

EXPERIMENTAL RESEARCH ON THE MOVEMENT STABILITY OF A PLOUGHING AGGREGATE, COMPOSED ACCORDING TO THE "PUSH-PULL" SCHEME

PĒC «PUSH-PULL» SHĒMAS KOMPLEKTĒTA ARŠANAS AGREGĀTA KUSTĪBAS STABILITĀTES EKSPERIMENTĀLS PĒTĪJUMS

PhD. Ivanovs S.¹⁾, Prof.PhD. Bulgakov V.²⁾, Prof.PhD. Adamchuk V.³⁾,
Prof.PhD. Kyurchev V.⁴⁾, Prof.PhD. Kuvachov V.⁴⁾

¹⁾Latvia University of Agriculture / Latvia;

²⁾National University of Life and Environmental Sciences of Ukraine / Ukraine;

³⁾National Scientific Centre "Institute for Agricultural Engineering and Electrification" / Ukraine;

⁴⁾Tavria State Agrotechnological University / Ukraine

Tel: +37129403708; E-mail: semjons@apollo.lv

Keywords: ploughing aggregate, «push-pull», movement stability, experimental researches.

ABSTRACT

The conducted researches on a ploughing aggregate, composed according to the "push-pull" scheme as part of the HTZ-16131 tractor with a frontal two-bottom plough and a rear-mounted four-bottom plough, show that there is a positive correlation between the input impact – the turning angle of the driven wheels of the tractor, and the output parameter – its relative bearing. The maximum value of the mutual correlation function between these parameters is quite high, reaching mark 0.88. The researched ploughing aggregate, operating according to the "push-pull" scheme, has satisfactory path indicators. The path variations of the furrow laid by this aggregate are of a low-frequency nature. Arrangement of the supporting wheel of the frontal plough outside the furrow and its movement across an undeveloped agrophone does not lead to the deterioration in the steering ability of the explored ploughing aggregate.

ABSTRAKTS

Pēc «push-pull» shēmas komplektētu aršanas agregātu: traktora HTZ-16131 ar pakaļējās uzkares četru korpusu un ar frontālo divu korpusu arklu pētījumi liecina, ka starp ieejas parametru – traktora vadriteņu pagrieziena leņķi un izejas parametru – agregāta kursa leņķi pastāv pozitīva korelācijas sakarība. Savstarpējās korelācijas funkcijas maksimālā vērtība starp šiem parametriem ir pietiekami augsta un sasniedz atzīmi 0.88. Pētāmajam, pēc «push-pull» shēmas komplektētajam aršanas agregātam ir apmierinoši trajektorijas parametri. Ar šo agregātu veidotās vagas trajektorijas svārstībām ir zema frekvence. Frontālā arkla atbalsta riteņa novietojums vagā vai uz neapstrādāta agrofona nesamazina pētāmā aršanas agregāta vadāmību.

INTRODUCTION

Despite the high energy intensity, arable farming still occupies an important place in the soil tillage system (Barwicki et al., 2014; Meca and Cârdei, 2012). Under the conditions of many soil and climatic zones it is impossible to replace completely ploughing with other ways of soil treatment, such as boardless and shallow ploughing. Therefore, constant search is going on for improved machines and operating tools for ploughing, there is continued improvement of the aggregation schemes, and so on (Rucins and Vilde, 2005; Nadykto et al., 2017).

For instance, already now there is a widespread scheme in the world of a ploughing aggregate, composed of a tractor, a frontal and a rear-mounted plough, conventionally called "push-pull" (Bulgakov et al., 2008; Nadykto et al., 2016). But practical experience of their use has shown that, in case the frontal ploughing tool is not properly attached, there may arise not loading but, conversely, unloading of the frontal driven wheels of the tractor with inevitable loss of stability and steering ability of the entire ploughing aggregate (Bulgakov et al., 2017; Nadykto et al., 2017). Hence it follows that the presence of a frontal plough may significantly worsen the stability of the movement of the ploughing aggregate, composed according to the "push-pull" scheme.

According to the scientific hypothesis, developed by us, it was assumed that increase in the adhesive force of the aggregating tractor due to the use of a frontal plough can ensure increased operating width of the ploughing aggregate, composed according to the "push-pull" scheme, at least by the width of one plough

body in contrast to the aggregates with only one rear-mounted implement. Increase in the adhesive force of the aggregating tractor should, in its turn, lead to increase in the stability of the operating movement, reduced skidding of its propulsors and the specific fuel consumption by the ploughing aggregate, composed according to the "push-pull" scheme (Macmillan, 2002).

When choosing a scheme for aggregating a frontal implement, there is a variant prevailing among the scientists about a pivotal attachment of the implement to the tractor (Dontsov, 2008). They explain the choice of such a constructive solution by the fact that the ploughing implement, when encountering a mechanical obstacle, may deviate aside and avoid being damaged. Besides, it is claimed that, in order to ensure stable movement of the frontally mounted implement, the instantaneous turning centre of the frontally mounted tractor linkage must be in front of the suspension axis.

Certain attention should be paid to the postulate that, in order to increase the stability of the movement of the frontal pivotally attached implement, its operating elements must be arranged in the form of a wedge (Dontsov, 1989).

Some scientists argue that the stability of the movement of the tools operating in the pushing mode can be ensured by introducing flexible elements into the structure of the frontally mounted mechanism of the aggregating tractor (Ploschadnov et al., 2005).

Therefore, to ensure efficient application of the ploughing machine-and-tractor aggregates in agriculture, which are composed according to the "push-pull" scheme, it is expedient to study more deeply the stability issues of their movement.

The aim of this study is to increase the stability of the movement in a horizontal plane of a ploughing aggregate, assembled according to the "push-pull" scheme on the basis of data obtained during the field experimental data.

MATERIALS AND METHODS

The experimental studies were carried out on the basis of modern methods of conducting field experimental studies using strain gauge equipment and a measuring complex based on the analogue-to-digital converter. Processing of the obtained data on a PC was carried out by statistical methods applying a correlation-spectral analysis.

As a research object was chosen a ploughing machine-and-tractor aggregate on the basis of the tractor HTZ-16131 (Fig. 1). The technological part of the machine-and-tractor aggregate included a test sample of a two-bottom frontal plough (Fig. 2) and a rear-mounted tensometric plough (Fig. 3) with a 35 cm operating width of each body.



Fig. 1 - Tractor HTZ-16131 in the aggregate with a frontal (two-bottom) plough and a rear-mounted (four-bottom) strain-gauge plough (the "push-pull" scheme)

In the theoretical studies conducted by us it was established that, in order to avoid insufficient loading and, on the contrary, unloading of the front wheels of the aggregating tractor with a rated tractive effort of 30...32 kN, the frontal plough should have two bodies, and the rear plough should have 4 bodies (the "2 + 4" scheme) (Nadykto et al., 2017). Thus an experimental ploughing machine-and-tractor aggregate was composed, working according.



Fig. 2 - A frontal double-bottom plough



Fig. 3 - A rear-mounted tensometric plough

In the theoretical studies conducted by us it was established that, in order to avoid insufficient loading and, on the contrary, unloading of the front wheels of the aggregating tractor with a rated tractive effort of 30...32 kN, the frontal plough should have two bodies, and the rear plough should have 4 bodies (the "2 + 4" scheme) (Nadykto *et al.*, 2017). Thus an experimental ploughing machine-and-tractor aggregate was composed, working according to the "2 + 4" scheme and equipped with a frontal two-bottom plough and a rear-mounted four-bottom plough.

The first pass of the aggregate across the selected section of the field during the field experimental studies was carried out using a stable reference point, which ensured rectilinearity. Then the aggregate, composed according to the "push-pull" scheme, moved across a control section, 250 m long, in the forward and reverse directions.

The movement of the aggregating tractor HTZ-16131 within the above-described ploughing aggregate took place by means of the right-side wheels in the furrow, and with the left-side ones running across the undeveloped agrophone. It was assumed that the nature of the vertical oscillations of the left and the right sideboards of the aggregating tractor is practically the same.

Taking into account the design features of the researched ploughing aggregate, a set of measuring and recording equipment was developed using an analogue-to-digital converter that ensured unbiased assessment of the parameters to be studied.

To record the relative bearing of the tractor working within the ploughing machine-and-tractor aggregate, composed according to the "push-pull" scheme, a gyroscopic semi-compass GPK-52 was used, which was located in the zone of the longitudinal coordinate of the centre of mass of tractor HTZ-16131 (Fig. 4). The alternating current of voltage 36 V and a frequency of 400 Hz, necessary for the GPK-52 operation, were produced by a special PT-70 converter (Fig. 5).

The deviation of the path of the furrow from the straight line was measured by a metric ruler. The base straight line was staked out with a length of 250 m. The measurements were carried out in steps of 1 m. The frontal and the rear-mounted ploughs of the ploughing aggregate to be researched were adjusted to a depth of 25 cm. The aggregate moved on the control section with a forward velocity, which was determined by means of a track-measuring wheel and was fixed on the PC within the velocity range of 1.4...2.2 m·s⁻¹ allowed from agrotechnical standpoint.

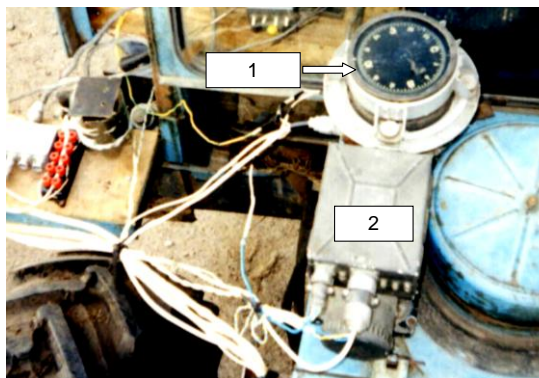


Fig. 4 - Installation of the gyroscopic semi-compass GPK-52 (1) and the current transducer PT-70 (2) on tractor HTZ-16131

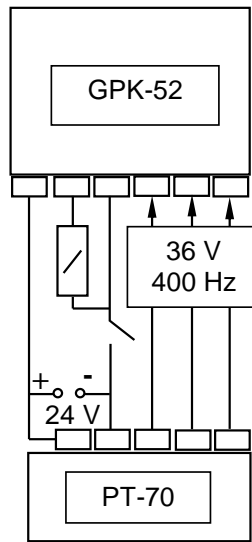


Fig. 5 - The connection diagram of the gyroscopic semi-compass GPK-52 with the PT-70 current transducer

Experimental researches of this ploughing aggregate were carried out on an agrophone (disked sunflower stubble), the average moisture content of which in the 0...30 cm layer was 13.8%. The soil density was within the range of 1.26...1.29 g·cm⁻³. Weediness of the field did not exceed 95 g·m⁻².

RESULTS

It has been established during the conducted research that the variation in the relative bearing (φ) of the tractor was insignificant, the dispersion of the process was 0.96 deg². Analysis of the normalised spectral density of this process showed that the frequency range of its course is 0...3 s⁻¹ (Fig. 6).

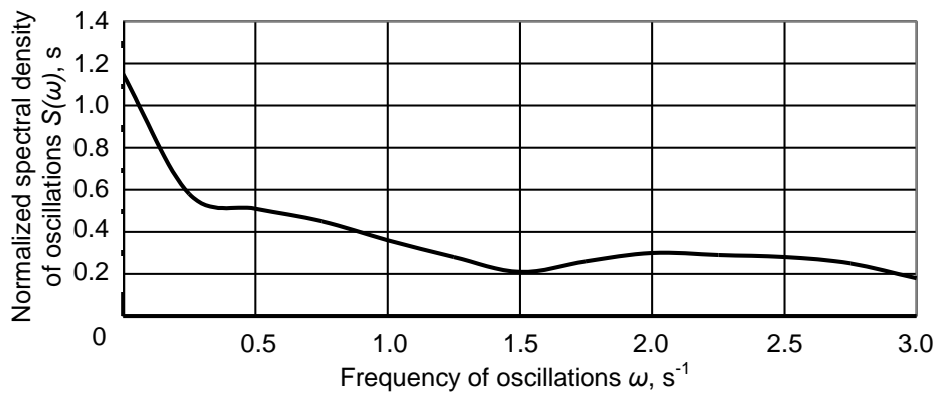


Fig. 6 - Normalised spectral density of variations of the relative bearing of the aggregating tractor HTZ-16131

Having determined the mean square deviation and the normalised spectral density of variations of relative bearing φ , we found the required experimental amplitude-frequency characteristic of the experimental ploughing aggregate (Fig. 7).

The nature of the experimental amplitude-frequency characteristic of the experimental ploughing aggregate shows (Fig. 7) that tractor HTZ 16131, together with the frontal plough, responds most noticeably to disturbances the frequency of which occurs within the range of 1...2 s⁻¹. In general, the process of changing the experimental amplitude of the frequency-frequency characteristic of the ploughing aggregate is close to the theoretical one (Bulgakov et al., 2016). The actual discrepancy between these comparable characteristics is not more than 8%.

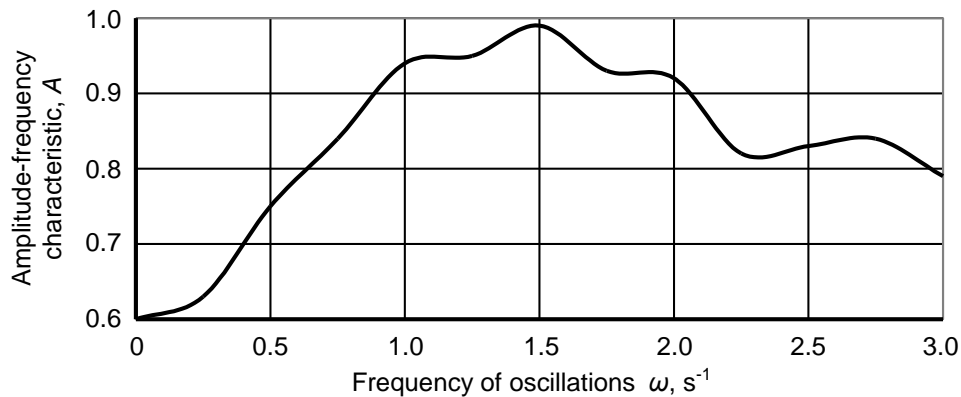


Fig. 7 - An experimental amplitude-frequency characteristic of the researched ploughing machine-and-tractor aggregate

By the conducted research it was established that the ploughing aggregate, composed according to the "push-pull" scheme of tractor HTZ-16131 with a frontal two-bottom and a rear-mounted four-bottom plough, has satisfactory path indicators. The basis for such a conclusion is the nature of variations of the furrow path, laid by this aggregate. In reality, they are of a sufficiently low frequency (Fig. 8).

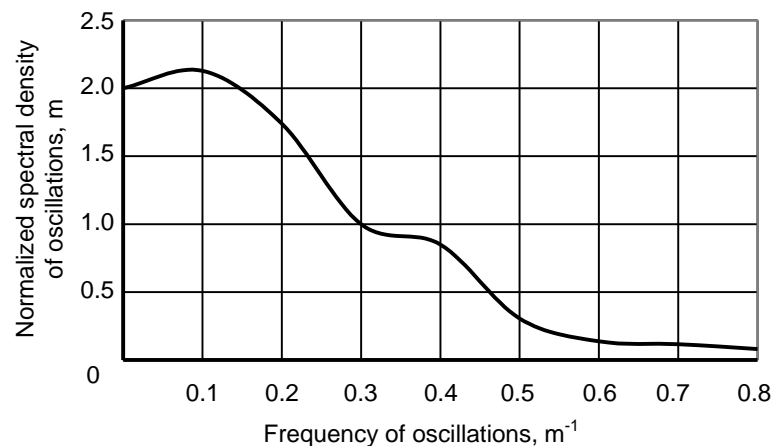


Fig. 8 - Normalised spectral density of the furrow path variations laid by the aggregate operating according to the "push-pull" scheme

The main dispersion spectrum, the value of which is 69.16 cm^2 , is concentrated in the frequency range $0 \dots 0.50 \text{ m}^{-1}$. At a velocity of the aggregate movement $2 \text{ m} \cdot \text{s}^{-1}$, it is $0 \dots 1.0 \text{ s}^{-1}$ or only $0 \dots 0.16 \text{ Hz}$. The length of the correlation link of the furrow path variations of the ploughing aggregate is at least 11 m.

Such a result is satisfactory since the cut-off frequency of the spectral density of the furrow path variations is 0.50 m^{-1} , which is only twice as large as the frequency that represents the acceptable non-rectilinearity of the row crops (Nadykto et al., 2009).

Since the tractor HTZ-16131 with aggregated ploughs moves with its right-side wheels along the furrow, the statistical characteristics of the turning angle of its driven wheels (parameter α) do not differ significantly from the similar dispersion characteristics, or from the normalised correlation function and spectral density, representing variations of the furrow path.

However, as relates to the relative bearing of the aggregating tractor (parameter φ), the statistical characteristics are basically different. Due to the lateral drift angles of the tires of the running wheels of the aggregating tractor, the energy (it is the same dispersion) and the internal structure of the variations of its relative bearing are a little different. In a numerical expression, the dispersion of the variations of parameter φ was 2.96 deg. , and parameter α – 2.10 deg.

The statistical processing on the PC was performed by 250 ordinates of the parameters α and φ . For such arrays of initial data, the tabular value F of Fisher's ratio test at the statistical significance level of 0.05 turned out to be equal to 1.39 (Dospechov, 2012; Gerber and Green, 2012).

Because the actual value F of Fisher's ratio test (equal to 1.41) is greater than the tabular (equal, 1.39), the null hypothesis about the equality of the estimated variances is not rejected. With a probability of 95%, it can be claimed that the variation dispersion of the relative bearing of the tractor is by no means greater than a similar indicator for the relative bearing of its driven wheels.

Perhaps because of this the variations spectrum of parameter φ is wider in comparison with angle α . Thus, if the cut-off frequency for the spectral density of the variations of the driven wheel turning angle is 0.3 s^{-1} , then for the relative bearing it is approximately 0.42 s^{-1} (Fig. 9).

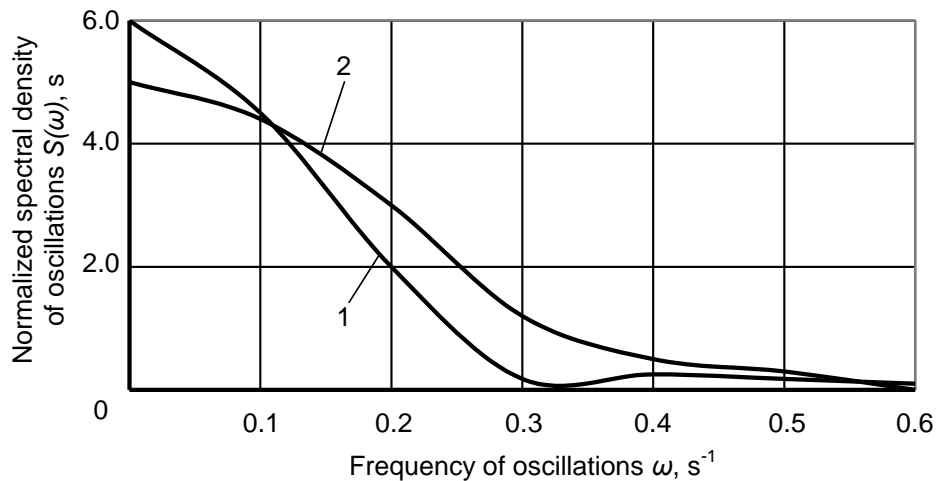


Fig. 9 - Normalised spectral densities of variations of the driven wheels turning angle of the tractor HTZ-16131 (1) and its relative bearing (2)

Despite the difference in the nature of variations of parameters α and φ , there is a close correlation between them. It is unambiguously represented by the normalised correlation function. Analysis of its behaviour shows (Fig. 10) that there is a positive correlation between the input impact – the turning angle of the driven wheels of the tractor, and the output parameter – its relative bearing. The maximum value of the mutual correlation function is quite high, reaching mark 0.88.

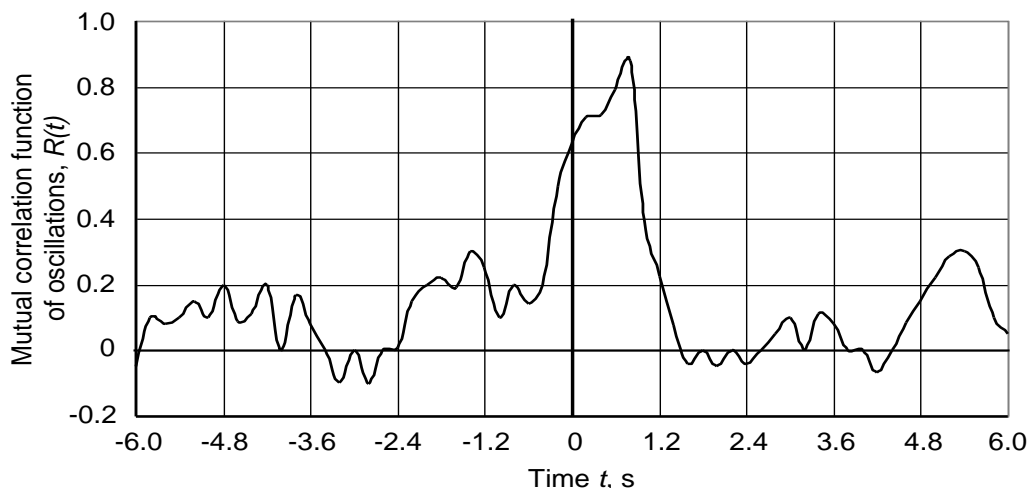


Fig. 10 - Mutual correlation function of variations in the relative bearing of the tractor HTZ-16131 by the turning angle of its driven wheels

The shift of the maximum value of the mutual correlation function to the right indicates that the relative bearing of the aggregating tractor is the turning function of its driven wheels, and not vice versa. If this maximum were in the second quadrant, value α would be considered as a reaction of the operator-driver to such a disturbance as an unwanted turn of the tractor body to one or the other side.

The shift of the maximum value of the mutual correlation function to the right of the vertical axis by 0.8 s indicates that it takes place precisely at the time when the change in the relative bearing of the tractor for the control action – the turning angle of its driven wheels – is delayed.

On the basis of what was laid out above, you can conclude the main thing. In the proposed variant of the ploughing machine-and-tractor aggregate, composed according to the "push-pull" scheme, the supporting wheel of the frontal plough is running outside the furrow. On the field it is moving across an undeveloped agrophone. This is in contrast to the world-wide variants of ploughing aggregates operating according to the "push-pull" scheme, which provide for the movement of the supporting wheel of the frontal implement in the furrow thus as if providing satisfactory control and stability of the movement of such an aggregate. But, on the basis on the analysis of the above-mentioned mutual correlation function (Fig. 10), it can be claimed that this decision does not lead to deterioration in the control of the movement of the researched ploughing aggregate assembled according the "push-pull" scheme.

The conducted research allows substantiating practical recommendations on the choice of a scheme and parameters of the ploughing aggregate, composed according to the "push-pull" scheme on the basis of the tractor HTZ-16131, from the position of satisfactory stability of its movement. So, the scheme of placing the tractor in the structure of ploughing aggregate is direct. When working in an aggregate with frontal and rear-mounted ploughs, the tractor HTZ-16131 should move with the right-side wheels running in the furrow. The air pressure in the tires should be as follows: the frontal wheels (with the tractor running straight) - 0.125 MPa, the rear wheels – 0.170 MPa. Any mobility of the frontal plough in a horizontal plane relative to the tractor is undesirable. During the operation the supporting wheel of the frontal plough moves outside the furrow. Although its removal from the connecting triangle of the frontal plough reduces the vertical load on the frontal wheels of the tractor, the change of this indicator is significant. Proceeding from this, when choosing the location of the wheel mentioned, it is necessary to carry out constructive limitations.

CONCLUSIONS

1. The ploughing aggregate, composed according to the "push-pull" scheme as part of the HTZ-16131 tractor with a frontal two-bottom and a rear-mounted four-bottom plough, has satisfactory path indicators. The variations of the furrow path laid by this aggregate are of a low-frequency nature. The basic dispersion spectrum, the value of which is 69.16 cm^2 , is concentrated within the frequency range $0 \dots 0.50 \text{ m}^{-1}$. At the velocity of the ploughing aggregate $2.0 \text{ m} \cdot \text{s}^{-1}$, it is $0 \dots 1.0 \text{ s}^{-1}$ or only $0 \dots 0.16 \text{ Hz}$.

2. There is a positive correlation between the input impact – the turning angle of the driven wheels of the tractor HTZ-16131, and the output parameter – its relative bearing. The maximum value of the mutual correlation function between these parameters is quite high, reaching mark 0.88. The shift of the maximum value of the mutual correlation function to the right by 0.8 s indicates that the relative bearing of the tractor is the turning function of its driven wheels, but the reaction of the tractor to the control impact lags precisely by the same time.

3. Arrangement of the supporting wheel of the frontal plough outside the furrow and its movement across an undeveloped agrophone does not lead to deterioration in the steering ability and stability of the movement of the researched ploughing aggregate, composed according to the "push-pull" scheme.

REFERENCES

- [1] Barwicki J., Gach St., Ivanovs S., (2012), Proper utilization of soil structure for crops today and conservation for future generations. *Proceedings of 11th International Scientific Conference "Engineering for Rural Development"*, Volume 11, pp.10-15, Jelgava/Latvia;
- [2] Bulgakov V., Kravchuk V., Nadykto V., (2008), Aggregation of ploughs (Агрегатирование плугов). *P.H. Agrarian Science*, 152 p., Kyiv/Ukraine;
- [3] Bulgakov V., Adamchuk V., Nadykto V., Kistechok O., Olt J., (2017), Theoretical research into the stability of motion of the ploughing tractor-implement unit operating on the 'push-pull' principle // *Agronomy Research*, 15(4), 1517-1529, Tartu/Estonia;
- [4] Dontsov I., (1989), Influence of the linkage parameters on stability of rectilinear uncontrolled motion of a frontal implement (Влияние параметров навески на устойчивость прямолинейного неуправляемого движения фронтального орудия) / *Collection of scientific works VISKHOM (Сборник научных трудов ВИСХОМ)*, 119 p., Moscow/Russia;
- [5] Dontsov I., (2008), Stability of the MTA movement with frontal and rear-mounted implements (Устойчивость движения МТА с орудиями фронтальной и задней навески), *Tractors and agricultural machinery (Тракторы и сельскохозяйственные машины)*, No.9, pp.27-29, Moscow/Russia;

- [6] Dospetchov B., (2012), Methodology of a field experiment (Методика полевого опыта (с основами статистической обработки результатов исследований). *Agropromizdat*, 352 p. Moscow / Russia
- [7] Gerber A., Green D., (2012), *Field Experiments: Design, Analysis and Interpretation*, 480 p., Yale/USA;
- [8] Meca V. A., Cârdei P., (2012), Studies and researches for the unification of resistance expression of machines designed to soil tillage with applications in optimization of their working regime, *INMATEH - Agricultural Engineering*, vol. 36, No. 1/2012, Bucharest / Romania;
- [9] Nadykto V., Nazarova O., Chernaya T., (2009), The frequency-dispersion indicator of non-rectilinearity of the row crops rows (Частотно-дисперсионный показатель непрямолинейности рядков пропашных культур) / *Tractors and agricultural machinery (Тракторы и сельскохозяйственные машины)*, No.8. p. 12-14, Moscow/Russia;
- [10] Nadykto V., Kyurchev V., Beloev H., Kistechok A., (2017), Study of push-pull plough combination / *Journal of Agriculture and Environment*, Volume 1, No 1, pp. 4-9;
- [11] Nadykto V., Ivanovs S., Kistechok OI., (2016), Research on the draft-and-power and agrotechnical indicators of the work of a ploughing aggregate, created according to the scheme "push-pull" / *Journal of Research and Applications in Agricultural Engineering* Nr. 62(1), pp. 136.-139, Poznan/Poland;
- [12] Macmillan, R.H. (2012). *The Mechanics of Tractor Implement Performance. Theory and Worked Examples*. University of Melbourne, 165 p. Melbourne/Australia;
- [13] Ploschadnov A., Kursov I., Marshalov E., (2005), Increasing the stability of the movement of machine-and-tractor aggregates (Повышение устойчивости движения машинно-тракторных агрегатов). *Collection of scientific works of Tula State University (Известия Тульского государственного университета)*, pp.171-176, Tula/Russia;
- [14] Rucins A., Vilde A., (2005), Modelling forces acting on the plough body. *Simulation in Wider Europe - 19th European Conference on Modelling and Simulation, ECMS 2005*, pp. 425-430, Riga/Latvia.