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PLOUGHING DEPTH STABILITY WITH FRONT PLOUGH WITHOUT SUPPORT WHEEL

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Petrov G.A., Nadykto V.T. ***Ploughing depth stability with front plough without support wheel***

Abstract. *Then aggregating a front plow, an important aspect is ensuring the stability of the plowing depth. This issue becomes especially relevant if this implement does not have a support wheel. In view of this, the purpose of this article is to find out the influence of the operation of a front plow without a support wheel on the stability of the depth of soil cultivation by a plowed machine-tractor unit according to the "push-pull" scheme. Plowing was carried out by two units. One of them (option 1) had a front plow with a support wheel, and the other (option 2) had one without it. Laboratory and field studies revealed that the null hypothesis about the equality of the average values of plowing depth in the compared units is not rejected. The proof of this is the* HIP_{05} *of this statistical indicator, which is equal to 0.81 cm, which is greater than the real difference between the compared values of the plowing depth, which is 0.50 cm. It follows that the removal of the support wheel from the front plow does not lead to a significant change in the average value of the plowing depth. On the other hand, the null hypothesis about the equality of the compared variances of the plowing depth fluctuations by plowing aggregates of both options is rejected at the statistical significance level of 0.05. According to the obtained data, the actual significant Fisher's F-test at 1.69 is greater than the tabulated one, which is 1.39. In view of this, it can be stated that the use of a front plow (option 2) leads to a decrease in the dispersion of plowing vibrations in comparison with a plow unit equipped with a front plow with a support wheel (option 1). The process of fluctuating the plowing depth in MTA with a front plow without a support wheel is more low-frequency than a similar process in a plow unit with a front plow tool equipped with a support wheel. This is evidenced by both the course of the normalized spectral densities of the fluctuations of the compared dispersions and the coefficients of variation of the fluctuations of the tillage depth.*

Key words: *arable unit, longitudinal field profile, fluctuations, dispersion, normalized correlation function, normalized spectral density.*

Петров Г.А., Надикто В.Т. ***Стабільність глибини оранки агрегатом із фронтальним плугом без опорного колеса***

Анотація. *При агрегатуванні фронтального плуга важливим аспектом є забезпечення стабільності глибини оранки. Особливо актуальним це питання стає за умови відсутності у даного орного знаряддя опорного колеса. З огляду на це метою даної статті є з’ясування впливу функціонування фронтального плуга без опорного* *колеса на стабільність глибини обробітку грунту ораним машинно-тракторним агрегатом за схемою «push-pull». Оранку здійснювали двома агрегатами. У одного із них (варіант 1) фронтальний плуг був з опорним колесом, а у іншого (варіант 2) – без нього. Лабораторно-польовими дослідженнями з’ясовано, що нуль-гіпотеза про рівність середніх значень глибини оранки у порівнюваних агрегатів не відхиляється. Доказом цього є HIP_{05} даного статистичного показника, яка дорівнює 0,81 см, що більше за дійсну різницю між порівнюваними значеннями глибини оранки, яка становить 0,50 см. Із цього випливає, що видалення опорного колеса у фронтального плуга не приводить до значущої зміни ним середнього значення глибини оранки. Натомість, нуль-гіпотеза про рівність порівнюваних дисперсій коливань глибини оранки орними агрегатами обох варіантів на статистичному рівні значущості 0,05 відхиляється. Згідно з отриманими даними, дійсна значина F-критерію Фішера на рівні 1,69 є більшою за табличну, яка становить 1,39. З огляду на це можна стверджувати, що використання фронтального плуга (варіант 2) обумовлює зменшення дисперсії коливань оранки у порівнянні з орним агрегатом, обладнаним фронтальним плугом з опорним колесом (варіант 1). Процес коливання глибини оранки у МТА з фронтальним плугом без опорного колеса є більш низькочастотним, ніж аналогічний процес у орного агрегату з фронтальним орним знаряддям, обладнаним опорним колесом. Доказом цього є як перебіг нормованих спектральних щільностей коливань порівнюваних дисперсій, так і коефіцієнтів варіації коливань глибини обробітку грунту.*

Ключові слова: *орний агрегат, поздовжній профіль поля, коливання, дисперсія, нормована кореляційна функція, нормована спектральна щільність.*

Introduction

One of the mostof the energy-intensive operations of soil cultivation is plowing, which accounts for more than 40% of energy costs (Kraut-Cohen, J. et al., 2023) [1]. Over the years of technical progress, the design of the plow and the scheme of the plow unit have not undergone significant changes. At the same time, plowing machine-tractor units (MTA) according to the "push-pull" scheme are becoming more and more widely used. Their design feature is the presence of frontal plows (Bulgakov, V. et al., 2023) [2], which are attached to the tractor's front attachment mechanism (PNM). At the same time, the method of selecting PNM parameters is standardized (ASAE Standards S513, 2003) [3].

Usuallythe front plow is equipped with a support wheel. Its main function is to regulate the plowing depth. In addition, the support wheel of the front plow affects the dynamics of the vertical load of the wheels of the front axle of the tractor (Zhang, Sh. Et al., 2022) [4]. In case of incorrect selection of PNM parameters of the power tool and an unreasonable place for installing the support wheel of the front plow, it may not be additional loading, but on the contrary, unloading of the front steered wheels of the tractor may occur. As a result, such a result is able to condition not only the deterioration of traction and energy indicators of the plow unit according to the "push-pull" scheme, but also lead to the loss of its controllability of movement on the field's working furrow.

The work of Singh, N. & Pandey, K. (2017) [5] presents the analysis of the dynamics of the plowing process with a unit with a front plow without a support wheel. At the same time, these studies are aimed at developing a specialized computer program for calculating the forces acting on the central and lower traction of the PNM of the tractor. In view of this, the design proposed by the researchers does not contain a mechanism that would limit the depth of immersion into the soil of the frontal plow without a support wheel. Moreover, the forces and reactions from the front plow tool considered by the authors do not reflect its influence on the amount of vertical additional load on the front axle of the tractor. Taking this into account, the analysis presented by the authors has limited application for further research.

Analysis of recent researches

A version of the operation of a plow unit with a front plow without a support wheel, devoid of the above-mentioned disadvantages, is considered in the work (Nadykto, V. et al., 2024) [6]. The authors analyzed the nature of changes in the amplitude and frequency characteristics of the vertical oscillations of the front axle of a tractor with a front implement under the influence of external disturbance. At the same time, it was established that an increase in the vertical load on the front axle of the tractor by 600 kg leads to a desired decrease in its vertical oscillations. At the same time, the estimated amplitude-frequency characteristics are practically invariant in relation to the change in the damping coefficient of the tires of the front wheels of the tractor in the range from 1 to 3 kN·s/m. At the same time, the value of the coefficient of stiffness of the tires of the front wheels of the tractor should be as small as possible, which is ensured by adjusting the air pressure in the tires.

Then aggregating a front plow, an important aspect is ensuring the stability of the plowing depth. This issue becomes especially relevant if this implement does not have a support wheel.

The aim and objectives of research

In view of this, the purpose of this article is to find out the influence of the operation of a front plow without a support wheel on the stability of the depth of soil cultivation by a plowed machine-tractor unit according to the "push-pull" scheme.

Research results

Laboratory and field dthe research was carried out with two variants of plowing machine-tractor units as part of the KhTZ-16131 tractor, the rear-mounted four-body plow PLN-4-35 and the frontal plow under the conventional brand PLN-2-35 (Fig. 1). Option 1 is an MTA, which has a front plow equipped with a support wheel. Instead, option 2 is a plow unit with a front plow without a support wheel.

Fig. 1. Experimental plow machine-tractor unit

Before conducting field research, the longitudinal profile of the field was recorded. For this purpose, the profilograph developed at Dmytro Motornyi Tavria State Agrotechnological University was used (Fig. 2).The body of this device is mounted on a 4 m long wooden rail and is located on supports parallel to the field surface. A rotating spring-loaded lever is hinged to the body. At one end, it contacts the profile of the agricultural background through a wheel with a radius of 5 cm. A variable resistor SP-3A (Ukraine) with a nominal value of 470 Ohm is attached to the axis of the hinge of the spring-loaded lever.

Fig. 2. Device for recording fluctuations of the profile of the field surface

During the movement of the device body along the rail, the wheel of the lever, copying the irregularities of the field profile, forces the lever to make angular oscillations (turns) relative to the axis of its suspension. When turning, the lever rotates the rotor of the SP-3A resistance, thereby changing its electrical resistance. The electrical signal from the SP-3A via the microcontroller Arduino Uno (Italy) is sent to a portable computer, where it is digitized in the form of ordinates of the field profile with the help of a specially developed program.

Fluctuations in the depth of plowing were registered by the device developed at Dmytro Motornyi Tavria State Agrotechnological University based on the Arduino Uno controller (Fig. 3). The measuring element of this device is the ultrasonic sensor HC-SR04 (China), installed in the registration and measurement unit 1 together with the Arduino and the electronic panel. Block 1 is connected to the moving rod 3.

In the process of measurements, the device was installed with support 2 on the ground, and then the rod 3 was immersed in the furrow to the depth of plowing l. Block 1 with the help of an ultrasonic sensor fixes the distance L (see Fig. 3). As $L = f(l)$, then the depth of tillage (plowing) of the soil in centimeters is displayed on the board of block 1.

Field profile fluctuations were recorded along a 30 m long field section. Measurement data were obtained at intervals of 1 s. At a speed of movement of the profilograph along the rail of approximately 0.05 m/s, this interval was 0.05 m (5 cm).

The plowing depth of each MTA was recorded on a 50 m long section every 0.2 m. The number of measurements of this parameter was at least 150. Measurements of vertical fluctuations of unevenness of the longitudinal profile of the field were carried out on stubble of winter wheat in the conditions of southern Ukraine (Zaporizhia region, Melitopol district, Lazurne village). The obtained data made it possible to construct the normalized spectral densities of the specified oscillations (Fig. 4).

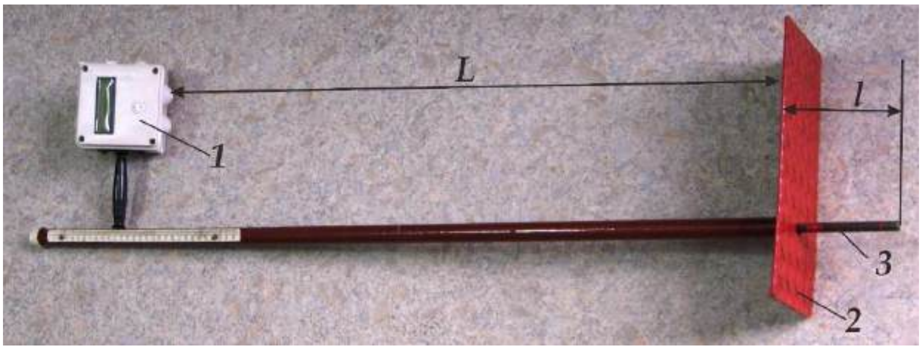

Fig. 3. Depth gauge: 1 – registration and information block; 2 - support; 3 - moving rod

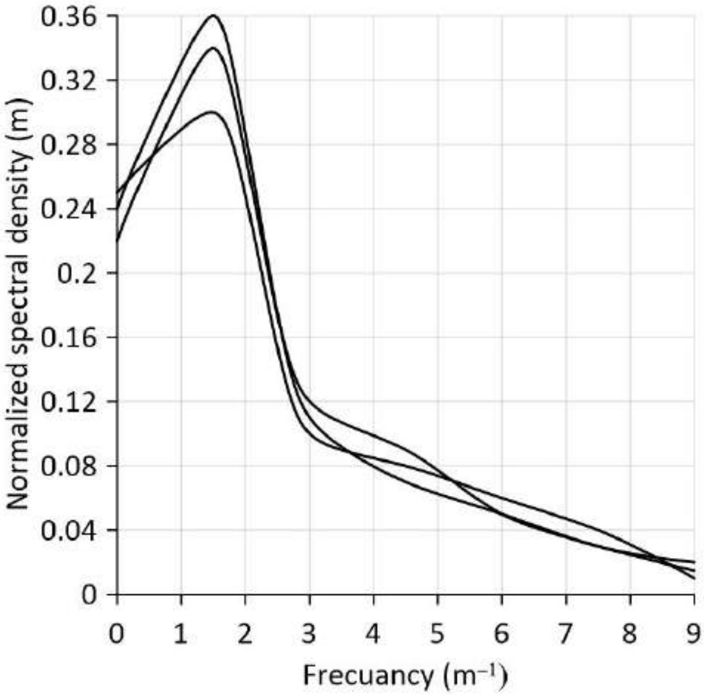

Fig. 4. Normalized spectral densities of fluctuations of the longitudinal profile of the experimental field

Analysis of these statistical characteristics shows that all of them have a cutoff frequency (ω_c) is equal to 9 m^{-1}. We will remind that the cut-off frequency is the frequency in which at least 95% of the variance or normalized spectral density of the fluctuations of the studied process is concentrated in the range of its change (Gumen M.B. et al., 2017) [7]. To translate the value of this parameter into the time dimension (s^{-1}), it (spectral density) should be multiplied by the rate of change of the process of fluctuations of the field profile irregularities. In practice, this speed will depend on the speed of movement of the plow unit (V_a).

The long-term practice of testing such MTA in the soil conditions of southern Ukraine proves that the parameter is significant Va varies within 7...9 $km \cdot h^{-1}$ or 1.94...2.50 $m \cdot s^{-1}$. In this case, at the average value of the parameter Va = 2.22 $m \cdot s^{-1}$, the cutoff frequency of the normalized spectral densities will be $=\omega_c 2.22 \cdot 9 = 19.98\ s^{-1}$. In conclusion, for the implementation of theoretical and analysis of experimental data, we assume that the frequency of the disturbing influence in the form of vertical fluctuations of the irregularities of the longitudinal profile of the treated field varies in the range of 0...9 m^{-1} in spatial dimensions, or 0...20 s^{-1} – in time dimensions.

The analysis of the obtained research results with a confidence probability of 95% proves that the null hypothesis about the equality of the average values of the plowing depth in the compared units is not rejected. The proof of this is the HIP_{05} of this statistical indicator, which is equal to 0.81 cm (Table 1). And this is more than the real difference between the compared values of plowing depth, which is 0.50 cm. It follows that the removal of the support wheel from the front plow does not lead to a significant change in the average value of the plowing depth.

Table 1

Statistical indicators of plowing depth by compared plowing machine-tractor units

Indicator	Variant of arable MTA	
	with support wheel (option 1)	without support wheel (option 2)
The average value of plowing depth, cm	25.4	25.9
Error of the average value, cm	0.28	0.30
Mean square deviation, ± cm	2.6	2.0
Dispersion, cm^2	6.76	4.00
Coefficient of variation, %	10.2	7.7
The smallest significant difference (HIP_{05}), cm	0.81	

At the same time, the null hypothesis about the equality of the compared variances of the plowing depth fluctuations with plow aggregates of both options (Table 1) is rejected. At least at the statistical significance level of 0.05. According to the obtained data, the actual significant Fisher's F-test at the level of 1.69 (6.76/4.00) is greater than the table one, which in this case is 1.39.

In view of this, it can be stated that the use of a front plow (option 2) leads to a decrease in the dispersion of plowing vibrations in comparison with a plow unit equipped with a front plow with a support wheel (option 1).

This result can be explained as follows. Provided that the front plow is equipped with a support wheel, the plow directly reacts to the fluctuations of the unevenness of the longitudinal profile of the cultivated field. On the other hand, in the absence of this wheel, fluctuations of the field profile affect the front-mounted plow implement not directly, but indirectly – that is, through the front axle of the tractor. As a result, a corresponding dynamic delay link is created, due to the manifestation of which the disturbing effect of lateral fluctuations of vertical irregularities of the path (field) profile on the front plow without a support wheel is carried out with a corresponding time delay and a certain decrease in amplitude.

It should be emphasized that dispersion is characterized both by its energy and frequency of distribution. It was established that the internal spectrum of dispersion of plowing depth fluctuations for the compared variants of plowing MTA is different. In the unit with a front plow, the length of the correlation bond(the length of the correlation bond is the abscissa of the first intersection with the normalized correlation function of the zero ordinate) of the normalized correlation function of this process is almost 0.4 m (option 1, Fig. 5).

In the aggregate of option 2, this indicator reaches the mark of 0.72 m, that is, 1.8 times larger (option 2, Fig. 5). Practically, this means that the process of fluctuating the plowing depth in a machine-tractor unit with a front plow without a support wheel is more low-frequency than a similar process in a plowing unit with a front plow equipped with a support wheel.

Additional proof of this iscourse of the normalized spectral densities of the fluctuations of the compared dispersions (Fig. 6).

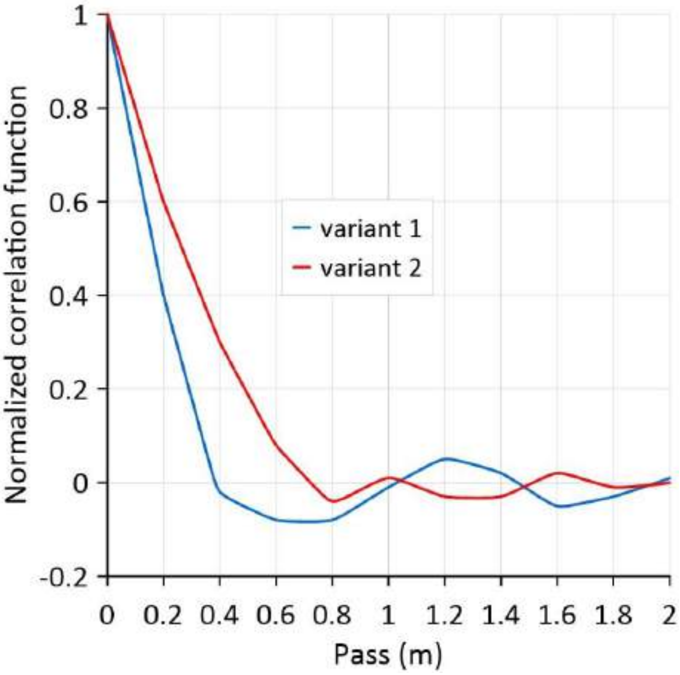

Fig. 5. Normalized correlation functions of plowing depth fluctuations by compared MTA

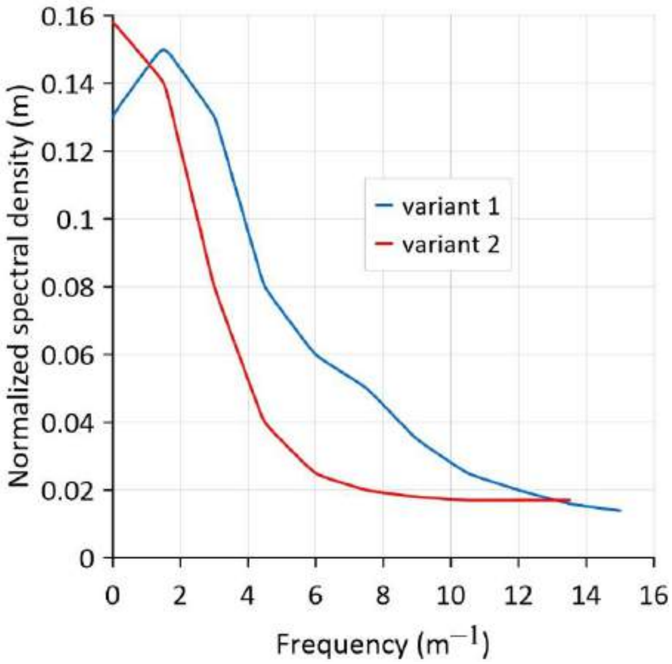

Fig. 6. Normalized spectral densities of plowing depth fluctuations by compared MTA

As evidenced by the analysis of these statistical characteristics, at least 95% of the variance of the variation of plowing depth by the unit according to option 1 is concentrated in the frequency range 0...15 m^{-1}. At the speed of movement of this MTA at the level of 2.20 $m \cdot s^{-1}$, it is 0...33 s^{-1} or 0...5.3 Hz.

In the plowing machine-tractor unit according to option 2, the main spectrum of dispersion of plowing depth fluctuations is concentrated in the range of 0...8 m^{-1} (red curve,

Fig. 6). The operating speed of this MTA was at the level of 2.36 m·s-1. It follows from this that the concentration range of at least 95% of the variance of the plowing depth fluctuations with such a unit is 0...18.9 s^{-1} or 0...3.0 Hz. Compared to option 1, it is 43% less. In other words, the use of a plowing unit with a front plow without a support wheel forms a narrower (by 43%) range of plowing depth fluctuations.

Next, we note the following: the variation coefficient of plowing depth fluctuations by the unit according to option 2 is 7.7%, which is less than 10%. According to (Golub G.A., 2024) [8], this value of this statistical characteristic represents a low variable process. On the other hand, the value of the coefficient of variation at the level of 10.2% characterizes the process of fluctuations in the depth of plowing as moderately variable, which qualitatively correlates with the above correlation-spectral analysis.

Finally, we note once again that the spectrum of plowing depth fluctuations of the compared machine-tractor units is different. At the same time, for a plowing unit with a front plow with a support wheel (i.e. option 1), the spectrum of dispersion of fluctuations of the depth of plowing is approximately comparable to the spectrum of fluctuations of the unevenness of the longitudinal profile of the field (see Fig. 4). Both processes are characterized by approximately equal values of the cut-off frequencies of the corresponding normalized spectral densities, which are at the level of 9 m^{-1}.

At the same time, the range of fluctuations of plowing depth dispersions in MTA according to option 2 is somewhat narrower (0...8 m^{-1}) for the spectrum of fluctuations of field profile irregularities, which is a desirable fact.

Conclusions

1. The analysis of the obtained research results with a confidence probability of 95% proves that the null hypothesis about the equality of the average values of the plowing depth in the compared units is not rejected. The proof of this is the HIP_{05} of this statistical indicator, which is equal to 0.81 cm, which is greater than the real difference between the compared values of the plowing depth, which is 0.50 cm. It follows that the removal of the support wheel from the front plow does not lead to a significant change in the average value of the plowing depth.

2. The null hypothesis about the equality of the compared variances of the fluctuations of the depth of plowing by plowing aggregates of both options is rejected at the statistical significance level of 0.05. According to the obtained data, the actual significant Fisher's F-test at 1.69 is greater than the tabulated one, which is 1.39. In view of this, it can be stated that the use of a front plow (option 2) leads to a decrease in the dispersion of plowing vibrations in comparison with a plow unit equipped with a front plow with a support wheel (option 1).

3. The process of plowing depth fluctuations in MTA with a front plow without a support wheel is more low frequency than a similar process in a plowing unit with a front plow tool equipped with a support wheel. This is evidenced by both the course of the normalized spectral densities of the fluctuations of the compared dispersions and the coefficients of variation of the fluctuations of the tillage depth.

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