Investigation of the damping properties of the process module for a tractor of traction class 1.4

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Abstract. To analyze the positive influence of the technological module on the fluctuations of the external load of the tractor, the methods of statistical dynamics are used. A dynamic model of a process module with two rotating masses is considered: the rim and tire of the drive wheel and the translational mass of the process module. Using the transfer function, the spectral functions of the output process (the horizontal component of the force on the MTZ-82 tractor) were determined when performing a machine-tractor unit (MTA) technological operation with heavy disks (BDT-7) intended for a class 3 tractor. The developed mathematical model of the technological module allowed us to construct theoretical spectral densities of the horizontal component of the force on the tractor hitch when completing it with the technological module. The use of the process module allows the frequency range of forces on the tractor hitch to be shifted to a lower zone from 0 to 2.5 Hz, excluding high-frequency components compared to the standard configuration of the tractor.

1. Introduction

Since the middle of the last century, the energy saturation of tractors has increased dramatically. The excess power, which could not be realized through the traction force, was used to drive the active working bodies of agricultural machines [1, 2]. When using an energy-saturated tractor with working tools without active working bodies, ballasts were widely used, which allowed to realize the excess power through the creation of additional traction force [3, 4].

In the 70s, an alternative solution was proposed for the implementation of the excess power of the engine of an energy-saturated tractor, the use of a technological module (TM) [5-7]. The technological module was a third drive bridge to the tractor equipped with hydraulic suspension equipment [8-10]. With its main purpose of creating an additional tractive effort, TM found a side positive property of
smoothing out the fluctuations in the resistance force of the working bodies of an agricultural machine or tool [11, 12]. Damping of external vibrations occurs due to the elastic damping parameters of the wheel tires, as well as the inertia of the translational and rotating masses of the technological module [11, 13].

The purpose of the work is to confirm the hypothesis about the damping properties of the process module.

2. Materials and methods

To analyze the positive influence of the technological module on the fluctuations of the external load of the tractor, the methods of statistical dynamics are used [14, 15].

Knowing the spectral density of the input process (force fluctuations on the hitch of the process module) $S_{\text{entrance}}(\omega)$ and using the transfer function $W_{TM}(j\omega)$ it is possible to determine the spectral density of the output process (force fluctuations on the tractor hitch) $S_{\text{exit}}(\omega)$:

$$S_{\text{exit}}(\omega) = |W_{TM}(j\omega)|^2 \cdot S_{\text{entrance}}(\omega). \quad (1)$$

To determine the transfer function, the process module is considered as a separate dynamic model, shown in figure 1.

![Diagram of the dynamic model of the process module.](image)

The technological module is represented by a model with rotating masses with moments of inertia: rims $J_1$ and tires $J_2$ driving wheel and translational mass $m_{TM}$.

According to the dynamic model (figure 1), the motion of the process module is described by a system of equations:

$$m_2 \frac{dv_2}{dt} = \frac{M_{\phi,\text{moment}}}{r_3} - P_{f,\text{moment}} + P_{\text{max,\text{moment}}} - P_{\text{machine\ resistance}};$$

$$v_2 = \omega_12 r_3 = \frac{d\lambda}{dt} - \beta_3 \lambda;$$

$$M_{\phi,\text{moment}} = \left( k_{12.2} \frac{d\lambda}{dt} + c_{12.2} \lambda + a_{R,\text{moment}} \right) r_3;$$

$$P_{f,\text{moment}} = a_{R,\text{moment}};$$

$$a = a_{0,\text{moment}} + \lambda_{\text{moment}};$$

$$a_{0,\text{moment}} = f_{\text{moment}} r_3.$$
where $P_{\text{max moment}}$ и $P_{\text{machine resistance}}$ - traction forces on tractor and process module hitches, respectively;

$M_{\Phi,\text{moment}}$ - the moment of interaction of the driving wheels with the soil [11, 16];

$\alpha_{O,\text{moment}}$ - offset of the vertical reaction $R_{M}$ relative to the axis of the drive wheel of the process module;

$\lambda_{\text{moment}}$ - longitudinal deformation of the drive wheel tire of the process module;

$r_{3}$ - dynamic wheel radius;

$v_{2}$ - actual speed of the process module;

$\omega_{12}$ - angular velocity of the tires of the driving wheels of the technological module;

$\beta_{3}$ - the coefficient of slipping of the driving wheels of the technological module.

Using the Laplace transform [8, 10] and zero initial conditions, we obtain the transfer function from equation (2):

$$W_{\Delta M_{\Phi,\text{moment}} \Delta P_{\text{machine resistance}}} (s) = \frac{Q_{1}P_{2} - P_{1}}{Q_{2}},$$

here the following notation of polynomials from is accepted $s$:

$$\begin{align*}
Q_{1} &= m_{2}s; \\
Q_{2} &= (k_{12,2}s + c_{12,2})r_{3} + m_{2}g; \\
P_{1} &= k_{12,2}s + c_{12,2}; \\
P_{2} &= s + \beta_{3}.
\end{align*}$$

3. The results of the study

Using the transfer function was determined by the spectral function of the output process (the horizontal component of the stress on the tractor MTZ-82) in the performance of MTA technological operations with hard disks (BDT-7), intended for tractors of class 3.

In figure 2 shows the comparison of theoretical and experimental spectral density of the output process of the module (horizontal component of stress on the tractor MTZ-82).

The adequacy of the given dynamic model of the technological module is confirmed by the minimum sum of the squares of the difference in the amplitudes of the theoretical and experimental spectral densities shown in figure 2. At the same time, we can note the visual coincidence of the main frequencies of the curves of the theoretical and experimental spectral densities of the output processes.

Analyzing the spectral densities of the input and output processes (figure 3), it can be noted that the maximum values of the spectral density (energy) of the traction force acting on the lower axis of the tractor hitching mechanism in the horizontal plane at frequencies of 0..0.25 Hz are 2.5 times less than the process of loading the hitch of the technological module.
Figure 2. Spectral densities of the horizontal component of the force on the hitch of the MTZ-82 tractor with the technological module: - - - - - - - - theoretical and ——— ——— - experimental.

The values of the spectral density of the traction force acting on the lower axis of the tractor hitching mechanism are also reduced for other frequencies and practically have a small energy compared to the spectral density of the traction force acting on the lower axis of the hitching mechanism of the technological module in the horizontal plane from the side of the tool. This indicates the stabilization of the horizontal component of the force on the tractor hitch and confirms the hypothesis of the presence of elastic-damping properties of the process module.

Figure 3. Estimates of the spectral density of the traction force acting on the lower axis of the hitch mechanism in the horizontal plane: _ _ _ _ _ _ _ _ _ _ _ _ _ _ - tractors; ______________ - technological module.
4. Discussion and conclusion

The developed mathematical model of the technological module allowed us to construct theoretical spectral densities of the horizontal component of the force on the tractor hitch when completing it with the technological module. The use of the process module allows the frequency range of forces on the tractor hitch to be shifted to a lower zone from 0 to 2.5 Hz, excluding high-frequency components compared to the standard configuration of the tractor.

The tests were carried out on the equipment of the Shared Use Center "Materials Research Center".

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