VOL. 13, NO. 22, NOVEMBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SOME WAYS TO REDUCE THE DYNAMIC LOADS OF AGRICULTURAL MACHINE-TRACTOR AGGREGATES

A. S. Ovchinnikov, N. G. Kuznetsov, D. D. Nekhoroshev, D. S. Gapich, D. A. Nekhoroshev, S. D. Fomin, B. P. Zagorodskikh, V. M. Slavutsky, M. N. Shaprov, A. I. Ryadnov and A. N. Tseplyaev
Volgograd State Agrarian University, Volgograd, Russian Federation
E-Mail: fsd_58@mail.ru

ABSTRACT

One of the ways to increase the efficiency of the transmission system of an agricultural tractor traction concept is to introduce a clutch coupling with a pneumatic-hydraulic elastic element into the transmission. Installation of an elastic element in the form of a pneumo-hydraulic accumulator (PHA) in the clutch is associated with the need to implement a calculated loading regime for any technological operation on the same engine operating mode, as well as the need to mitigate impact phenomena. In this case, it should be possible to change its stiffness depending on the technological operation being performed. This can be done by justifying the working area of the elastic characteristics of the PHA under operating conditions. It is determined by the possible range of variation (oscillation) of the tractor pulling force. It is within its limits that the elastic properties of the shaft line must be manifested, which ensure the stabilization of the loading regime. Numerous studies machine-tractor aggregates show that the maximum deviations of the pulling force *P* from its average value are under extreme conditions up to 35%.

Keywords: wheeled tractor, transmission, clutch, pneumo-hydraulic accumulator, engine.

INTRODUCTION

The level of load oscillations, both on the hook of the tractor and in the transmission is determined by the rigidity of the transmission shafts and the elastic properties of the tractor's hinged system.

A stepless transmission with a power flow separation based on a planetary mechanism is known [3]. One part of the flow is transferred hydrostatically, the other mechanically, which increases the efficiency of this type of transmission in comparison with hydrostatic. However, such a transmission is unable to accumulate elastic energy and return it to the machine-tractor aggregates (MTA). In [2], the device, the choice of the rigidity of the elastic link, which is determined by the frequency of the oscillation of the acting force in the MTA traction power realization system, is proposed as a dampener of dynamic loads. Moreover, the resulting oscillations of the working member contribute not only to reducing impact loads on the hook of the traction device, but also to saving the energy stored by the elastic elements, and then using it to maintain a higher average operating speed of the unit. The foregoing allows the shock energy to partially accumulate and return to the machine-tractor unit, increasing its useful power. This way of increasing of efficiency coefficient of MTA is widely used in various drive schemes of working machines.

Another way of reducing the resistance to motion is demonstrated in the mechanics of soils by Florin's hypothesis, which suggests the creation of oscillations in the heap (or rather, in loose soils), contributing to a decrease in the tangent of internal friction, and at the same time creating the possibility of their condensation [11].

When the machine-tractor unit is operating, similar conditions can arise with variable active effort, especially characteristic for zones of insufficient moisture. In this case, the talk is not about the soil or other processed material, which is limited in movements in almost all directions by the supports (as in the contact spot of the propulsors with the soil), but about the working organ that acts as a vibrator in the open space. This creates the conditions for soil vibrations, contributing to a reduction in the coefficient of internal friction of the particles of the processed material, reducing the value of the tangent of internal friction, and at the same time the total resistance force. To this end, the working body needs to provide the required acceleration, determined on the basis of structural mechanics data, corresponding to the ratio $\frac{a}{g} \simeq 1$ Figure-1, where a is the acceleration of the working element; g - acceleration of gravity.

According to the mechanics of soils, such interaction of the working element and loose soils according to Florin's hypothesis creates a condition that reduces the overall resistance to relative movement of particles. This decrease is achieved, as evidenced by the available experimental data for oscillations with acceleration a corresponding to the ratio $\frac{a}{g} \approx 1.05 - 1.00$, while the total resistance in soils is reduced by 50%.

VOL. 13, NO. 22, NOVEMBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

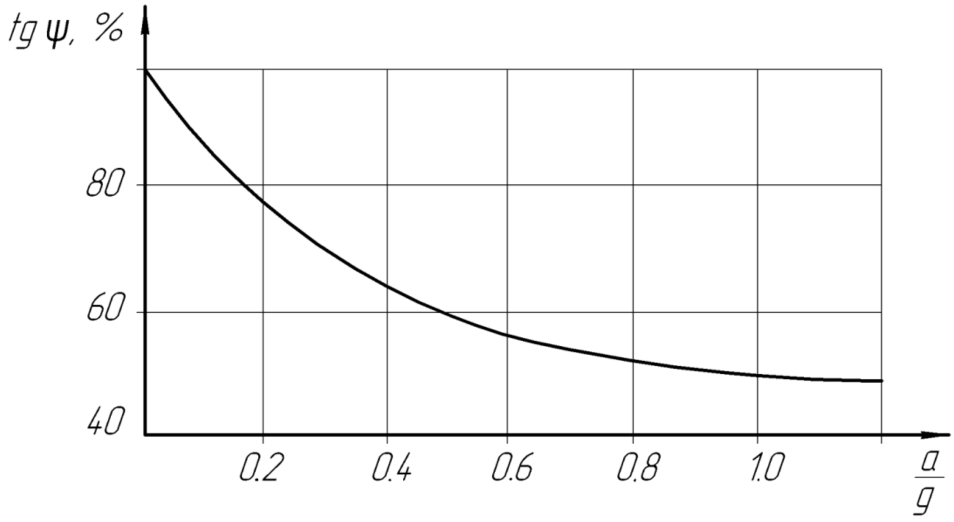

Figure-1. Changing the tangent of the angle of internal friction.

MATERIALS AND METHODS

Based on the analysis of theoretical studies of the parameters of the planetary clutch [4, 7, 9, 10], it was decided to use as a resilient element a pneumo-hydraulic accumulator (PHA). The peculiarity of the installation of an elastic element in the form of PHA in the clutch (Figure-2) consists in its ability to smooth blow impacts, ensuring a smooth connection of the engine with the propulsors.

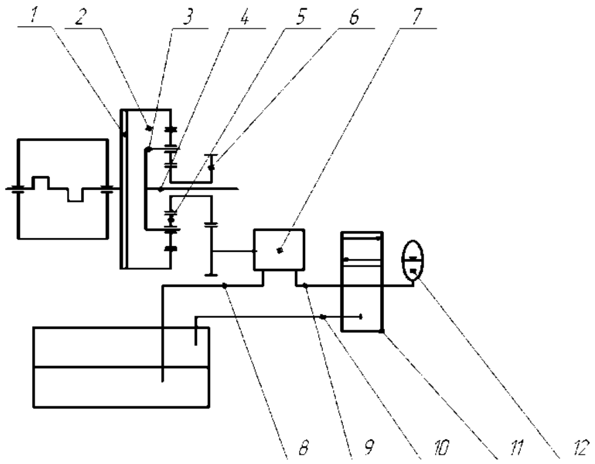

Figure-2. Planetary clutch: 1 - a flywheel; 2 - a ring gear; 3 - carrier; 4 - driven shaft; 5 - satellites; 6 - the sun gear; 7 - hydraulic pump; 8 - a suction main; 9 - discharge line; 10 - drain line; 11 - the distributor; 12 - the pneumo-hydraulic accumulator.

Studies have shown that the parameters of the gaseous medium (pressure and volume) determine the necessary rigidity of the pneumo-hydraulic clutch.

RESULTS AND DISCUSSION

When searching for a method for controlling the rigidity of a fluid-hydraulic elastic element, one should take into account the formula (1), which allows to determine the optimal gas volume of a pneumo-hydraulic accumulator [6, 8, 10], necessary to ensure the required rigidity of the elastic element while maintaining the design pressure at the same level:

$$V = \frac{\pi \cdot n \cdot M_D \cdot (m_{TR} + m + \frac{I_{TR}}{r^2}) \cdot i_{TR}^2 \cdot i_{PD}(k+1)^2 v \cdot z \cdot \eta_{PD} \cdot \eta_{TR} \cdot \eta}{(\delta_{RM} \cdot m_{TR} + m)^2 \cdot r^2 \cdot \lambda^2 \cdot k} \quad (1)$$

Where

n is the polytropic index; M_D - moment on the motor shaft, N · m; m_{TR} - tractor mass, kg; m is the mass of the agricultural implement, kg; I_{TR} - reduced moment of inertia of the transmission to the tractor's driving wheel, kg · m; r is the dynamic radius of the wheel, m; i_{TR} - transmission ratio; i_{PD} - gear ratio of the pump drive; $(k + 1)$ - gear ratio from the carrier to the sun gear; v - the volume of fluid supplied by one tooth of the pump gear, m^3; z - the number of teeth of the pump gear, pcs; η_{PD} - efficiency coefficient of pump drive; η_{TR} - efficiency coefficient of transmission; η - efficiency coefficient of transmission from the carrier to the sun gear; δ_{RM} - factor of the account of rotating masses of a tractor; λ - frequency of forced oscillations of the transmission, c^{-1}; k is the gear ratio of the planetary gear.

The size of the injection volume of the gas space of the PHA essentially depends on the accuracy of the choice of the factors influencing it. Therefore, in order to achieve this goal, it is necessary to have sufficiently complete information on the influence of these factors on the formation of the volume of the gas space of the fluid-hydraulic elastic element.

The most significant impact on the theoretical optimization of the determined values will be provided by:

- the volume of fluid applied to one tooth of the pump in the PHA, v, since with a decrease in the volumetric efficiency coefficient its reduction occurs, then the rigidity of the PHA increases;

VOL. 13, NO. 22, NOVEMBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

- number of teeth sensing the moment of loading of the pump from the sun gear side of the planetary gear. In accordance with [1], their value will be in the range from one to two, which we took into account when determining the blocking pressure in the discharge line;
- factors of usefulness of transmission units;
- the polytropic index n.

The evaluation analysis of the studied interaction factors of the elements of the MTA oscillatory system revealed that theoretically the calculated PHA parameters are the upper limit of its stiffness under optimal conditions [5].

Let us reconstruct the loading characteristic of the pneumo-hydraulic clutch in the p-V diagram from the gas volume (Figure-3), where p is the pressure in the gas cavity of the PHA at the nominal engine speed. The points (1, 2, 3, 4) are the working points of the PHA on the theoretical characteristic and the experimentally corrected characteristics.

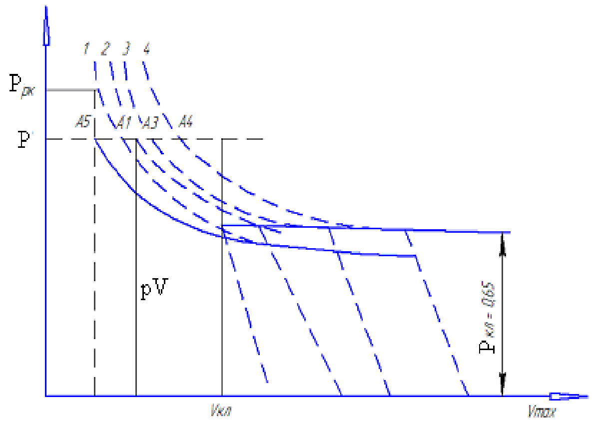

Figure-3. Characteristics of PHA at a constant maximum gas volume V_{max} (p_{01} = 0.1 MPa) with a change in its initial pressure.

Under these conditions, the stiffness of the PHA is regulated by the change in the gas volume of the initial pressure (at a volume V_{max}). We will study the change in the rigidity of PHA, with increasing initial pressure in the gas volume of PHA (V_{max}).

In this case, the rigidity of the gas volume will be expressed by the following relationship [10]:

$$C_{PHA} = -n \cdot \frac{\overline{\overline{p}}}{V} \tag{2}$$

Where

$\overline{\overline{p}}$ is the pressure in the liquid cavity of the PHA, MPa; V - volume of the gas cavity, m^3.

The presence of the minus sign in this expression indicates that the rigidity of the gas volume in terms of physical meaning is the tangent of the angle of inclination of the tangent to any point of the polytropic $p \cdot V^n = const$ [1]. This fact is confirmed by the Figure 3, where the angle of inclination of the tangent is blunt (more than 90°).

The parameters of the gas state $\overline{\overline{p}}$, V at the point $A1$. Under the condition that the volume V_{max} and the pressure p remain constant, a change in the initial pressure in the PHA from p_0 to p_{0i} will lead to a change in volume, which will be calculated through p_{0i}, from the expression:

$$p \cdot V^n = p_{0i} \cdot V_{\max}^n ;$$

$$V = V_{\max} \cdot \left(\frac{p}{p_0} \right)^{1/n} . \tag{3}$$

The effect of p_{0i} on the rigidity of the gas volume can be determined by the formula:

$$C = -n \frac{p}{\left(\frac{p_{0i}}{p} \right)^{\frac{1}{n}} \cdot V_{\max}} = -n \frac{p^{\frac{n-1}{n}}}{V_{\max} \cdot p_{0i}^{\frac{1}{n}}} = -n \cdot p^{\frac{n-1}{n}} \cdot p_{0i}^{\frac{-1}{n}} \cdot V_{\max}^{-1} .$$

(4)

Using the derivative of C with respect to p_{0i}, we determine the change in the stiffness of the gas volume:

$$\frac{dC}{dp_{0i}} = -n \cdot p^{\frac{n-1}{n}} \cdot \left(-\frac{1}{n} \right) \cdot p_{0i}^{\frac{-n-1}{n}} \cdot V_{\max}^{-1} = p^{\frac{n-1}{n}} \cdot p_{0i}^{\frac{-n+1}{n}} \cdot V_{\max}^{-1} . \tag{5}$$

Thus,

$$\frac{dC}{dp_{0i}} = \frac{p^{\frac{n-1}{n}}}{V_{\max}} \cdot p_{0i}^{\frac{-n+1}{n}} \cdot \frac{1}{V_{\max}} . \tag{6}$$

It should be noted that the sign of the stiffness of C and its derivative is different, therefore, at constant values of p and V_{max}, the stiffness of the gas volume modulo (and hence also the PHA) decreases with increasing initial pressure in the volume V_{max}, since the factors with increasing p_{0i} decrease together with the factor:

$$p_{0i}^{\frac{-n+1}{n}} = \frac{1}{p_{0i}^{\frac{n-1}{n}}} . \tag{7}$$

The displacement of the calculated point to the point $A4$ ($V = V_{max}$) in the estimation according to formula (3) allows to reduce the stiffness and increase the initial pressure to p_{0i} = 0.1538 MPa. Increase the stiffness at constant p and V_{max} by decreasing the initial pressure, making it (0.1 MPa), so when the working point moves to point $A5$ in the gas volume, the initial pressure will be equal to 0.074 MPa.

To test and refine the optimum parameters of the elastic element of the planetary clutch, an experiment was carried out using an MTA with a wheeled tractor class 14 kN, equipped with a PHA. Analysis of the obtained experimental data allows concluding that in the studied area of initial pressures of PHA, the hourly fuel consumption of the unit under test decreased in comparison with the serial MTA in the field prepared for sowing by 22.4%, on stubble - by 14.5%, on the road - on 19%. The productivity of MTA increased on the field prepared for sowing by 21.7%, and on stubble - by 26.6%.

CONCLUSIONS

Based on the analysis of the experimental data, it can be concluded that in the studied area of the initial pressures of the PHA, the hourly fuel consumption of the unit under test decreased by 22.4% relative to the serial MTA, on the field prepared for sowing, by 14.5% on stubble, by 14.5% road - by 19%. Productivity increased in the field, prepared for sowing, by 21.7%, and on stubble - by 26.6%. This is due to the ability of the PHA to quench fluctuations of the hook force, which provides an increase in the efficiency of the experimental MTA, in comparison with the serial one. At the same time, according to the regulatory characteristic, the main advantage of the unit was the ability to approach the operating modes of the engine to stationary loading modes: the power realized by the engine of the experimental tractor increased with respect to the serial tractor, on stubble by 19% and on the field prepared for sowing by 15.6%. The main reason that made it possible to obtain improved performance of the MTA under study (as compared to the serial one) was the ability of the PHA to reduce the fluctuations of the hook load.

All the arguments about the experimental data obtained on the basis of the results of theoretical comprehension of the possibility of using elastic elements as a means of reducing the level of shock (dynamic) influences and the means of saving part of the energy costs for impact in the subsequent operation of the unit show the adequacy of the presented actual MTA model to the actual process of interaction of all complex of transfer devices from the engine to the working machine. However, the results achieved were less than theoretically predicted when using the second method of vibratory oscillation, which promises a higher positive result.

REFERENCES

[1] Bashta T.M. 1972. Hydraulic drive and hydro-pneumatics. Moscow, Mechanical Engineering. p. 320.

[2] Fomin S.D. 2011. Working process in the pneumo-hydraulic accumulator of an elastic element of an agricultural tractor. Proceedings of Nizhnevolzhsky Agrouniversity Complex: science and higher vocational education. 3(23): 248-251.

[3] Kirka A. 2002. Sinchronines hidrostatines pavaros kinematiniu parametru tyrimas (Investigation of the kinematic parameters of a synchronous hydrostatic drive). Zernes dikio inzinerija. Institute and Universiteto moksio darbai. 34(3).

[4] Kostyleva L.V., Ovchinnikov A.S., Gapich D.S., Fomin S.D. 2017. Gradient hardening chisel plow from nodular iron. ARPN Journal of Engineering and Applied Sciences. 12(7): 2085-2091.

[5] Kuznetsov N.G. 2006. Stabilization of operating modes of high-speed machine-tractor units. Volgograd, Publishing and printing complex of the Volgograd State agricultural academy "Niva". 423 p.

[6] Kuznetsov N.G., Nekhoroshev D.A., Nekhoroshev D.D. 2004. Optimization of the stiffness of planetary pneumatic-hydraulic coupling. Mechanization and electrification of agriculture. 8: 11.

[7] Nekhoroshev D.A. 2014. Stabilization of operating modes of MTA using pneumatic hydraulic clutch. Dissertation of doctor of technical sciences. Volgograd. 283 p.

[8] Nekhoroshev D.A., Nekhoroshev D.D. 2004. Optimization of the parameters of planetary cohesion with an elastic element. Mechanization and electrification of agriculture. 8: 16.

[9] Nekhoroshev D.A., Nekhoroshev D.D. 2009. Planetary elastic coupling in the transmission of a wheeled tractor of class 1.4. Achievements of science and technology of agro-industrial complex. 12: 60-61.

[10] Nekhoroshev D.D. Improving the performance of AIT by using a tractor with pneumatic clutch coupling. Dissertation of candidate of technical sciences. Volgograd. p. 125.

[11] Tsytovich N.A. 1983. Soil mechanics. Moscow, Higher School. p. 288.