

Dudnikov, Anatolii; Dudnikov, Ihor; Dudnyk, Volodymyr et al.

Article

Increasing the resource of agricultural machines

Technology audit and production reserves

Provided in Cooperation with:

ZBW OAS

Reference: Dudnikov, Anatolii/Dudnikov, Ihor et. al. (2021). Increasing the resource of agricultural machines. In: Technology audit and production reserves 5 (1/61), S. 6 - 11.
<http://journals.uran.ua/tarp/article/download/242256/240360/556083>.
doi:10.15587/2706-5448.2021.242256.

This Version is available at:
<http://hdl.handle.net/11159/7185>

Kontakt/Contact

ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: [rights\[at\]zbw.eu](mailto:rights[at]zbw.eu)
<https://www.zbw.eu/>

Standard-Nutzungsbedingungen:

Dieses Dokument darf zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden. Sie dürfen dieses Dokument nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen. Sofern für das Dokument eine Open-Content-Lizenz verwendet wurde, so gelten abweichend von diesen Nutzungsbedingungen die in der Lizenz gewährten Nutzungsrechte. Alle auf diesem Vorblatt angegebenen Informationen einschließlich der Rechteinformationen (z.B. Nennung einer Creative Commons Lizenz) wurden automatisch generiert und müssen durch Nutzer:innen vor einer Nachnutzung sorgfältig überprüft werden. Die Lizenzangaben stammen aus Publikationsmetadaten und können Fehler oder Ungenauigkeiten enthalten.

Terms of use:

This document may be saved and copied for your personal and scholarly purposes. You are not to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public. If the document is made available under a Creative Commons Licence you may exercise further usage rights as specified in the licence. All information provided on this publication cover sheet, including copyright details (e.g. indication of a Creative Commons license), was automatically generated and must be carefully reviewed by users prior to reuse. The license information is derived from publication metadata and may contain errors or inaccuracies.



<https://savearchive.zbw.eu/termsfuse>



Anatolii Dudnikov,
Ihor Dudnikov,
Volodymyr Dudnyk,
Vladyslav Mykhailichnko,
Oleksii Burlaka,
Oleksander Kanivets

INCREASING THE RESOURCE OF AGRICULTURAL MACHINES

The object of research is the technological process of increasing the service life of pointed cultivator shares of tillage machines through the use of a progressive method of vibration hardening. One of the most problematic areas is the inadequate study of the investigated technological process of restoring the working bodies of agricultural machines. In order to gain a deeper understanding of the process of vibration processing of the material of these machine parts during their restoration, it is necessary to conduct further experimental studies.

In the course of the study, it has been found that the use of vibration deformation of the surface layer of the material of parts contributes to an increase in their resource. The optimal parameters of vibration hardening of the cutting elements of the cultivator shares of tillage machines have been determined, which makes it possible to increase their durability. The main parameters of vibration hardening are revealed: the vibration amplitude of the processing tool is 0.75 mm; vibration frequency – 1400 min^{-1} ; hardening time – 30 s.

As a research result, the assessment of the change in linear wear along the width of the cutting element of the cultivator duckfoot of tillage machines was carried out. In cultivators with tines restored by welding angle plates made of 45 steel (GOST 1050-2013, GB 699-88), sormite surfacing and vibration hardening, the linear wear rate by weight of cutting elements is 35–43 % less than in new tines. A study of changes in the wear of the cutting edge of cultivator shares was carried out, which, when restored by welding corner plates made of steel 45 (GOST 1050-2013, GB 699-88), surfacing with sormite and vibration hardening, is 1.57–1.68 times less than in new shares.

In comparison with existing technologies, the developed technology provides a reduction in the wear of cutting elements by 10–17 %, in comparison with new ones made of 65G steel (GOST 14959-2016, GB 1222). The coefficient of technical utilization of the cultivator with tines restored according to the developed technology, in comparison with the new ones, is 1.07 times higher.

Keywords: vibrations, linear wear, cultivator share, cutting edge, tillage machines, vibration hardening.

Received date: 05.05.2021

Accepted date: 11.06.2021

Published date: 13.10.2021

© The Author(s) 2021

This is an open access article
under the Creative Commons CC BY license

How to cite

Dudnikov, A., Dudnikov, I., Dudnyk, V., Mykhailichnko, V., Burlaka, O., Kanivets, O. (2021). Increasing the resource of agricultural machines. *Technology Audit and Production Reserves*, 5 (1 (61)), 6–11. doi: <http://doi.org/10.15587/2706-5448.2021.242256>

1. Introduction

Insufficient reliability of agricultural machines causes significant costs of spare parts, and, as a consequence, increases the cost of their operation and repair [1].

In order to increase the resource of machine parts in mechanical engineering, various technologies of surface plastic deformation are used, which provide in the deformable layer:

- increased hardness;
- reducing the roughness of the treated surface;
- formation of favorable residual compressive stresses.

Vibration treatment is widely used in various technological processes, which arouses interest in this problem of relevant specialists in various industries.

Restoration of parts is a technically sound and economically justified measure that allows repair companies

to reduce downtime, improve the quality of repairs, and have a positive effect on improving the reliability and use of agricultural machinery [2].

The economic aspect of the feasibility of carrying out work on the restoration of parts consists in reducing the cost of repairing units and machines by reducing the cost of new spare parts, as well as in reducing production costs during their operation.

Expansion of technological capabilities and the use of vibration processing both in mechanical engineering and in repair production is an urgent task [3].

2. The object of research and its technological audit

The object of research is the technological process of increasing the service life of pointed cultivator shares of

tillage machines through the use of a progressive method of vibration hardening.

In this work, an analysis of the working conditions is carried out and an assessment of the reliability of the working bodies of cultivators is given. The issues of determining the optimal parameters of the technological process of vibration treatment during their restoration are considered.

In this regard, research on the development of technology for strengthening such parts using vibrational vibrations can be classified as promising.

Analysis of the available technological solutions for hardening the material of the surface layer of parts indicate insufficient data on the value of the parameters of vibration processing of these working bodies [4].

It is of practical interest to conduct research on the technological process of vibration hardening of parts for the development of a technology that ensures an increase in their resource.

3. The aim and objectives of research

The aim of research is to develop a technological process for the restoration of cultivator duckfoot by the method of vibration hardening, which ensures an increase in their resource.

To achieve this aim, it is necessary to solve the following objectives:

1. To analyze the working conditions and assess the reliability of the working bodies of cultivators.
2. To assess the wear resistance of cultivator shares with different methods of their restoration.

4. Research of existing solutions to the problem

Measures to improve the wear resistance and durability of the blades of cutting elements of agricultural machines in industrial and repair industries can be divided into three main groups [5]:

1. The choice of rational, from the point of view of wear, design parameters of the cutting element, such as the value of the sharpening angle, the location and value of the additional chamfer of the blade, the value of the angle of sliding of the blade.

2. Selection of the optimal parameters of the cutting mode: the value of the cutting speed, the thickness of the cut layer.

3. The use of wear-resistant materials for the manufacture and restoration of parts and various types of hardening, such as surface and volumetric heat hardening, mechanical hardening, application of wear-resistant coatings, vibration hardening.

The use of these measures can give the greatest effect.

In work [6] it is noted that most of the worn-out parts of tillage machines have a significant residual value. To restore them, 20–30 times less materials are used than in the manufacture of new ones. The authors consider this issue only conceptually, therefore there is a need to study it in more detail.

The restoration of worn-out parts allows to reuse the exhausted resource of the part, thanks to the use of effective restoration technologies [7, 8].

The method of increasing wear resistance and fatigue strength can be attributed to chemical heat treatment, plastic deformation, and some special methods [9].

However, these technologies are comparatively high in complexity, require the use of special equipment and have not yet found wide application in repair production when restoring machine parts.

The literature [10] describes a method for restoring tillage working bodies by welding sectors (plates) to them with a tungsten electrode in an argon atmosphere with a magnetically controlled arc. However, given the complexity, this method has not yet found proper application in the repair industry.

There is a method of restoration by the method of welding in laps [11]. However, it is complex and does not provide a guarantee against the likelihood of fatigue failure in service.

The more common methods for restoration of cultivator shares are:

- a) pull-back: worn-out working bodies are heated to a temperature of 800–1100 °C and pulled back on a pneumatic hammer; after which sharpening and heat treatment are carried out;

- b) cutting out the worn out part of the share blade with a flame cutter. Instead of the cut out part, a profile plate is made of steel 65G (GOST 14959-2016, GB 1222), which is welded with a continuous seam to the part being restored.

Blades with welded plates or, after being pulled back, are subjected to surfacing with wear-resistant metal powders from the bottom side, which, to a certain extent, provides a self-sharpening blade.

However, these methods are very laborious and do not provide high wear resistance. In addition, the level of the stress-strain state of the restored part increases.

The literature [12] provides data on the restoration of cultivator shares by freezing surfacing on a workpiece. The essence of the technology consists in feeding a portion of the molten wear-resistant alloy into the gap between the surface of the workpiece being welded and the wall of the mold. After filling the mold, the filler alloy solidifies with the formation of a wear-resistant layer of a given size and shape.

In the repair industry, surfacing with a sormite alloy with the use of a gas flame has found a certain application, which provides a strong retaining layer of a uniform thickness on the blade. However, the performance of this method is very low [12].

Work [13] is devoted to increasing the durability of parts by using electrohydraulic machining. Given the complexity of technological operations, this process has not been properly applied in repair production.

Table 1 shows the main methods of restoration and hardening of the working bodies of agricultural machines and the numerical values characterizing the wear resistance.

Table 1
Basic methods of restoration of cultivator shares

Hardening method	Applied material	Hardening depth, mm	Total wear, mm
1. Bulk hardening	–	0.6–1.2	11.40
2. Induction surfacing	ΠС-14-60	0.6–1.2	3.61
3. Induction surfacing	ΠГ-С27	0.4–1.3	3.41
4. Surface hardening of the blade by high-frequency currents	–	0.8–1.0	416
5. Plasma surfacing continuous	ΠГ-С27	0.6–0.9	8.65
6. Freeze surfacing	ΠГ-ФБХ-6-2	2.0–3.0	3.42
7. Electrical contact surfacing	УС-25	0.4	0.56
8. Gas metallization	ΠГ-12Н-02	0.4–0.1	1.45

Despite the importance of the issue of restoring and hardening the working bodies of cultivators, these methods, due to the high complexity and cost of processing, have not yet found proper application in repair production.

Increasing the durability of the tillage working bodies is also achieved by the use of advanced technologies to improve the properties of materials, including the use of vibration vibrations. It was noted in [14] that this can be achieved by using various design schemes in the process of pressure treatment. Nevertheless, the scheme induced in the work does not allow using it when restoring parts.

The authors of [15] considered the issues of increasing the durability of parts when processing their material using plastic deformation. However, it does not fully disclose the issue of finding the optimal parameters for restoring parts by this method.

The use of hardening technologies contributes to an increase in the operational properties of the restored parts of agricultural machines and, consequently, their durability and resource.

Analysis of the literature data allows to conclude that the available technological solutions indicate unused reserves of hardening processing of parts.

5. Methods of research

Based on the analysis of publications on increasing the durability, reliability, and wear resistance of pointed cultivator shares, the following research areas have been identified:

- development of a highly efficient technological process for the restoration of worn-out surfaces of cutting elements of cultivator duckfoot;
- increasing the resource of the duckfoot shares due to the use of the developed vibration hardening technology.

The distinctive parameters of the technological process of processing cultivator shares, which reduce their wear, were determined.

Micrometry of the thickness of the cutting edge of the cultivator shares was carried out with an MKII-25 micrometer (China) with a digital reading device with an accuracy of 0.001 mm (GOST 6507). The main angles of the shares were measured with a digital goniometer with an accuracy of 5' (GOST 5378).

The design parameters of the cultivator shares were measured with a IIII-II-500 caliper (Russia) with a digital reading device with an accuracy of 0.01 mm (GOST 166).

The process of restoration of cultivator duckfoot was carried out on a vibration unit (Fig. 1).

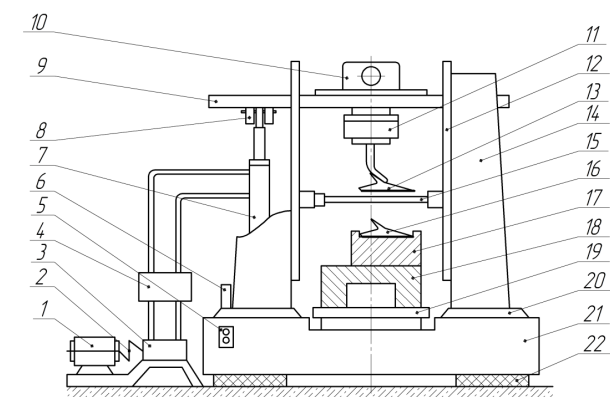


Fig. 1. Diagram of the vibration unit: 1 – electric motor; 2 – clutch; 3 – hydraulic pump; 4 – distributor; 5 – starter; 6 – tank; 7 – hydraulic cylinder; 8 – rubber shock absorbers; 9 – vibration exciter plate; 10 – vibration exciter; 11 – clamping device; 12 – guide; 13 – processing tool; 14 – rack; 15 – screed; 16 – detail; 17 – matrix; 18 – base; 19 – plate; 20 – support plate; 21 – timber; 22 – rubber shock absorber

The deformation force was recorded with a manometer and a device for stabilizing its values.

6. Research results

During the operation of cultivators, the size and shape of the shares changes, which causes an increase in traction resistance. The value of the traction resistance depends on the dimensions, the shape of the working bodies, the physical and mechanical properties of the soil, the depth of processing and the speed of the unit [9].

The wear pattern of the cultivator share blade depends to a greater extent on soil moisture, which at the depth of cultivation during the season changes more intensively than at the depth of plowing, and with a decrease in which the upper edge of the cutting edge wears out more actively [12]. The intensity of blade wear increases as the soil density increases.

The wear pattern of cultivator shares depends significantly on the moisture content and structure of the soil. When working on wet and loose soil, the wear rate is reduced and the upper part of the blade wears out slightly [16].

Cultivator shares remain functional until sweat, as long as their design parameters ensure the performance of the specified functions within acceptable limits.

The criterion for the limiting state of the working bodies should be considered a design feature or a set of features related to changes in design parameters, shape or condition of working surfaces and causing it to go into an inoperative state [17].

Studies of the effect of vibration deformation on the quality of material processing were previously carried out on samples, and then on parts.

The reliability assessment of pointed cultivator shares, restored by various methods, was made by comparison with the same indicators of new parts, using mathematical dependences of the theory of probability, as well as by the magnitude and nature of wear both in the process of laboratory and bench tests [18].

Studies have established that during vibration hardening of the cutting elements of cultivator shares, as a result of obtaining a finer-grained structure in the surface layers of their material, there is an accumulation of small deformations that cause a rearrangement of the dislocation structure with the formation of dislocation networks. The material is shifted along them and a small plastic deformation occurs, which does not cause fracture [19]. This can explain the decrease in residual stresses in the blade material of the cultivator shares during vibration hardening.

On the basis of theoretical and experimental studies and tests carried out, a technological process for the restoration and hardening of pointed cultivator shares by the vibration method has been developed and implemented.

Research has established that in order to obtain a hardened layer of high quality, it is necessary to follow the modes recommended for this technological recovery process.

Taking into account the above requirement, a technological scheme for the restoration and hardening of cultivator duckfoot has been developed: surface cleaning, trimming of the worn part, sharpening of the cutting edge, surfacing with sormite, welding of corner plates, vibration hardening, quality control.

The worn part of the cultivator share blade was removed with an A24SBF cut-off grinding wheel (Ukraine) using MIIIV-2-230-2-230 angle grinder (Ukraine).

The angle plate is made by bending at an angle of 60° strip steel 45 (GOST 1050-2013, GB 699-88) 5 mm thick using a press KD2128K (Russia). The press force is 630 kN, the crosshead stroke rate is 140 min^{-1} .

The cutting part of the plate is sharpened at an angle of sharpening of 14° on a universal grinding machine 3Д642Е (Russia).

The workpiece (corner plate) is welded to the restored share with a continuous seam by electric arc welding with a wire with a diameter of 2 mm made of steel grade 08GS (GOST 1050-2013, GB 699); welding current strength – 180 A.

Surfacing of the welded corner plate along the leg perimeter was performed with sormite powder.

Vibration hardening of the duckfoot cutting edges was carried out on a vibration installation with the following parameters: the vibration amplitude of the processing tool is 0.75 mm; vibration frequency 1400 min^{-1} ; hardening time 30 s. The duckfoot was restored by welding an angle plate (Fig. 2).

Cultivator shares, restored using the proposed technology, are shown in Fig. 3.

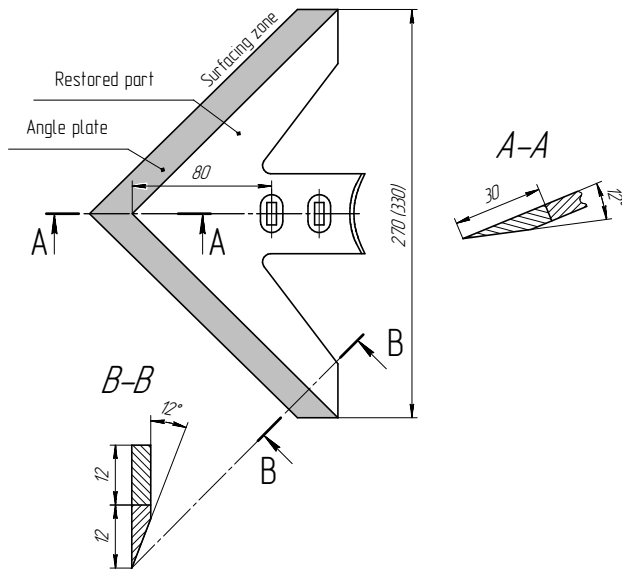


Fig. 2. Scheme of the restored cultivator duckfoot cultivator

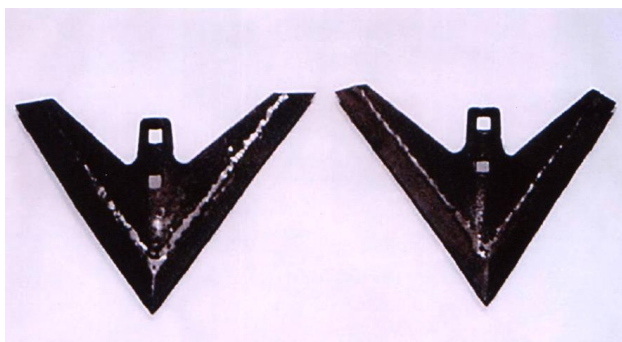


Fig. 3. Cultivator shares restored using the proposed technology

The durability of the cultivator duckfoot was assessed by comparing the following options:

- new steel 65G (GOST 14959-2016, GB 1222) (option 1);
- restored with sormite (option 2);

- restored by welding angle plates made of steel 45 (GOST 1050-2013, GB 699-88), deposited with sormite followed by vibration hardening (option 3).

Determination of the amount of wear of the blades and toes of the cultivator shares was carried out every 6 hours of operation. The tillage depth was 12–16 cm, the speed of the cultivator section was 2.2 m/s. The moisture content of the working mixture in the soil canal varied within 10–21 %.

The results of changing the linear wear along the width of the share element are presented in Table 2.

Table 2

Change of linear wear along the width of the cutting element of the shares

Cultivator share variant	Linear wear in width, mm			
	6 h	12 h	18 h	24 h
Variant 1	1.52	3.03	4.56	6.03
Variant 2	1.34	2.62	3.94	5.22
Variant 3	1.15	2.29	3.47	4.61

Studies show that for feet restored by welding angle plates made of 45 steel (GOST 1050-2013, GB 699-88), deposited with sormite and subject to vibration hardening for the specified period of operation, the amount of linear wear is 1.16–1.17 times less, compared to newer samples.

The decrease in the amount of wear of the shares subjected to vibration treatment can be explained by the hardening of the metal caused by both a change in its structure during deformation and a decrease in residual stresses.

Since, in the process of abrasive wear, the cutting elements decrease both in width and thickness, studies were carried out on the dependence of the intensity of their wear by weight, presented in Table 3.

Table 3

The amount of wear of the cutting element by weight

Cultivator share variant	Wear by weight, g			
	6 h	12 h	18 h	24 h
Variant 1	6.32	10.30	14.97	18.24
Variant 2	4.82	8.51	11.73	15.12
Variant 3	4.40	7.54	18.81	14.02

Studies have shown that when restoring shares by welding angle plates made of 45 steel (GOST 1050-2013, GB 699-88), surfacing with sormite and vibration hardening, the amount of wear by weight of cutting elements is 35–43 % less than that of new shares.

Studies of the dynamics of changes in the cutting edge of cultivator shares showed that with an increase in operating time, changes in their radius are observed (Table 4).

Table 4

The dependence of the wear of the radius of the cutting edge

Cultivator share variant	Wear of the radius of the cutting edge, mm			
	6 h	12 h	18 h	24 h
Variant 1	0.61	0.84	1.02	1.36
Variant 2	0.37	0.48	0.56	0.63
Variant 3	0.25	0.37	0.44	0.49

The analysis of the obtained data of bench tests showed that the greatest wear of the cutting edge radius (0.61–1.36 mm) was noted when restoring the cutting element of a new cultivator share. Accordingly, the least wear (0.25–0.49 mm) is when restored by welding the angle plates made of 45 steel (GOST 1050-2013, GB 699-88) with sormite surfacing and vibration hardening.

Reducing the wear of the cutting edge radius during restoration by welding on corner plates made of steel 45 (GOST 1050-2013, GB 699-88) by surfacing with sormite and vibration hardening is 1.57–1.68 times less than that of new feet made of 65G steel (GOST 14959-2016, GB 1222).

The analysis of the bench test data allows to conclude that the wear resistance, and, consequently, the resource of the cultivator duckfoot depends both on their geometric parameters and, to a large extent, on the restoration method.

The results of bench tests of the cutting elements of cultivator shares showed that linear wear along the width of the cutting elements when using different methods of restoration with an increase in operating time increases, however, with unequal intensity. This is due to structural changes in the hardened layers, an increase in their hardness.

The change in the wear of cutting elements and its intensity in cultivator shares, restored by welding angle plates made of steel 45 (GOST 1050-2013, GB 699-88), surfacing with sormite and vibration hardening, is reduced by 10–17 %, compared with new ones made of steel 65G (GOST 14959-2016, GB 1222).

On the basis of the data obtained, a technology was proposed for the restoration of pointed cultivator shares by welding angle plates made of steel 45 (GOST 1050-2013, GB 699-88) with sormite surfacing and vibration hardening.

7. SWOT analysis of research results

Strength. The use of the developed technological process of restoration by vibration hardening provides a decrease in the wear rate of the blades of cultivator shares by 1.84 times and their wear by 1.88 times, compared to new ones, which contributes to an increase in their resource.

Weaknesses. The weaknesses of this research are related to the fact that the developed technological process of restoration is only for cultivator duckfoot. The application of the developed recovery technology for their other types should also be indicated.

Opportunities. The obtained basic data of the parameters of the technological process of restoration by the method of vibration hardening will be used in the continuation of studies of the problem of increasing the resource of parts both during manufacture and during restoration.

Treats. Achievement of the best indicators of reliability of restored parts by vibration hardening at repair enterprises is possible provided that this issue is comprehensively resolved. On the other hand, the expediency of such work is to reduce the cost of repairs by reducing the cost of new spare parts, as well as to reduce production costs during their operation. Therefore, the risks are obvious and associated with the inconsistent legislative and economic policy of the state in the field of «energy saving».

8. Conclusions

1. The analysis of the nature and causes of wear of the cultivator duckfoot has been made. It has been found that during their operation, their parameters change, causing a decrease in the quality of soil cultivation. The limiting wear indicators for cultivator duckfoot with a grip width of 270 mm is the distance from the first attachment hole to the toe of 130 mm, the wing width in the middle part is 36–38 mm.

2. The main parameters of vibration processing of the blade material of cultivator shares and their distinctive values have been established: the amplitude of the processing tool $A=0.75$ mm; vibration frequency $n=1400$ min⁻¹; hardening time $t=30$ s.

Reducing the wear of the radius of the cutting edge when restoring by welding corner plates made of 45 steel (GOST 1050-2013, GB 699-88) by surfacing with sormite and vibration hardening is 1.57–1.68 times less than that of new feet made of 65G steel (GOST 14959-2016, GB 1222).

References

1. Babichev, A. P., Babichev, I. A. (2008). *Osnovy vibratsionnoy tekhnologii*. Rostov-na-Donu: Izdatel'skiy tsentr DGTU, 694.
2. Voitiuk, V. D., Rublov, V. I. (2005). *Upravlinnia yakistiu tekhnichnoho servisu i silskohospodarskoi tekhniki pry postachanni*. Kyiv: Vydavnytstvo NAU, 192.
3. Voitiuk, D. H., Havryliuk, R. H. (2004). *Silskohospodarski mashyny*. Kyiv: Karavella, 552.
4. Downham, E. (1986). Vibration in rotating machinery: Malfunction diagnosis – Art Science. *Proceedings of the Institution of Mechanical Engineers – Vibrations in Rotating Machinery*, 1–6.
5. Levin, E. L. (1998). *Vybor optimal'nogo sposoba vosstanovleniya iznoshennykh detaley*. Ufa: Bashgosagrouniversitet, 20.
6. Świercz, R., Oniszcuk-Świercz, D. (2017). Experimental Investigation of Surface Layer Properties of High Thermal Conductivity Tool Steel after Electrical Discharge Machining. *Metals*, 7 (12), 550. doi: <https://doi.org/10.3390/met7120550>
7. Bowden, F. P., Tabor, D. (2001). *The friction and lubrication of solids*. Oxford University Press, 424.
8. Dudnikov, A., Dudnik, V., Ivankova, O., Burlaka, O. (2019). Substantiation of parameters for the technological process of restoring machine parts by the method of plastic deformation. *Eastern-European Journal of Enterprise Technologies*, 1 (1 (97)), 75–80. doi: <https://doi.org/10.15587/1729-4061.2019.156779>
9. Stepanova, T. Yu. (2009). *Tekhnologii poverhnostnogo uprochneniya detaley mashin*. Ivanovo: NGHTU, 64.
10. Richard, D. D. (1998). *Corede Electrodes*. New York: Chemerton Corporation USA, 26.
11. Augusti, G., Baratta, A., Casciati, F. (2014). *Probabilistic methods in structural engineering*. CRC Press, 582. doi: <https://doi.org/10.1201/9781482267457>
12. Chernoiyanov, V. I. (1999). *Optimizatsiya i tekhnologiya vosstanovleniya detaley mashin*. Moscow: Agropromizdat, 336.
13. Świercz, R., Oniszcuk-Świercz, D., Chmielewski, T. (2019). Multi-Response Optimization of Electrical Discharge Machining Using the Desirability Function. *Micromachines*, 10 (1), 72. doi: <https://doi.org/10.3390/mi10010072>
14. Nikolaenko, A., Hussein, A. T. (2014). Modelling of vibrating machine-tool with improved construction. *TEKA. Commission of motorization and energetics in agriculture*, 14 (1), 174–181. Available at: https://yadda.icm.edu.pl/yadda/element/bwmeta1.element.agro-48b712f4-c1ef-4471-9486-916bbdbd7ad0/c/18_174-181.pdf
15. Lou, Y., He, J. S., Chen, H., Long, M. (2016). Effects of vibration amplitude and relative grain size on the rheological behavior of

- copper during ultrasonic-assisted microextrusion. *The International Journal of Advanced Manufacturing Technology*, 89 (5-8), 2421–2433. doi: <https://doi.org/10.1007/s00170-016-9288-7>
16. Huz, V. P., Lisovon, A. P., Andrienko, V. O., Rybak, M. F. (2007). *Zemlerobstvo z osnovamy gruntoznavstva i ahrokhimiyi*. Kyiv: Tsentr uchbovoi literatury, 408.
 17. Pasuta, A. (2014). Determination of wear pattern of cutting elements of tillage machines. *Technology Audit and Production Reserves*, 6 (1 (20)), 8–11. doi: <https://doi.org/10.15587/2312-8372.2014.34778>
 18. Dudnikov, A. A., Bilovod, O. I., Pasiuta, A. H. (2014). Ekonomichna otsinka ekspluatatsiynoi nadiynosti robochykh orhaniv gruntoobrobnykh mashyn. *Shosta mizhnarodna naukovo-praktychna konferentsiya molodykh vchenykh*. Kyiv, 60–62.
 19. Djema, M. A., Hamouda, K., Babichev, A. P., Saidi, D., Halimi, D. (2012). The Impact of Mechanical Vibration on the Hardening of Metallic Surface. *Advanced Materials Research*, 626, 90–94. doi: <https://doi.org/10.4028/www.scientific.net/amr.626.90>

Anatolii Dudnikov, PhD, Professor, Head of Department of Technologies and Means of Mechanization of Agricultural Production, Poltava State Agrarian University, Poltava, Ukraine, ORCID: <http://orcid.org/0000-0001-8580-657X>

Ihor Dudnikov, PhD, Associate Professor, Department of Industrial Engineering, Poltava State Agrarian University, Poltava, Ukraine, ORCID: <http://orcid.org/0000-0002-0448-2241>

✉ **Volodymyr Dudnyk**, PhD, Associate Professor, Department of Life Safety, Poltava State Agrarian University, Poltava, Ukraine, e-mail: prepoddv@ukr.net, ORCID: <http://orcid.org/0000-0002-6553-2951>

Vladyslav Mykhailichnko, Postgraduate Student, Department of Life Safety, Poltava State Agrarian University, Poltava, Ukraine, ORCID: <https://orcid.org/0000-0003-1549-339X>

Oleksii Burlaka, PhD, Associate Professor, Department of Technologies and Means of Mechanization of Agricultural Production, Poltava State Agrarian University, Poltava, Ukraine, ORCID: <http://orcid.org/0000-0002-2296-7234>

Oleksander Kanivets, PhD, Associate Professor, Department of Technologies and Means of Mechanization of Agricultural Production, Poltava State Agrarian University, Poltava, Ukraine, ORCID: <http://orcid.org/0000-0003-4364-8424>

✉ Corresponding author