ENGINEERING MANAGEMENT OF TILLAGE EQUIPMENT WITH CONCAVE DISK SPRING SHANKS
/
ІНЖЕНЕРНИЙ МЕНЕДЖМЕНТ ҐРУНТООБРОБНИХ АГРЕГАТІВ З ПРУЖНИМИ СТОЯКАМИ СФЕРИЧНИХ ДИСКІВ

***Ivan* Rogovskii [1], *Luidmyla* Titova [1], *Viktor* Trokhaniak V.I.[1], *Oleksandr* Haponenko [1,2], *Mykola* Ohiienko [1], *Vasyl* Kulik [1]** [1]

[1] National University of Life and Environmental Sciences of Ukraine / Ukraine;

[2] Scientific Organization "Leonid Pogorilyy Ukrainian Scientific Research Institute of Forecasting and Testing of Machinery and Technologies for Agricultural Production" / Ukraine

Tel: +380673513082; E-mail: Trohaniak.v@gmail.com

DOI*: https://doi.org/10.35633/inmateh-60-05*

Keywords: *disk, spring shank, soil medium, dynamic characteristics, deflections.*

ABSTRACT

The programme and the procedure of the experimental laboratory and field investigations of the shank parameters and the interaction process of a concave disk spring shank and a soil medium under ballast operating element loading, if there is a change in the travelling speed of a unit, have been developed. Estimation of the measurement results has been conducted based on the uncertainty concept. Under ballast loading (optimal reduced mass), the influence of the random components of a draft force on the process of interaction of a concave disk on a spring shank and the soil is at least one and a half times less. According to the results of the experimental studies, the dependences that show the influence of a unit speed and an operating element reduced mass on the drag force (energy indicator) and the elastic deflections of a shank (an agro-technical indicator) have been determined. Technical and economic assessment of the operating efficiency of tillage equipment according to the operating cost structure and based on practical implementation has been conducted.

РЕЗЮМЕ

В статті обґрунтовано програму і методику експериментальних досліджень з визначення параметрів пружного стояка сферичного диска і режимів процесу його взаємодії з ґрунтовим середовищем при використанні баластного довантаження при зміні поступальної швидкості мобільного енергетичного засобу. Адекватність результатів вимірювань виконано за концепції невизначеності. Встановлено, що з баластним довантаженням за оптимальної зведеної маси, безпосередній вплив випадкових складових тягового опору на процес взаємодії сферичного диска на пружному стояку з ґрунтом, щонайменше в півтора рази, менший. За даними експериментальних досліджень встановлено залежності з визначення впливу швидкості мобільного енергетичного засобу та зведеної маси на робочому органі на енергетичний показник, а саме тяговий опір, та агротехнічний показник, а саме пружні відхилення стояка. Представлено результати техніко-економічної оцінки ефективності експлуатації дискового ґрунтообробного агрегату за структурою експлуатаційних витрат і на основі виробничого застосування.

INTRODUCTION

There are significant quality changes taking place in modern agricultural production engineering caused by intensification of production processes together with efficient use of resources (*Vlăduţ D.I. et al, 2018*). According to these changes, it is necessary to improve agricultural equipment in order to provide their optimum process conditions with minimum energy consumption and improve reliability of individual parts and units (*Xiong P. et al, 2018*). The accomplishment of these tasks is of great importance for soil-tilling equipment, namely for disk headers, since they provide 60–80% of soil pre-treatment and basic cultivation (*Razzaghi E. & Sohrabi Y., 2016; Srivastava A.K. et al, 2016*).

---

[1] *Rogovskii I.L., Prof. Ph.D. Eng.; Titova L.L., Assoc. Prof. Ph.D. Eng.; Trokhaniak V.I., Assoc. Prof. Ph.D. Eng.; Haponenko O.I., Ph.D. Eng.; Ohiienko M.M., Assoc. Prof. Ph.D. Eng.; Kulik V.P., Ph.D. Eng.*

The non-market harvest part left on the surface of a field is the determining factor for further performance of technological operations and developing requirements for operational devices, namely, for the development of disk tillage equipment with new design and technical characteristics in order to provide quality stubble cleaning, the decrease of energy consumption and the increase of operational reliability (*Vlăduţ V. et al, 2018*). The experience of using spring shanks of cultivator operating elements and their positive assessment opens up fresh opportunities for the improvement of disk tillage equipment reliability (*Dewangan A. et al, 2017*).

Operating elements arranged on spring shanks oscillate due to the irregularity of soil drag forces (*Gheorghiță N.E. et al, 2018; Badegaonkar U.R. et al, 2010*). As a result, soil breakdown takes place with less energy consumption that decreases the rate of fuel consumption by tillage equipment *(Klendii M.B. & Klendii O.M., 2016*). A disk header with spring shanks can be better adjusted to a field surface texture and, thus, can provide the required quality of soil cultivation (*David A. et al, 2014*).

Thus, a relevant applied scientific task is the substantiation of the dynamic characteristics and the design parameters of the spring shanks of the disk operating elements of soil-tilling equipment *(Hevko B.M. et al, 2018; Hevko R.B.et al, 2017*).

The aim of the research – is to improve the operating efficiency of disk tillage equipment by means of substantiating their design parameters and the dynamic characteristics of operating element spring shanks.

MATERIALS AND METHODS

The general research technique provided the use of modern methods of theoretical and experimental investigations, the theoretical substantiation was conducted with the help of the methods of mathematics, theoretical mechanics, oscillation theory, differential and integrated calculation (*Asejeva A. et al, 2013*). The experimental research was conducted in the field environment based on standard practices and the specific techniques developed by the author. The procedure of measuring elastic deflections of the operating elements provided for the use of the information and measurement system and the method of strain measurement (*Tutunaru L.F. et al, 2014*). The research data processing was conducted with the help of mathematical methods of statistics. The method of regression analysis was applied.

The design and engineering characteristics of disk tillage equipment are improved in case of the arrangement of disk operating elements on spring shanks due to their oscillations. Substantiation of the design parameters and the dynamic characteristics of shanks as a system “soil – disk – spring shank” allows for improving the efficiency of equipment operation in terms of operational reliability and energy consumption.

The analysis of the existing scientific research suggests that the significant influence on the operation process of a tillage unit on a spring shank is characterized by the models that take into account the influence of empirical factors and design parameters with coefficient matrices. The application of complex models makes it almost impossible to solve the problem of the description of a spring shank with a concave disk movement (*Barwicki J. et al, 2012*).

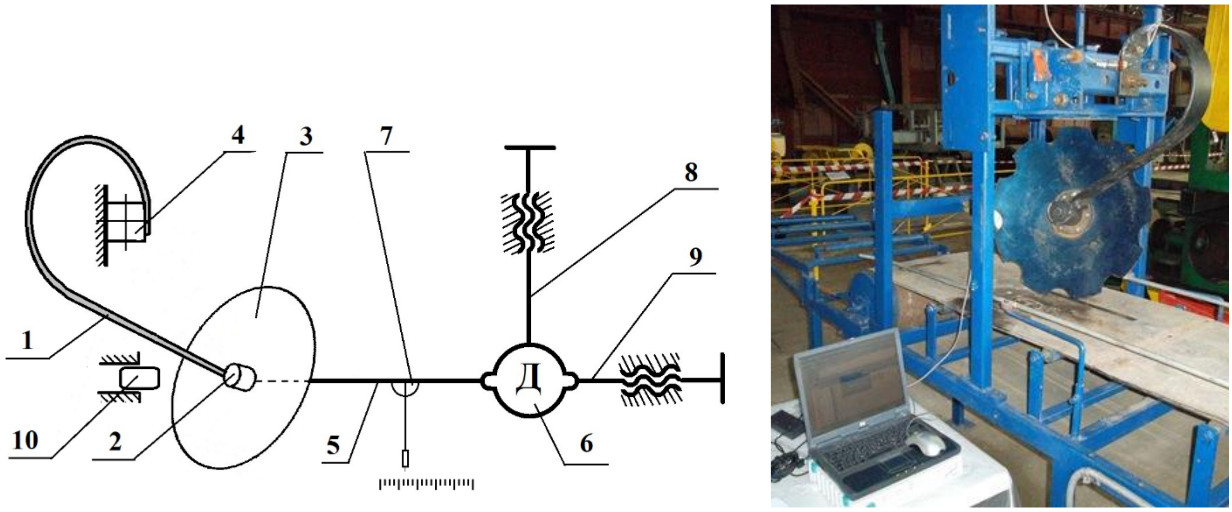
Thus, it is necessary to solve the applied scientific task – substantiate the dynamic characteristics and the design parameters of a spring shank of disk tillage equipment (*Constantin N. & Cojocaru I., et al, 2012*).

The programme of the experimental investigation on spring shanks of concave disks allowed for:

- substantiating the measuring diagram and estimating the dynamic characteristics of a concave disk spring shank;
- determining the design parameters and the dynamic characteristics of a spring shank;
- investigating the influence of the dynamic characteristics of an operating element spring shank on the efficiency of equipment, taking into account the randomness of soil reaction (field research);
- comparing the theoretical and the experimental data and their compliance.

The scheme of the measuring system, taking into account the information flow of the changes in soil properties, was substantiated (*Galat U.N. & Ingale A.N. et al, 2016*). There were KF-5P1 full-bridge strain gauge sensors arranged on a shank and they were connected through SPIDER-8 analog-to-digital converter with CatMan Express 4.5 software (*Trokhaniak V.I., et al, 2019*). The converter performed scanning with a frequency of 250 Hz, analog-to-digital signal conversion and digital array generation as a *.xls file (*Gheres M.I., 2014*). The sensors were cable connected to the equipment and protected from the effect of inferences (*Rogovskii I.L. et al, 2019*). In order to conduct experimental research (testing and assessment of spring shank performance), an experimental plant was developed (Fig. 1).

The information obtained as a result of the laboratory experiments was presented in the form of calibration curves of “deflection” and “loading” (*Rogovskii I.L. et al, 2019*). Simulation of the change in spring shank dynamic characteristics was performed by applying lumped mass to an operating element mounting and bearing unit (impact factor at the following levels: reduced mass and mass plus added weight) (*Rogovskii I.L. et al, 2019*). The investigation was conducted with the use of a multilevel experiment (*Constantin N. & Cojocaru I., 2008*). The peculiarity and the advantage of this pattern is the most complete estimation of the investigation process (Table 1). The increase in the level of external impact (by means of increasing travelling speed) determines the level of influence on a spring shank and ballast loading determines the sublevel.



a) b)

Fig. 1 - An experimental plant (technical equipment) for testing and evaluation of spring shank operation efficiency

a – structural diagram; b – general view; 1 – spring shank of a concave disk; 2 – bearing unit; 3 – operating element (concave disk); 4 – fixed base; 5 – wire rope; 6 – dynamometer; 7 – level; 8 – screw-type vertical regulator; 9 – screw-type horizontal regulator; 10 – percussive mechanism for disturbing shank equilibrium.

Table 1

Investigation Pattern

Impact factors				**Optimization Parameters**					
Travelling speed, *v* [km/h]		**Reduced mass, *m* [kg]**		**External impact / draft force [N]**		**Deflection [mm]**		**Generalized coordinate [deg.]**	
Level (total levels)	Variability interval	Level (total levels)	Variability interval	Average value	Mean square deviation	Average value	Mean square deviation	Average value	Mean square deviation
1 (5)	2	30	0.5 (2)	F	F_{MSD}	δ	δ_{MSD}	λ	λ_{MSD}

Process parameters were recorded in real time in the course of unit operation rounds with the predefined sampling period. Recording areas under steady-state loading conditions were considered. The defined digital array obtained from the analog-digital converter contained several thousand values of the variable under study. If there are many observations, the “n” testing error is less than 0.5–1%. According to “loading” calibration curves, the digital array of the external impact values was processed and statistical process parameters were determined.

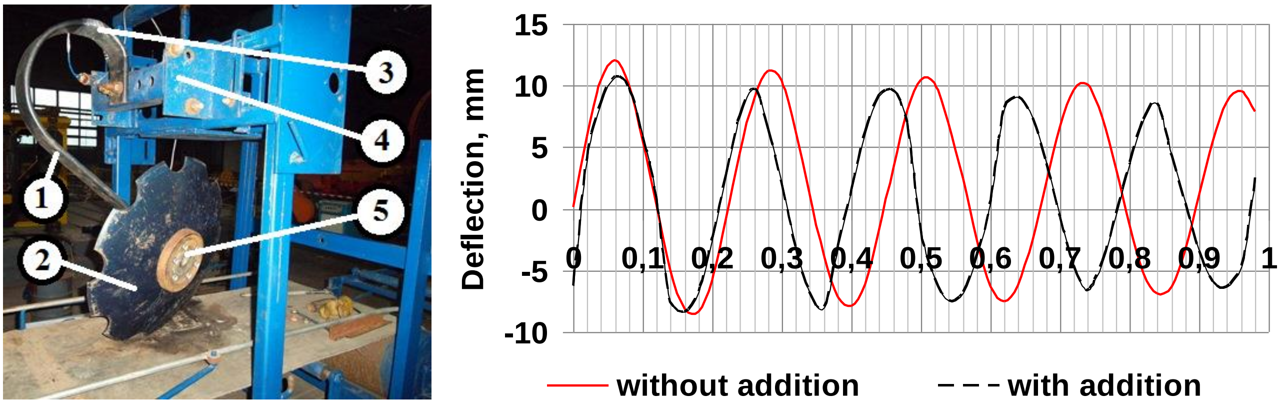
In order to process the experimental data, the methods of mathematical planning and mathematical statistics were used. The estimation of the research findings was performed on the basis of the uncertainty conception describing the dispersion of the values, which could be reasonably assigned to the variable to be measured.

RESULTS

The procedure of determining the design parameters and the dynamic characteristics of spring shanks was investigated using the suggested fabricated and approved design of the experimental plant, the values of the reduced mass (Fig. 2, a) were determined, a load-deflection curve was defined and free spring shank oscillations were observed (Fig. 2, b).

Field experiments were conducted in the process of breaking grain crop fallen seeds germination (second de-husking). The experimental spring shank was attached to the frame of DL-2.5 unit (Fig. 3).

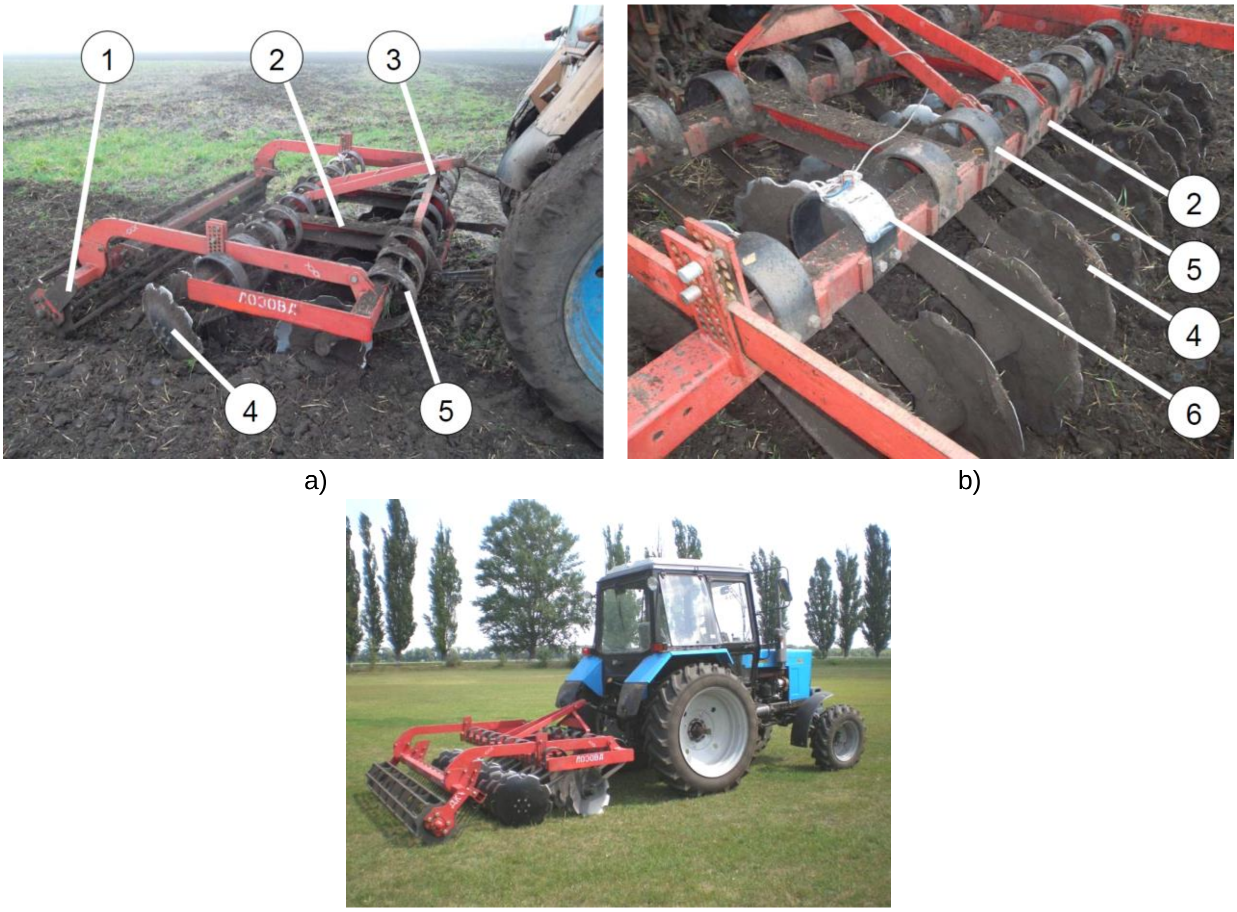
It was determined that the interaction process of a disk operating element on a spring shank and the soil is unsteady and its statistic performance varies with time (Fig. 4). Process unsteadiness is caused by quick changing conditions of operation in a soil medium and the influence of meso- and micro-relief of a field surface.



a) *b)*

Fig. 2 - Realization of laboratory investigations: a – exterior of a spring shank with ballast loading while determining the reduced mass; *b* – free spring shank oscillations

1 – a spring shank of a concave disk; 2 – an operating element (a concave disk);
3 – resistive strain gauges on the surface of a spring shank; 4 – a fixed base; 5 – ballast loading



a) b)

Fig. 3 - General view of a disk header with spring shanks

a – general view of the unit; b – spring shanks under study; 1 – roller; 2 – unit frame; 3 – hitch linkage; 4 – operating element (a concave disk); 5 – spring shank; 6 – resistive strain gauges on the surface of a spring shank.

The probability laws of the instantaneous indicator values of the interaction process of the soil and an operating element on a spring shank (Fig. 4, b) show two vertices in the distribution series, which proves the unsteadiness of the phenomenon under study, the degree of the distribution asymmetry is within the range from 0.1 to -0.1. The shape of the correlation function (Fig. 4, c) meets a zero value that corresponds to the cycle of latent periodical vibrations; however, since the influence of random noise is significant, if there are considerable shifts, the value of the correlation coefficient tends to zero.

The conducted spectral analysis (Fig. 4, d) shows that shank oscillations is a mixed random process with a polyharmonic deterministic component.

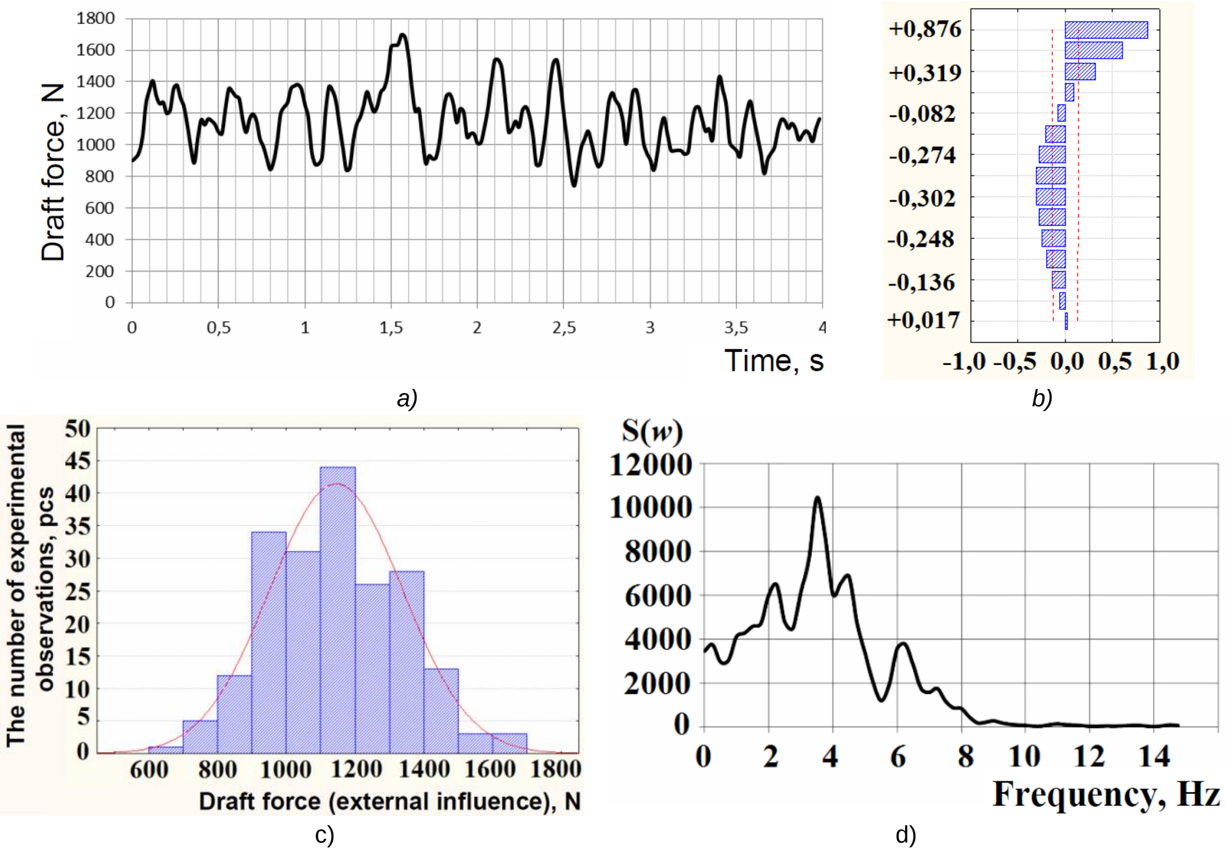


Fig. 4 - Statistical characteristics of the interaction process of an operating element on a spring shank and the soil

a – behaviour of spring shank response to the external impacts; b – autocorrelation function; c – density of distribution; d – spectral analysis.

The investigation results prove that there is a change of spring shank response to a soil medium under additional operating element loading. The increase of the draft force was F = 1180…1300 N of the device speed without additional operating element loading, which was equal to 17%, and under additional loading it was F_{load} = 1170…1240 N or 11%. If a unit travelling speed is 4 m/s, the difference between additional loading options is equal to 10% (Fig. 5, Fig. 6).

Vibroactivity F_{MSD} = 180…290 N of a spring shank without additional loading increases almost linearly and within the speed range from 1.9 to 4 m/s it increases for 78%, and under additional loading it increases for 136% – in 2.36 times. The increase of operating element vibroactivity influences a soil medium and decreases its resistance to breaking down, which explains the decrease of the drag force under additional loading.

Estimation of the process-dependent parameters of a disk header with spring shanks was conducted according to the statistical characteristics of elastic deflections in the process of interaction of an operating element and the soil (Fig. 7, Fig. 8).

Mean-square spring shank deflection describes the uniformity of tillage depth provided by an operating element, according to the reference conditions the non-uniformity is σ = 15 mm. That is to say, the increase of a unit's energy efficiency (draft force decrease) is limited by the qualitative process flow indicator at the speed value of 4 m/s.

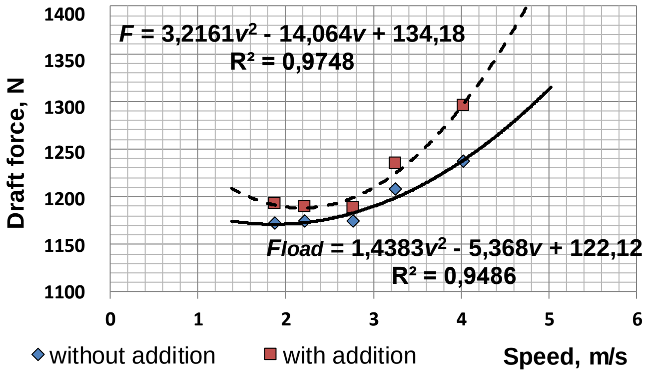


Fig. 5 - Draft force-vs-unit travelling speed characteristic curve (according to calibration curves)

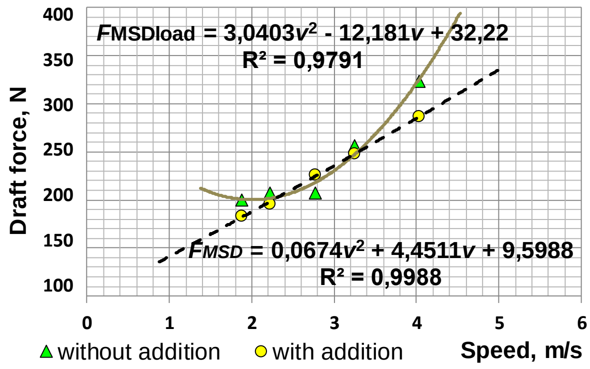


Fig. 6 - Mean-square draft force deviation-vs-unit travelling speed curve

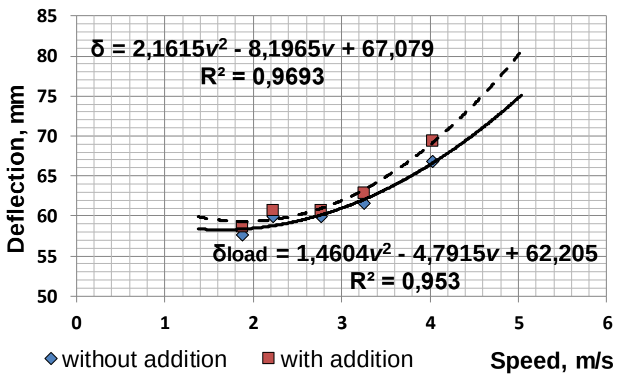


Fig. 7 - Average deflection value-vs-unit travelling speed curve (according to calibration curves)

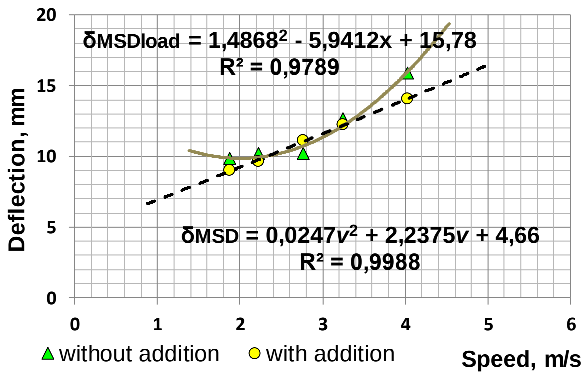


Fig. 8 - Mean-square value of shank deflections-vs-unit travelling speed characteristic curve *σ = f(δ)*

Based on the minimum draft force criterion, the aimed speed rate is 10 km/h, and the value of draft force is equal to approximately 12 kg per one shank.

When comparing the uncertainties of the measurements, it can be concluded that, if there is ballast additional operating element loading, the influence of random components on the interaction process of a concave disk on a spring shank and the soil is at least one and a half times less.

The theoretical and the experimental investigation results on the change of the generalized coordinate during process performance were compared (Fig. 9), the difference in the values under various unit speed rates increases with speed gain, the decrease rate at the speed of 4 m/s is by 1.33% greater compared to the theoretical dependence. The average deviation of the experimental data (rate 2.77 m/s) from the theoretical ones is equal to 0.164 deg., which does not exceed the expanded measurement uncertainty.

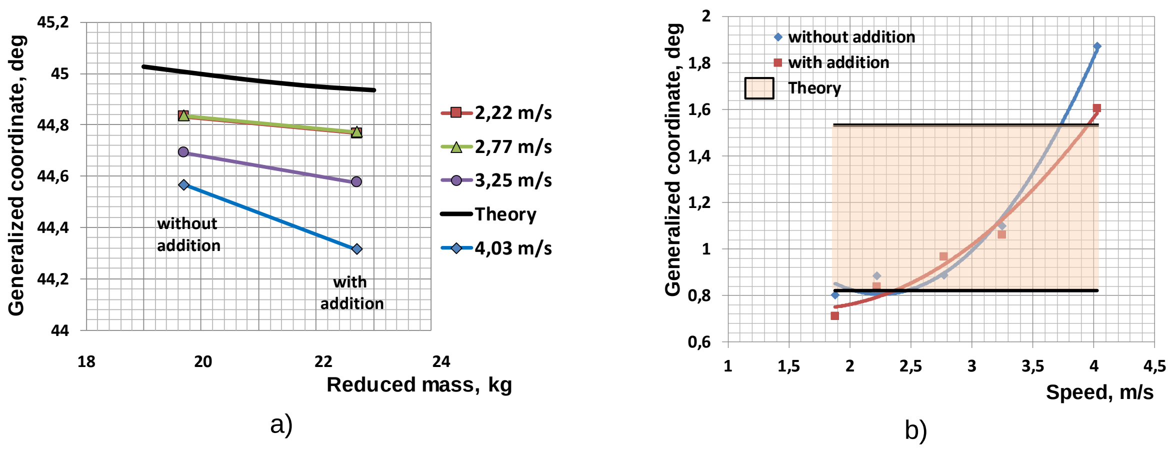


Fig. 9 - Comparison of the theoretical dependences and the experimental data

a – generalized coordinate value in dynamic equilibrium;

b – generalized coordinate value as a mean-square deviation from dynamic equilibrium

When comparing the theoretically obtained dependences of the generalized coordinate deviations and the mean-square values from the experimental data, it is obvious that there is their significant compliance according to the range of values. The lower limit to the range of values obtained theoretically (Fig. 9, b) approximates the experimental data at the rate of 2.22 m/s, the upper limit approximates at the rate of 3.25 m/s, here, the value deviations exceed the uncertainty of measurements by 4.3 and 1.7 times, respectively. Thus, it can be concluded that deviations from the dynamic equilibrium are determined by the influence of a soil medium, however, if the reduced mass is increased, the uncertainty decreases – the interaction process of a concave disk on a spring shank and the soil acquires 2.5 times better controllability.

CONCLUSIONS

1. The dependences obtained from the experimental investigations prove that there is a change in the interaction characteristics of an operating element on a spring shank and a soil medium on condition of the reduced mass change. While in operation, the increase of the draft force produced by the change of the speed from 2 to 4 m/s is equal to 17% for a unit equipped with typical spring shanks and it is equal to 11% in case of the shanks with the substantiated reduced mass indicators, which proves the weightage of the reduced mass influence on process performance. If a unit speed is 4 m/s, the advantage of the spring shanks with the substantiated parameters makes the difference of 5%, or 60 N per each shank.

2. Due to the use of the improved procedure of estimating measurement results it has been determined that the influence of random components on the interaction process of the system “soil – disk – spring shank” is at least one and a half times less in case of the operating elements with the substantiated reduced mass. The mean difference of the experimental and the theoretical data according to a shank deflection parameter is equal to 0,164 deg. (speed rate 2.77 m/s), which does not exceed the permissible measurement uncertainty.

3. The recommended rational parameters of spring shanks, which have been determined according to the investigation results, are the following: the rigidity (20 – 40 kN/m), the reduced mass (10 – 30 kg), the frequency (1.6 – 4 Hz and 3.5 – 7 Hz) and the amplitude (1 – 9 deg. and 2.5 deg.) of oscillations. It has been determined that the use of spring shanks with the defined parameters allows for decreasing energy consumption in the process of soil tillage by a disk operating element by 7% without degrading the quality of process performance, compared to a typical spring shank with the parameters that are substantiated only in terms of the functional need to protect an operating element from overloading.

REFERENCES

[1] Asejeva A., Kopiks N., Viesturs D., (2013), Optimal distribution of the amount of work among the tractor aggregates considering set agrotechnical terms. *Proceedings of the International scientific conference "Economic science for rural development”*: *Production and cooperation in agriculture. Finance and taxes*, no. 30, pp. 38-42, Jelgava / Latvia;

[2] Badegaonkar U.R., Dixit G. Pathak K.K., (2010), An experimental investigation of cultivator shank shape on draft requirement. *Archives of Applied Science Research*, no. 2, issue 6, pp. 246-255, Chhattisgarh / India;

[3] 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”*, vol. 11, pp. 10-15, Jelgava / Latvia;

[4] Constantin N., Irimia D., Persu C., (2012), Testing the multifunctional aggregate for soil tillage works – MATINA, *INMATEH Agricultural Engineering*, vol. 36, issue 1, pp. 5-12, Bucharest / Romania;

[5] Constantin N., Cojocaru I., (2008), Large working capacity technical equipment for overturning the stubble field and preparing the germinating bed in all types of soil designed to tractors of 120-220 HP, *Scientific Papers INMATEH*, no. 26, pp. 102-108, Bucharest / Romania;

[6] David A., Voicu Gh., Persu C., Gheorghe G., (2014), The Determination of the Resistant Forces for Deep Loosening of Soil Machines with Active Organs. *INMATEH Agricultural Engineering*, vol. 42, issue 1, pp. 5-12, Bucharest / Romania;

[7] Dewangan A., Singh Rajput N., (2017), Stress Analysis of Cultivator: A Survey Approach. Crop cultivation. *International Research Journal of Engineering and Technology*. vol. 04, issue 01, pp. 692-696, Delhi / India;

[8] Galat U.N., Ingale A.N., (2016), Failure Investigation & Analysis of Agricultural 9 Tyne Cultivator Used In Various Soil Condition. *International Journal on Recent and Innovation Trends in Computing and Communication*. vol. 4, issue 1, pp. 173–179, Delhi / India;

[9] Gheorghiță N.E., Biriș S.Șt., Ungureanu N., Ionescu M., (2018), Contributions to the analysis of the vibratory working tools by FEM. *International Symposium ISB INMA TEH Agricultural and Mechanical Engineering*, 01-03 November, pp. 579-582, Bucharest / Romania;

[10] Gheres M.I., (2014), Mathematical model for studying the influence of tillage tool geometry on energy consumption. *INMATEH Agricultural Engineering*, vol. 42, issue 1, pp. 5-12, Bucharest / Romania;

[11] Hevko B.M., Hevko R.B., Klendii O.M., Buriak M.V., Dzyadykevych Y.V., Rozum R.I., (2018), Improvement of machine safety devices. *Acta Polytechnica,* vol. 58, no. 1, pp. 17-25, Prague / Czech Republic.

[12] Hevko R.B., Yazlyuk B.O., Liubin M.V., Tokarchuk O.A., Klendii O.M., Pankiv V.R., (2017), Feasibility study of the process of transportation and stirring of mixture in continuous-flow conveyers. *INMATEH: Agricultural engineering*, vol. 51, issue 1, pp. 49-58. Bucharest / Romania;

[13] Klendii M.B., Klendii O.M., (2016), Interrelation between incidence angle and roll angle of concave disks of soil tillage implements. *INMATEH: Agricultural engineering,* vol. 49, issue 2, pp. 13-20, Bucharest / Romania;

[14] Razzaghi E., Sohrabi Y., (2016), Vibratory soil cutting a new approach for the mathematical analysis. *Soil and Tillage Research*. vol. 159, pp. 33-40, Kiel / Germany;

[15] Rogovskii I., Titova L., Trokhaniak V., Trokhaniak O., Stepanenko S., (2019), Experimental study on the process of grain cleaning in a pneumatic microbiocature separator with apparatus camera. *Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering*, vol. 12 (61), issue 1, pp. 117-128, Brasov / Romania;

[16] Rogovskii I.L., Titova L.L., Trokhaniak V.I., Rosamaha Yu.O., Blesnyuk O.V., Ohiienko A.V., (2019), Engineering management of two-phase coulter systems of seeding machines for implementing precision farming technologies. *INMATEH Agricultural Engineering*, vol. 58, issue 2, pp. 137-146, Bucharest / Romania;

[17] Rogovskii I.L., Titova L.L., Trokhaniak V.I., Solomka O.V., Popyk P.S., Shvidia V.O., Stepanenko S.P. (2019), Experimental studies of drying conditions of grain crops with high moisture content in low-pressure environment. *INMATEH Agricultural Engineering*, vol. 57, issue 1, pp. 141-146, Bucharest / Romania;

[18] Srivastava A.K., Goering C.E., Rohrbach R.P., Buckmaster D.R., (2016), Soil tillage. Chapter 8, Engineering Principles of Agricultural Machines, *Monography*, 2nd ed., St. Joseph, Michigan: ASABE. Copyright American Society of Agricultural and Biological Engineers, pp. 169-230, Michigan / USA;

[19] Trokhaniak V.I., Rutylo M.I., Rogovskii I.L., Titova L.L., Luzan O.R., Bannyi O.O., (2019), Experimental studies and numerical simulation of speed modes of air environment in a poultry house. *INMATEH Agricultural Engineering*, vol. 59, issue 3, pp. 9-18, Bucharest / Romania;

[20] Tutunaru L.F., Nagy E.M., Coţa C., (2014), Influence of tillage tools cutting edge wear over technical and economic indicators. *INMATEH Agricultural Engineering*, vol. 44, issue 3, pp. 5-12, Bucharest / Romania;

[21] Vlăduţ D.I., Biriş S., Vlăduţ V., Cujbescu D., Ungureanu N., Găgeanu I., (2018), Experimental researches on the working process of a seedbed preparation equipment for heavy soils. *INMATEH Agricultural Engineering*, vol. 55, issue 2, pp. 27-34, Bucharest / Romania;

[22] Vlăduţ V., Gheorghe G., Marin E., Biriş S. Șt., Paraschiv G. Cujbescu D., Ungureanu N., Găgeanu I., Moise V., Boruz S., (2017), Kinetostatic analysis of the mechanism of deep loosening system of arable soil. *45th International Symposium "Actual tasks on agricultural engineering"*, 21-24 February, ISSN 1848-4425. pp. 217-227, Opatija / Croatia;

[23] Xiong P., Yang Z., Sun Z., Zhang Q., Huang Y., Zhang Z., (2018), Simulation analysis and experiment for three-axis working resistances of rotary blade based on discrete element method. *Nongye Gongcheng Xuebao, Transactions of the Chinese Society of Agricultural Engineering*, vol. 34, issue 18, pp. 113-121, Beijing / Chine.