Research on experimental machine-tractor aggregates equipped with pneumatic hydraulic planetary clutch at road works

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Abstract. The use of modern energy-rich equipment in agricultural production led to the increase in the operating speeds of machine-tractor aggregates (MTA), and, accordingly, to the further increase in dynamic loads in the engine-transmission unit. This also influenced the increase in hook load fluctuations relative to the average value up to 30 ... 35%, which led to the occurrence of negative phenomena in the tractor running system interaction with the road. The installation of elastically damping elements in the tractor structure is one of the ways to reduce hook load fluctuations in the tractor transmission during road works [3, 6]. The presence of the elastic element in the tractor structure reduces the transmission shafts stiffness by 5 ... 10 times. In this case, dynamic loads in transient modes are reduced by 1.1 ... 1.28 times, and with the clutch sharp engagement - by 1.6 times.

1. Introduction
The issues of the increased operating engine power rational combination, while simultaneously reducing dynamic loads in the transmission, exacerbate the problem of the machine-tractor aggregate running system rational operating modes choosing. An uneven hook load causes fluctuations in the engine crankshaft rotation speed, the increase in the load on the transmission parts, and, consequently, the decrease in power and the increase in engine fuel consumption [1, 2]. The design features of the control systems and other components included in the transmission mainly form these indicators. The wider the regulating capabilities of the motor-transmission unit, the greater the functionality of the tractor and the higher its capabilities when road working, as well as when aggregating agricultural machines [3, 4]. However, in each specific case, the tractor operation quality depends on the degree of correspondence between the transmission installation regulating ranges and methods, the machine-tractor aggregate specifics and operating conditions [5].

Therefore, the choice of the transmission optimal type for various traction classes, power and purpose agricultural tractors is one of the key issues in improving the tractor dynamics and its fuel efficiency.

2. Materials and methods
Proving the possibility of using a pneumohydraulic planetary clutch on the agricultural tractor and the adequacy of the mathematical model for determining the pneumohydraulic accumulator (PHA) characteristics became the main task of the experiment. The experiments were carried out with varying the initial pressure in the gas volume of the pneumohydraulic accumulator within small limits (0.10 ... 0.25 MPa), close to the previously determined theoretically optimal zone [6].

The experimental data obtained in the field conditions were reflected in the records of the force and speed parameters measuring oscillograms characterizing the process of the initial pressure change in the pneumohydraulic accumulator under the study. The results of the machine-tractor aggregate with the experimental tractor research are presented in the Table 1.

3. Results and discussions
During the experiment, a slight discrepancy between the calculated pressure in the gas cavity of the pneumohydraulic accumulator (0.1 MPa) with the experimentally determined one (0.19 MPa) was found. This is due to the inaccurately selected parameters that determine the maximum gas volume of the pneumohydraulic accumulator, and additionally revealed circumstances: the increased actual speed of movement in comparison with the theoretical one due to the reduction of slipping and the reduced frequency of forced vibrations from 14 s\(^{-1}\) to 10 s\(^{-1}\).

The mathematical model \([1]\) of the pneumohydraulic accumulator operation in the shafting line should be used to analyze these changes. Provided all other things are equal, it can be written as:

\[
V = \text{const} \frac{M_d}{\lambda^2}
\]

where \(M_d\) is the moment on the motor shaft, N\(\cdot\)m; \(\lambda\) is the frequency of forced oscillations, s\(^{-1}\); that is, the pneumohydraulic accumulator optimal volume if all other things are equal, is determined by the ratio \(M_d / \lambda^2\).

In earlier studies, it was found that the value of \(V_{\text{max}}\) at \(p_0=0.1\) MPa determines the pneumohydraulic accumulator rigidity and the clutch: the larger the maximum gas volume, the more elastic the clutch (the less its stiffness). All tests, as already mentioned, were carried out in one gear, therefore, the changes in the machine-tractor aggregate operating conditions (the engine and propellers loading conditions influence on the pneumohydraulic accumulator optimal characteristic can be revealed by analyzing the equation (1).

The decrease in the engine load (it is determined by the instability of the hook load) should have increased the pneumohydraulic accumulator optimal rigidity \([7-9]\). There was practically no experimental machine-tractor aggregate engine underload when the tractor was operating on hard-surfaced road (this practically coincides with the experimental data in the Table 1).

If we take the serial tractor hook load change frequency as the calculated unit \(10 \ldots 10\) s\(^{-1}\), then the optimal stiffness should decrease by

\[
\left(\frac{\lambda_{\text{расч}}}{\lambda_2}\right)^2 = \left(\frac{14}{10}\right)^2 = 196 \text{ times}.
\]

With the pneumohydraulic accumulator fixed maximum gas volume, the stiffness is determined by the initial pressure \(p_0\), and under the new conditions created by the pneumohydraulic accumulator presence in the clutch, it should be equal to:

\[
p_{\text{расч}} = p_0: \frac{\lambda^2}{M_d} = p_0: 1.96
\]

where \(p_{\text{расч}}\), \(p_0\) are the optimal initial pressures in the pneumohydraulic accumulator gas cavity, MPa, for the experimental unit real operating conditions and conditions theoretically calculated from the stationary regulatory characteristic.

The calculated pressure \(p_0\) was equal to 0.1 MPa, but corrected according to the conditions of the machine-tractor aggregate operation on the stubble field experimental studies, it should have been 0.196 MPa, this practically coincides with the experimental data in the Table 1.

\[\text{Table 1. The study results on the experimental machine-tractor aggregate for road work on the hard-surface road.}\]

| № | \(P_0\), MPa | \(P_{\text{расч}}\), kg/s | \(V_{\text{раб}}\), \(\text{km/h}\) | \(N_{\text{раб}}\), kW | \(M_0\), kN\(\cdot\)m | \(\omega_0\), s\(^{-1}\) | \(N_k\), kW | \(\eta_{\text{расч}}\) | \(G_k\), kg/h |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.14 | 280 | 8.54 | 6.60 | 2.76 | 3.13 | 17.61 | 0.373 | 5.46 |
| 2 | 0.15 | 270 | 8.64 | 6.78 | 2.86 | 3.16 | 18.07 | 0.374 | 5.37 |
| 3 | 0.19 | 296 | 8.98 | 7.15 | 3.03 | 3.19 | 18.96 | 0.375 | 5.24 |
| 4 | 0.23 | 285 | 8.84 | 6.71 | 2.86 | 3.16 | 18.21 | 0.373 | 5.28 |
| 5 | 0.25 | 279 | 8.54 | 6.59 | 2.81 | 3.12 | 17.87 | 0.372 | 5.38 |
where $P$ is the pneumohydraulic accumulator pressure in the air cavity; $P_{ap}$ is the hook force; $V_{раб}$ is the machine-tractor aggregate working speed; $N_{ap}$ is the hook power; $M_k$ is the torque on the wheel; $\omega_k$ is the wheel angular rate; $N_k$ is the power on the propellers; $\eta_{усл}$ is the conditional traction efficiency; $G_t$ is the hourly fuel consumption.

$$\text{Figure 1. Fuel consumption during the machine-tractor aggregate operation on road works.}$$

It should be noted that a significant increase in the machine-tractor aggregate movement speed (by about 21%) obtained due to the installation of the elastic element did not lead to the decrease in the hook force by the average value when the units performed the same work. Thus, the main gain was given not by the running system (as is the case when installing the elastic element in the hitch), but by the engine operating modes approach to the stationary loading modes according to the regulatory characteristic: the realized power by the experimental tractor engine turned out to be 13% higher than in the serial tractor.

Such a choice of operating conditions for the experimental unit was due to the need to check the possibility of the pneumohydraulic accumulator performing its functional purpose: to stabilize the operation of the running system and the engine when changing the dynamics of the tractor loading within wide limits [10].

All of the above facts do not have any negative effects on the machine-tractor aggregate operation with a planetary clutch equipped with the pneumohydraulic accumulator and prove the possibility of its use on an agricultural tractor.

4. Conclusion

1. The experimental data analysis presented in the Table 1 makes it possible to identify the optimal zone of hourly fuel consumption at the experimental unit operation during the hard-surface road work (Figure 1) (it corresponds to the pneumohydraulic accumulator pressure of 0.19 MPa).

2. It should be noted that fluctuations in the serial machine-tractor aggregate hourly consumption during road works were within 5%. At the same time, the experimental machine-tractor aggregate hourly fuel consumption in the studied area of the pneumohydraulic accumulator initial pressures turned out to be 12.7% less than that of the serial machine-tractor aggregate.

3. The increase in the experimental machine-tractor aggregate movement speed, in comparison with the serial one, when operating on road works was 21%.

4. The main factor in improving the experimental machine-tractor aggregate performance, in road works in comparison with the serial one, was the pneumohydraulic accumulator ability to stabilize the engine operation at overloads and to damp fluctuations in the hook force.

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