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Imitation modeling and Calculation of the parameters ofLateral forces components of guide wheels of Cotton-picker MH-1.8

B.M.Azimov, D.K.Yakubjanova

Professor, The Center for Software and Hardware-Software Development Complexes at the Tashkent University of Information Technologies, Tashkent, Uzbekistan
Senior Lecturer, Samarkand branch of Tashkent university of Informational technology, Samarkand, Uzbekistan

ABSTRACT: Models and algorithms for optimal control of guide wheels of cotton-picker MH-1.8 are developed in the paper on the basis of the derived equations of motion. The values of vertical and horizontal oscillations of cotton-pickerMH-1.8 (HUM MH-1.8) are determined in the course of motion along the roughness on turning strips of cotton fields, as well as the values of grip coefficient of the steering wheels, which reduce the accuracy of turning and create difficulties for the orientation of the driver-mechanic when driving. The shortcomings of the means of turning the HUM MH-1.8 with rear steering wheels are revealed: the complexity of the steering control drive, the uneven distribution of the mass between the front, guide and rear steering wheels.

KEY WORDS: Cotton-picking machine, Steering wheels, Modeling, Optimal control, Lateral forces.

I.INTRODUCTION

The tasks of research, analysis of the processes of developing and improving the conceptual basis of fundamental principles, methods that determine the qualitative control of machine and tractor units are directly related to the definition and evaluation of their analytical and information characteristics. This predetermines the practical possibilities for the formation of simulation processes in calculation of the components of lateral forces of guide wheels of a cotton picker.

The stages of research and development of these methods, models, algorithms and software complexes for the implementation of the problems are aimed at solving complex technological, hydraulic and technical and economic problems associated with determining relevant indicators and making decisions on the analysis of operation and day-to-day management of machine and tractor units.

Machine and tractor units are the working sections of machine-testing systems, and, as complex technical control systems, occupy a fundamentally important place in the complex tasks of modeling the processes of functioning and optimizing the parameters of hinged systems of these units [1].

The study of these systems development, their evaluation and management are conditioned by the interrelationship of two objective structural components:

- internal quantitative and qualitative changes occurring in the structure and functioning of this system;
- external changes caused by the influence of uncontrolled external excitations of various kinds and nature.

Currently, existing methods and approaches to the actual analysis of operation and day-to-day management of machine and tractor units in a complex, including cotton picking machines, require constant improvement, allowing to show all sets of emergency situations occurring in this complex.

The development of such a system takes on an actual urgency when researching the tasks of guiding the cotton harvesting machines that allow to assess, at a qualitatively new level, the technical, technological and environmental conditions affecting the machine performance, at the same time, reducing the maintenance costs of the entire complex.

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II. LITERATURE SURVEY

Analysis of methods of mathematical modeling in assessing the identification of indicators of the functioning of technological machines and systems in recent years shows that the studies conducted are characterized by not very precise values of the parameters of control objects to support transient processes within established limits due to the absence of interacting subsystems for assessing the state and control. The necessity and urgency of research in this field is due to insufficient knowledge of the application of a multilevel structure of modeling and optimal control of dynamic regimes in the process of identifying the parameters of technological machines.

Studies aimed at analyzing and assessing the manageability and sustainability of cotton-pickers are due to a number of common technical parameters. These parameters affect the controllability and stability of the machine unequally, which requires consideration of the issues of improving and developing methods of analytical and simulation and applied modeling to assess these properties together, while highlighting the effects inherent in each property.

K. Shannon substantiates that the behavior of the system, the principles of constructing theories and hypotheses, which can explain the observed behavior, are described on the basis of simulation modeling. The use of these theories to predict future behavior and evaluate various strategies ensures the effective functioning of this system. These rules and hypotheses are aimed at researching, to a greater extent, those systems for which all classical methods of mathematics and modeling are possible.

S.Yu. Zhuravlev notes that when solving certain technical problems of the functioning of complex systems, the problem usually arises of establishing the functional dependence of the output parameters of the system on the input effects. The problem of describing this dependence with the help of classical analytical methods is rather complicated. Therefore, the question arises of the use of more adequate or less demanding and at the same time more effective methods of optimization. It is estimated that genetic algorithms can be used as such methods, within the framework of which the modeling of processes based on evolution is applied.

G.Tayanovsky, V.Tanas developed methodical methods for estimating dynamic tractor attach ability on a mathematical model using the Monte Carlo statistical test method. A system of equations describing the oscillations of the adopted model was compiled using the d'Alembert principle. To solve the system of differential equations, the fourth-order Runge-Kutta method was used.

S.V. Kalachin examines the optimization of operating modes of the machine-tractor unit based on the developed:
- mathematical model of the functioning of the machine-tractor unit, which is the basis for the development of models for forecasting changes in operational parameters, taking into account the way of realizing the power of the tractor engine;
- a complex system of mathematical models for predicting changes in controlled operational parameters, taking into account the probabilistic nature of changes in the external load, dynamic properties, technical condition and operation modes of the machine-tractor unit;
- mathematical model of multi criteria optimization of the operation modes of the machine-tractor unit taking into account the methods of operational control.

III. PROBLEM STATEMENT AND METHODS OF SOLUTION

The problem of developing a model and an algorithm for optimal control of the steering wheels of a cotton picking machine MH - 1.8 is solved to determine the values of vertical and horizontal oscillations of HUM MH-1.8 during machine motion along the roughness on the turning strips of cotton fields. At the same time, the grip coefficient of guide wheels influencing the accuracy of the turn of cotton picker is also estimated.

At the initial stage of the study, technical characteristics and parameters of the kinematics of the turn of cotton picking machine HUM MH-1.8 are given, the problem being solved in curvilinear motion: the turning radius, the displacement of the turning center, angular and linear velocities, the motion of tractor wheels, the trajectory of its motion – all these depend on structural and operational factors.

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In real operating conditions of the tractor curvilinear motion, there is always observed a wheel slipper. Estimate the ratios of the angles of rotation of different wheels, assuming that the wheels are rigid in lateral direction, i.e. there is no wheel slipper and the wheels roll in the plane of their rotation [2-4].

Taking into account the above, we shall generalize a mathematical model that simulates the HUM MH-1.8 oscillations in the course of motion along the roughness on turning strips of cotton fields in the form of Lagrange equations of the second kind [5-7].

- for horizontal oscillations:

$$\left.\begin{aligned} &m_{м}\ddot{x}_{м} = F_x - b_1(\dot{x}_{м} - \dot{x}_1) - c_1(x_{м} - x_1) - b_2(\dot{x}_{м} - \dot{x}_2) - c_2(x_{м} - x_2) \\ &(m_1 + m_3)\ddot{x}_1 = b_1(\dot{x}_{м} - \dot{x}_1) + c_1(x_{м} - x_1) + (m_1 + m_3)\frac{4\pi^2 V_{м}^2}{l_n^2} r_1 \sin\frac{2\pi V_{м}}{l_n} t \\ &(m_2 - m_3)\ddot{x}_2 = b_2(\dot{x}_{м} - \dot{x}_2) + c_2(x_{м} - x_2) + (m_2 - m_3)\frac{4\pi^2 V_{м}^2}{l_n^2} r_2 \sin\frac{2\pi V_{м}}{l_n} t \end{aligned}\right\}, \quad (1)$$

- for vertical oscillations:

$$\left.\begin{aligned} &m_{м}\ddot{y}_{м} = F_y - b_1(\dot{y}_{м} - \dot{y}_1) - c_1(y_{м} - y_1) - b_2(\dot{y}_{м} - \dot{y}_2) - c_2(y_{м} - y_2) \\ &(m_1 + m_3)\ddot{y}_1 = b_1(\dot{y}_{м} - \dot{y}_1) + c_1(y_{м} - y_1) - (m_1 + m_3)\frac{4\pi^2 V_{м}^2}{l_n^2} r_1 \cos\frac{2\pi V_{м}}{l_n} t \\ &(m_2 - m_3)\ddot{y}_2 = b_2(\dot{y}_{м} - \dot{y}_2) + c_2(y_{м} - y_2) - (m_2 - m_3)\frac{4\pi^2 V_{м}^2}{l_n^2} r_2 \cos\frac{2\pi V_{м}}{l_n} t \end{aligned}\right\}, \quad (2)$$

Where $b_{i,}$, c_i–are viscous drag coefficient and tire rate of machine wheel, respectively; m_i- the mass distributed over machine supports; $r_1 r_2$– dynamic radii of the driving and driven wheels of machine; $V_{м}$- is a machine speed; l_1,$l_2$andl_n– are the distances between the supports and roughness.

In testing the machines under given operating conditions, the quality criterion can be thevalue of operation speed.

When investigating the necessary conditions for optimal control, the Pontryagin maximum principle is used [8,9].

To formulate the maximum principle, the Hamilton-Pontryagin function is introduced

$$H = (q,u,t,\psi_i,\psi_0) = -f^0(q,u,t) + \langle\psi,u\rangle \quad (3)$$

into conjugate system

− for horizontal oscillations:

$$\left.\begin{aligned} &\frac{d\psi_1}{dt} = -\frac{\partial H_x}{\partial x_1} = -m_{м}^{-1}(c_1 - c_2)\psi_2, \quad \frac{d\psi_2}{dt} = -\frac{\partial H_x}{\partial x_2} = -\psi_1 + m_{м}^{-1}(b_1 - b_2)\psi_2 \\ &\frac{d\psi_1}{dt} = -\frac{\partial H_1}{\partial x_3} = -(m_1 + m_3)^{-1} c_1\psi_2, \quad \frac{d\psi_2}{dt} = -\frac{\partial H_1}{\partial x_4} = -\psi_1 + (m_1 + m_3)^{-1} b_1\psi_2 \\ &\frac{d\psi_1}{dt} = -\frac{\partial H_2}{\partial x_5} = -(m_2 - m_3)^{-1} c_2\psi_2, \quad \frac{d\psi_2}{dt} = -\frac{\partial H_2}{\partial x_6} = -\psi_1 + (m_2 - m_3)^{-1} b_2\psi_2 \end{aligned}\right\}, \quad (4)$$

− for vertical oscillations:

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$$\left.\begin{array}{l}\dfrac{d\psi_1}{dt}=-\dfrac{\partial H_y}{\partial y_1}=-m_M^{-1}(c_1-c_2)\psi_2,\;\dfrac{d\psi_2}{dt}=-\dfrac{\partial H_x}{\partial y_2}=-\psi_1+m_M^{-1}(b_1-b_2)\psi_2\\ \dfrac{d\psi_1}{dt}=-\dfrac{\partial H_1}{\partial y_3}=-(m_1+m_3)^{-1}c_1\psi_2,\;\dfrac{d\psi_2}{dt}=-\dfrac{\partial H_1}{\partial y_4}=-\psi_1+(m_1+m_3)^{-1}b_1\psi_2\\ \dfrac{d\psi_1}{dt}=-\dfrac{\partial H_2}{\partial y_5}=-(m_2-m_3)^{-1}c_2\psi_2,\;\dfrac{d\psi_2}{dt}=-\dfrac{\partial H_2}{\partial y_6}=-\psi_1+(m_2-m_3)^{-1}b_2\psi_2\end{array}\right\}\quad (4a)$$

with restriction on control $|u|\leq 1$.

Solving the problem under consideration, a fulfillment of necessary condition was investigated [7] and, according to the Pontryagin maximum principle, the structure of optimal control of guide wheels motion of a cotton picker was formed. To determine the auxiliary functions (4), (4a) by a numerical method, the conjugate system with variation of structural parameters b_i, c_i, j_i is investigated.

Evaluation of above analytical and calculation modules is carried out by the numerical Runge-Kutt method.

The control $u_k(t)$, providing the maximum of functions for the necessary condition [7], is defined in the region of specified control $u_k(t)$, which can have only one switching point.

Thus, from the Pontryagin maximum principle, the structure of an imitation model is obtained; it makes possible to estimate the parameters of the components of lateral forces of guide wheels of a cotton picker MH-1.8.

IV. COMPUTATIONAL EXPERIMENT ANDITSRESULTS

Computational experiment was carried out at the following values of the parameters of cotton harvestingmachineMH-1.8: c_1=1433381.14 N/m; b_1 = 17287.226 Ns/m; c_2=795501.8 N/m; b_2= 9594.11 Ns/m; m_M=7714 kg; m_1=5114 kg; m_2=2600 kg; m_3=1262 kg; r_1=0.74 m; r_2=0.4175m; V_M=1.21m/s; $F_k=F_x=17200N$; $F_y=F_x\sin\dfrac{2\pi V_M}{l_n}t$; $F_3=m_3\ddot{y}_{K_1}$, diagram of transition processes is shown in the following figure

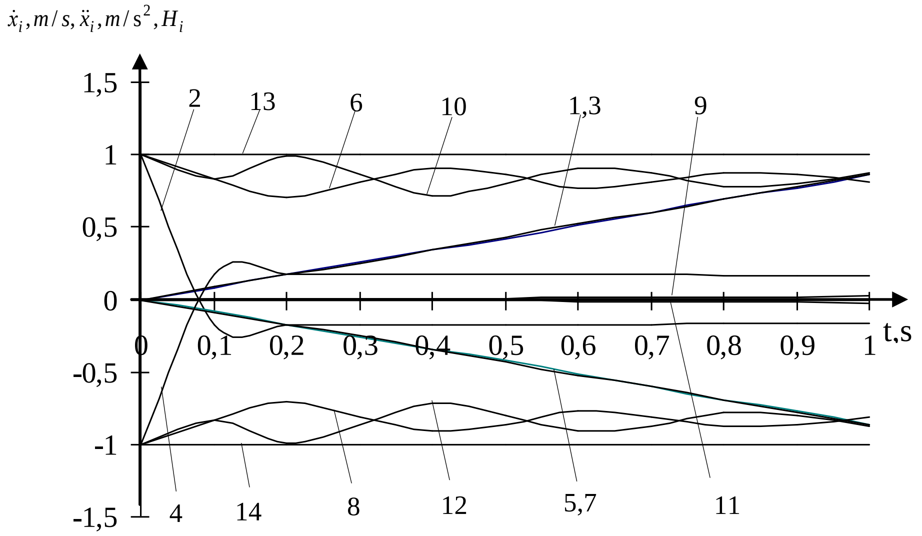

Figure 1. Diagram of transition processes: 1,3,5,7,9,11 – angular velocities $\dot{x}_M, \dot{x}_1, \dot{x}_2$; 2,4,6,8.10,12 - angular accelerations $\ddot{x}_M, \ddot{x}_1, \ddot{x}_2$ and 13,14 – *H*-functions for horizontal oscillations of HUM MH-1.8 at 1,2,3,6,9,10,13 - u(t)= +1; 4,5,7,8,11,12,14 - atu(t)= - 1.

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As a result of computational experiments, graphical dependences of velocities and accelerations for horizontal oscillation of a cotton picker are obtained, as well as the maximum value of *H*-function; the values are given in Tables 1 and 2.

Table 1. Parameters values of longitudinal oscillations of HUM

T. s	$\dot{x}_M$, m/s	$\ddot{x}_M$, m/s^2	$F_{ì}$, N	$\dot{x}_1$, m/s	$\ddot{x}_1$, m/s^2	F_{k1}, N	$\dot{x}_2$, m/s	$\ddot{x}_2$, m/s^2	F_{k2}, m/s
1	2	3	4	5	6	7	8	9	10
0	0	2.23	17200	0	0	0	0	0	0
0.1	0.15	0.52	4040	0.07	1.86	9549	0.12	2.7	3609.82
0.2	0.22	0.73	5631.5	0.25	2.1	10751	0.28	0.61	816.98
0.3	0.35	1.3	9983.7	0.38	1.14	5827.36	0.31	1.04	1389.5
0.4	0.49	1.01	7831	0.47	1.15	5904.21	0.48	2.6	3466.32
0.5	0.61	0.98	7604	0.59	1.61	8268.3	0.64	0.99	1330.7
0.6	0.71	0.93	7217.2	0.73	1.68	8600.6	0.7	1.03	1387.5
0.7	0.84	1.03	7951.9	0.86	1.32	6774.1	0.83	1.85	2482.48
0.8	0.97	1.1	8513.6	0.96	1.3	6658.9	0.98	1.52	2040.36
0.9	1.09	0.95	7353.7	1.08	1.6	8127.4	1.09	1.3	1737.41
1	1.21	0.97	7487.9	1.22	1.54	7872.6	1.2	1.4	1864.5

Figure 2 shows the graphical characteristics of parameters change in motionof cotton harvesting machine MH-1.8 for horizontal oscillations.

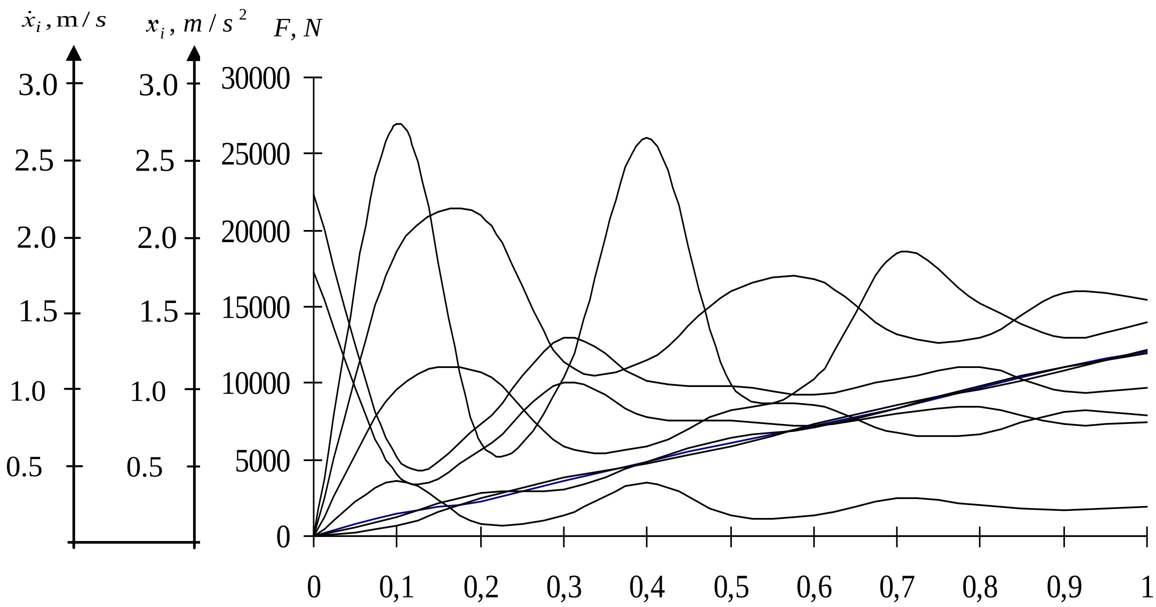

Figure 2.Patternoftheparameterschange in motion of HUM MH-1.8 for horizontal oscillations

Thus, the steadiness of machine motion depends on the mass and parameters of controlled axes, the values of which are determined by numerical solution of system (1), (2) and conjugate system (4), (4a) with the variation of motion parameters F_i and the design parameters *b*, *c*, $j_i$for given road roughness.

As is known, at curvilinear motion of HUM MH-1.8, an additional component of lateral force increases, and slippage of the tire on the bearing area occurs. Here, the motion steadiness is affected not only by the rate of turn, but also by elastic and damping characteristics of the entire steering linkage and tires.

Consider the kinematic scheme of HUM MH-1.8 turn with front driving and rear controlled wheels (Figure 2). Let's assume that HUM MH-1.8 moves with a slow constant speed and the centrifugal force can be neglected.

Table 2.Parametersvaluesofverticaloscillations of HUM

T. s	$\dot{y}_M$, m/s	$\ddot{y}_м$, m/s^2	$F_ì$, N	$\dot{y}_1$, m/s	$\ddot{y}_1$, m/s^2	F_{k1}, H	$\dot{y}_2$, m/s	$\ddot{y}_2$, m/s^2	F_{k2}, m/s
1	2	3	4	5	6	7	8	9	10
0	0	0.34	2666	0	0	0	0	0	0
0.1	0.024	0.08	626.25	0.01	0.29	1480.2	0.018	0.42	559.52
0.2	0.035	0.11	872.84	0.039	0.32	1666.5	0.043	0.094	126.64
0.3	0.05	0.2	1547.43	0.06	0.17	903.17	0.048	0.16	215.38
0.4	0.07	0.15	1213.52	0.07	0.18	915.13	0.075	0.4	537.33
0.5	0.09	0.15	1177.7	0.09	0.25	1281.7	0.099	0.15	206.52
0.6	0.11	0.14	1118.15	0.11	0.26	1332.7	0.11	0.16	215.08
0.7	0.13	0.16	1231.8	0.13	0.2	1049.1	0.13	0.28	385
0.8	0.15	0.17	1317.97	0.15	0.2	1031.2	0.15	0.23	316.75
0.9	0.17	0.147	1137.8	0.17	0.24	1258.5	0.17	0.2	269.6
1	0.18	0.149	1156.41	0.19	0.23	1219.4	0.187	0.21	290.02

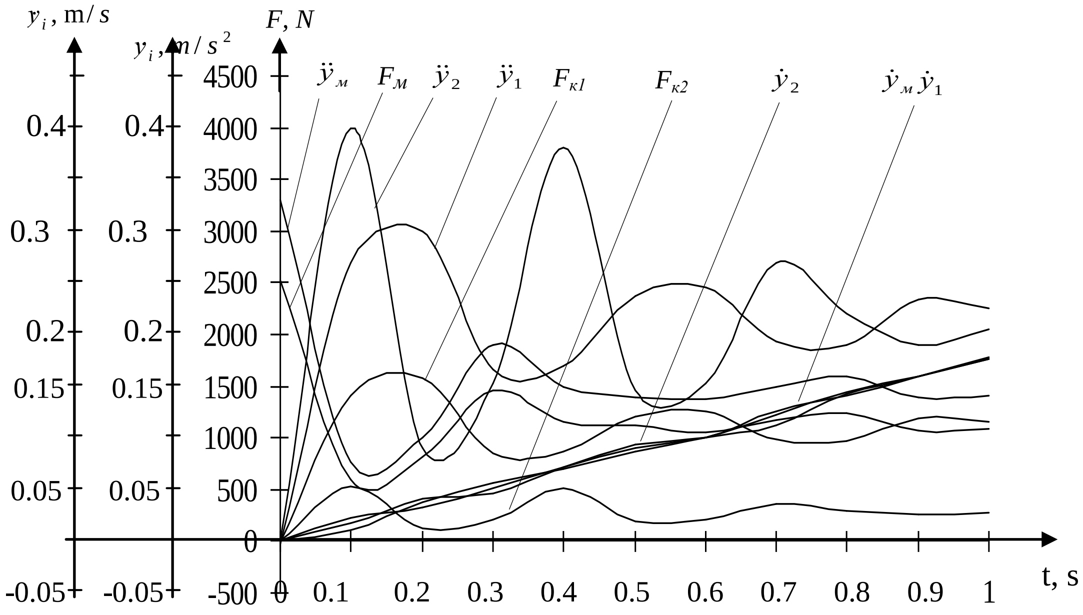

Figure 3.PatternofparameterschangeofHUMMH -1.8 for vertical oscillations

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Tangential traction force of the front axle $F_к$ is applied at point A_1 and is directed along the longitudinal axis of the tractor. In this case, the point A_1 moves at a speed V_1 in the direction of traction force action of the front axle, since in the absence of lateral forces there are no reasons for its change. The steering wheels of the rear axle, turned by wheel base angle $\alpha = 49.15^o$, are moved by drag force $F_{пром.} = (m_2 - m_3)\ddot{x}_2$ transmitted to the axle from longitudinal frame of the HUM. The drag force is applied at point $B_1$and acts along the longitudinal frame of HUM MH-1.8. This force is expanded into two components: a force $F_л = F_{пром.}\cos\alpha$ directed at an angle α to the longitudinal axis of machine and a force $F_п = F_{пром.}\sin\alpha$ perpendicular to the force F_{k1}.

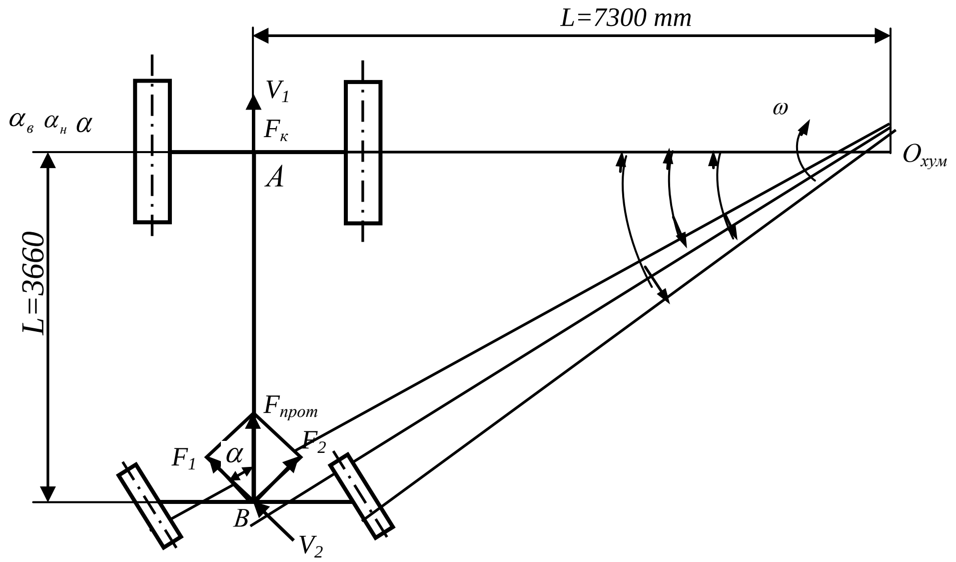

Figure 4. Kinematic scheme of the turn of HUMMH1.8 with rear controlled wheels

Analyzing the results obtained, the following can be noted: at curvilinear motion of HUM, the main parameters determining the turning of machine are the tractor base, the wheel base angle of the steering wheels and the slip angles of the front and rear axles. It should be noted that the slip angles of the front and rear axle of the tractor (their values and changes) will have a significant impact on the kinematics of machine turning. It is the presence of lateral skid that is the main source of significant deviations from the specified trajectory of HUM motion on turning strips of cotton fields. Moreover, their influence will be rendered to a greater extent under conditions of HUM motion on unstable soils: in the early spring period, in the period of soil water logging, etc. In addition, the lateral skid is the same parameter that reflects the impact on the machine of external force factors accompanying the curvilinear motion.

Under real operating conditions, slip angles δ_i of lateral skid can reach the value from $7^0$to 12^0[2,9]. For our case, it is $\delta = 7^0$.

In general case, with account of the angle of lateral skid, it is possible to determine the drag coefficient of the lateral skid of steering wheels according to formula [4]

$$K_л = F_л \cdot \delta, \quad K_п = F_п \cdot \delta \quad ,(5)$$

As is known, the value of lateral skid at tractor turn is affected by side-slip and lateral strain of the elements of motion.

Substituting the values of the forces obtained by solving the system (1) and (2), the values of the coefficient of traction of the wheel (grip of wheels) are obtained

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$$\varphi_{clutch}=\frac{fF_{\kappa_2}}{F_{\kappa_2}\cos\alpha}=\frac{f(m_2-m_3)\ddot{y}_2}{(m_2-m_3)\ddot{y}_2\cos\alpha}=\frac{0.03\cdot(126.64,...,559.52)}{(126.64,...,559.52)\cdot 0.65}=0.046<\varphi_{rear.},$$

where*f*–is a coefficient of rolling resistance of the controlled wheel.

Tomove the controlled driven wheels in the plane of rotation, the drag force should not be greater than the force of traction to the bearing area [2,9]

$$F_{npom.}\leq\phi_{cu}(m_2-m_3)\ddot{y}_2.$$

In our case it is 1331.28,…,3609.82>0.046(119.51,…529.81).

Table 3. The values of the components of longitudinal forces of the coefficient of traction of the wheels

T, s	F_l	$F_{\ddot{i}}$	K_l	Kn	φ_{clutch}
0	-1.8	0	-0.257	0	0
0.1	1401.44	529.81	200.2	75.687	0.046
0.2	1578.15	119.51	225.45	17.07	0.046
0.3	854.42	203.73	122.06	29.1	0.046
0.4	865.66	508.85	123.66	72.69	0.046
0.5	1212.84	195.056	173.26	27.86	0.046
0.6	1261.75	203.6	180.25	29.08	0.046
0.7	992.78	364.3	141.82	52.04	0.046
0.8	976.02	299.88	139.43	42.43	0.046
0.9	1191.53	255.07	170.2	36.43	0.046
1	1153.53	274.65	164.79	39.23	0.046

The results obtained show that vertical oscillations of the rear guide wheels reduce the coefficient of traction $\varphi_{clutch}=0.046<\varphi_{rear.}=0.4,..,0.6$ [2,9]. Consequently, with the decrease of the coefficient of traction, the accuracy of the turn is reduced and the skid of machine is increased, this creates the difficulties for the orientation of the driver-mechanic when driving and in turning strips of cotton fields.

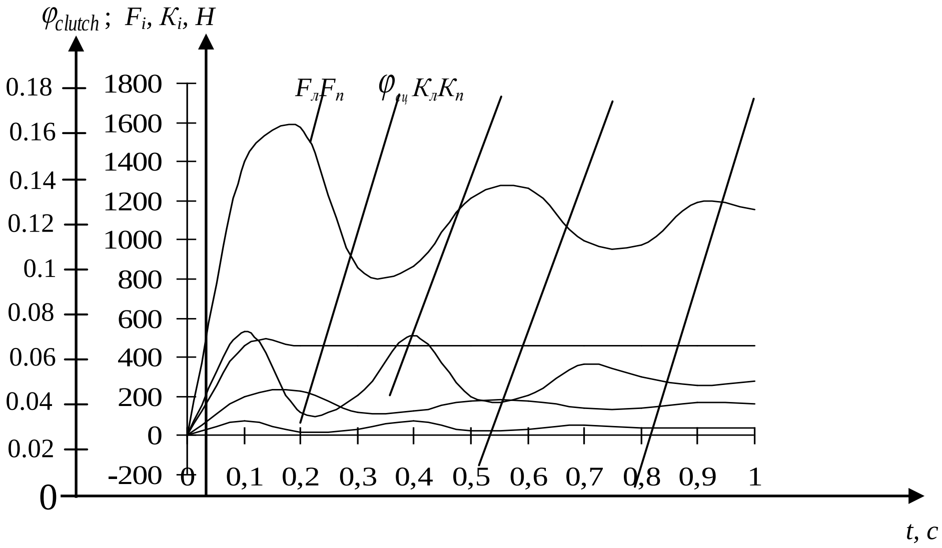

Figure 5 - Pattern of changes in the components of longitudinal forces, the coefficient of traction and resistance to lateral skid of the wheel in HUM MH-1.8

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V. CONCLUSIONS AND RECOMMENDATIONS

Based on the obtained equations of motion, the models and algorithms for optimal control of the steering wheels of cotton picker MH-1.8 are developed. The steadiness of machine motion depends on the mass and parameters of the controlled axes, the values of which are determined by the numerical solution of the conjugate system (4), (4a) with the variation of the parameters of motion F_i and the design parameters *b, c, j* at given road roughness. By the solution of the boundary value problem according to the Pontryagin maximum principle, transition processes are obtained for horizontal and vertical oscillations in the course of HUM MH-1.8 motion.

Physical meaning of the results obtained can be formulated as follows. If at the initial moment of time the conditions of optimal control problem are satisfied, then the optimal speed of operation is achieved at controls where the force of transformation $u_0 = +1$ has a maximum value at time interval [t_0, t]. Hence, at the interval [t_0, t] there is afull forward mode and the speed of machine will increase to $V_м=1$ *m/s*, and at this moment the wheels of machine rise to the upper edge of the roughness.
At the interval [t, T], the machine descends, and at this moment the force of transformation switches to $u_δ=-1$, i.e. there is a full back mode, providing the steadiness of motion of directing wheels of a cotton picker.

The results obtained by solving mathematical models of longitudinal and vertical oscillations of HUM MH-1.8 while moving along the roughness on turning strips of cotton fields show that vertical oscillations of the rear guide wheels reduce the coefficient of traction $φ = 0.046 < φa_{зад} = 0.4\text{-}0.6$. So, with the reduction of the coefficient of traction, the accuracy of the turns is also reduced and the skid of machine is increased, this creates the difficulties for the orientation of the driver-mechanic when driving in turning strips of cotton fields.

The revealed disadvantages of the turn of HUM MH-1.8 with rear steering wheels are the complexity of the steering drive, non-uniform distribution of the mass between the front, driving and rear steering wheels.

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