

THE STUDY OF MOVEMENT WIDE SPAN TRACTOR (VEHICLES) WITH KINEMATIC (TURN OF WHEELS) METHOD OF ITS CONTROL

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Abstract: Prospective energy technology devises for controlled traffic farming is the wide span tractor (vehicles). Their driving can be built behind the kinematic or force principle of the turn. At the kinematic turn, the schemes are applied by turning the steered wheels (front, rear or both front and rear) relative to the car's frame. The widest distribution in wide span tractor (vehicles) was obtained by turning schemes with all steerable wheels. The theoretical foundations of the dynamics of the parallel-span parallel motion tractor (vehicles) in the horizontal plane are presented in the article under the kinematic method of its control (by turning the wheels). Theoretical research is based on the basic principles of theoretical mechanics, tractor theory, statistical dynamics and the theory of automatic control of linear dynamical systems when they reproduce statistically random control and disturbing input effects. The amplitude and phase frequency characteristics are based on the analysis of the evaluation of the degree of influence of the circuit and parameters of the investigated wide span tractor (vehicles) on its controllability and stability of motion. The physical object of the theoretical studies was the prototype of the wide span tractor (vehicles) of the new design. Mathematical models of the wide span tractor (vehicles) movement are represented in the differential and operator form of recording. On the basis of mathematical models, the calculated amplitude and phase-frequency characteristics of the dynamic control system development are plotted, represented by the average rotation angle of the front wheels of the wide span tractor (vehicles). The constructed mathematical models, amplitude and phase-frequency characteristics allow estimating the effect of the control parameter of the wide span tractor (vehicles), as well as its design and other parameters on the controllability and stability of motion.

KEY WORDS: CONTROLLED TRAFFIC FARMING, WIDE SPAN TRACTOR (VEHICLES), THEORETICAL STUDIES, KINEMATIC METHOD OF CONTROL

1. Introduction

Analysis of the prospects for the introduction of controlled traffic farming [1-4] found that the wide span tractor (vehicles) is the main autonomous mobile energy technology complex characterized by high potential technological properties [5-9].

Research and study of the stability and controllability of the wide span tractor (vehicles) movement is the subject of special attention, since the trajectory parameters of their movement are limited by the parameters of the constant technological track. In this regard, from the position of satisfactory controllability and the stability of their movement, unresolved questions arise concerning the study of conditions that are superimposed on constructive and other parameters of the wide span tractor (vehicles). Therefore, carrying out, first of all, theoretical studies of the wide span tractor (vehicles) movement, choosing the most rational of their layout scheme, and also constructive and regime parameters, provides it with an optimal transformation of the control and disturbing influences acting on it.

Wide span tractor (vehicles) for controlled traffic farming, like any vehicle, is a rather complex control object that can be adapted to manual or automatic control and built after the kinematic or force principle of the turn. The kinematic turn is known to be realized by turning the steered wheels (front, rear or both front and rear) relative to the car's frame. The most widely used schemes are the rotation of a wide span tractor (vehicles) with steerable wheels [5-8].

It is known that the operation of a wheeled vehicle occurs under the conditions of a large number of disturbing factors (forces and their moments) that change its position in space and deflect movement from a given trajectory. The quality of development of a particular dynamic system of input variables depends on its characteristics. Relatively wide span tractor (vehicles) such are its scheme, as well as constructive and other parameters. Therefore, the correct choice of the latter, from the position of the necessary controllability and stability of its movement, ensures to it the optimal transformation of the controlling and perturbing influences acting on it.

2. Preconditions and means for resolving the problem

2.1. Analysis of recent research and publications

All known studies on this issue are aimed at studying the dynamics of the movement of agricultural units built on the basis of traditional tractors and do not concern the solution of this problem. The accumulated scientific and practical experience of using traditional machine-tractor units in controlled traffic farming allowed to substantiate certain requirements to the parameters of the constant technological track and power facilities [10]. However, these requirements do not take into account the atypical layout of the wide span tractor (vehicles), the specifics of their aggregation and the operating conditions, and therefore must be specified. At the same time, the currently known methodology for selecting design schemes, parameters and operating modes of machine-tractor aggregates can not be used to study the dynamics of the wide span tractor (vehicles). In this connection, from the position of effective use of the wide span tractor (vehicles), there are unsolved questions concerning the study of conditions that are superimposed on their constructive and other parameters.

2.2. Purpose of the study

The purpose of researches is the development of a dynamic model of a plane parallel motion in the horizontal plane of a wide span tractor (vehicles) under the kinematic way of its control (by turning the wheels), by means of which it is necessary to investigate the influence of the parameters of the control and disturbing influences on the controllability and stability of its motion.

3. Results and discussion

The theoretical studies are based on the foundations of theoretical mechanics, the theory of mobile energy facilities, statistical dynamics and the theory of automatic control of linear dynamical systems when they reproduce statistically random control and disturbing input effects. In particular, the amplitude and

phase frequency characteristics are based on an analysis of the evaluation of the degree of influence of the circuit and parameters of the investigated wide span tractor (vehicles) on its controllability and stability of motion.

Wide span tractor (vehicles) is a fairly complex dynamic system. This complexity is determined by its multidimensionality, the high order of the differential equations of motion, and especially the presence of nonlinear dependences between its individual coordinates. Therefore, at this stage of studying the dynamics of the wide span tractor (vehicles), it is advisable to consider its simplified scheme in the form of a stationary linear model (Fig. 1). Such idealization of the system in many cases is quite effective for complex agricultural aggregates and their control systems, the dynamics of which have not yet been studied sufficiently.

In the presented scheme (see Fig. 1), the influence of all the forces acting on the wide span tractor (vehicles) on the part of agricultural implements, we express through their main vector R (the components R_x and R_y , respectively) and the main moment M_R .

The nature of the perturbations depends entirely on the constructive scheme of the wide span tractor (vehicles) and its technological purpose.

In view of the foregoing assumptions, we assume that the investigated wide span tractor (vehicles) carries out uniform translational motion at a speed V_0 with respect to the immovable horizontal plane XOY (see Fig. 1).

In the process of performing the work, its skeleton under the influence of random perturbations deviates from the initial position and receives additional velocities, - its relative motion relative to the plane X_1OY_1 begins. In this case, the $X_rS_rY_r$ plane, connected to the center of mass of the wide span tractor (vehicles), wraps it in the plane X_1OY_1 around the axis passing through the point S_r . The measure of this rotation is the angle φ , which is constructed by the longitudinal axis S_rY_r wide span tractor (vehicles) and the axis OY_1 . In the process of relative motion, its center of mass moves along the axis OX_1 , which is characterized by a change in the abscissa X_S . Thus, the investigated wide span tractor (vehicles) with respect to the plane X_1OY_1 has two degrees of freedom, corresponding to two generalized coordinates: the angle φ and the displacement of the abscissa X_S of the center of its masses S_r .

It should be noted that even in a linear interpretation, the mathematical model of the wide span tractor (vehicles) movement is a system of rather complex differential equations. Therefore, in order to simplify their compilation, the following assumptions are accepted: roll and trim wide span tractor (vehicles) are absent; Wide span tractor (vehicles) is regarded as a physical solid body that has a longitudinal plane of symmetry passing through the center of its masses; The oscillation of the traction resistance of agricultural implements does not significantly affect the speed of translational motion, so that it is assumed to be constant; The lateral interaction of wide span tractor (vehicles) tires with a deformable surface is considered within the framework of the hypothesis of "lateral withdrawal"; The gyroscopic and stabilizing moments of the tires and the moments of resistance to their twisting, relative to the vertical axis, are not taken into account due to their smallness.

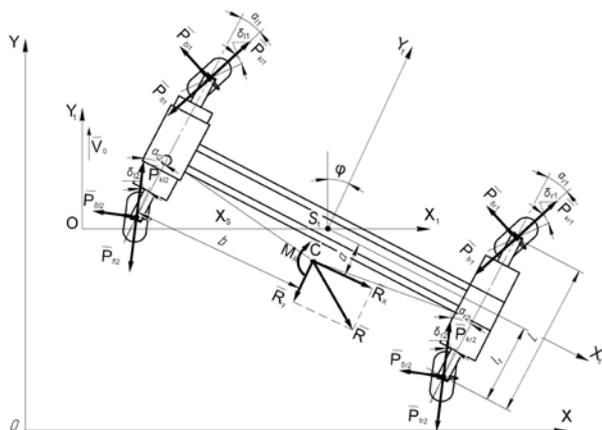


Fig. 1. The scheme of the forces acting on the wide span

tractor (vehicles) in the horizontal plane with the kinematic way of its control (by turning the wheels)

In the mathematical modeling of the motion in the horizontal plane of the wide span tractor (vehicles), the dynamic model of its functioning is conveniently considered in the form of reactions to input control and disturbing influences, which uniquely determine in the first case – controllability, and in the second – the stability of its motion.

To external forces acting on the wide span tractor (vehicles) with its plane-parallel motion, it is possible to refer:

- drag forces of rolling front (P_{f11}, P_{fr1}) and rear (P_{f12}, P_{fr2}) wheels wide span tractor (vehicles);
- tangential forces $P_{k11}, P_{k12}, P_{kr1}, P_{kr2}$;
- Lateral forces $P_{\delta11}, P_{\delta12}, P_{\delta r1}, P_{\delta r2}$, which lead to angles of displacement of front δ_{11}, δ_{r1} and rear δ_{12}, δ_{r2} wheels wide span tractor (vehicles);
- the main vector R and the main moment of the M_R forces acting on the part of agricultural implements.

For the mathematical description of the lateral interaction of a wheeled vehicle with an agrophone, the hypothesis of "lateral deviation" in linear interpretation is most often used. In this case, to determine the lateral horizontal forces in the places of contact between the wheels and the soil, the coefficients of resistance to the lateral bushing of tires according to the Rocard hypothesis are used. So:

$$\begin{aligned} P_{\delta11} &= k_{l1} \cdot \delta_{11}, \quad P_{\delta r1} = k_{r1} \cdot \delta_{r1}, \\ P_{\delta12} &= k_{l2} \cdot \delta_{12}, \quad P_{\delta r2} = k_{r2} \cdot \delta_{r2}. \end{aligned} \quad (1)$$

Where: k_{l1}, k_{l2} and k_{r1}, k_{r2} are the drag coefficients of the wheels of the left and starboard side of the wide span tractor (vehicles).

The differential equations of the movement of the agri-devices with respect to the plane X_1OY_1 (see Figure 1) will be in the form of Lagrange equations of the second kind.

The kinetic energy of the wide span tractor (vehicles) relative to the X_1OY_1 plane (Figure 1) consists of two terms representing its translational and rotational motion:

$$T = \frac{(M_t \cdot V_s + J_{st} \cdot \omega_t)}{2}, \quad (2)$$

where: M_t is the mass of the wide span tractor (vehicles), V_s – the linear velocity of the center of mass of the wide span tractor (vehicles) relative to the plane X_1OY_1 , J_{st} – the moment of inertia of the wide span tractor (vehicles) relative to its center of mass, ω_t – the angular velocity of the wide span tractor (vehicles).

Obviously, the parameters entering into (2) will be:

$$\begin{aligned} V_s &= \dot{X}_S, \\ \omega_t &= \dot{\varphi} \end{aligned} \quad (3)$$

After substituting in (2) the derivatives of the angular and linear velocities (3), we obtain:

$$T = \frac{1}{2} (M_t \cdot \dot{X}_S^2 + J_t \cdot \dot{\varphi}^2). \quad (4)$$

Taking the derivatives with respect to the accepted generalized coordinates, after differentiation, we obtain:

$$\left. \begin{aligned} M_t \cdot \dot{X}_S &= Q_X, \\ J_t \cdot \dot{\varphi} &= Q_\varphi, \end{aligned} \right\} \quad (5)$$

where: Q_X and Q_φ are generalized forces that determine the movement of the wide span tractor (vehicles) along the corresponding generalized coordinates.

Taking into account the smallness of the latter, the equations for determining the generalized forces have the following form:

$$\begin{aligned} Q_X &= (P_{k11} - P_{f11} + P_{kr1} - P_{fr1})\alpha - \\ &\quad - (P_{k12} - P_{f12} + P_{kr2} - P_{fr2})\beta + R_x - P_{\delta11} - P_{\delta12} - P_{\delta r1} - P_{\delta r2}; \\ Q_\varphi &= (L - l_t)(P_{k11} - P_{f11} + P_{kr1} - P_{fr1})\alpha + \\ &\quad + l_t(P_{k12} - P_{f12} + P_{kr2} - P_{fr2})\beta + \\ &\quad + b(P_{k11} - P_{f11} + P_{k12} - P_{f12}) - (K - b)(P_{kr1} - P_{fr1} + P_{kr2} - P_{fr2}) - \\ &\quad - (L - l_t)(P_{\delta11} + P_{\delta12}) + l_t(P_{\delta12} + P_{\delta12}) + M_R - R_x a, \end{aligned} \quad (6)$$

where: L, l_i and K , and a are design parameters, the nature of which is clear from Fig. 1; α and β – the average rotation angles of the front and rear wheels of the wide span tractor (vehicles), respectively.

After determining the angle of the tire's wide span tractor (vehicles) and lateral forces, after substituting (6) into (5) and carrying out a series of transformations, we obtain a mathematical model of the wide span tractor (vehicles) movement in the horizontal plane under the kinematic method of controlling it in a differential form Records:

$$\left. \begin{aligned} A_{11} \cdot \ddot{X}_s + A_{12} \cdot \dot{X}_s + A_{13} \cdot \varphi + A_{14} \cdot \varphi &= f_{11} \cdot \alpha + f_{12} \cdot \beta + R_x, \\ A_{21} \cdot \ddot{\varphi} + A_{22} \cdot \dot{\varphi} + A_{23} \cdot \varphi + A_{24} \cdot \dot{X}_s &= f_{21} \cdot \alpha + f_{22} \cdot \beta - \\ - R_x a + M_R - (K - b)(P_{kr1} - P_{fr1} + P_{kr2} - P_{fr2}) + \\ + b(P_{kl1} - P_{fl1} + P_{kl2} - P_{fl2}), \end{aligned} \right\} \quad (7)$$

where: $A_{11} = M_i$;

$$\begin{aligned} A_{12} &= (k_{l1} + k_{l2} + k_{r1} + k_{r2})/V_0; \\ A_{13} &= ((k_{l1} + k_{r1}) \cdot (L - l_i) - (k_{l2} + k_{r2}) \cdot l_i)/V_0; \\ A_{14} &= - (k_{l1} + k_{l2} + k_{r1} + k_{r2}); \\ f_{11} &= (P_{kl1} - P_{fl1} + P_{kr1} - P_{fr1}) + k_{l1} + k_{r1}; \\ f_{12} &= k_{l2} + k_{r2} - (P_{kl2} - P_{fl2} + P_{kr2} - P_{fr2}); \\ A_{21} &= J_i; \\ A_{22} &= ((k_{l1} - k_{r1}) \cdot (L - l_i)^2 + (k_{l2} - k_{r2}) \cdot l_i^2)/V_0; \\ A_{23} &= -(k_{l1} + k_{r1}) \cdot (L - l_i) + (k_{l2} + k_{r2}) \cdot l_i; \\ A_{24} &= (k_{l1} + k_{r1}) \cdot (L - l_i) - (k_{l2} + k_{r2}) \cdot l_i; \\ f_{21} &= (L - l_i) \cdot ((P_{kl1} - P_{fl1}) + (P_{kr1} - P_{fr1}) + k_{l1} + k_{r1}); \\ f_{22} &= l_i \cdot ((P_{kl2} - P_{fl2}) - (P_{kr2} - P_{fr2}) - k_{l2} - k_{r2}). \end{aligned}$$

In the operator form of writing, the system of differential equations (7) has the following form:

$$\left. \begin{aligned} K_{11} \cdot X_s(s) + K_{12} \cdot \varphi(s) &= F_{11} \cdot \alpha + F_{12} \cdot \beta + F_{13} \cdot R_x + \\ + F_{14} \cdot M_R + F_{15}, \\ K_{21} \cdot X_s(s) + K_{22} \cdot \varphi(s) &= F_{21} \cdot \alpha + F_{22} \cdot \beta + F_{23} \cdot R_x + \\ + F_{24} \cdot M_R + F_{25}, \end{aligned} \right\} \quad (8)$$

где: $K_{11} = A_{11} \cdot s^2 + A_{12} \cdot s$; $K_{21} = A_{24} \cdot s$;
 $K_{12} = A_{13} \cdot s + A_{14}$; $K_{22} = A_{21} \cdot s^2 + A_{22} \cdot s + A_{23}$;
 $F_{11} = f_{11}$; $F_{21} = f_{21}$;
 $F_{12} = f_{12}$; $F_{22} = f_{22}$;
 $F_{13} = 1$; $F_{23} = -(l_m + a)$;
 $F_{14} = 0$; $F_{24} = 1$;
 $F_{15} = 0$;
 $F_{25} = -(K - b) \cdot (P_{kr1} - P_{fr1} + P_{kr2} - P_{fr2}) +$
 $+ b \cdot (P_{kl1} - P_{fl1} + P_{kl2} - P_{fl2})$;
 $s = d/dt$ – differentiation operator.

The constructed mathematical models (7) and (8) allow estimating the stability and controllability of the motion of practically any wide span tractor (vehicles) with its kinematic control method.

In the mathematical model (8) of the dynamical system under consideration in the operator form of recording, control operators are the angles of rotation of the front α and rear β wheels. And the characteristics of the disturbing effect are: the component R_x of the principal vector R of the resistance of the agricultural implement and the main moment of the M_R . For the construction of amplitude and phase-frequency characteristics of the expression transfer functions of the dynamics of plane-parallel motion in the horizontal plane of the wide span tractor (vehicles) with the kinematic method of its control have the form:

1) on the control effect of the angle of rotation of the front wheels α :

– linear displacement X_S :

$$W_1 = \frac{D_1 + (0,5L - l_m) \cdot D_3}{D_\Delta}; \quad (9)$$

– relative to the course angle φ :

$$W_3 = \frac{D_3}{D_\Delta}; \quad (10)$$

2) by the disturbing effect of force R_x :

– linear displacement X_S :

$$W_2 = \frac{D_2 + (0,5L - l_m) \cdot D_4}{D_\Delta}; \quad (11)$$

– relative to the course angle φ :

$$W_4 = \frac{D_4}{D_\Delta}; \quad (12)$$

where: $D_\Delta, D_1 \dots D_4$ – the determinants, the expressions of which are defined as follows:

$$\begin{aligned} D_\Delta &= K_{11} \cdot K_{12} - K_{12} \cdot K_{21}; \\ D_1 &= A_{21} f_{11} s^2 + (A_{22} f_{11} - A_{13} f_{21}) s + (A_{23} f_{11} - A_{14} f_{21}); \\ D_2 &= A_{21} F_{13} s^2 + (A_{22} F_{13} - A_{13} F_{23}) s + (A_{23} F_{13} - A_{14} F_{23}); \\ D_3 &= A_{11} f_{21} s^2 + (A_{12} f_{21} - A_{24} f_{11}) s; \\ D_4 &= A_{11} F_{23} s^2 + (A_{12} F_{23} - A_{24} F_{13}) s. \end{aligned}$$

After substituting these determinants in (9-12), each i-th transfer function takes the form:

$$W_i = \frac{b_2 \cdot s^2 + b_1 \cdot s^1 + b_0}{a_4 \cdot s^4 + a_3 \cdot s^3 + a_2 \cdot s^2 + a_1 \cdot s^1 + a_0}, \quad (15)$$

where: $a_4 = A_{11} \cdot A_{21}$,

$$\begin{aligned} a_3 &= A_{11} \cdot A_{22} + A_{12} \cdot A_{21}, \\ a_2 &= A_{11} \cdot A_{23} + A_{12} \cdot A_{22} - A_{13} \cdot A_{24}, \\ a_1 &= A_{12} \cdot A_{23} - A_{14} \cdot A_{24}, \\ a_0 &= 0, \end{aligned}$$

$b_0 \dots b_2$ – coefficients, the nature of which is due to the functional relationship between the design and technological parameters of the wide span tractor (vehicles) and the characteristics of the disturbing and control actions:

– for W_1 :

$$\begin{aligned} b_2 &= (0,5L - l_i) \cdot A_{11} f_{21} + A_{24} f_{11}; \\ b_1 &= A_{12} f_{11} - A_{13} f_{21} + (0,5L - l_i) \cdot (A_{12} f_{21} - A_{24} f_{11}); \\ b_0 &= A_{23} f_{11} - A_{14} f_{21}; \end{aligned}$$

– for W_2 :

$$\begin{aligned} b_2 &= (0,5L - l_i) \cdot A_{11} F_{23} + A_{24} F_{13}; \\ b_1 &= A_{22} F_{13} - A_{13} F_{23} + (0,5L - l_i) \cdot (A_{12} F_{23} - A_{24} F_{13}); \\ b_0 &= A_{23} F_{13} - A_{14} F_{23}; \end{aligned}$$

– for W_3 :

$$b_2 = A_{11} f_{21}; \quad b_1 = A_{12} f_{21} - A_{24} f_{11}; \quad b_0 = 0;$$

– for W_4 :

$$b_2 = A_{11} F_{23}; \quad b_1 = A_{12} F_{23} - A_{24} F_{13}; \quad b_0 = 0.$$

The physical object of the theoretical studies was the prototype wide span tractor (vehicles) for the track farming system developed by us [11]. The results of calculating the amplitude- and phase-frequency characteristics from (15) are shown in Fig. 2-5.

Analysis of the calculated amplitude-phase and phase-frequency characteristics under the kinematic control method of wide span tractor (vehicles) showed that its controllability is essentially dependent on the speed of motion. At low velocities ($V_0 = 1.0 \text{ m} \cdot \text{s}^{-1}$), we have a significant under-regulation in the dynamical system (curve 1, figure 2). At the same time, the desired oscillation frequency of the angle of rotation α of the front wheels is at the level of 0.5 s^{-1} , where the value of the gain of the input control is approaching 1.

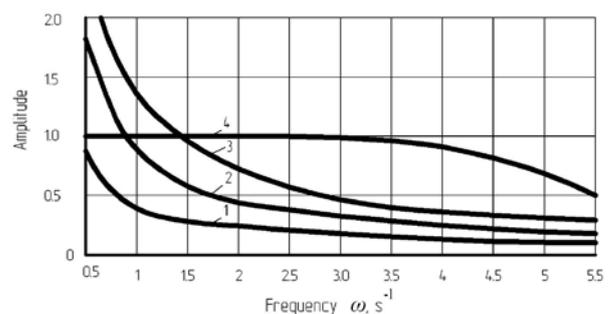


Fig. 2. Amplitude-frequency characteristics of the wide span tractor (vehicles) fluctuations in the course of controlling it (the angle of rotation α of the front wheels) with the kinematic method of its control and various speeds of motion:

- 1 – 1.0 m·s⁻¹;
- 2 – 2.0 m·s⁻¹;
- 3 – 3.0 m·s⁻¹;
- 4 – ideal characteristics.

Together with this, the increase in the speed of the wide span tractor (vehicles) to 2.0 and 3.0 m·s⁻¹ at low frequencies ($\omega < 1.3$ s⁻¹) contributes to the overshoot of the dynamic system (curve 2 and 3, figure 2). And at frequencies $\omega > 1.3$ s⁻¹, on the contrary, we have a slight under-regulation with respect to the ideal characteristic (curve 4, figure 2).

As for the phase shift of the development by the dynamic control system, as the working speeds of the wide span tractor (vehicles) increase to 3.0 m·s⁻¹ (curve 3, figure 3), the phase-frequency response is closest to ideal.

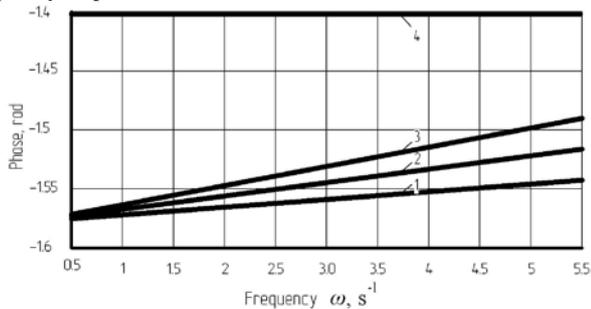


Fig. 3. Phase-frequency characteristics of fluctuations in the course angle φ wide span tractor (vehicles) when exercising control action (the angle of rotation α of the front wheels) with the kinematic method of its control and various speeds of motion:

- 1 – 1.0 m·s⁻¹;
- 2 – 2.0 m·s⁻¹;
- 3 – 3.0 m·s⁻¹;
- 4 – ideal characteristics.

An analysis of the amplitude and phase-frequency characteristics of working out the wide span tractor (vehicles) for controlling the angle of rotation α of the front wheels with respect to the transverse deviation of X_S (Figures 4 and 5) showed that as the speed of motion increases, the amplitude X_S also increases. This process is most pronounced at the oscillation frequencies of α close to zero.

At the same time, the maximum amplitude of the transverse deflection of the wide span tractor (vehicles) at low frequencies ($\omega = 0.5$ s⁻¹) and low speed mode ($V = 1.0$ m·s⁻¹) is 2 m per 1 radian (Figure 4). And with the increase in the speed regime to $V = 3.0$ m·s⁻¹, the amplitude of the transverse deflection of the wide span tractor (vehicles) is increased by 8 times, which, in practice, can lead to overshooting of the dynamic system and the complexity of its control. The information obtained allows us to predict the actual width of the constant track for the motion of the wide span tractor (vehicles), which is very important for the arrangement of the engineering zone of the field of controlled traffic farming.

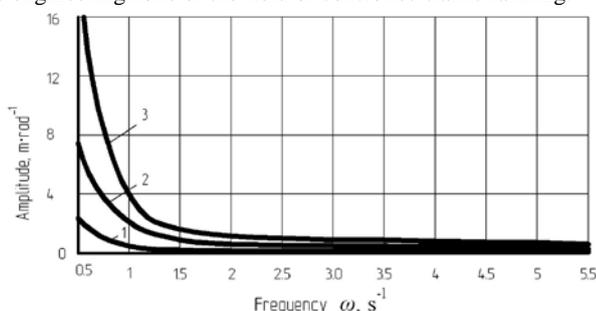


Fig. 4. Amplitude-frequency characteristics of the X_S -wide span tractor (vehicles) vibration oscillations when working out the control influence (the angle of rotation α of the front wheels) with the kinematic method of its control and various speeds of motion:

- 1 – 1.0 m·s⁻¹;
- 2 – 2.0 m·s⁻¹;
- 3 – 3.0 m·s⁻¹.

As for the phase shift of the development by the dynamic control system, when the working speeds of the wide span tractor (vehicles) are increased to 3.0 m·s⁻¹ (curve 3, figure 5), the phase-frequency response is also closest to the ideal.

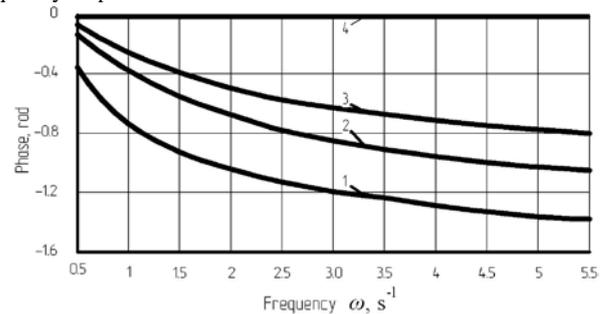


Fig. 5. Phase-frequency characteristics of the X_S -wide span tractor (vehicles) oscillations in the process of controlling it (angle of rotation α of the front wheels) under the kinematic method of its control and different speeds:

- 1 – 1.0 m·s⁻¹;
- 2 – 2.0 m·s⁻¹;
- 3 – 3.0 m·s⁻¹;
- 4 – ideal characteristics.

The amplitude and phase-frequency characteristics of working off the wide span tractor (vehicles) of the steering action of the angle of rotation β of the rear wheels are analogous.

From the above analysis, it can be stated that when a wide span tractor (vehicles) is operating at a high speed mode (close to 3.0 m·s⁻¹), only an effective control system will allow it to have satisfactory traffic controllability.

4. Conclusion

Mathematical models have been developed and new regularities of the parallel span tractor (vehicles) for controlled traffic farming under kinematic control have been obtained. Theoretically, new schemes, design parameters and operating modes can be substantiated with acceptable controllability and stability of movement in the horizontal plane.

From the position of minimizing the area of the field to the engineering zone for the movement of the wide span tractor (vehicles) at a high speed mode (close to 3.0 m·s⁻¹), only an effective control system will allow it to have satisfactory controllability and stability of motion.

5. Literature

1. Chamen T. Controlled traffic farming – from world wide research to adoption in europe and its future prospects / T. Chamen // Acta Technologica Agriculturae Nitra. – 2015. – №3. – P. 64-73.
2. Kingwell R. The whole-farm benefits of controlled traffic farming: An Australian appraisal / R. Kingwell, A. Fuchsichler // In Agricultural Systems. – 2011. – vol. 104, №7. – P. 513-521.
3. Chamen W.C.T. Assessment of a Wide Span Vehicle (Gantry), and Soil and Cereal Crop Responses to Its Use in a Zero Traffic Regime / W.C.T. Chamen // Soil & Tillage Research. – 1992. – №24(4). – P. 359-380.
4. Chamen W.C.T. Design, Operation and Performance of a Gantry System: Experience in Arable Cropping / W.C.T. Chamen // Journal of Agricultural Engineering Research. – 1994. – №59(1). – P. 45-60.
5. Onal I. Controlled Traffic farming and Wide span tractors / I. Onal // Journal of Agricultural Machinery Science. – 2012. – №8(4). – P. 353-364.
6. Pedersen H.H. Harvest Capacity Model for a Wide Span Onion Bunker Harvester / H.H. Pedersen // In Automation and System Technology in Plant Production / CIGR section V & NJF section VII conference, 30 June – 2 July 2011.

7. Chamen W.C.T. A New Methodology For Weed Control And Cereal Crop Production Based On Wide Span Vehicles And Precision Guidance: Biotrac // 4th EWRS Workshop on Physical Weed Control, Elspeet, The Netherlands, 20-22 March 2000. – P.51-55.

8. Pedersen H.H. User requirements for a Wide Span Tractor for Controlled Traffic Farming / Pedersen H.H., Sørensen C. G., Oudshoorn F.W., McPhee J.E. // International Commission of Agricultural and Biological Engineers, Section V. CIOSTA XXXV Conference "From Effective to Intelligent Agriculture and Forestry", Billund, Denmark, 3-5 July 2013.

9. Volodymyr Bulgakov. Investigation of technological properties of wide span tractors for controlled traffic farming / Volodymyr Bulgakov, Valerii Adamchuk, Volodymyr Kuvachov,

Semjons Ivanovs // ENGINEERING FOR RURAL DEVELOPMENT: 16 International Scientific Conference, Proceedings, Volume 16. – Jelgava, Latvia, May 24 – 26, 2017. – P. 303-308.

10. Nadykto V.T. Wide-span and pavement system of agriculture. Monograph / Nadykto V.T., Uleksin V.O, 2008. – 270 p.

11. Bulgakov Volodymyr. Research of possibilities for efficient use of wide span tractor (vehicle) for controlled traffic farming / Bulgakov Volodimir, Adamchuk Valeriy, Kuvachov Volodymyr, Ivanovs Semjons // ENGINEERING FOR RURAL DEVELOPMENT: 16 International Scientific Conference, Proceedings, Volume 16. – Jelgava, Latvia, May 24 – 26, 2017. – P. 281-287.