THE ANALYTICAL RESEARCH OF THE DYNAMIC LOADING EFFECT ON THE ROAD-HOLDING ABILITY CHARACTERISTIC SIGNS OF EARTH-MOVING MACHINE

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Abstract: *In the process of performing of technological operations motor-graders are undergone severe loading conditions. The process of working medium development is accompanied by the action of time-varying parameters reluctances on the working equipment. At the situation of operative bodies blocking which are accompanied by intensive vehicle braking loads on working equipment are of shock character and can exceed considerably neutral layer of usual loads. Such loading can lead to the crabbing of the vehicle from projected path of motion. The developed dynamic model of earth-moving machine allows to take into consideration dynamic loads effect on the path configuration of its motion and formulate prompts to stabilize the characteristic signs of earth-moving machine road-holding ability.*

Keywords: EARTH-MOVING MACHINES (EMM), MOTOR GRADER, ROAD-HOLDING ABILITY CHARACTERISTIC SIGNS, DYNAMIC LOADING, PATH OF MOTION.

1. Introduction

One of the characteristic sings of earth-moving machines (EMM) road holding ability are parameters characterising the quality of the work performed. In particular for machines realizing earth fill building one of the main parameters is a holding ability characteristic sing shoving the crabbing of operating trajectory of working unit path of motion from the projected trajectory. In the cases if EMM path of motion crabs considerably from the projected trajectory the need arises to perform additional passage ways that inevitably leads to productivity decrease and energy requirement increase. Taking into consideration the general trend in the EMM development in the direction of global automatisation of carrying out technological operations up to excluding “man-operator” from regulating system problems of pilot operation of motion path under conditions of severe external power action become burning.

Peculiar features of EMM behavioral analysis in the process of carrying out technological operations are important for investigation of algorithm designs allowing machine regulating problems turn over on-board computer.

2. Analysis of publications

The review of scientific researches devoted to the problem of road holding ability loss in the process of technological operations showed that the greatest attention to this problem is devoted by the experts in the field of transport engineering, farm machine industry and earthmoving engineering. Among them: Podrygalo M. A., Pevsner Ya. M., Farobin Ya. Ye., Litvinov A. S., Knoroz V. I., Sevrov K. T., Alekseeva T. A., Artemiev K. F., Bromberg A. A., Malinovsky Ye. Yu., Koval A. B., Dontsov I. Ye., Bulgakov V. M., Usenko M. V., Prishlyak V. M., Tsygankov T. V., Artemov N. P., Huskov V. V., Ksenevich I. P., Petrov A. B. and others.

The loss of road-holding ability of vehicles (passenger cars and trucks) is linked first of all with the phenomenon of wheels drift which is caused by its elastic deflection in lateral direction while moving on turn. The reason of road-holding ability loss become centrifugal forces emerging at vehicle curvilinear motion [1, 2]. As a characteristic signs demonstrating the given process it is recommended to consider wheels coefficient.

$$k_y = \frac{d\gamma}{d\delta}. \qquad (1)$$

Or vehicle drift coefficient

$$k_{\text{y}} = \frac{\grave{a}}{b} \cdot \frac{R_{\delta 1}}{R_{\delta 2}}, \qquad (2)$$

where γ – transversal force acting along the wheel axle; δ – slip angle; a, b – projection coordinates of vehicle mass center into a horizontal plane; $R_{\delta 1}, R_{\delta 2}$ – road cornering force affecting wheels of front and rear axles.

As researches show the main reasons of road-holding ability loss are transversal efforts acting on working units, knee joint deformation between operating equipment and tool carrier as well as transverse grade of seating.

As a criterion of road-holding ability the authors use usually allowable transversal deflection in relation to initial trajectory [3]. Maximum allowable values of transversal deflections are assigned depending upon the kind of the technological operation performed. To estimate the mentioned parameters dynamic models of plane motion of articulated systems are considered. Comparison of the projected trajectory with the assigned one permits to estimate vehicle transversal deflection and offer actions excluding drift from the assigned trajectory.

The peculiar feature of the total drag formation acting on the operating equipment is the main reason of the EMM drift from path of motion. One can single out here two specific situations. When operating equipment has possibility of positioning in space as for example at motor-graders the resultant vector of external resistance may be positioned asymmetrically in relation to vehicle longitude axis [4, 5]. This phenomenon causes the emerging of the additional disturbing moments capable to drift the vehicle relatively the assigned path of motion. In this case the situation of static loading is considered most often. Herewith the characteristic sign of road-holding ability is estimated by means of coefficient:

$$k = \frac{M_s}{M_d} > 1,2, \qquad (3)$$

where M_s – stabilizing moment; M_d – disturbing moment.

The situation when operating mobile equipment is installed on the machine besides static loadings it is offered to take into consideration fatigue stressing [6]. Estimation of the road-holding parameters is carried out according to dependency (3), and as a main parameter determining the value of the stabilizing moment the coefficient of adhesion with supporting surface is applied.

All approaches considered as a rule don't take into consideration peculiar features of EMM lading, in particular motor graders, and correspondently don't determine exactly parameters value which characterise formation process of machine path of motion during technological operation realization.

The purpose and objectives

The development of motor grader motion mathematical model allowing to estimate objectively reasons of machine misalignment from initially assigned path of motion.

Factors affecting the formation of motor grader path of motion

Experimental studies carried out at the testing ground of the department of building and road machines of the Kharkiv National Automobile and Highway University allowed to single out a number of factors affecting the formation of motor grader path of motion at carrying out technological operations [7, 8, 9]. Firstly, one must stress that the motor grader path of motion is affected mostly by the peculiar features forming power pattern of machine landing namely:

- coefficient of application of resultant vector external impedances resultant vector on working equipment;
- direction of external impedances resultant vector;
- time variation character of external impedances.

All mentioned above parameters are variable and depend on type of technological operation performed and geometric parameters characterising operating unit position relatively medium developed.

For example at carrying out seating planning and profiling the expected application coordinate of external impedances vector $\sum W$ falls at blade midpoint (fig. 1, a). Soil gouging operations the point of application $\sum W$ misaligns to the blade edge (fig. 1, b).

As the resultant vector of external impedances is directed on the mitre to the machine longitudal axis it causes the emergence of the additional lateral loading W_s and misalignment of the resultant impedances vector $\sum W$ in relation to longitudal axis emergence of additional torques in horizontal plane. Both these factors may lead to the variation of machine path of motion.

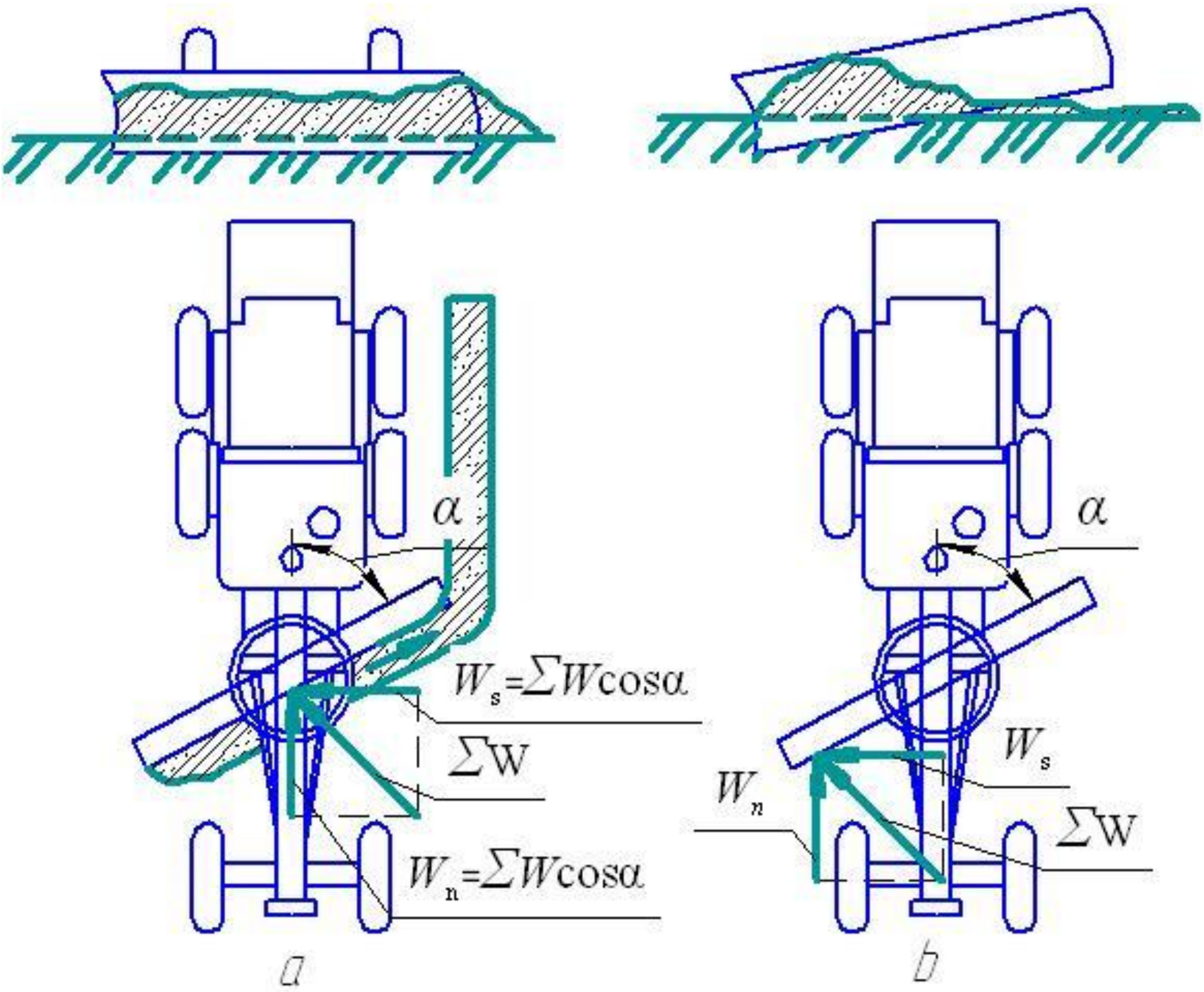

Fig.1 *Application coordinate variation impedances resultant vector determining upon the type of the operation performed: a – seating planning and profiling; b – soil gouging*

The performed experimental studies [7, 8] showed that in case of road cut in accordance with the scheme presented on the fig. 1, b, the possibility of misalignment of the real trajectory from the planned one will increase considerably. One must mark especially path configuration of motion which consists of linear selections. From the physical viewpoint motor graders motion is implemented in the following way (fig. 2). At the section of AB trajectory soil gouging and formation from it the prism in front of blade. This leads to the growth of $\sum W$ values. At the point A it machine stops and simultaneously turn about the point of the blade barring which coincides with the application coordinate of the resultant vector external impedances $\sum W$. While motor grader turning the volume of soil prisms decreases and consequently decreases the $\sum W$ value.

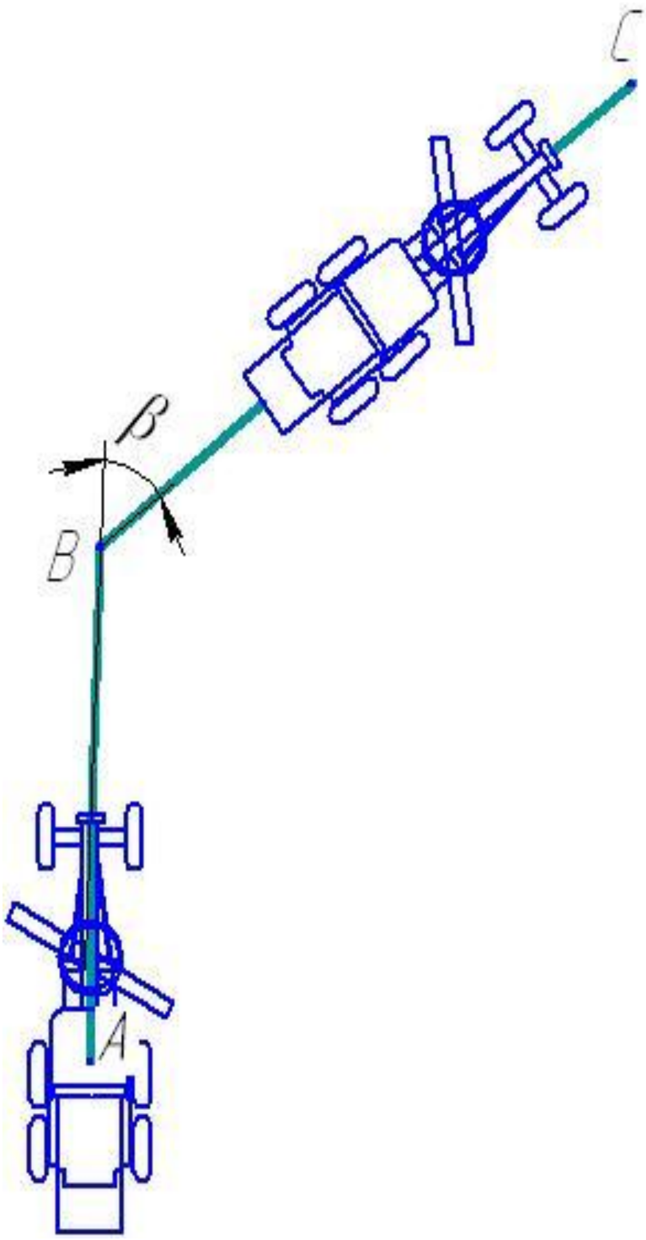

Fig.2 *Motor grader path of motion*

Machine turn is realized by means of wheels transversal motion. Herewith practically 100% of driving wheels spinning is registered. After turn the motor grader shifting along linear path of motion occurs. The given process may repeat further.

As the load on the operating equipment from the part of the developed medium may change in the function of motor grader misalignment for analytical studies of its path of motion it is necessary to consider the dynamic model taking into consideration the results of the experimental researches carried out.

In the process of compiling dynamic model the following simplifications were adopted:

- road cut is carried out on the horizontal location without top and side rakes;
- tractive efforts are developed by motor grader balance truck. Herewith the front axle is driven. This arrangement is characteristic for 70% of motor graders produced;
- cut soil homogeneous and possesses isotropy properties. This simplifications permits to use the determined dependencies for resistance forces description.

While developing motor grader's dynamic model the authors were coming to conclusion that the formation process of the path of motion may be described objectively by means of two different dynamic models:

1. at the initial stage of motion motor grader may be considered as the body performing plane motion along surface (fig. 3);
2. at the moment of barring operating equipment (blade) the application coordinate of resultant vector external impedances may be considered as unique point of attachment. Herewith motor grader perform rotating motion around this point (fig. 4).

Fig.3 calculation model corresponds to the plane motion of motor grader. As all the forces acting in the system are functions x, y, φ, $\dot{x}$, $\dot{y}$, $\dot{\varphi}$, then the path of motion can be determined in terms of shell's equation [10, 11]:

$$\begin{cases} m\ddot{x}_c = \sum_{k=1}^{n} F_{kx}^{e} \\ m\ddot{y}_c = \sum_{k=1}^{n} F_{ky}^{e} \\ m\ddot{\varphi}_c = \sum_{k=1}^{m} m_c(F_{kx}^{e}) \end{cases} \qquad (4),$$

where m - motor grader's mass; y_c - motor grader inertia about axis passing over its mass center C; $\sum_{k=1}^{n} F_{kx}^{e}$ - the sums of projections of all external forces on the axis Ox; $\sum_{k=1}^{n} F_{ky}^{e}$ - the sums of projections of all external forces on the axis Oy; $\sum_{k=1}^{m} m_c(F_{kx}^{e})$ - - the sums of torques of all external forces in relation to C.

So, to describe path of motion three generic coordinates are used: misalignment along axis x, y and turn φ around machine mass center.

We receive the following system of the second power differential equations:

$$\begin{cases} m\ddot{x}_c = (T_1 + T_2 - W_{f1} - W_{f2} - W_n - W_{fn}) \cdot \cos(\varphi_0 + \varphi) - \\ -(P_{\acute{a}1} + P_{\acute{a}2} + W_s - P_{\acute{a}n}) \cdot \sin(\varphi_0 + \varphi) \\ m\ddot{y}_c = (T_1 + T_2 - W_{f1} - W_{f2} - W_n - W_{fn}) \cdot \sin(\varphi_0 + \varphi) + \\ +(P_{\acute{a}1} + P_{\acute{a}2} + W_s - P_{\acute{a}n}) \cdot \cos(\varphi_0 + \varphi) \\ m\ddot{\varphi}_c = (-T_1 + T_2 + W_{f1} - W_{f2}) \cdot \frac{l_{\acute{a}}}{2} - (P_{\acute{a}1} + P_{\acute{a}2}) \cdot l_1 + \\ +W_s \cdot l_2 + W_n \cdot l_3 - P_{\acute{a}n} \cdot l_3 \end{cases} \qquad (5),$$

where T_1, T_2 - tractive efforts developed by right and left sides correspondently; W_{f1}, W_{f2} - the forces resisting the rolling of the right and left balance truck; W_{fn} - the forces resisting the rolling of the front axle wheels; $P_{\acute{a}1}, P_{\acute{a}2}, P_{\acute{a}n}$ - the forces resisting the skidding of the right and left balance truck wheels as well as front axle; φ_0 - start angle of motor grader longitudinal axis.

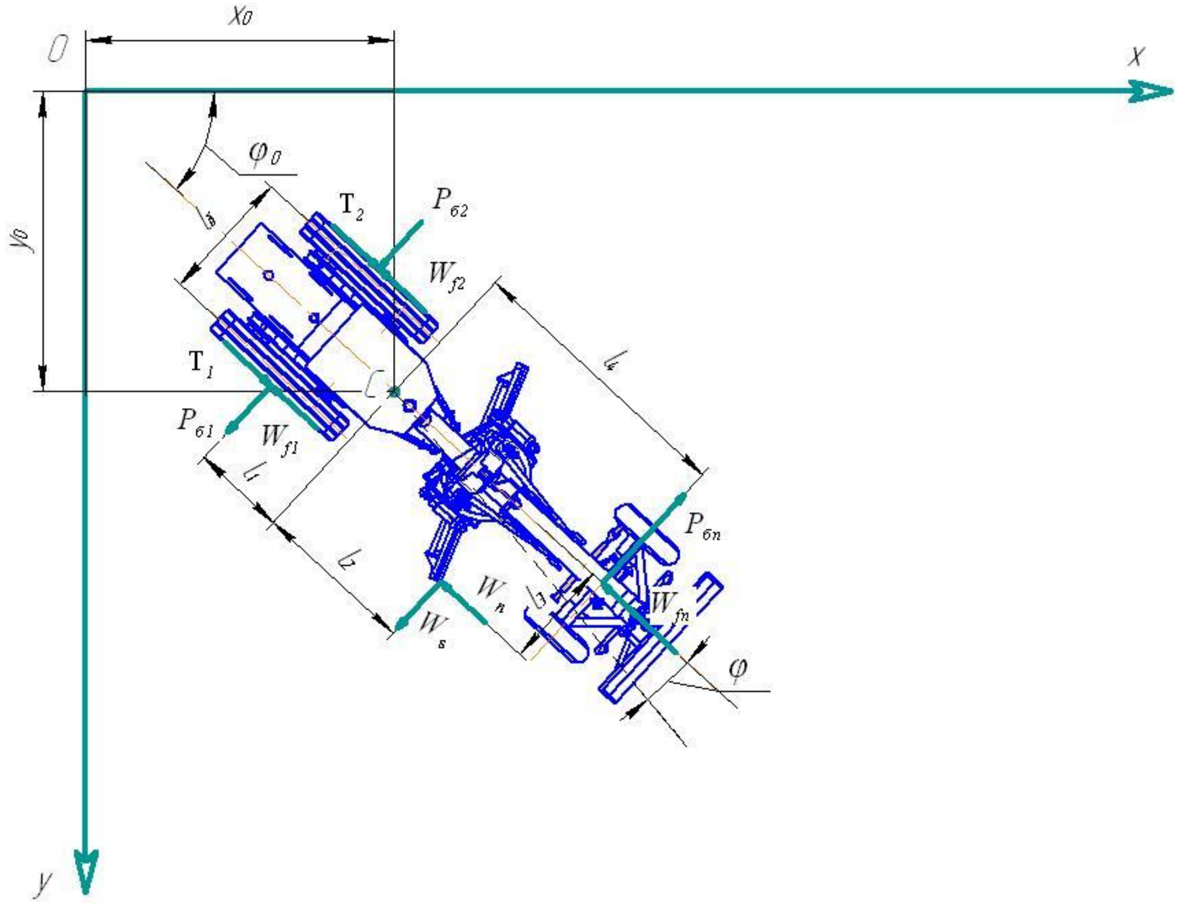

Fig.3 *Calculation model for the case of motor grader motion at the initial stage.*

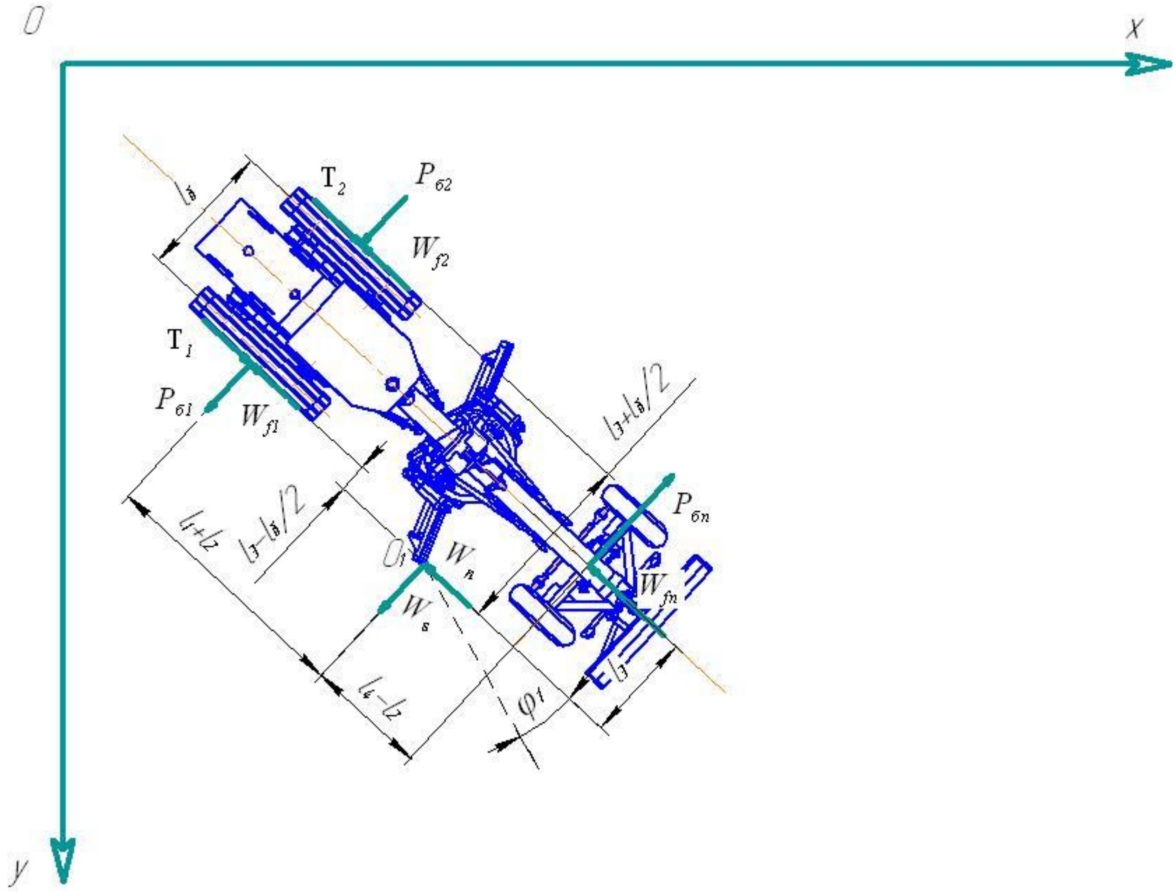

Fig.4 *Calculation model for the second stage of motor grader motion (turn around O_1)*

At the second stage of motion while crossing over motor grader in the 100% mode of skidding the turn of machine in relation to blade O_1 blocking point may start. In this case the equation of motion is described by the equation:

$$I_{O_1} \cdot \ddot{\varphi}_1 = \sum_{k=1}^{m} m_{O_1}(F_k^e), \qquad (6),$$

Or after transformations

$$\left[I_c + m \cdot (\frac{l_{\acute{a}}^2}{4} + l_2^2) \right] \cdot \ddot{\varphi}_1 = (T_1 - W_{f1}) \cdot (l_3 - \frac{l_{\acute{a}}}{2}) + \\ +(T_2 - W_{f2}) \cdot (l_3 - \frac{l_{\acute{a}}}{2}) - (P_{\acute{a}1} + P_{\acute{a}2}) \cdot (l_1 + l_2) - \qquad (7). \\ -P_{\acute{a}n} \cdot (l_4 + l_2) - W_{fn} \cdot l_3$$

Transition from equations system (5) to the dependence (7) occurs in the case when the total force of traction $\sum T = T_1 + T_2$ will be equal tractive force according to the conditions of greaten wheeled move with s.

Each of the forces compelling equations (5) and (7) depends upon are the velocity or motor grader acceleration [12]. In the process in machine motions this parameters will change. In the context of problem decide sold by us the estimations of the possibility of misalignment of the motor grader real path of motions from the planned one remains current.

The study cases of the comp roost dynamic models to needs to put down the conditions of motor grader road-holding ability loss:

at the first stage of motion

$$k_1 = \frac{T_1 \cdot \frac{l_{\acute{a}}}{2} + W_{f2} \cdot \frac{l_{\acute{a}}}{2} + (P_{\acute{a}1} + P_{\acute{a}2}) \cdot l_1 + P_{\acute{a}n} \cdot l_4}{T_2 \cdot \frac{l_{\acute{a}}}{2} + W_{f1} \cdot \frac{l_{\acute{a}}}{2} + W_n \cdot l_3 + W_s \cdot l_2} \le 1; \qquad (8)$$

at the second stage of motion

$$k_2 = \frac{(P_{\acute{a}1} + P_{\acute{a}2}) \cdot (l_1 + l_2) + W_{f1} \cdot (l_3 - \frac{l_{\acute{a}}}{2}) + W_{f2} \cdot (l_3 + \frac{l_{\acute{a}}}{2}) + P_{\acute{a}n} \cdot (l_4 - l_2) + W_{fn} \cdot l_3}{\left[I_c + m \cdot (\frac{l_{\acute{a}}^2}{4} + l_2^2) \right] \cdot \ddot{\varphi}_1 + T_1 \cdot (l_3 - \frac{l_{\acute{a}}}{2}) + T_2 \cdot (l_3 + \frac{l_{\acute{a}}}{2})} \le 1; \qquad (9)$$

As causations when wraith wield performed technological operating by the motor grader it is necessary to carry out their recalculation during the whole operating period.

Conclusions

In terms of the carried out researches one can conclusions:

1. For the period of technological operating realization motor graders path of motion can be described by means of two dynamic models: plane motion of machine in the surface plane and rotary motion in relation to blade blocking point;

2. The calculus of the numerical values of motion stability coefficient k_1 and k_2 permits on the basis of analytical calculation determine if would occur the misalignment of motor grader real path of motion from planned one

References

1. Устойчивость колесных машин при заносе и способы ее повышения / [Подригало М.А., Волков В.П., Доброгорский М.В., Степанов В.Ю.]. – Харьков: Изд-во ХНАДУ, 2006. – 335 с.

2. Литвинов А.С. Автомобиль: Теория эксплуатационных свойств [учебник для вузов]/Литвинов А. С, Фаробин Я.Е — М.: Машиностроение, 1989. – 240 с.

3 Артемов Н.П. Повышение устойчивости движения піхотного агрегата при изменении технических параметров системы управления : автореф. дис. на здобуття наук. ступеня канд. техн. наук : спец. 05.05.11 «Машины и средства механизации сельскохозяйственного производства» / Н.П. Артемов. – Х., 2006. – 179 с.

4. Севров К.П. Автогрейдеры. Конструкции, теория, расчет / К.П. Севров, Б.В. Горячко, А.А. Покровский. – М. – Машиностроение, 1970. – С. 95–121

5. Дорожные машины. Машины для земляных работ / [Алексеева Т.В., Артемьев К.А., Бромберг А.А. и др.]; [Изд. 3-е, перераб. и доп.]. — М.: Машиностроение, 1972. — 504с.

6. Коваль А.Б. Визначення умов забезпечення курсової стійкості універсальних землерийних машин : автореф. дис. на здобуття наук. ступеня канд. техн. наук : спец. 05.05.04 «Машини для земляних, дорожніх і лісотехнічних робіт» / А.Б. Коваль. – Дніпропетровськ, 2014. – 21 с.

7. Чаплыгина А.М Экспериментальное оценка показателей курсовой устойчивости автогрейдера/ А.М Чаплыгина // Вестник НУВГП. – Рівне: Изд-во НУВГП, 2015. – № 2(70) – С. 342 – 353.

8. Chaplygina O. Methods to determine measures providing a motor-grader road-holding ability/ O. Chaplygina, V. Shevchenko, Zh. Beztsennaya // "Machines, Technologies, Materials "INTERNATIONAL JOURNAL, issue 12/2015, ISSN 1313-0226 – Sofia, Bulgaria: Publisher scientific technical union of mechanical engineering, 2015 p.78-83

9. Chaplygina A.M. Road-holding ability of the motor grader in the process of performing work operations / A.M.Chaplygina, V.O.Shevchenko, Zh.P. Beztsennaya // VIII International Conference. Heavy Machinery-HM 2014 Proceedings – Zlatibor, 2014 – С. 59–67.

10. Курс теоретической механики. Том 2. Динамика (2-е издание). / [Бутенин Н.В., Лунц Я.Л., Меркин Д.Р.] – М.: Наука. Физматлит, 1979. – 544 с.

11. Бать М. И. Теоретическая механика в примерах и задачах: в 3 т./ М. И. Бать, Г.Ю Джанелидзе., А.С. Кельзон/. Изд. 9. – М.: Наука, 1990. -1309 с.

12. Shevchenko V. The analitical research of the process of forming the motor-grader motion path at implementation of working operations / V. Shevchenko, A. Chaplygina, Zh. Beztsennaya // International scientific journal trans & motauto world, issue 2/2017, ISSN 2367-8399 – Scientific technical union of mechanical engineering industry-4.0, Sofia, Bulgaria, 2017 – С. 81–84.