In the transmission of the 1.4 drawbar category mobile power vehicle on the performance indicators of machine and tractor units

Vladimir Kravchenko[1] and *Lyudmila* Kravchenko[1*]

[1]Don State Technical University, 1, Gagarin Sq., 344003, Rostov-on-Don, Russia

Abstract. The aim of the work is to scientifically substantiate a way to improve the technical, economic and agrotechnological performance indicators of machine-tractor units, compiled on the basis of traction power equipment of category 1.4, the main technological operations in the cultivation of various crops by reducing the level of dynamic processes in their connections.

It is established that the elastic damping mechanism with nonlinear characteristics and optimal parameters installed in front of the drive shaft of the power transmission of a traction power tool of category 1.4 provides favorable conditions for the functioning of all links of machine-tractor units for agricultural purposes, with them the main technological operations are performed, which contributes to the improvement of its technical, economic and agrotechnological indicators.

The installation of an elastic-damping mechanism with nonlinear characteristics and optimal parameters in front of the drive shaft of the tractor traction category 1.4 provides an increase in productivity by more than 8% while reducing specific fuel consumption by 9% or more, as well as improving the quality performance of machine-tractor units when they perform basic technological operations.

1 Introduction

The food security of the country undoubtedly depends on the yield of cultivated crops, which largely depends on the timeliness and quality of technological operations, including the main tillage (plowing), continuous cultivation before sowing and sowing itself [1-3]. However, the technical, economic and qualitative indicators of the performance of technological operations associated with the contact of the operating elements of aggregated agricultural machines and tools with different horizons of cultivated soil are reduced due to the fact that all links of machine-tractor units (MTU) experience the negative influence of external forces and moments that have a stochastic character [4-8].

As a result of the impact of variables in the nature of fluctuations in the load on operating elements of agricultural machines and tools, the productivity of the MTU

* Corresponding author: Lyudmila.Vl.Kravchenko@yandex.ru

decreases with the increase in the cost of operations, such agrotechnological indicators worsen as the depth of soil cultivation, uniformity of seed placement, and others [2, 3].

Therefore, the *purpose of the research* is scientific substantiation of the method of improving the technical, economic and agro-technological indicators of the performance by machine-tractor units, compiled on the basis of 1.4 drawbar category power equipment, main technological operations in the cultivation of various crops by reducing the level of dynamic processes in their links.

2 Method of the research

During the scientific research of the influence of the elastic-damping mechanism (EDM) installed between the clutch coupling and the drive shaft of the 1.4 drawbar category MPT power transmission class on the technical, economic and agro-technological indicators of various agricultural MTUs, the theoretical and experimental method was adopted.

In the process of comparative tests, serial and experimental machine-tractor units were aggregated by the same MTZ-80 tractor, which has in its power transmission proposed elastic-damping mechanism with optimal parameters for each technological operation [9, 10, 11] (with tests of the serial version of the EDM was blocked).

The conditions and procedure for conducting MTU tests corresponded to the requirements of the relevant state standards GOST 7057-2001 and GOST 24055-2016 and industry methods.

3 Results of the research

In many works, in order to ensure the achievement of potential MTU indicators, testers and researchers suggest installing various devices in the power transmissions of their MPTs designed to smooth out fluctuations in internal and external forces and moments: torque converters, elastic and damping mechanisms. But, due to the design feature, torque converters, in the presence of certain positive qualities, contribute to the drop in the traction efficiency of the MPT, and various damper and elastic elements proposed for installation in the power transmission have common disadvantages: they have significant overall dimensions and, most importantly, a linear characteristic, which prevents them from effectively performing the necessary functions with the stochastic nature of external and internal influences on the agricultural unit as a whole.

The proposed mechanism for installation in the MPT power transmission in front of its drive shaft, which combines elastic and damping properties, has small dimensions and a non-linear characteristic, which contributes to the significant drop in the dynamic loads that occur in the MTU links (see patents of the Russian Federation No. 2222440, 2299135, 2398147, 2739100, etc.). His operation is described in detail in the literature [2, 3, 9, 10, 11].

The analysis of the data of preliminary experimental studies made it possible to conclude that the accuracy of the measurements of the parameters characterizing the dynamic processes in the MTU links during their operation was at the satisfactory level, since their maximum error was in the range of 1.35 ... 4.00%.

The obtained experimental data show that the installation of EDM in the power transmission of the 1.4 drawbar category MPT has a positive effect on the dynamic processes that occur in all elements of the MTU.

The data of the conducted operational tests, which were carried out on plowing, continuous cultivation and sowing, showed that the studied EDM with optimal parameters [9-11], located in the power transmission of the 1.4 drawbar category MPT at the

sufficiently high level provides protection for all components links of the MTU from fluctuations of external and internal links, which has a positive effect on the dynamic processes that occur in all elements of the MTU [2-8]. So, for example, as a result of testing an plowing MTU in the field, it was found that the application of EDM into the power transmission of the 1.4 drawbar category mobile power tool helps to reduce the amplitude of the hook force fluctuations compared to the serial version to 15 ... 20%.

The analysis of the oscillograms obtained during scientific research allows concluding that the performance of agricultural MTUs with EDM in the MPT transmission has improved.

In connection with the provision of the high degree protection by the elastic-damping mechanism of the MTU links from the negative impact of oscillatory changes in external and internal disturbances during the execution of the technological operation, compared to the serial version, the rotational speed of the crankshaft of the power unit becomes higher, the slipping of the propellers is less, which ultimately leads to increase in the operating speed of the MTU.

For the quantitative assessment of the security of the constituent links of the MTU from the dynamic process of fluctuations in internal and external connections, correlation-spectral analysis of the traction forces that create the operational elements of aggregated agricultural tools and machines was carried out (Figure 1).

For example, there is considered graphical representation of the normalized autocorrelation function of the traction resistance of the plowing unit (Figure 1 a). It shows that the decrease in the normalized autocorrelation function for the serial plowing unit is observed for only three seconds. In the experimental unit, the rate of its decrease is higher, despite the fact that along the entire length of the existing implementation it is different from zero, i.e. the process of the work performed (plowing) by the experimental unit has a greater smoothness.

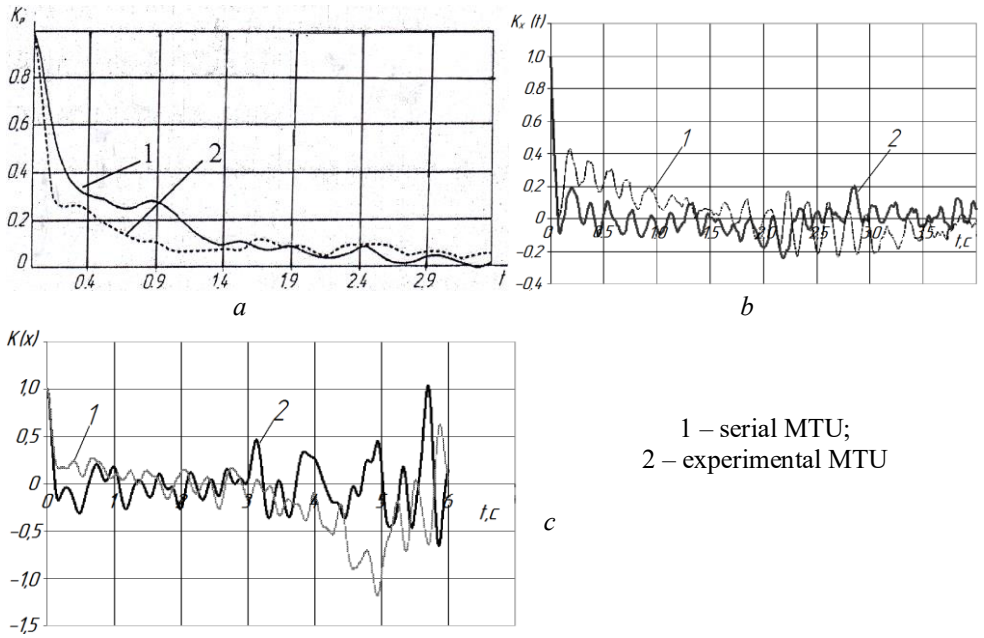

Fig. 1. Graphic representation of normalized autocorrelation functions for traction resistance of sowing (a), cultivator (b) and sowing MTU (c).

The behavior of the correlation functions for other aggregates (see Figure 1), obtained by processing experimental data from comparative tests of serial and experimental MTUs, shows their rapid decrease over time. By the time during which the function declines, the speed of the reaction of the MTU to the dynamism of external links, when they act on the aggregate, can be evaluated. The flow of correlation functions emphasizes the slower adaptation of serial MTUs to changing external conditions than experimental units in which the elastic-damping mechanism is installed before the power transmission of 1.4 drawbar category MPTs.

The results of the energy assessment of various agricultural MTUs with the1.4 drawbar category EDM installed in the power transmission of the MPT (Table 1) show that the mathematical expectation of the traction resistance of the operating elements of the aggregated agricultural machines becomes lower to 11%.

The introduction of EDM into the power transmission of the 1.4 drawbar category mobile power tool provides more comfortable working conditions for all parts of the MTU in the process of performing various technological operations. Therefore, the forward speed of the MTU increases from 6.0 to 12.3%, hook force fluctuations decrease by 15 ... 20%, depending on the type of performed work. In this regard, there is an increase in MTU productivity by more than 8%, decrease in hourly fuel consumption by the mobile power tool by 2.6 ... 8.6% with its simultaneous consumption per volume of performed work (per hectare) from 9.1 to 15.4%.

Significant contribution to improving the performance of the experimental MTU is made by reducing the slipping of the driving wheels of the MPT. Statistical analysis of data from field studies on the propellers' slippage of 1.4 drawbar category mobile power vehicles as part of agricultural units showed that EDM helps to reduce the amount of slippage of MPT propellers by almost 1.3 times, moreover, its dispersion value becomes lower to 37.6% and standard deviation is more than 21% lower.

Table 1. Energy performance of MTU, aggregated by 1.4 drawbar category MPT.

Indicators MTU	Experimental unit			Serial unit		
	Plowing	Cultivator	Sowing	Plowing	Cultivator	Sowing
Hook force, N	12229	9202	5079	13522	9289	5715
MTG operating speed, m/s	2.14	1.97	2.49	1.97	1.80	2.33
Rotation frequency of the crankshaft of the power unit, rad/s	244.74	244.76	246.50	235.31	235.31	239.31
Fuel consumption per hour of operation, kg/h	12.88	9.11	9.16	13.23	9.97	9.85
Slippage of the MTU propellers, %	11.50	14.64	13.22	14.97	14.97	14.32
MTU productivity for one hour of work, per hour	0.811	2.822	4.812	0.747	2.611	4.552
Specific fuel consumption, kg/ha	16.03	3.22	1.90	17.65	3.83	2.18

The conducted comparative analysis of the results of laboratory and field tests showed that the indicators (Table 2), characterizing the quality of the execution of technological operations, for the MTU, which is equipped with the proposed elastic-damping mechanism in the power transmission of the 1.4 drawbar category MPT retains their specified parameters more stably..

During field tests of plowing MTU (MTZ-80 + PLN-3-35), the quality indicators of the plowing unit were determined, which, from the point of view of agrotechnical characteristics, are: cultivation depth, furrow depth, soil crumbling, cutting crop residues and weeds, conservation stubble.

The comparative analysis of the results of laboratory and field tests showed that the depth of processing and the stability of the working width during the plowing operation in MTU with EDM in the power transmission of the 1.4 drawbar category tractor maintain the specified parameters more stably.

The obtained values of statistical indicators of the tillage depth and grip width (coefficient of variation and standard deviation) for MTU with the experimental tractor transmission were 1.20 ... 2.17 and 1.32 ... 2.35 times less, respectively.

MPT of 1.4 drawbar category with EDM in power transmission as part of the plowing unit showed a higher quality of the state of the cultivated field.

So, the average deviation Δh_{av}^{d} surface of the bottom of the arable furrow from the average value of its profile for the unit with the experimental power tool is more than 50 percent less compared to the serial one.

The indicator that determines the quality of plowing Δ (Table 2) was determined from the results of measurements:

$$\Delta = \Delta h_{\text{av}}^{d} - \Delta h_{\text{av}}^{p}, \quad (1)$$

As a result of the tests, it was found that the quality indicator for the plowing unit with the experimental power tool is negative, and for the serial one it is positive. These data show that the first ensures the leveling of arable land, and the second makes it more ridged.

The power tool with EDM in the transmission as part of the plowing unit showed that it provides a higher leveling of the arable land surface than the serial version. That is, the use of a serial plowing unit determines the need for additional processing in order to ensure the evenness of the surface of the plowed field. As a result, the elastic-damping mechanism introduced into the power transmission of the 1.4 drawbar category MPT contributes to the increase in the stability of the plowing process by the MTZ-80+PLN-3-35 machine-tractor unit in terms of all agrotechnical indicators.

Table 2. Agrotechnological indicators of MTU, aggregated by the 1.4 drawbar category mobile power tool.

Indicators	Serial unit	Experimental unit
Plowing unit (MTZ-80 + PLN-3-35)		
Plowing depth (mathematical expectation), cm	20.2	20.8
Root-mean-square deviation of plowing depth, cm	1.91	1.07
Plowing depth variation coefficient, %	8.4	5.1
Aggregate working width (mathematical expectation), cm	107	106
Root-mean-square deviation of capture width of the unit, cm	1.98	1.65
Capture width variation coefficient, %	2.6	2.5
The average value of the deviation of the furrow bottom profile from the conditional average line of the height of microroughnesses, cm	5.6	2.8
The average value of the deviation of the field surface profile from the conditional average line of the height of microroughnesses, cm	4.2	3.1
Difference of deviations from the conditional average line of the furrow profiles and the field surface, cm	1.4	- 0.3
Cultivator unit (MTZ-80+KPS-4)		
Cultivating depth (mathematical expectation), cm	10.88	11.2
Standard deviation of cultivating depth, cm	2.42	2.14
Cultivating depth variation coefficient, %	0.22	0.19
Seeding unit (MTZ-80 + SZ-5.4A)		
Seeding depth (mathematical expectation), cm	5.3	5.1
Root-mean-square deviation of seeding depth, cm	0.86	0.62
Coefficient of variation of seeding depth, %	0.16	0.12

The introduction of the elastic-damping mechanism into the power transmission of the 1.4 drawbar category power tool contributes to the increase in the quality of the work performed and the unit for continuous cultivation (MTZ-80 + KPS-4): the dispersion of the depth of tillage becomes 22% lower while increasing the uniformity of the depth of tillage by 16% (Table 2).

The installation of EDM in the power transmission of the 1.4 drawbar category power tool provides an increase in the agrotechnological indicators of the MTZ-80+ SZ-5.4A sowing unit (see Table 2): there is a decrease in the variability of the seeding depth (its standard deviation becomes lower by 24, 7%, and the value of the coefficient of variation decreases from 15.1 to 11.9%).

Graphic images of the normalized spectral density characterizing the depth of seed sowing (Figure 2) indicate that the experimental unit has one maximum dispersion value corresponding to the frequency of 1.0 s^{-1}, and the serial unit has 0 ... 1 in the frequency range, 5 s^{-1} four maximum values at one prevailing frequency of 1.6 s^{-1}. At the same time, the serial version of the sowing unit has two pronounced peaks in the higher frequency range.

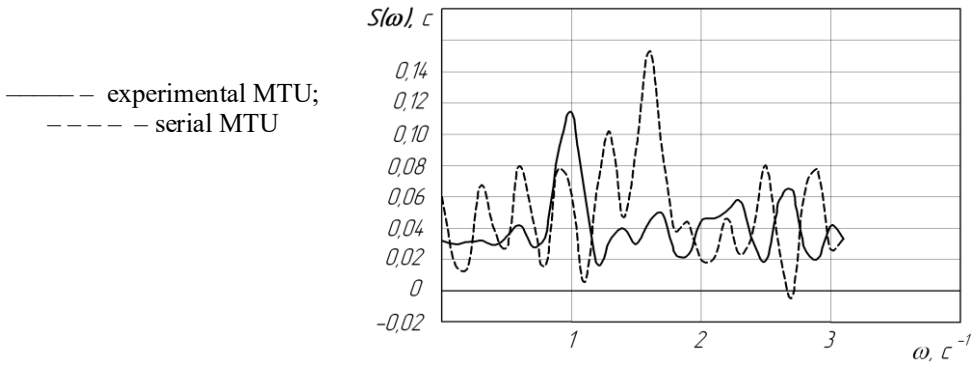

Fig. 2. Graphical representation of normalized spectral densities characterizing the depth of seed sowing.

Therefore, it can be argued that the seeds, when sown by the experimental unit, which has the elastic-damping mechanism in the power transmission of the 1.4 drawbar category mobile power tool, are distributed at the same depth. At the same time, when sowing, the serial unit distributes the seed material at different depths.

The quantitative assessment of ensuring the uniformity of the sowing depth of seeds showed a more qualitative process of sowing seeds with the experimental sowing MTU.

Indicators of the economic efficiency of the functioning of the MTU based on the 1.4 drawbar category mobile power tool with EDM in power transmission when performing various technological operations are presented in Table 3.

Table 3. Indicators of economic efficiency of MTU with UDM in power transmission MPT class 1.4.

Indicators	Aggregate type		
	plowing	cultivating	sowing
Growth in labor productivity, times	1.08	1.09	1.06
The degree of reduction in the complexity of the work performed,%	7.07	6.67	7.69
The degree of reduction in operating costs, %	5.07	9.65	5.75
Return on investment ratio	2.60	1.24	0.90
Payback period for modernization, years	1.77	2.48	3.00
Degree of material consumption reduction, %	6.38	7.90	4.70
The degree of energy intensity reduction, %	7.58	6.67	8.33

Based on the analysis of the data in Table 3, it can be affirmatively concluded that the modernization of the 1.4 drawbar category MPT by introducing the elastic-damping mechanism into its power transmission contributes to the increase in labor productivity from 6 to 8% during various operations, saving direct operating costs by 5 ... 10%, reduction of material consumption from 4.7 to 7.9% and energy intensity of the process by almost 6.67 ... 9.33% with the payback period of investments within three years.

4 Conclusion

1. The unsteady nature of internal factors and external influences causes the increase in the dynamic loading of parts in all structural units of the MTU;
2. Installation in the 1.4 drawbar category MPT transmission of the proposed EDM, which has optimal parameters for this technological operation, helps to reduce dynamic loading for parts of all structural parts of the MTU;
3. The proposed elastic-damping mechanism with optimal parameters, when installed in the 1.4 drawbar category MPT transmission, contributes to the increase in the technical, economic and agrotechnological indicators of plowing, cultivating and sowing machine-tractor units compiled on its basis;
4. Modernization of 1.4 drawbar category MPT by introducing EDM into the power transmission contributes to the increase in labor productivity from 6 to 8% when performing various operations, the decrease in hourly fuel consumption by 2.6 ... 8.6%, the decrease in specific fuel consumption from 9.2 to 15.9%;
5. EDM in the power transmission of 1.4 drawbar category MPT helps to increase the stability of the technological process of the main technological operations in the production of cereals: plowing, continuous cultivation and sowing in all agrotechnical indicators.
6. Modernization of the 1.4 drawbar category MPT by introducing the elastic-damping mechanism into the power transmission contributes to the increase in labor productivity from 6 to 8% when performing various operations, saving direct operating costs by 5 ... 10%, reducing material consumption from 4.7 to 7.9% and energy intensity of the process by 6.7 ... 9.3% with the payback period of investments within no more than three years.

References

1. V. A. Kravchenko et al., Agrarnaya Nauka **37(100)**, 36
2. S. Senkevich, V. Kravchenko, P. Lavrukhin, P. Ivanov, A. Senkevich, Theoretical study of the effect of an elastic-damping mechanism in the tractor transmission on a machine-tractor unit performance while sowing. Handbook of Research on Smart Computing for Renewable Energy and Agro-Engineering. Ser. "Advances in environmental engineering and green technologies" Hershey, PA, USA, 2020)
3. V. Shehovtsov, N. Sokolov-Dobrev, M. Lyashenko et al., Mechanika **20(2)**, 190-196 (2014)
4. V. V. Shekhovtsov et al., *Decreasing of the dynamic loading of tractor transmission by means of change of the reactive element torsional stiffness*, In Proceedings of the International Conference on Industrial Engineering, ICIE 2016 Procedia Engineering, **150**, 1239-1244 (2016)
5. D. D. Nekhoroshev, D. A. Nekhoroshev, P. V. Konovalov, A. Yu. Popov, Research on experimental machine-tractor aggregates equipped with pneumatic hydraulic planetary

clutch at road works. IOP Conference Series: Earth and Environmental Science, 012016 (2021)

6. A. S. Ovchinnikov, N. G. Kuznetsov, D. D. Nekhoroshev, et al., ARPN Journal of Engineering and Applied Sciences **13**, 8776 (2018)
7. N. G. Kuznetsov, A. A. Shatokhin, D. D. Nekhoroshev, S. D. Fomin, D. A. Nekhoroshev, Mathematical model studying the operation of a machine-tractor unit with a tractor "dt-175s" with an elastic element in the linkage system. IOP Conference Series: Earth and Environmental Scicnge. Ser. "International Conference on Engineering Studies and Cooperation in Global Agricultural Production", 012076 (2021)
8. S. Senkevich, V. Kravchenko, V. Duriagina, A. Senkevich, E. Vasilev, Advances in Intelligent Systems and Computing **866**, 168-177 (2019)
9. S. Senkevich, D. Pavkin, V. Duryagina, I. Gamolina, V. Kravchenko, Advances in Intelligent Systems and Computing 1072, 204-213 (2020)
10. S. Senkevich, V. Bolshev, E. Ilchenko, et al., *Elastic damping mechanism optimization by indefinite lagrange multipliers*, In Proceedinngs of the IEEE Access 9, 71784-71804 (2021)
11. V. Kravchenko, L. Kravchenko, V. Oberemok, A. Avanesyan, *Analysis of the influence of design parameters on the agro-ecological qualities of tractor tires*, In Proceedings of the Fundamental and Applied Scientific Research in the Development of Agriculture in the Far East (AFE 2021), 032010 (2021)
12. O. Didmanidze, A. Dorokhov, M. Mosyakov, et al., *Results of ultrasonic effects studied in pre-sowing barley seed stimulation*, In Proceedings of the Fundamental and Applied Scientific Research in the Development of Agriculture in the Far East (AFE 2021), 022119 (2021)
13. A. Nesmiyan et al., Lecture Notes in Networks and Systems **246**, 88-101 (2022)
14. O. González, C. E. I. Coronel, E. López, C. A. Recarey, and M. Herrera, Journal of Terramechanics **63**, 61–67 (2016)
15. H. Taghavifar, A. Mardani, Journal of the Saudi Society of Agricultural Sciences **13(1)**, 35-43 (2014)