment involves determination of the parameters C and the structure of the object model on the basis of an experimental study. The preliminary execution of the above operations enables to synthesize an adaptation system that implements adaptive control of a technical object.

The lowest level of the adaptation algorithm assumes the implementation of parametric adaptation, which involves correcting the parameters C of the model caused by a change in the characteristics of a technical object (EMM, LM). The adaptation operation is performed based on the mismatch of the response information of the object and the model.

If the structure of a technical object (EMM, LM) changes during its operation, then there is a need for structural adaptation of the model, for example, by moving from one alternative model to another, after which the stage of successive identification and adaptation of the model parameters begins. As a rule, at this stage an evolutionary change in the structure of an object under conditions of normal functioning is considered. The parametric and structural adaptation of the model makes it possible to synthesize a corrective adaptive effect on a technical object (EMM, LM) within the limits of its virtually unchanged design scheme and the physical way of accomplishing the actions.

If a given level of adaptation criteria is not achieved by either parametric or structural adaptation of the model, it becomes necessary to move to the next stage of adaptation – adaptation of the technical object itself. This stage of adaptation involves a change in the design of the very object: introducing additional structural elements, control and adaptation systems, changing the physical principles of functioning. The decision to change the design of a technical object (EMM, LM) is made on the basis of heuristic search using the algorithm for solving ingenious problems, brainstorming, heuristic methods, etc.

A higher level of adaptation is adaptation of the parameters of the surroundings, which is reduced to a change in the characteristics and the parameters of external influence on a technical object (EMM, LM). With that, not only the parameters of the impact can change, but also its functional characteristics. The systems that allow performing such actions can be both located at the technical object itself, and implemented by auxiliary technical objects, which significantly complicates the synthesis of the general adaptation system.

The highest level of adaptation comes down to the adaptation of the very criteria and goals. If all the previous types of adaptive impact have exhausted their capabilities in achieving the assigned levels of criteria, then in this situation it is necessary to determine a new set of goals and criteria for adaptation. Here L.A. Rastrigin proposes to use the term “adaptation of the needs” of the subject which uses this technical object (EMM, LM).

Experimental

To evaluate the efficacy of our proposed method, we conducted an analysis of its applicability in adapting the motor grader to external loading, when performing the cutting operation and moving the processed surroundings.

During the execution of such a technological operation, the main blade of the motor grader is positioned at a cutting angle different from 90° and with a tilt angle in the vertical plane up to 25-30°. This leads to the generation of additional lateral forces and moments in the horizontal plane, contributing to deviation from the planned trajectory of the motor grader's movement during operation.

According to our developed methodology, the initial stage involves using the road-holding ability indicator of the motor grader as an adaptation criterion. The analysis of scientific and technical data has revealed that researchers employ coefficients as the measure of road-holding ability, representing the ratio of the total force promoting the machine's retention on the intended trajectory of movement to the total force contributing to the machine's displacement from this trajectory.

$$k_y = \frac{P_{\text{уд}}}{P_{\text{дест}}} \tag{4}$$

where $P_{\text{уд}}$ is the cumulative force factor responsible for maintaining the vehicle on the intended path of motion; $P_{\text{дест}}$ is the overall destabilizing force factor that contributes to the machine's deviation from the intended path of motion.

Such an approach only partially aligns with the technological operations performed by the motor grader. To substantiate the criterion of road-holding ability and the structure of the dynamic model of machine movement, exploratory experimental studies were conducted at the educational and research facility of the Kharkiv National Automobile and Highway University. These experiments involved recording the motor grader's trajectory during the execution of various technological operations. The experiments took place during the summertime on soil classified as category II. The Kryukov Railway Car Building Plant's DZk-251 motor grader was utilized as the base machine.

Results and discussion

Experimental studies have demonstrated that the motor grader's trajectory is influenced by various factors: a linear trajectory occurs when the blade encounters relatively low resistance. In such situations, deviations between the actual and planned trajectories are negligible. Conversely, when the traction coefficient between the moving parts and the supporting surface is low, the motor grader moves along a curved path during operational tasks. Additionally, during soil cutting operations, a segmented-linear trajectory of the motor grader's movement was observed. Initially, the machine moves in a straight line, but as external resistances increase, it decelerates, pivots around the blade lock point, and then continues in a straight path.

When road-holding ability is compromised, it is important to note that the lateral displacement of the machine gradually accumulates over the course of movement (pass). Considering that the majority of technological operations conducted by the motor grader are advised to incorporate overlapping passes, the overlap coefficient k_n or the corresponding lateral displacement of the blade edge (machine) can be initially considered ε_1 as the criterion for road-holding ability.

In this scenario, the criterion $y_p(x)$ for road-holding ability on passes of length l requires the following condition.

$$y_p(x) \le y_n(x) \pm \varepsilon_l \tag{5}$$

where y_p is stands for the lateral displacement of the machine as it moves along the current trajectory, y_n is while indicates the lateral displacement of the machine along the intended trajectory.

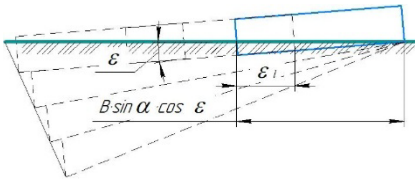
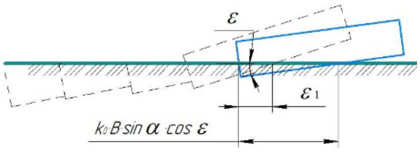
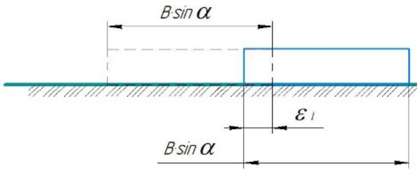
Table 1 shows the values of ε_l determined based on the information given in the reference literature [9-11, 15-18, 22].

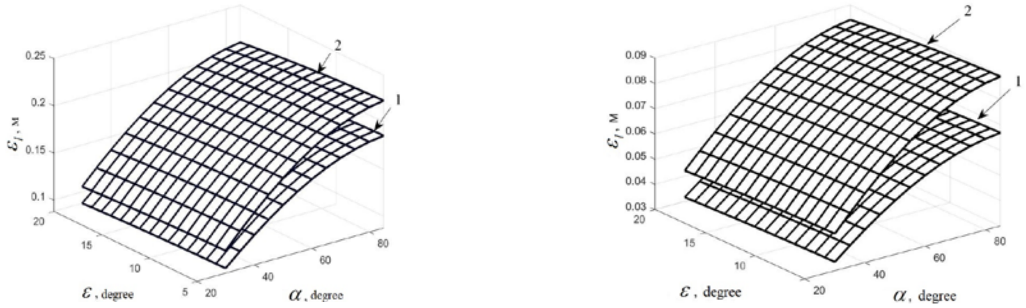
The coefficient k_0 is influenced by the depth of soil cutting and the angle of blade tilt in the vertical plane, which are determined by the specific type of technological operation being executed. According to previous assessments, the value of this coefficient typically ranges from 0.2 to 0.65.

The coefficient of variation k_v is established based on the regulatory standards governing the quality of the executed work. and by technical and economic indicators that characterize the operation of the motor grader. These indicators include productivity and the cost of production per unit. Past analyses have demonstrated that the coefficients value falls within the interval of 0.05 to 0.25. [22].

The calculation results of the permissible displacement ε_1 for k_v=0.1 are presented in Figure 5 a-b. The value of ε_1 varies widely from 0.033 m to 0.186 m. The permissible range of values for ε_1 is contingent upon the specific type of technological operation underway, as well as the physical and mechanical attributes of the excavated soil. Increasing the installation angle in the plan from 45⁰ to 70⁰ leads to an increase of up to 35% in the indicator ε_1. Increasing the skew angle in the vertical plane to 15⁰ contributes to a decrease in ε_1 the indicator by 8%.

Table 1. Reference values for acceptable displacement of the blade edge of a motor grader during the execution of operational tasks

Type of technological operation	Calculation scheme	Value of k_n	Value of ε_1	
Cutting, beam development pattern		Loosened soil 1.15–1.3 Unbroken soil 1.25-1.6	$(k_n-1)\cdot B\cdot k_v\times$ $\times\sin\alpha\cdot\cos\varepsilon$	(2)
Cutting, layer-by-layer development pattern		Loosened soil 1.45-1.7 Unbroken soil up to 2	$(k_n-1)\cdot k_0\cdot B\cdot k_v\times$ $\times\sin\alpha\cdot\cos\varepsilon$	(3)
Soil displacement		1.1-1.15	$B\cdot k_v\cdot\sin\alpha\cdot(k_n-1)$	(4)



a b

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

Fig. 5. Graph illustrating the relationship between the allowable lateral displacement ε_1 and the grip angle α during operation: a – cutting the soil using the beam pattern b – cutting the soil using the layer-by-layer pattern

Considering the evaluation of the roadholding ability criterion, it is imperative to compute the deviation of the actual trajectory of the motor grader's blade edge from the planned trajectory at a given distance, corresponding to the length of the cut or pass.

On the second stage of the methodology, the main grader blade was installed with the angle involving technological adaptation of the machine, in our scenario of attack and tilt angle in the vertical plane according to regulatory recommendations. Our research has shown that due to the variation of properties of the developed environment and the specificity of the performed technological operation, there is a possibility of changing the recommended geometric characteristics of the main grader blade installation. The precise values can be ascertained through the resolution of the optimization challenge inherent in the environmental development process. In this case, the performance criterion for the specific technological operation is employed as the objective function.

During the third phase of the adaptation methodology for motor graders, it is necessary to formulate recommendations to ensure that the machine stays on the intended trajectory within the specified magnitude of the adaptation criterion. This can be achieved through two approaches:

– theoretical research involving the development of a mathematical model describing the movement process of the motor grader, followed by an analysis of the resulting trajectory;

– analysis of experimental data to determine the optimal trajectory.

The present study incorporates findings from a comprehensive experiment conducted by the authors at the Kharkiv National Automobile and Highway University trial location employing the DZk-251 motor grader. Throughout the experiment, the geometric characteristics of the blade installation remained constant, while significant predetermined factors were systematically varied. These factors comprised the cross-slope angle of the surface, the adhesion coefficient between the motor grader wheels and the supporting surface, the rotation angle of the front wheels in the horizontal plane, and the skew angle of the front wheels in the vertical plane. Analysis of the acquired data revealed that the cross-slope angle and the coefficient of adhesion act as destabilizing factors, whereas variations in the alignment angles of the front wheels facilitate the maintenance of the motor grader on the intended trajectory.

Therefore, selecting optimal values for these angles enables the motor grader to adjust to diverse operating conditions and maintain its trajectory within the specified adaptation criterion.

Based on the experimental investigation, regression equations were derived, correlating all four variable parameters [19, 20, 22].

The regression equations obtained enable the visualization and quantification of the impact of concurrent variations in multiple factors on road-holding stability indicators, specifically on the motor grader's deviation from the intended trajectory, both graphically and numerically.

The graphs depicting the relationship between the lateral displacement H of the motor grader and the front wheels' horizontal plane rotation angle γ as well as the vertical plane skew angle ρ, across various cross slopes of the supporting surface 0º…8º (Fig.6).

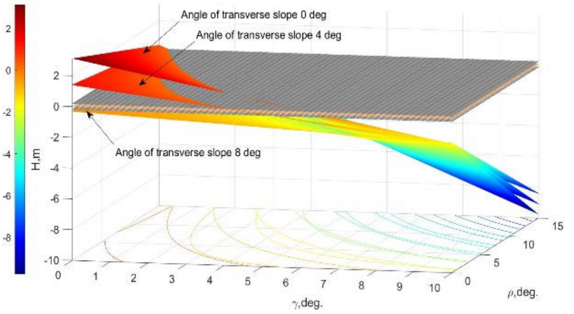


Fig. 6. The graph depicting the lateral displacement of the motor grader as a function of the horizontal steering angle and inclination in the vertical plane of the front wheels for various values of transverse slope of the supporting surface.

Similar graphs illustrating variations for different coefficients of friction are presented in Fig. 7. All depicted surfaces exhibit nonlinearity. The largest deviations from the intended trajectory of the motor grader were observed when the front axle wheels were tilted and turned at 10 degrees, resulting in deviations ranging from 8.5 to 10 meters over a grip length of 20 meters. Conversely, in the absence of tilt and turn of the front axle wheels $(\gamma = 0^\circ, \rho = 0^\circ)$, the deviations ranged from 1.5 to 3 meters.

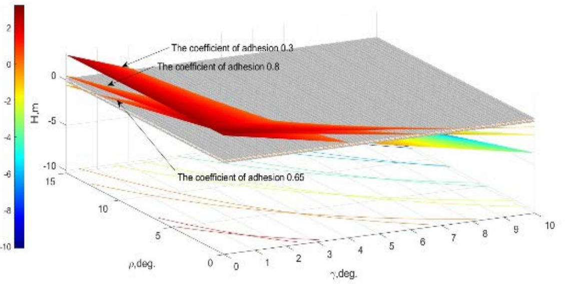


Fig. 7. The graph of the lateral displacement of the motor grader as a function of the steering angles in the horizontal plane and the inclination in the vertical plane of the front wheels for various coefficients of adhesion.

The examination of regression equations indicates that, given specific values of the cross slope and the coefficient of adhesion, it becomes feasible to establish the correlation between the angles γ and ρ ensuring the fulfillment of the road-holding stability criterion. Graphically (fig.6, 7), these multiple values intersect within the area defined by two parallel planes relative to zero displacement within the specified range – $\varepsilon_l = \pm 0.18$ m.

Hence, adapting a motor grader based on the road-holding stability criterion for various cross-slope angles of the supporting surface and adhesion coefficients involves selecting wheel alignment angles concurrently in both horizontal and vertical planes from the suggested options.

On the basis of the study, a system has been patented that allows you to automatically change the angles of the front wheels of the motor grader, and thereby ensure its directional stability in the course of technological operations. The system of automatic wheel tilt of a motor grader (Fig. 8) is controlled by a hydraulic control system for running equipment, consisting of a hydraulic cylinder for tilting the driving wheels, a pump with a safety valve, a hydraulic tank, and a hydraulic distributor [21]. Speed converters are installed on the output shafts of rotation of the driving wheels, and an electronic control unit is introduced, through which a signal is sent to a standard hydraulic distributor with proportional electromagnetic control, and system operation is controlled by feedback through a rod hydraulic cylinder displacement converter. Instead of pumps, drive wheel speed converters and a standard hydraulic valve with proportional solenoid control are used. The introduction of an electronic unit and control of the system operation by means of feedback in the form of a rod hydraulic cylinder movement converter significantly increase the accuracy and reliability of work.

Current and future developments

The main feature of modern earth-moving and loading machines is the performance of a wide range of different operations. In this case, the loading mode changes, which depends on the coordinates, the magnitudes of the applied forces acting on the machine, and their variations at each moment of the machine's forward movement. To enable a machine to adjust to these variables, it needs to be equipped with suitable systems. However, current calculation methods are limited in their ability to consider the full range of these factors. This article substantiates the methodological foundations for adapting earth-moving and loading machines to variable operating conditions.

The research aimed to intellectualize machines of these types. It's necessary to integrate various automation systems, constraining them under conditions to maintain road-holding ability, and develop an artificial intelligence module that makes optimal decisions based on data analysis.

Conclusions

In conclusion, the research presented in this scientific article demonstrates the efficacy of the proposed method for adapting EMM and LM systems to variable operating conditions. Through the synthesis of an adaptation system tailored to specific criteria, the study showcases its applicability, particularly in motor graders of classical design. This adaptation system simplifies the decision-making process by selecting optimal angles of rotation for the front wheels in the horizontal plane and corresponding skew angles in the vertical plane, based on predetermined graphical dependencies. The findings underscore the practical utility of this approach in enhancing the performance and operational versatility of motor graders, offering a promising avenue for further advancements in the field of construction and road machinery adaptation

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Адаптивний підхід до процесів виконання технологічних операцій землерийно-транспортними та вантажопідіймальними машинами

Анотація. Проблема. *Під час проєктування машин найчастіше розглядається їхня робота лише з основним видом робочого обладнання, зміна робочих органів з одночасною зміною режиму навантаження може призвести до зниження ефективності. Одним із можливих рішень є адаптація машин до мінливих умов експлуатації.* ***Мета.*** *Метою роботи є розробка основних положень методології адаптації землерийно-транспортних і вантажопідіймальних машин до мінливих умов експлуатації; впровадження даного підходу сприятиме підвищенню ефективності роботи техніки..* ***Методологія****. Синтезована система адаптації базується на структурному та параметричному підходах. Еволюційні зміни в структурі об'єкта розглядаються за допомогою переходу від однієї альтернативної моделі до іншої. Синтез корегувальних структурних адаптивних дій здійснюється шляхом евристичного пошуку. Запропонована методологія була експериментально перевірена на автогрейдері під час різання та переміщення оброблюваного середовища..* ***Результати.*** *Детальні експериментальні дослідження показали основні етапи формування траєкторії руху залежно від опору, що виникає на відвалі автогрейдера. Аналіз отриманих результатів продемонстрував, що кут бокового нахилу та коефіцієнт зчеплення є дестабілізуючими факторами, а варіювання кутів нахилу передніх коліс дозволяє утримувати автогрейдер на запланованій траєкторії руху.* ***Оригінальність.*** *Оригінальність дослідження полягає у розробці синтезованої системи адаптації автогрейдера, яка, на відміну від традиційних статичних моделей, базується на поєднанні* *структурного та параметричного підходів. Це досягається шляхом врахування еволюційних змін у структурі об'єкта через перехід між альтернативними моделями та синтезу корегувальних адаптивних дій з використанням методів евристичного пошуку. Новизна також підтверджується виявленням синергетичного впливу кута бокового нахилу та коефіцієнта зчеплення як ключових дестабілізуючих факторів, а також встановленням регресійних залежностей, що дозволяють у режимі реального часу регулювати кути нахилу передніх коліс для збереження заданої траєкторії руху в мінливих умовах експлуатації.* ***Практичне значення****. Отримані регресійні залежності дозволяють оцінювати одночасний вплив множини факторів на показники стійкості руху в графічному та числовому вигляді і, як наслідок, адаптувати параметри машини до мінливих умов роботи. На основі проведених досліджень розроблено та запатентовано систему автоматичного регулювання навантаження на колеса автогрейдера.*

Ключові слова: *землерийно-транспортні машини, виконання технологічних операцій, адаптація машин, формування траєкторії руху, траєкторія руху, метод адаптації, змінні умови експлуатації.*

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