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ALGORITHM FORMATION AND ANALYSIS OF MOTION STABILITY OF THE MX-1.8 COTTON-PICKER AND THE HITCH SYSTEM OF HARVESTING UNITS UNDER VERTICAL VIBRATIONS

Azimov Bakhtiyor, Kubaev Saidazim, Yakubjanova Dilfuza[3]
[1] Scientific and Innovation Center of Information-Communication Technologies at the Tashkent University of Information Technologiesafter Muhammad al-Khorezmi, Tashkent, Uzbekistan
[2,3]Samarkand Branch of Tashkent University of Information Technologyafter Muhammad al-Khorezmi, Samarkand, Uzbekistan.

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Abstract:

The problem of studying the motion stability of the MX-1.8 cotton picker and the hitch system of harvesting units under vertical vibrations is considered and solved in the paper. The main objective of the study is to assess the stability of mechanical system; it is necessary to consider the stability of both the system as a whole and the stability of thehitch system relative to the tractor, this remains an urgent task that requires further study.In the formation of the motion stability algorithm, it is necessary to study the equations of motion of the MX-1.8 cotton picker and the hitch system of the harvester under vertical vibrations, when the hydraulic cylinder for raising and lowering the harvesting units is installed on the left edge of the rocking shaft; the rigidity of the rocking shaft is considered absolute, left and right harvesting unitsoscillate uniformly. The motion stability is checked by the Hurwitz criterion.

Keywords: Model, hydraulic cylinder, algorithm, vertical oscillations, motion stability, hitch mechanism, characteristic equation, cotton picker, design parameters, rocking shaft, shaft rigidity.

1. INTRODUCTION

Tractor transport is widely and increasingly used in various sectors ofnational economy. However, tractor transport is most widespread in agriculture. Sustainability in agricultural machinery operation is one of the most urgent problems of modern times.

As is well known, the stability of a wheeled machine is built into design and this determines its potential capabilities. Therefore, the purposeful formation of agricultural machine stability at the design stage is impossible without the development of calculation methods to find the ways of machine safe operation while maintaining its functionality. The specified calculation methods should establish the relationship between the functional properties and the parameters of machines, to give acceptable accuracy in determining indicesat low complexity of the calculations and the amount of necessary source data.

Currently, the issues ofmotionstability of tractor transport units arecompletely investigated in the studiesconductedby P.P. Artemyev, Yu.E. Atamanov, N.V. Bogdan, V.N.Boltinsky, P.P. Gamayunov, V.P. Goryachkin, L.V. Gyachev, P.M. Vasilenko, A.V. Startsev A.M. Fedorov, V.A. Kim, N.A. Razorenov, I.L. Trofimenko, G.A. Novokshenov, D.A. Chudakov, V.F.Konovalov, A.B. Lurie, V.A. Skotnikov, M.I. Lyasko and other researchers. Some authors dealing with this problem have proposed specific technical solutions that improve the stability of various modes of motion [1-3].

Among analytical studies on motion stability of hitched agricultural machines and mobile machine units, the work of P.M. Vasilenko [4] could be noted; the author, using the Lagrange equations of the second kind, investigated the process of random disturbanceoccurrence of thebasic motion. It is noted that the performance and operational and technical indices of mobile machine units operation largely depend on the nature of their motion; therefore, the laws of motion of mobile machine units should be the subject of deep study in development of new designs.

The studies by X. X. Khayrullaev [5] were devoted to the stability of rectilinear motion and controllability of row-crop tractors in irrigated agriculture at a change in track width, longitudinal base, hook load and other indices at different motion speeds [5].

In [6], the results of a study of roadholding ability of tractor trains were considered. The effectof structural parameters of the steering control of these tractorson the indices of stability of motion and controllability was shown. As the indicescharacterizing stability of rectilinear motion, the following were adopted: the coefficient of relative lengthening of the path and the standard deviation of the train links. As an index of the driver’s workstress level, the standard deviation of the steering angle was used.

V.F.Konovalov noted in [7] that the stability of motion of machine-tractor aggregates was considered as a set of aggregate properties, capable of preserving the nature of the system’s motion under small deviations of the system both during the action of disturbing forces and some time after the impact termination.

According to Prof. L. V. Gyachev [8], machine-tractor aggregates should possess asymptotic stability, i.e. keep the motion close to the basic one or tend to it after receiving initial disturbances.

On cars, there are the suspension elements on the track frame, and on agricultural machines there are practically none. The drive wheel axle is rigidly fixed to the body, and the lay of land is realized(to avoid the hanging ofone of the wheels when driving on complex surfaces), by the steering wheel barrocking on the hinge. This design is simple, reliable, unpretentious, but it introduces certain features into the process of stabilityloss, which affects the safety of machine operation. This is due to the necessity to care for the life and health of machine operators, and the problem of machine safety. In addition, when tipping over, the machine receives significant damage and is out of service for an indefinite period of time, and this entails a loss of crop yield as the harvesting is not done on time [9].

The stabilization features of the rear steered wheels are the most important factors that determine the worst stability characteristics of the rectilinear motion of the machine with the rear steered wheels. At the same time, the issues of stabilization of steered wheels and stability of machine motion with a rear arrangement of steered wheels are not fully understood and require further research.

The cotton-picking unit (TTZ-80.11 tractor + MX-1.8 cotton-picker) is mounted on a specially prepared tractor on its front part and is made according to a four-wheel design with two rear steering wheels.

2. STATEMENT OF THE PROBLEM

In accordance with the design scheme shown in Figure 1, where the hydraulic cylinder for raising and lowering the harvesting units is installed on the left edge of the rocking shaft, the rigidity of the rocking shaft is taken to be absolute. Left and right harvesting unitstremble non-uniformly when the machine oscillates vertically. Let's compile a generalized mathematical model of the HUM MX-1.8 vertical vibrations in the process of moving along the bumps on thecotton field headland in the form of Lagrange equations of the second kind [10-12]:

$$\left.\begin{aligned}
&m_м \ddot{y}_м = F_y - b_1(\dot{y}_м - \dot{y}_{к_1}) - c_1(y_м - y_{к_1}) - b_2(\dot{y}_м - \dot{y}_{к_2}) - c_2(y_м - y_{к_2}) \\
&m_1 \ddot{y}_{к_1} = b_1(\dot{y}_м - \dot{y}_{к_1}) + c_1(y_м - y_{к_1}) - m_1 \frac{2\pi^2 V_{к_1}^2}{l_5^2} h_n \left(1 - \cos\frac{2\pi V_{к_1}}{l_5} t\right) \\
&(m_2 - m_3)\ddot{y}_{к_2} = b_2(\dot{y}_м - \dot{y}_{к_2}) + c_2(y_м - y_{к_2}) - (m_2 - m_3)\frac{2\pi^2 V_{к_2}^2}{l_5^2} h_n \left(1 - \cos\frac{2\pi V_{к_2}}{l_5} t\right) \\
&j_{гц}\ddot{\varphi}_{гц} = F_{гц} \cdot l_6 - b_3(\dot{\varphi}_{гц} - \dot{\varphi}_{вк}) - c_3(\varphi_{гц} - \varphi_{вк}) - l_7 \cdot m_a \ddot{y}_м \\
&j_{вк}\ddot{\varphi}_{вк} = b_3(\dot{\varphi}_{гц} - \dot{\varphi}_{вк}) + c_3(\varphi_{гц} - \varphi_{вк}) - l_7 \cdot m_a \ddot{y}_м \\
&m_{гц}\ddot{y}_{гц} = \frac{j_{гц}\ddot{\varphi}_{гц}}{l_7 - l_6} \\
&m_{вк}\ddot{y}_{вк} = \frac{j_{вк}\ddot{\varphi}_{вк}}{l_7}
\end{aligned}\right\}, \quad (1)$$

Where $\dot{y}_i$ and $\ddot{y}_i$ - are the linear speed and acceleration of machine, of the front and rear wheels, of hydraulic cylinderlevers and the rocking shaft of the mechanism for hitch devices; $\dot{\varphi}_i$ and $\ddot{\varphi}_i$ $\dot{\varphi}_i$ и $\ddot{\varphi}_i$ –are the angular speeds and acceleration of torsional vibrations of hydraulic cylinder levers and the rocking shaft; b_i, c_i–are the coefficients of viscous resistance and stiffness of the tire of machine wheel, the rocking shaft of the hitch mechanism of the harvesting units; m_i is the mass distributed over the machine supports and the hitch mechanism of the harvesting units; $h_п$–is the height of the road roughness; $F_м$, F_y, and $F_{гц}$ - are the traction forces of machine under horizontal and vertical vibrations and the force in the hydraulic cylinder of the hitch system of harvesting units; l_1, l_2, l_3, l_4 and l_5 – are the distances between supports and road roughness; l_6 and l_7 are the length of the lever and the levers of the harvester hitching; $j_{гц}$ and $j_{вк}$–are the moments of inertia of theconnection levers of hydraulic cylinder and the hitch of the harvesting units; V_i–is the speed of machine motion, its front and rear wheels.

The system has a single stationary motion $\varphi_{гц} = y_{гц} = \varphi_{вк} = y_{вк} = y_м = y_{k_1} = y_{k_2} = 0$

$$\left.\begin{aligned}
&m_{м}\ddot{y}_{м} - F_y + b_1(\dot{y}_{м} - \dot{y}_{k_1}) + c_1(y_{м} - y_{k_1}) + b_2(\dot{y}_{м} - \dot{y}_{k_2}) + c_2(y_{м} - y_{k_2}) = 0 \\
&m_1\ddot{y}_{k_1} - b_1(\dot{y}_{м} - \dot{y}_{k_1}) - c_1(y_{м} - y_{k_1}) + m_1\frac{2\pi^2 V_{k_1}^2}{l_5^2}h_n\left(1 - \cos\frac{2\pi V_{k_1}}{l_5}t\right) = 0 \\
&(m_2 - m_3)\ddot{y}_{k_2} - b_2(\dot{y}_{м} - \dot{y}_{k_2}) - c_2(y_{м} - y_{k_2}) - (m_3 - m_2)\frac{2\pi^2 V_{k_2}^2}{l_5^2}h_n\left(1 - \cos\frac{2\pi V_{k_2}}{l_5}t\right) = 0 \\
&j_{гц}\ddot{\varphi}_{гц} - F_{гц}\cdot l_6 + b_3(\dot{\varphi}_{гц} - \dot{\varphi}_{вк}) + c_3(\varphi_{гц} - \varphi_{вк}) + l_7\cdot m_a\ddot{y}_{м} = 0 \\
&j_{вк}\ddot{\varphi}_{вк} - b_3(\dot{\varphi}_{гц} - \dot{\varphi}_{вк}) - c_3(\varphi_{гц} - \varphi_{вк}) + l_7\cdot m_a\ddot{y}_{м} = 0 \\
&m_{гц}\ddot{y}_{гц} - \frac{j_{гц}\ddot{\varphi}_{гц}}{l_7 - l_6} = 0 \\
&m_{вк}\ddot{y}_{вк} - \frac{j_{вк}\ddot{\varphi}_{вк}}{l_7} = 0
\end{aligned}\right\} ,(2)$$

at $0 \le t \le 1$, substitute for $V_{k_1} \approx \dot{y}_{k_1}$, $V_{k_2} \approx \dot{y}_{k_2}$, $F_y \approx m_{м}\ddot{y}_{м} = m_{м_1}\ddot{y}_{м}$, $F_{гц} \approx \dfrac{j_{гц}\ddot{\varphi}_{гц}}{l_7 - l_6}$.

$$\left.\begin{aligned}
&a_5\ddot{y}_{м} + b_1(\dot{y}_{м} - \dot{y}_{k_1}) + c_1(y_{м} - y_{k_1}) + b_2(\dot{y}_{м} - \dot{y}_{k_2}) + c_2(y_{м} - y_{k_2}) = 0 \\
&m_1\ddot{y}_{k_1} - b_1(\dot{y}_{м} - \dot{y}_{k_1}) - c_1(y_{м} - y_{k_1}) + \dot{y}_{k_1}a_3 = 0 \\
&(m_2 - m_3)\ddot{y}_{k_2} - b_2(\dot{y}_{м} - \dot{y}_{k_2}) - c_2(y_{м} - y_{k_2}) - \dot{y}_{k_2}a_4 = 0 \\
&a_2\,\ddot{\varphi}_{гц} + b_3(\dot{\varphi}_{гц} - \dot{\varphi}_{вк}) + c_3(\varphi_{гц} - \varphi_{вк}) + l_7\cdot m_a\ddot{y}_{м} = 0 \\
&j_{вк}\ddot{\varphi}_{вк} - b_3(\dot{\varphi}_{гц} - \dot{\varphi}_{вк}) - c_3(\varphi_{гц} - \varphi_{вк}) + l_7\cdot m_a\ddot{y}_{м} = 0 \\
&m_{гц}\ddot{y}_{гц} - a_6\,\ddot{\varphi}_{гц} = 0 \\
&m_{вк}\ddot{y}_{вк} - a_7\,\ddot{\varphi}_{вк} = 0
\end{aligned}\right\} , \quad (3)$$

where,

$$a_0 = 1 - \cos\frac{2\pi V_{k_1}}{l_5}t\ ,\ a_1 = 1 - \cos\frac{2\pi V_{k_2}}{l_5}t\ ,\ a_2 = \frac{(l_7 - 2l_6)\,j_{гц}}{l_7 - l_6},\ a_3 = m_1\frac{2\pi^2 V_{k_1}}{l_5^2}h_n a_0\ ,$$

$$a_4 = (m_3 - m_2)\frac{2\pi^2 V_{k_2}}{l_5^2}h_n a_1\ ,\quad a_5 = m_{м} - m_{м_1},\ a_6 = \frac{j_{гц}}{l_7 - l_6},\ a_7 = \frac{j_{вк}}{l_7}.$$

3. SOLUTION METHOD

The stability of system (3) is validated by the Hurwitz criterion. For this, the roots of the characteristic equation of system (3) are determined. From the coefficients of the system of equations (3) we make the determinant

$$\begin{vmatrix}
a_5\lambda^2 + (b_1 + b_2)\lambda + (c_1 + c_2) & -b_1\lambda - c_1 & -b_2\lambda - c_2 & 0 & 0 & 0 & 0 \\
-b_1\lambda - c_1 & m_1\lambda^2 + (a_3 + b_1)\lambda + c_1 & 0 & 0 & 0 & 0 & 0 \\
-b_2\lambda - c_2 & 0 & (m_2 - m_3)\lambda^2 + (b_2 - a_4)\lambda + c_2 & 0 & 0 & 0 & 0 \\
l_7\cdot m_a\lambda^2 & 0 & 0 & a_2\lambda^2 + b_3\lambda + c_2 & -b_3\lambda - c_2 & 0 & 0 \\
l_7\cdot m_a\lambda^2 & 0 & 0 & -b_3\lambda - c_2 & j_{вк}\lambda^2 + b_3\lambda + c_2 & 0 & 0 \\
0 & 0 & 0 & -a_6\lambda^2 & 0 & m_{гц}\lambda^2 & 0 \\
0 & 0 & 0 & 0 & -a_7\lambda^2 & 0 & m_{вк}\lambda^2
\end{vmatrix} = 0$$

The characteristic equation (3) after calculating the determinant has the form

$$A_1\lambda^7 + A_2\lambda^6 + A_3\lambda^5 + A_4\lambda^4 + A_5\lambda^3 + A_6\lambda^2 + A_7\lambda + A_8 = 0 \quad , \quad (4)$$

A computational experiment was conducted under the following parameter values:

- at tire deflection h_{tire}*=30 mm=0.03m:*

$a_0 = 0.54\,\mathrm{rad}; a_1 = 0.63\,\mathrm{rad}; a_2 = 110.14\,\mathrm{Nm}rad; a_3 = 2071.66\,kgf/\mathrm{rad}; a_4 = 632\,\mathrm{k}gf/\mathrm{rad};$

$a_5 = 1.05\,kg$; $a_6 = 1906{,}76\,N\,c^2$; $a_7 = 432\,Nc^2$; c_1=16722278N/м; b_1=140845.65Nc/m; c_2=850200 N/m; b_2=71607.1 Nc/m; c_3=263377.3 Nm/rad; b_3=22182.643 Nmc/m; $m_м$=7714 kg; m_1=5114 kg; m_2=2600 kg; m_3=1262 kg; m_a=675 kg; $m_{гц}$=276.48 kg; ; $m_{вк}$=48 kg; $j_{гц}$=552.96 Nmc^2; $j_{вк}$=276.48 Nmc^2; $r_{к1}$=0.785 m; $r_{к2}$=0.43 m; $h_п$=0.07m; $F_{гц} = 2345\,H$;$h_ш$ =0.03 M; $V_м$=1.21 m/c; $F_y = F_M \sin\alpha = 17970 \sin 45^0 = 12706.7T$

Then the coefficients of the characteristic equation (5) have the form

$$
\begin{aligned}
A_1 &= 4240952177 \cdot 10^7 ,\\
A_2 &= 8596031797 \cdot 10^{12} ,\\
A_3 &= 2838949574 \cdot 10^{15} ,\\
A_4 &= 1702371496 \cdot 10^{17} ,\\
A_5 &= 4158378576 \cdot 10^{18} ,\\
A_6 &= 4535341474 \cdot 10^{19} ,\\
A_7 &= 1861329500 \cdot 10^{20} ,\\
A_8 &= 3929741589 \cdot 10^{19} .
\end{aligned}
\qquad (6)
$$

After substituting (6) in (4), the characteristic equation looks as follows:

$$4240952177 \cdot 10^7 \lambda^7 + 8596031797 \cdot 10^{12} \lambda^6 + 2838949574 \cdot 10^{15} \lambda^5 + 1702371496 \cdot 10^{17} \lambda^4$$
$$+ 4158378576 \cdot 10^{18} \lambda^3 + 4535341474 \cdot 10^{19} \lambda^2 + 1861329500 \cdot 10^{20} \lambda + 3929741589 \cdot 10^{19} = 0$$

To make the system of equations (3) stable, it is necessary to show the positive values of the basicsevenminors of the Hurwitz determinant, the last of these minors is the Hurwitz determinant.
By calculating these minors we find:

$$
\begin{aligned}
d_1 &= 8596031797 \cdot 10^{12} ,\\
d_2 &= 2439648113 \cdot 10^{37} ,\\
d_3 &= 3845934019 \cdot 10^{62} ,\\
d_4 &= 1289075809 \cdot 10^{91} ,\\
d_5 &= 4649521809 \cdot 10^{119} ,\\
d_6 &= 8451595596 \cdot 10^{148} ,\\
d_7 &= 3321258670 \cdot 10^{177} .
\end{aligned}
$$

As can be seen, all the minors of the Hurwitz determinant are positive and the system is stable.
- at tire deflection *h_{tire}=40 mm=0.04m*

$a_0 = 0.54\,\mathrm{rad}; a_1 = 0.63\,\mathrm{rad}; a_2 = 110.14\,\mathrm{Nm}rad; a_3 = 2071.66\,kgf/\mathrm{rad}; a_4 = 632\,\mathrm{k}gf/\mathrm{rad};$

$a_5 = 1.05\,kg$; $a_6 = 1906{,}76\,N\,c^2$; $a_7 = 432\,Nc^2$; c_1=1254208N/м; b_1=105634.2Nc/m; c_2=637650 N/m; b_2=53705.3 Nc/m; c_3=263377.3 Nm/rad; b_3=22182.643 Nmc/m; $m_м$=7714 kg; m_1=5114 kg; m_2=2600 kg; m_3=1262 kg; m_a=675 kg; $m_{гц}$=276.48 kg; ; $m_{вк}$=48 kg; $j_{гц}$=552.96 Nmc^2; $j_{вк}$=276.48 Nmc^2; $r_{к1}$=0.785 m; $r_{к2}$=0.43 m; $h_п$=0.07m; $F_{гц} = 2345\,H$;$h_ш$ =0.03 M; $V_м$=1.21 m/c; $F_y = F_м \sin\alpha = 18050 \sin 45^0 = 12763.277\,H$

Then the coefficients of the characteristic equation (5) look as follows

$$
\begin{aligned}
A_1 &= 8282715172 \cdot 10^{8} , \\
A_2 &= 6479643494 \cdot 10^{12} , \\
A_3 &= 2044328088 \cdot 10^{15} , \\
A_4 &= 1054323614 \cdot 10^{17} , \\
A_5 &= 2382102728 \cdot 10^{18} , \\
A_6 &= 2530541358 \cdot 10^{19} , \\
A_7 &= 1038577621 \cdot 10^{20} , \\
A_8 &= 2186454399 \cdot 10^{19} .
\end{aligned} \qquad (8)
$$

Substituting (8) in (4), the characteristic equation has the form:

$$
8282715172 \cdot 10^{8} \lambda^{7} + 6479643494 \cdot 10^{12} \lambda^{6} + 2044328088 \cdot 10^{15} \lambda^{5} + 1054323614 \cdot 10^{17} \lambda^{4} + 2382102728 \cdot 10^{18} \lambda^{3} + 2530541358 \cdot 10^{19} \lambda^{2} + 1038577621 \cdot 10^{20} \lambda + 2186454399 \cdot 10^{19} = 0
$$

In this case, to make the system of equations (3) stable, it is necessary to show the positive values of the basic seven minors of the Hurwitz determinant. Calculatingtheminors (7) wefind

$$
\begin{aligned}
d_1 &= 6479643494 \cdot 10^{12} , \\
d_2 &= 8937558245 \cdot 10^{36} , \\
d_3 &= 8362371944 \cdot 10^{60} , \\
d_4 &= 1307426852 \cdot 10^{90} , \\
d_5 &= 5277148226 \cdot 10^{118} , \\
d_6 &= 6586527412 \cdot 10^{146} , \\
d_7 &= 4778329072 \cdot 10^{176} .
\end{aligned}
$$

As can be seen, all the minors of the Hurwitz determinant are positive and the system is stable.

4. CONCLUSIONS

A generalized mathematical model of the HUM MX-1.8 cotton picker in the process of moving along theroughness of thecotton field headland was compiled in the form of Lagrange equations of the second kind.

The roots of the characteristic equation of the system were determined, a good agreement with real data was shown.

On the basis of our studies, an algorithm for the motion stability of the MX-1.8 cotton picker and the hitch system of the harvesting unit under vertical vibrationswas developed; there the hydraulic cylinder for raising and lowering the harvesting unit was installed on the left edge of the rocking shaft; the rigidity of the rocking shaft is taken as absolute, the left and right harvesting units oscillate uniformly.

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