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Study of smoothness of course of specialized wide-track agricultural vehicle

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The purpose. To heighten smoothness of course of specialized wide-track agricultural vehicles by justification of scheme, mechanically-technological and other parameters, and also performances of long-edged profile of unevenness of agricultural background in traces of shaped technological track. **Methods.** Original positions of theoretical mechanics, statistical dynamics of the theory of autocontrol of linear dynamic systems and theory of tractor, creation of programs and calculations for PC are used. **Results.** New mathematical models are elaborated of operation of the created specialized wide-track agricultural vehicle for track system of farming agriculture in vertical plane. Their use allows justifying demands to performances of long-edged profile of unevenness of agricultural background in traces of technological track, raising smoothness of a course in view of kinematic and power correlations of its power and technological part. **Conclusions.** Smoothness of course of specialized wide-track agricultural vehicle as dynamic system, which moves on traces of the fixed technological track, essentially depends on structure of its long-edged profile, rigidness of tires of anvil wheels (which value can be influenced in the fixed limits by changing air pressure). Dynamics of vertical vacillating of technological part is caused by its operation mass.

Key words: *track system of farming agriculture, widetrack agricultural vehicle, differential equations, solutions on PC.*

Actuality of the question. One of the ways to increase the cultural and technological level of agriculture is the organization of strictly regulated (routed) traffic of all means of mechanization by means of pre-formed paths - permanent technological tracks. Due to their application, it is possible to resolve the contradictions in the "motive-soil" system, the physical essence of which is that the movement of technological and transport machines must be carried out on a dry and solid background (field engineering zone), and for productive plant growth it is necessary to loosen up And wet soil (agrotechnical zone of the field) [1].

It is known that reducing the area of transport and technological tracks and increasing the width of agricultural aggregates captures the land use indicators in the controlled traffic farming [2]. Significant efficiency in this plan is achieved through the use wide span tractors or specialized wide span vehicles [3-5], created specifically for the controlled traffic farming (fig. 1).

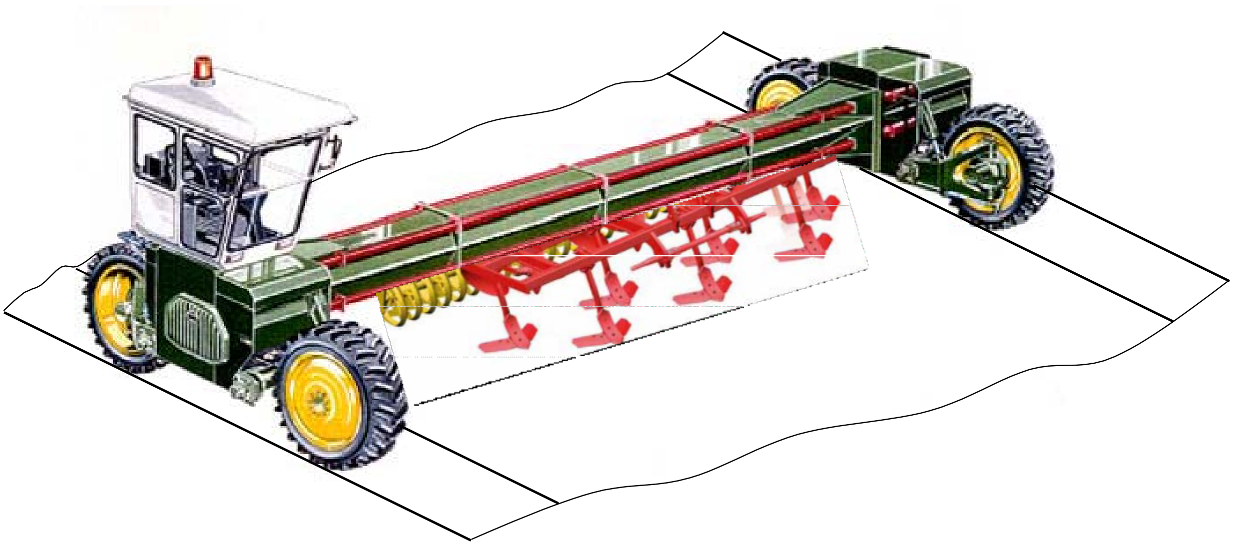

Fig. 1 - Constructive implementation of wide span vehicle in the controlled traffic farming

The subject of studying the theory of wide span vehicle for the controlled traffic farming will be considered as the methods for determining their properties, which include, in particular, the smoothness of the course.

It is clear that the dynamics of the movement of wide span vehicle in the vertical plane is determined by the input disturbing influences. The latter should include the inequality of the longitudinal profile of the permanent technological path and the unevenness of the traction resistance of the soil. It is clear that the nature of the internal structure of the longitudinal profile of the laid technological path certainly affects the smoothness of the course of wide span vehicle and the variations in its tractive effort with all negative consequences.

It is known that the quality of working out by any dynamic system of input variables depends on its characteristics. In the case of a wide span vehicle such as its scheme, as well as constructive and other parameters. Therefore, the correct choice of the latter from the position of the desired smoothness of the course provides him with the optimal transformation of disturbing influences that affect him.

Analysis of recent research and publications. All known studies on these issues, such as [5-7], are aimed at studying the dynamics of machine-tractor aggregates built on the basis of traditional tractors and do not address the solution of this problem. The accumulated scientific and practical experience of using traditional machine-tractor aggregates in the track system of agriculture allowed to substantiate certain requirements to the parameters of the constant technological track [1]. But these requirements do not take into account the atypical layout scheme of wide span vehicle, the specifics of their aggregation [9] and operating conditions, therefore, should be clarified. At the same time, the methodology of choice of design schemes, parameters and operating modes of machine-tractor aggregates is currently known, can not be used to study the dynamics of the movement of wide span vehicle in the vertical plane. In connection with this, from the point of view of the effective use of these wide span vehicle, there are unresolved issues regarding the study of conditions imposed on their constructive and other parameters.

The purpose. Improving of the smooth running of wide span vehicle by study schemes, technological, etc. parameters and characteristics of the longitudinal profile unevenness of the field of the soil fertility in the traces generated tramlines.

Methods. Method of use of theoretical mechanics, statistical dynamics of automatic control theory linear dynamical systems and the theory of the tractor, programming and calculations on a PC are used.

Results. The model of the functioning of a wide span vehicle, as a dynamic system, which is convenient to consider in the form of its reaction to incoming perturbations, the nature of the development of which uniquely determines the smoothness of the course. In this case, disturbances are shock and shock caused by the inequalities of the longitudinal profile of the permanent technological path and the unevenness of the traction resistance of the agricultural implements (the technological part of the wide span vehicle).

From the theory of automatic regulation of linear dynamical systems when reproducing them statistically random perturbing input influences it is known that the transforming properties of a dynamic system can be expressed by transfer functions and frequency characteristics. It is these characteristics, according to many scientists, give the most complete and physical representation of the reaction of the agricultural unit to various perturbations, as well as the transitional and stable processes of its work.

For a theoretical analysis of transfer functions and frequency characteristics, a system of corresponding differential equations that binds the input variables with input disturbances, that is, the mathematical model of the process itself, is required. At this stage of research it is expedient to consider it as a system of linear equations. Such an idealization is quite effective in this case, since the dynamics of the specialized wide span vehicle has not yet been sufficiently studied. And the knowledge gained on it gives an opportunity to physically comprehend the result and accumulate the experience of designing.

In the process of solving the problems of optimizing the parameters of a linear stationary dynamic system, we will use amplitude-frequency characteristics (AFCs) as operators. In order to simplify the compilation of differential equations, the following provisions and assumptions are adopted: angular oscillations of the technological part of a wide span vehicle are not considered; fluctuations in the traction resistance of agricultural implements do not affect the speed of its translational displacement, by virtue of which it is adopted constant; Inequalities of the profile of a constant technological path are a random ergodic stationary path function; The slope of wide span vehicle in the longitudinal-transverse plane is absent; the resistance forces in the tire of the support wheels are assumed to be proportional to the velocity of oscillation, and the characteristics of the elastic elements are linear.

Imagine a real wide span vehicle equivalent to the dynamic model (fig. 2), which has three degrees of freedom: the vertical movement z_T of the center of mass (S_T), the angular oscillations of the core φ_T and the vertical movement of z_3 of the center of the mass of the technolog ical part ($S_{c.-z.}$) Moving z_T and angular oscillations φ_T are related to the vertical movements of the front and back of the backbone of the gear (z_1 and z_2) (fig. 2). Therefore, for generalized coordinates, we take vertical moves z_1, z_2 and z_3 (fig. 2), respectively, the front and rear of the backbone of the wide span vehicle and the backbone of the technological part.

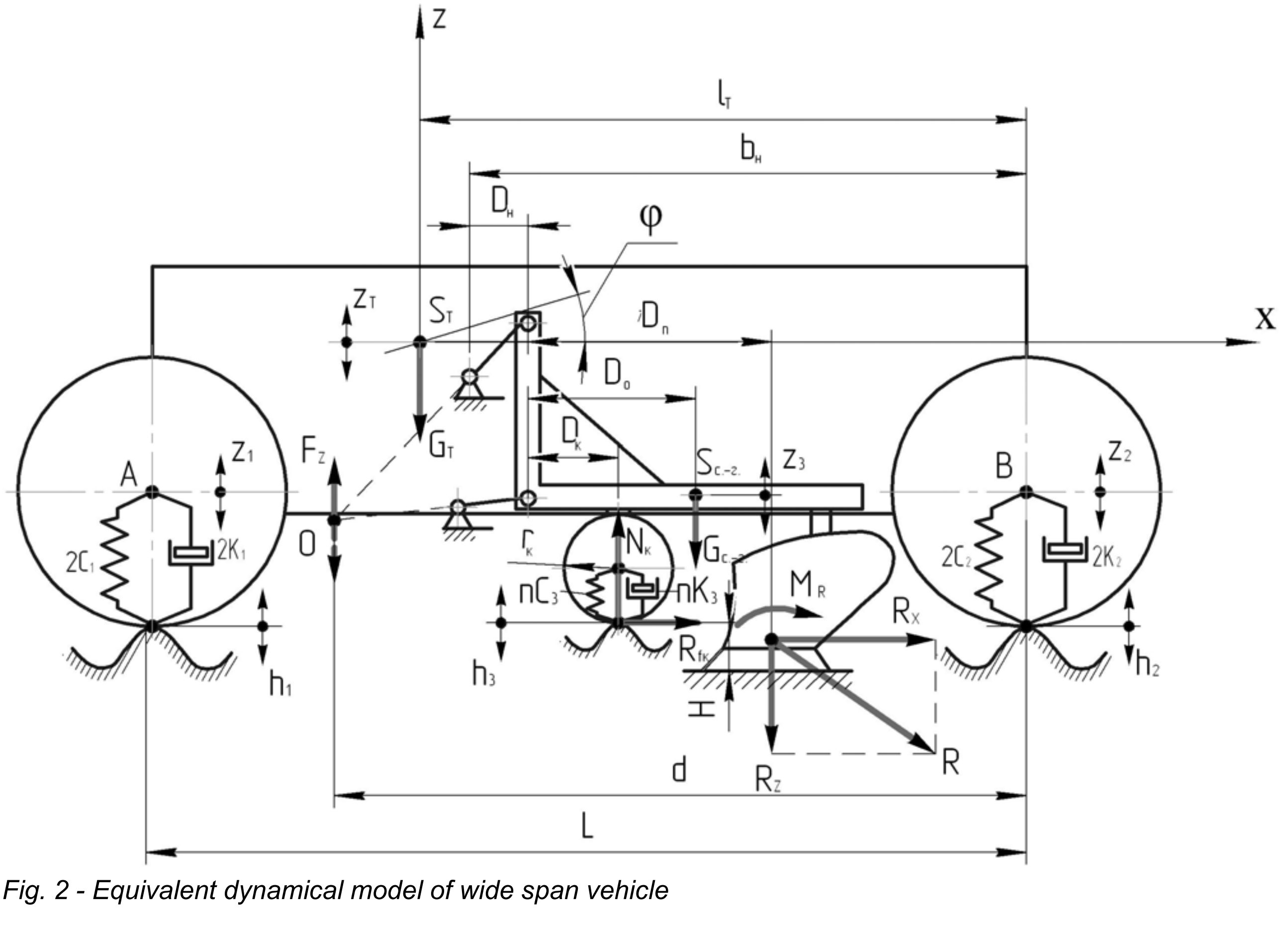

Fig. 2 - Equivalent dynamical model of wide span vehicle

The mathematical model of the plane-parallel motion of a broad wide span vehicle in a longitudinal vertical plane, constructed on the basis of the Lagrange II equation, has the form:

$$\begin{cases} \text{À}_{11}\cdot\ddot{z}_1+\text{À}_{12}\cdot\dot{z}_1+\text{À}_{13}\cdot z_1+\text{À}_{14}\cdot\ddot{z}_2=f_{11}\cdot\dot{h}_1+f_{12}\cdot h_1+f_{13}\cdot R_{\text{õ}}+f_{14}\cdot R_z+f_{15}\cdot M_R+f_{16}; \\ \text{À}_{21}\cdot\ddot{z}_2+\text{À}_{22}\cdot\dot{z}_2+\text{À}_{23}\cdot z_2+\text{À}_{24}\cdot\ddot{z}_1=f_{21}\cdot\dot{h}_2+f_{22}\cdot h_2+f_{23}\cdot R_{\text{õ}}+f_{24}\cdot R_z+f_{25}\cdot M_R+f_{26}; \\ \text{À}_{31}\cdot\ddot{z}_3+\text{À}_{32}\cdot\dot{z}_3+\text{À}_{33}\cdot z_3=f_{31}\cdot\dot{h}_3+f_{32}\cdot h_3+f_{33}\cdot R_{\text{õ}}+f_{34}\cdot R_z+f_{35}\cdot M_R+f_{36}, \end{cases} \quad (1)$$

where

$$\text{À}_{11}=\left(\text{Ì}_{\text{ò}}\cdot l_{\text{ò}}^2+J_{\text{òö}}\right)/L^2;\qquad \text{À}_{21}=\left(\text{Ì}_{\text{ò}}\cdot(L-l_{\text{ò}})^2+J_{\text{òö}}\right)/L^2;$$

$$\text{À}_{12}=2\text{Ê}_1;\quad \text{À}_{13}=2\text{Ñ}_1;\qquad \text{À}_{22}=2\text{Ê}_2;\quad \text{À}_{23}=2\text{Ñ}_2;$$

$$\text{À}_{14}=2\left(\text{Ì}_{\text{ò}}\cdot l_{\text{ò}}\cdot(L-l_{\text{ò}})-J_{\text{òö}}\right)/L^2;\qquad \text{À}_{24}=2\left(\text{Ì}_{\text{ò}}\cdot l_{\text{ò}}\cdot(L-l_{\text{ò}})-J_{\text{òö}}\right)/L^2;$$

$$\text{À}_{31}=\text{Ì}_{\text{ñ.–ã.}};\quad \text{À}_{32}=n\text{Ê}_3;\quad \text{À}_{33}=n\text{Ñ}_3;\qquad f_{21}=2\text{Ê}_2;\quad f_{22}=2\text{Ñ}_2;$$

$$f_{11}=2\text{Ê}_1;\quad f_{12}=2\text{Ñ}_1;\qquad f_{31}=n\text{Ê}_3;\quad f_{32}=n\text{Ñ}_3;$$

$$f_{13}=\frac{\square 0,5\cdot H\cdot d}{L(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};\qquad f_{23}=\frac{0,5\cdot H\cdot(1-d)}{L(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};$$

$$f_{14}=\frac{d\cdot(D_{\text{ï}}-D_{\text{ê}})}{L(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};\qquad f_{24}=-\frac{(1-d)\cdot(D_{\text{ï}}-D_{\text{ê}})}{L(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};$$

$$f_{15}=\frac{d}{L(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};\qquad f_{25}=\frac{(1-d)}{L(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};$$

$$f_{16}=\frac{d\cdot G_{\text{c.-ã.}}(D_0-D_{\text{ê}}+f_{\text{ê}}\cdot r_{\text{ê}})}{L(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};\qquad f_{26}=\frac{(1-d)\cdot G_{\text{c.–ã.}}\cdot(D_0-D_{\text{ê}}+f_{\text{ê}}\cdot r_{\text{ê}})}{L(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};$$

$$f_{33}=\frac{0,5\cdot H}{(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};\qquad f_{35}=-\frac{1}{(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};$$

$$f_{34}=\frac{(D_{\text{ï}}-D_{\text{ê}})}{(d-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})};\qquad f_{36}=\frac{G_{\text{c.–ã.}}(D_0-D_{\text{ê}}+f_{\text{ê}}\cdot r_{\text{ê}})}{(d_0-b_{\text{í}}+D_{\text{í}}+D_{\text{ê}})}.$$

In the system of equations (1) $M_{т}$, $J_{тц}$ - mass (kg) and moment of inertia (kN·m·s^2) of the wide span vehicle relative to the axis passing through $S_{т}$; K_1, K_2, K_3, C_1, C_2, C_3 – reduction of coefficients of resistance of dissipative (kH·s/m) and elastic (kN/m) elements of the system of sprinkling of the wide span vehicle and its technological part; n - number of supporting wheels of the technological part; $M_{с-г}$, $G_{с-г}$– weight (kg) and weight (kN) of the technological part; H - depth of cultivation of a ground, м; $r_{к}$, $f_{к}$ - radius and coefficient of rolling resistance of the support wheel of the technological part; L, $l_{т}$ - wheelbase and longitudinal coordinate of the center of the masses of the wide span vehicle; d, $b_{н}$, $D_{н}$, $D_{к}$, D_0, $D_{п}$ - constructive parameters, the nature of which is clear from fig. 2.

The main disturbances that cause the vertical movement of a wide span vehicle in the longitudinal vertical plane are the variations in the amplitude of the longitudinal profile of the technological track under the front (h_1) and rear (h_2) of its wheels and supporting wheels of the technological part (h_3), as well as the variations of the traction resistance of the technological part (R_x and R_z) and the main moment of resistance (M_R) (fig. 2). These disturbances are input values in the system of equations (3). And the initial parameters of the latter are the amplitudes of displacements of the front (z_1) and rear (z_2) part of the back of the ram wide span vehicle and the oscillation of the backbone of the technological part (z_3).

From the analysis of the mathematical model (1) it follows that the dynamics of vertical fluctuations of the wide span vehicle due to its range of constructive parameters. In the first place, they include the parameters of the tires of its wheels, in particular their rigidity coefficients. In the process of mathematical modeling of the dynamics of vertical fluctuations of the wide span vehicle of the TSAU [10] design adopted for the physical object of research, three potential variants of the standard sizes of tires of its wheels were considered: 1 - 11,2R20; 2 - 11.2R32; 3 - 9.5R42.

The rigidity of the tire and of the reference wheel of the wide span vehicle can be determined by the well-known Heydeckel formula [11]:

$$C_i = \pi \cdot \rho_W \cdot \sqrt{D \cdot B}\ , \qquad (2)$$

where D - static diameter of the tire, m; B - width of the profile of the tire, m; ρ_w - air pressure in the wheels, Pa.

As a result of mathematical modeling, it has been established that for the three variants of the standard sizes of tire wheels of a wide span vehicle of the TSAU design with a certain difference of their coefficients of stiffness C_2, the difference between the calculated AFC and the FFL is virtually insignificant (curves 1-3, fig. 3). But the very nature of working out the wide span vehicle of fluctuations inequalities of the profile constant technological path depends essentially on the frequency of perturbation. Thus, at the frequencies up to ω=7.0 s^{-1}, the effect of this parameter is practically not felt. At ω>7.0 s^{-1}, the increase in C_2 causes the lowering of the frequency response with the displacement of the resonance peaks towards higher frequencies (fig. 3). The latter are concentrated in the range ω=10-11 s^{-1} for the considered variants of standard sizes of tires. And this particular frequency band is most not desirable for the fluctuations of the inequalities of the profile of the constant technological path, since it amplifies the intrinsic perturbation with the gain of the amplification factor by a dynamic system (i.e. wide span vehicle) 6. The deterioration of the dynamics of vertical vibrations of the agro means can not be improved even by increasing the rigidity of its tires to 450 kN/m (curve 5, fig. 3). And the possible reduction of the latter to 150 kN/m reduces the frequency response with the simultaneous displacement of its resonant peaks in the direction of low frequencies (curve 6, fig. 3). However, the dispersion of the fluctuations of the inequalities of the profile of the constant technological path in the frequency range ω=13-15 s^{-1} for the considered three variants of the wheel tires is most desirable, since they approximate the characteristics to the ideal.

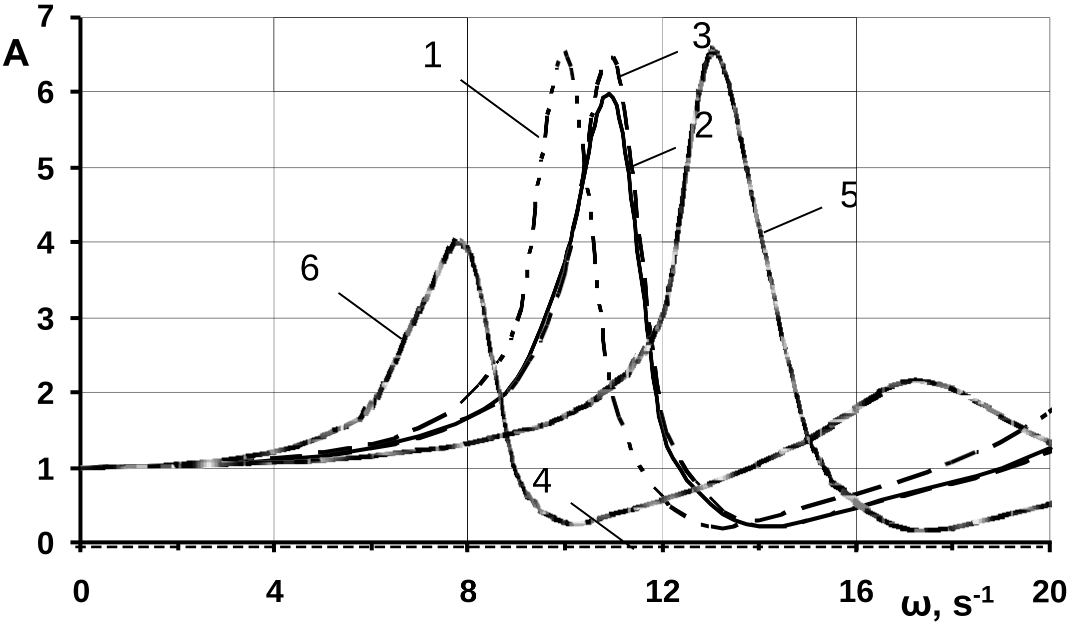

Fig. 3 - AFC working out the shield of the wide span vehicle of the structure TSAU fluctuations of the profile of the path with tires of different rigidity: 1 - 11,2R20 (C_2 = 254 kN/m); 2 - 11.2R32 (C_2=292 kN/m); 3 - 9.5R42 (C_2=296 kN/m); 4 - ideal characteristics; 5 - C_2=450 kN/m; 6 - C_2=150 kN/m

From the point of view of the desirable working out of the dynamic system of the perturbation considered, a significant increase in the rigidity coefficient of the wide span vehicle is effective only if the dispersion of the fluctuations of the inequalities of the constant technological path is concentrated in the frequency range ω $=0...8$ s^{-1} and $\omega=16...20$ s^{-1}. With a frequency of perturbations of less than 8 s^{-1}, the vertical fluctuations of the wide span vehicle depend little on the value of the rigidity of its tires. In this case, for the considered three variants of tire wheels of the agro, it is desirable that the dispersion of the inequalities of the profile of the constant technological path are concentrated in the frequency range $\omega=13\text{-}15$ s^{-1}, where the considered dynamic system almost does not react to the intrinsic perturbation. In practice, it is possible to achieve this by the appropriate technology of forming traces of a constant technological path, or by changing the stiffness of the pneumatic tire by selecting its air pressure, which would provide a minimum response to the dynamic system of input disturbance.

From the analysis of experimental data [1], the profiling of traces of a permanent technological tract, formed on unwrought field by wheel and crawler propulsion of energy means (respectively, MEZ-200 and T-150), follows that, with somewhat uniform unevenness of the profiles of the tracks, their internal structures are different. The most low-frequency character has the profile of the track laid by MEZ-200. The path of its correlation connection is about 0.57 m, which is 8 times more compared with the track profile laid by the tractor T-150. Even in comparison with the original unprocessed agrophon, the track system of the crawler tractor forms a higher-frequency track profile with a clearly expressed periodic component. The source of generation of the latter can be explained by the step of a caterpillar T-150 (17 cm), which practically coincides with the wavelength of the inequalities of the longitudinal profile of the track, equal to 17.4 cm. The motion of the wheeled energy MEZ-200 along the tracks of the tractor T-150 causes the fluctuations of the core of the first with a higher frequency character than when moving along its own trace. In the first case, the correlation time did not exceed 0.16 s, in the second case it increased to 1.5 s.

On the basis of the above analysis, it can be concluded that the reduction of the rigidity of the wide span vehicle in general is effective at the low frequency range of the fluctuations of the inequalities of the profile of the constant technological path.

The dynamics of vertical vibrations of the technological part of the wide span vehicle for (1) is due, first of all, to the rigidity of the tires of its supporting wheels and the operating mass $M_{\text{с.г}}$. As a result of the mathematical modeling, it has been established that an increase in the operating mass of $M_{\text{с.г}}$. from 300 to 500 kg leads to an undesirable rise in the frequency response of the working part of the vibration of the profile of the track along with the displacement of the resonance peaks towards the low frequencies (curves 2 and 3, fig. 4). If at the same time significantly reduce the rigidity of the tires of the supporting wheels of the technological part to 25 kN/m, that is 4 times (curve 5, fig. 4), then the resonant peaks of the frequency response are even shifted towards the low frequencies. At the same time, the gain of the dynamic input excitation system at the resonant frequency is reduced only by 2 times. And only at frequencies greater than 13 s^{-1} the AFC in general becomes less than one and converts the characteristics to the ideal. But the increase in rigidity of the tires of the supporting wheels up to 200 kN/m (curve 1, fig. 4), on the contrary, at low frequencies (up to $\omega=8…10$ s^{-1}) reproduces the technological part of practically no significant increase in the intrinsic perturbation, and only at the frequency $\omega=18$ s^{-1} the magnitude of the gain reaches 2.

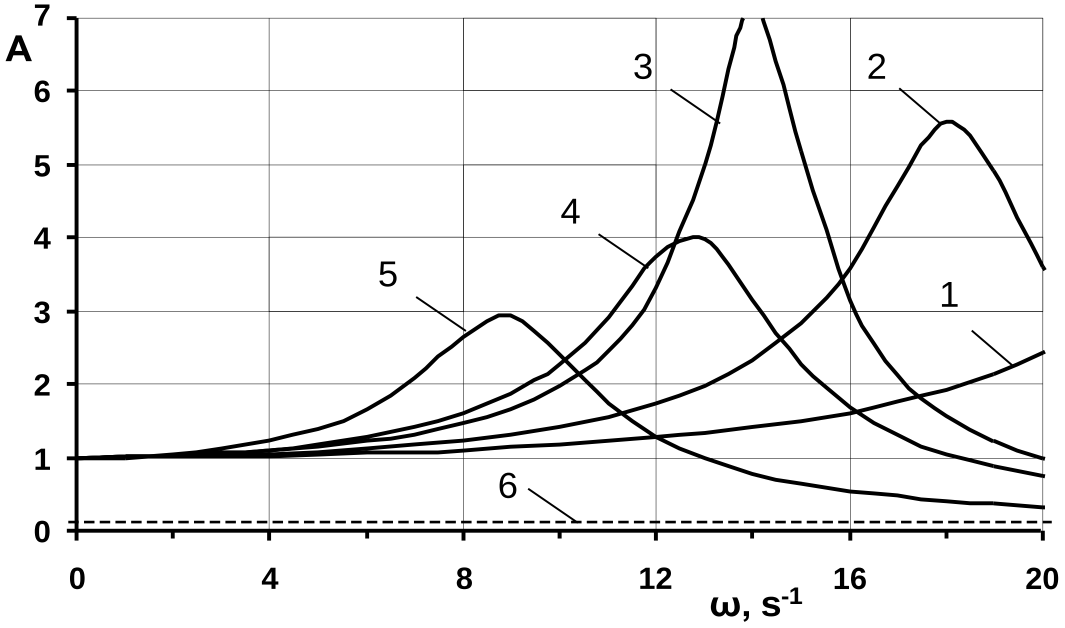

Fig. 4 - AFC working out the technological part of the fluctuations of the profile of the agrifon with different masses $M_{c.f.}$ and coefficients of rigidity of tires of supporting wheels (C_3): 1 - $M_{c.f.}$=300 kg; C_3=200 kN/m; 2 - $M_{c.f.}$=300 kg; C_3=100 kN/m; 3 - $M_{c.f.}$ =500 kg; C_3=100 kN/m; 4 - $M_{c.f.}$=300 kg; C_3=50 kN/m; 5 - $M_{c.f.}$=300 kg; C_3=25 kN/m; 6 - ideal characteristics

In the frequency range ω=13-15 s^{-1}, the fluctuations of the roughness profile of the agrophon which is most desirable for the motion of a wide span vehicle in the footsteps of a constant technological path, as noted earlier, the change In the rigidity of the tire of the support wheel of the technological part leads to the following. When the rigidity of the tire C_3=200 kN/m (curve 1, fig. 4), we have an amplification of the intrinsic perturbation with a coefficient not exceeding 1.5. Further increasing the rigidity of the tire, as well as the use of a rigid rim, brings the AFC to 1, that is, the dynamic system copies the inequality of the profile of the path. Reducing the rigidity of the tire from 200 kN/m to 100 kN/m (curve 2, fig. 4) in a certain frequency range increases the frequency response to 3, removing it from the ideal. With the subsequent reduction of the rigidity of the tire from 100 kN/m to 50 kN/m (curve 4, fig. 4), the dynamics of the motion of the technological part in the vertical plane deteriorates in the considered frequency range. And only a reduction in the rigidity of the tire to 25 kN/m brings the characteristics in the frequency range ω=13-15 s^{-1} to the ideal (curve 5, fig. 4).

Based on the above analysis it can be stated that an increase in the operating mass of the technological part is inappropriate. In the case when the main spectrum of the dispersion of the agrophobic unevenness is concentrated in the high frequency range ω=13-15 s^{-1}, then the value of the coefficient of hardness of its tires should not be greater than 25 kN/m. Otherwise, the use of support wheels of the technological part with a rigidity coefficient of tires up to 200 kN/m and greater is desirable for its dynamics of motion in the vertical plane.

Conclusions

The smoothness of the course of a wide span vehicle, as a dynamic system moving in the footsteps of a constant technological path, essentially depends on the characteristics of the inequalities of the longitudinal profile of the latter. Desired character of the internal structure of the longitudinal profile of the laid technological path can be practically obtained by the appropriate technology of its formation. The quality of working out with a dynamic system of input disturbances, which is the inequality of the longitudinal profile of the permanent technological runway and the unevenness of the traction resistance of the soil, depends on the scheme, as well as on the structural and other parameters of the wide span vehicle. Significant influence on the smoothness of the latter moves the rigidity of the tires of its support wheels, the magnitude of which can be influenced, within certain limits, by changing the air pressure in them. The dynamics of vertical vibrations of the technological part of the wide span vehicle due, first of all, to the rigidity of the tires of its supporting wheels and the operating mass. The improvement of the dynamics of its motion in the vertical plane is achieved by increasing the first and decreasing the latter.

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