Method of estimation of dynamic properties of transmissions of forestry units

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Abstract. When performing energy-intensive work in forestry related to the processing of stumpy soil, it is necessary to substantiate new requirements for forestry tractors in terms of weight, energy and dynamic parameters. Their change will cause a change in the disturbing forces acting on the transmission shafts of the unit, which can excite torsional vibrations in its dynamic system. When the natural frequencies of the oscillations coincide with the disturbing ones, unwanted resonant oscillations may occur. The most common models for studying dynamic properties are models in the form of complex multi-mass torsional dynamical systems.

To calculate the vibrations of torsional systems, an algorithm and a program for solving a system of differential equations were drawn up. Their solution made it possible to calculate the amplitude-frequency characteristics (AFC) of the dynamic systems of tractor units. The allocation of zones of forced oscillations in transmissions from the working bodies on the frequency response, as well as the coordination of the parameters of the working bodies with the parameters of the transmissions is a necessary condition for ensuring the effective operation of forestry units. When changing the moments of inertia of rotating masses, it is necessary to analyze the vibrations that occur in branched transmissions with active working bodies with significant moments of inertia. To determine their optimal parameters, the presented mathematical models can be used.

1. Introduction

Furrow plowing of the soil in cuttings when performing forestry work is accompanied by significant load fluctuations when overcoming root and stump inclusions. In this case, the engine operation is switched to the unregulated branch of its external characteristics, which makes it necessary to determine the rational degree of its loading, taking into account the correspondence of the dynamic reaction of the unit to overloads, the dynamics of the resistance forces on the working body [1,2,3,4].

When changing the energy and dynamic parameters of the unit, the disturbing forces acting on the transmission of the unit will change, exciting torsional vibrations in a multi-mass dynamic system. At the same time, the possibility of resonant vibrations in the transmission should be taken into account.

The analysis of dynamic models of forest reclamation units based on tractors has shown that the most common are mathematical models of complex torsional oscillatory systems [1,5,6,7,8]. They allow us to justify the aggregation of a forestry tractor and tillage tools with active working bodies in the direction...
of choosing their masses and moments of inertia in order to exclude the occurrence of resonant phenomena in the transmissions that can cause breakdowns or premature wear. On the basis of mathematical models of dynamic systems, it is possible to calculate the possibilities of matching the exciting frequencies both on the part of the working body and the natural frequencies of vibrations in the transmissions, in order to exclude their falling into harmonics.

2. Objects and methods of research

The objects of research are forestry and forest-reclamation tractors, which differ in their design, engine power and dynamic parameters, propulsion structures and layout. In the operation of these units, the load factor of the short circuit of their engines should be close to the value of 0.9. However, when performing the main energy-intensive work in forestry, the short circuit remains significantly lower, which indicates an irrational use of energy due to the discrepancy between the dynamics of external conditions and the dynamic characteristics of the units [1,9,10].

The calculations currently use dynamic models of transmissions and machine-tractor units in general in the form of torsional oscillatory systems. Calculations in the field of optimization of dynamic loading of power gears of tractor units with passive working bodies can be performed with sufficient accuracy and reliability on the basis of a mathematical model of the transmission in the form of a chain six-mass dynamic system (figure 1, a). For units with active working bodies such as disc cutters driven by a tractor PTO, it is necessary to consider branched ten-mass systems (figure 1, b).

![Figure 1. Six-mass (a) and ten-mass (b) equivalent dynamic circuit.](image-url)

The following symbols are used in the diagrams: $J$ – the given moments of inertia of the tractor and tool mechanisms; $c$ – the given stiffness coefficients of the transmission sections; $M_{10}$ – the torque from the engine; $M_{20}$ – the moment of resistance from the developed medium. So the upper branch of the transmission of the drive of the working body (figure 1, b) includes the rotating masses of the engine with the flywheel $J_{\text{engine}}$ and $J_{\text{traction}}$, the power take-off shaft with the gearbox $J_{\text{power shaft}}$, the driveshaft of the drive of the working body $J_{\text{cardan}}$ with the gearbox $J_{\text{gear box}}$, the drive shaft of the milling cutter with the milling cutter assembly $J_{\text{milling cutter}}$. The lower branch is the drive of the...
undercarriage of the tractors from the gearbox $J_{\text{transmission}}$, through the main gear $J_{\text{main gear}}$, side gears $J_{\text{on-board transmissions}}$ and propellers $J_{\text{mower}}$.

Based on the presented dynamic schemes, we will calculate the transfer functions for the torques on the transmission shafts in the form of a chain $n + 1$ mass vibrational dynamic system, which allows us to evaluate the resonant ones.

3. Results and discussion

When the speed of movement of the forestry unit LHT – 4 of the VNIMleskhoz design changes from 0.63 to 1.19 m/s (movement on I-IV gears), the frequency of oscillatory action from the caterpillar gearing varies from 37.05 to 70.00 rad/s, for the tractor LHT – 55, the values of the vibration frequencies from the tracks on the working gears are 37.01 – 64.76 rad/s, for the LHT – 100 A, they will be 31.19 – 54.58 rad/s. The transmission of the DT – 75 B reclamation tractor with the SCHDM-1 or MDN-3 slotted disc-milling tool experiences a crawler impact frequency of 6.82-9.34 rad/s in winter and 16.16-22.27 rad/s in summer. From the side of the guns, it is loaded through the PTO with frequencies of 716.22-994.75 and 733.23 – 1018 rad/s for the SCHDM – 1 and MDN – 3 slash-cutting guns, respectively [8].

An algorithm and a program for solving a system of differential equations based on the Runge-Kutta method in MathCAD using the eigenvals (M) functions were developed to calculate the free oscillations of systems with variable moments of inertia of the flywheel of the engine and the disc-milling active working body) [1,2,7,8]. According to the algorithm for finding the transfer functions, and according to them the frequency response, described in [7], the calculations of the frequency response and frequency response of dynamic systems of forestry aggregates were carried out.

To assess the dynamic properties of the transmissions of forestry and forest-reclamation units, their frequency response for the chain and branched transmission scheme was used when using tools with passive working bodies and driven by PTO. In the chain transmission, the values of the moments of inertia of the tractor engine flywheel varied from 2.9 to 6 kg·m².

As follows from the calculations of the frequency response for the unit based on the tractor LHT-55 with the plow PKL-70 when working in first gear with standard and increased flywheels ($J_{\text{max}} = 2.9$ and 6 kg·m²), significant oscillation amplitudes are observed in the natural frequency range and resonances coincide with the natural frequencies, and the oscillations from the propellers spread throughout the transmission, and also reach the primary shaft of the gearbox, the oscillations from the engine are significantly inferior in amplitude.

A comparison of the frequency response shows that when the power $J_{\text{max}}$ is increased from 2.9 to 6 kg·m², there are no significant changes in the transmission oscillation frequencies. The increase in the moment of inertia of the flywheel of the engine does not cause resonant phenomena in the tractor transmission, but increases its productivity by increasing the speed of movement.

In this case, the vibration energy excited by the action of the crawler gearing propagates through the transmission, and the vibrations in the direction of the tractor are significantly damped. The frequencies caused by the impact of track engagement in the first and third gears at the rated speed of the crankshaft of the tractor engine are for LHT – 55 37.01 – 64.76 rad/s and are not imposed on the natural vibration frequencies of the transmission.

The analysis of the dynamics of the transmission with a ten-mass scheme of the reclamation unit (tractor DT-75 B with MDN – 3 and SCHDM-1 guns) with active working bodies of the disc-milling type having a significant moment of inertia, for various options for changing the moments of inertia of the flywheel of the engine and the milling disc is presented in the graphs of the frequency response (figure 2). The working speed of the unit was assumed to be 0.2 m/s according to the technical characteristics of the guns. The moment of inertia of the flywheel of the engine was assumed to be 2.9 and 8.0 kg·m², the moment of inertia of the milling cutters brought to the crankshaft of the engine was 1.15 and 3.61 kg·m².
Figure 2. Frequency response of the DT-75 transmission with the SHCHDM - 1 gun:  
a – \( J_0 \) 2.9 kg·m²; \( J_6 \) 1.15 kg·m²;  
b – \( J_0 \) 2.9 kg·m²; \( J_6 \) 3.61 kg·m²;  
c – \( J_0 \) 8 kg·m²; \( J_6 \) 1.15 kg·m²;  
d – \( J_0 \) 8 kg·m²; \( J_6 \) 3.61 kg·m²;  
1 – impact of the milling cutter on the clutch shaft;  
2 – impact of the milling cutter on the power take-off shaft;  
3 – impact of the motor on the cutter;  
4 – impact of the milling cutter on the gearbox.

From the analysis of the frequency response data of the DT – 75 B tractor with the SHCHDM-1 tool,  

it follows that the energy from the impact of the inertial mass of the milling disc is concentrated within  
the frequencies of 40 and 230 rad/s. The energy of the impact of the crawler engagement on the  
transmission increases in the frequency range 190-210 rad/s, the vibrations propagating along the transmission in the direction of the tractor gradually fade and increase with the increase in the moment of inertia of the flywheel of the engine.

The analysis of the transmission of a fire-fighting unit based on the SH – 16 M self-propelled chassis with an end mill is presented in the frequency response graph. The calculations varied the number of knives on the milling disc, the speed of movement and cutting. The moment of inertia of the flywheel of the engine was 1.14 kg·m², the reduced moment of inertia of the milling disc was 0.16 kg·m². The speed of the unit during the tests was assumed to be constant 0.4 m/s, the cutting speed was 8 and 16 m/s.

The transmission of the forest fire unit based on the self-propelled chassis SH-16 M is affected by the working body (end mill), depending on the accepted cutting speed of 8 or 16 m/s, the excited frequencies of 169.72 or 339.45 rad/s do not affect the nature of the transmission vibrations. According to the frequency response of this unit, we can make a preliminary conclusion that its dynamic characteristics need scientific justification and constructive improvement in the direction of reducing the oscillation amplitudes of the drive section of the milling working body.

4. Conclusions
The influence of the gear ratios and the stiffness of the transmission sections on the change in the dynamic properties and characteristics of the unit should be modeled according to the appropriate methodology. Preference should be given to increasing the gear ratio of the gear unit with an active working body. Since the stiffness of this section decreases, the first two natural frequencies diverge, and the third increases, this has a favorable effect on the frequency range of disturbing vibrations in terms
of detuning from the resonance. Calculations should be performed with zero damping. If necessary, damping devices can be installed in the power chain of the transmission in the «power take-off shaft – working body» section. If we take even a slight damping (for example, with the attenuation decrement $\delta = 0.3$), then the values of the amplitudes in the high frequency region are reduced.

The presented mathematical models allow us to determine the load of the transmission sections of the units, to predict their change during the modernization of the base machine. They allow us to justify the aggregation of the tractor with the tools in the direction of choosing the moments of inertia of the rotating masses in order to prevent resonant phenomena in the transmissions of the units. On the basis of mathematical models of dynamic systems, it is possible to make a scientifically based agreement of the exciting frequencies on the part of the working body and the natural frequencies of transmission vibrations in order to avoid falling into harmonics.

From the analysis of the frequency response of tractor units with plow tools, it can be noted that the increase in the moment of inertia of the flywheel of the engine from 2.9 to 6 kg·m$^2$ does not cause significant changes in the vibration frequencies of the tractor transmission and resonant phenomena in it. The frequencies from the impact of the track gearing on the natural vibration frequencies in the transmission are not imposed.

In units with active disc-milling type workers with significant moments of inertia, the analysis of the frequency response showed: increased vibrations are observed in the transmission section between the primary shaft of the striker and the power take-off shaft gearbox due to the torsion shaft used there with low rigidity; an increase in the moment of inertia of the engine flywheel does not cause significant changes in the frequency response of resonant phenomena in the tractor transmission; an increase in the moment of inertia of the disc cutter in all cases reduces the level of vibrations in the transmission of the unit; the frequencies from the impact of track engagement (6.8 and 22.3 rad/s) do not fall into resonance; the frequencies from the interaction of the disc-milling working body with the peat deposit (716 -1018 rad/s) do not significantly affect the dynamic loading of the transmission sections of the unit.

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