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INVESTIGATION OF THE INFLUENCE OF VIBRATION OSCILLATIONS IN THE PROCESSES OF STRENGTHENING PROCESSING OF MACHINE PARTS

Об'єктом дослідження є технологічний процес підвищення н дійності відновлення дисків сошників зернових сів лок вібр ційним зміцненням. Одним з н йбільш проблемних місць є недост тня вивченість д ного технологічного процесу при відновленні сільськогоспод рських м шин. Для появи більш глибоких уявлень про процес вібр ційного зміцнення м тері лу дет лей необхідно проведення експеримент льних досліджень по вивченню впливу п р метрів обробки н ступінь зміцнення.

В ході дослідження процес вібр ційного зміцнення н пл вленої поверхні здійснюв вся н виготовленій втор ми д ного дослідження вібр ційній уст новці. Для вибору п р метрів обробки т визн чення їх оптим льних зн чень проведені мікроструктурні дослідження м тері лу дисків. Виявлено т обґрунтов но основні п р метри зміцнення: мплітуду і ч стоту колив нь обробного інструменту, ч с зміцнення, т визн чено їх зн чення: A=0,5 мм; n=1400 хв$^{-1}$; t=20 с.

В результ ті досліджень вст новлено, що при вібр ційному зміцненні структур м тері лу більш дрібнозерност . Збільшення мікротвердості н поверхні н пл вленого ш ру можн пояснити більшим дробленням зерен і збільшенням їх числ . Це, в свою чергу, виклик є ктивіз цію дислок цій у всіх зерн х, прилеглих до поверхні. При вібр ційному деформув нні протяжність гр ниць зерен збільшується і тим с мим утворюється більше зон ковз ння дислок цій. Цим можн пояснити мех нізм зміцнення.

Проведено оцінку експлу т ційної н дійності дисків з т кими пок зник ми: н пр цюв ння з сезон і коефіцієнт технічного використ ння. У сів лок з диск ми, відновленими прив рюв нням сегментів з н пл вленням сорм йтом і вібр ційним зміцненням, коефіцієнт технічного використ ння в 1,053 р зи вище, ніж у сів лок з новими диск ми.

З вдяки з стосув нню розробленої технології відновлення з безпечується можливість знизити в 1,49–1,70 р зи швидкість з туплення лез . Це з безпечує збільшення ч су його роботи. У порівнянні з н логічними відомими технологіями, розроблен технологія вібр ційного зміцнення лез дисків з безпечує н йбільшу зносостійкість і збільшення в 1,34 р зи н пр цюв ння в порівнянні з новими диск ми.

Ключові слова: *технологічний процес обробки, зміцнення вібр цією, зносостійкість дет лей, коефіцієнт технічної готовності.*

1. Introduction

Among the important tasks of engineering and agricultural production is the problem of improving the quality and durability of machine parts, both in the manufacture and restoration. The successful solution of this problem mainly depends on the development of advanced technologies and modern technological equipment, ensuring an increase in labor productivity, a decrease in labor intensity while improving the quality and high reliability in the manufacture and restoration of machine parts.

In recent years, to ensure the dimensional stability of parts, vibro-impact treatment has been used, contributing to a change in the state of the surface layer, a deeper penetration of the vibration effect on the material being processed.

The propagation of wave action in solids is of great interest for research related to the field of metalworking. However, in the literature special attention is not paid to the description of the physics of wave processes. The different behavior of materials is a consequence of the manifestation of the dynamic properties of inertia and elasticity [1].

Issues of vibration processing of parts, despite their relevance, are not sufficiently covered in the literature, which contains contradictory and partially outdated ideas about the possibilities and the achieved results [2].

Despite the large number of methods for hardening the material of parts, there is no universal, suitable for a large variety of them.

In this connection, the issues of conducting research on the influence of vibration processing parameters on the material quality characteristics of the parts being restored (manufactured) are topical.

2. The object of research and its technological audit

The object of research is the technological process of increasing the reliability of the recovery of disks of ploughshare of grain seeders by vibration hardening.

The scheme of the oscillating impact of the machining tool, to which the perturbing force P_{pf}=const and the inertia force P are applied, is shown in Fig. 1.

The pressure treatment of the working surface of the part can be considered as a technological operation (draft), at which its height h decreases and the width b increases along the circumference. In this case, the deformation along the axis of the acting force P is negative, but along the other two axes it is positive.

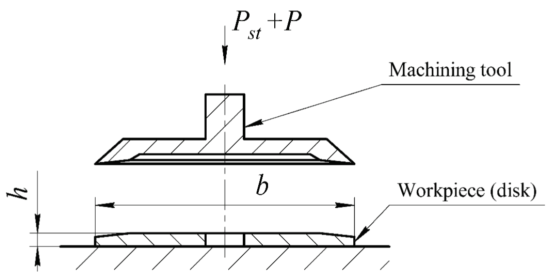

Fig. 1. Scheme of oscillatory impact of the machining tool on the workpiece (disk)

This paper discusses the creation of fundamentals to identify the optimal parameters of the technological process of vibration treatment of disk working bodies during their restoration.

Therefore, research aimed at the development of the process of hardening of such parts with the use of vibrational oscillations can be classified as promising for the agro-industrial complex.

Analysis of existing technological solutions for hardening the surface layer of parts indicates insufficient data on the influence of such parameters as: amplitude, oscillation frequency, strain rate on the amount of hardening of the material of the treated surface.

The wear resistance of the surface of parts treated with the vibration method largely depends on the depth of the hardened layer, however, there are no specific recommendations in the literature on its definition [3].

It is of practical interest to conduct further research on the process of vibratory hardening of parts operating under particularly loaded conditions, in order to develop a technology that will increase durability and reliability.

3. The aim and objectives of research

The aim of research is development of the technological process of restoring parts of the type «disks» using the vibration hardening of their cutting elements.

To achieve this aim, the following objectives are set:

1. To make an analysis of the working conditions and the reasons for the loss of performance of the disk working bodies.

2. To investigate the effect of vibration treatment on the character of hardening of repaired disks.

3. To perform an assessment of the reliability of the disc ploughshares of the grain seeders.

4. Research of existing solutions of the problem

During the operation of agricultural machines, the working bodies wear out as a result of the friction of their surfaces with the processed medium. At the same time, the geometric parameters of the cutting elements of tillage parts are changed.

Mechanical and molecular interactions arise in the surface layers of the mating surfaces, causing wear [4].

The intensity of the flow of wear depends on the speed of the process of destruction of the surface microvolumes of the material. All types of wear can be divided into fast flowing, medium speed and slow processes of destruction of micro volumes.

Fast flowing processes are particularly dangerous types of destruction. The processes of average wear rate are characteristic of cyclic types of destruction [5]. Slow processes are usually observed with fatigue and oxidative wear.

The above literary sources [6, 7] indicate the importance of developing the most effective technological processes of restoring the cutting elements of the disk working bodies of tillage machines.

To increase the durability of the cutting elements of the disk working bodies is sometimes used induction hardening method. The disadvantage of this method is that with a decrease in the thickness of the restored layer by welding up to 0.2 mm, the quality of hardening and a significant loss of shape of parts decrease [8].

In the repair industry, the following methods have some use: cladding method with wear-resistant tape, friction hardening method, laser cladding. However, these methods are quite complex, require special expensive equipment and have not yet found wide application in the restoration of disk working bodies.

There are data on the restoration of the disk surface by diameter by the method of contact seam overlap welding with further strengthening by powder materials based on sormite [9]. This technological process is complex, time-consuming and does not provide a full guarantee against possible fatigue failure during disk operation.

Considering the aforementioned drawbacks of the existing methods for restoring disk parts of working bodies of tillage machines, it is necessary to create conditions in their material for the occurrence of compressive stresses.

The analysis of the above methods for the restoration of worn out disk parts of tillage machines allows to conclude that for these parts it is advisable to use the method of hardening their working surface on the basis of the vibration oscillations of the processing tool.

Regarding the prospects for the use of mechanical vibrations of a different spectrum in technological processes of restoring parts, it should be noted that interest in this problem from the side of relevant specialists in the coming years will increase. The main prerequisites for this are:

– intensification of existing technological processes and methods of influence on the processed material of the object;
– possibility of developing new ways of processing materials;
– reduction of energy consumption and increase of economic efficiency in the restoration (manufacture) of machine parts.

Vibration oscillations allow to create new technological processes of processing.

To solve the problem, identified in the analysis of world scientific literature, the following aspects can be identified:

– development of resource-saving technologies, characterized by higher intensity and productivity, original quality indicators [2, 3];
– providing a higher degree of hardening and the level of residual compressive stresses, contributing to the improvement of the fatigue strength of parts, especially those working in an abrasive environment [5].

The development of technological bases for the restoration of disk working bodies with a lower wear rate by the method of welding segments with subsequent vibration hardening provides an increase in their durability and resource.

The authors of [10] note that during the operation of machine a part in the layers adjacent to the surfaces, a new structure is often formed, in which residual stresses arise. But there remains the unresolved question of their influence on the strength characteristics of the material of parts operating in the soil environment.

In particular, the work [11] is devoted to improving the durability of parts, which is achieved by using advanced technologies to improve the properties of materials, including the use of vibrational oscillations. The authors note that this can be achieved by using different structural schemes in the process of pressure exposure. However, the proposed scheme in this work does not allow to apply it when restoring the disks of grain seeders.

As the authors of [12] note, by giving the material of the surface layer the necessary physicomechanical properties by cyclic loading, the durability of the restored parts increases. In this case, all the characteristics of the resistance to deformation (the limits of hardness, elasticity, strength, fatigue, yield) appear in the surface layer, the ductility decreases and the metal becomes more fragile. However, the described parameters do not have actual confirmation when restoring parts working in the soil environment.

According to the authors of [13], the saving of wear resistance indicators and strength characteristics of the surfaces to be machined is partially achieved with the use of directional oscillations. However, this process does not fully disclose this process, which imposes certain restrictions on the use of the proposed solutions.

Issues of improving the durability of parts when processing their material using vibrational oscillations are considered in [14]. But there remains the unresolved question of finding the optimal parameters in the plastic deformation of parts.

As the authors of [15] note, during vibration processing, the surface of the tool working part is periodically separated from the workpiece surface. When this occurs, the microprocess unloading of the contact surfaces is occurred, which leads to an increase in dynamic effects with increasing amplitude and frequency of oscillation of the processing tool. According to the authors of [16], these parameters have a significant impact on the surface hardening of parts.

The wear resistance of parts operating in the soil environment, subjected to vibration deformation, is largely determined by the depth of the hardened layer. Nevertheless, the work [17] indicates the absence of specific recommendations on the definition of its values in the literature.

The results of the analysis of the literature data allow to conclude that the available technological solutions for hardening the material on the surface of the parts indicate unused reserves in the process of strengthening them.

5. Methods of research

The analysis of publications on increasing the durability of agricultural machinery parts allows to determine the following research directions:

– development of various effective technologies for restoring worn parts;

– improving the wear resistance of parts by applying the method of vibration hardening.

In the development of the technological process of restoration of disk working bodies made the choice of optimal processing parameters, reducing the amount of wear.

The thickness of the cutting part of the disk was measured with a MCC 25 micrometer (China) with an electronic reading device (GOST 6507), and a disk micrometer was performed with ШЦЦ-II caliper (Ukraine) with a reading accuracy of 0.01 mm (GOST 166).

The magnitude of the disk blade angle was estimated by a 5УМ goniometer (Russia, GOST 5378) with a sampling resolution of 5′.

Studies of the effect of conventional and vibration deformation on the hardening of the material being processed are carried out first on the model samples and then on the details. Samples are new disks, research on which allowed to exclude such factors as the amount of wear and the nature of its occurrence. This makes it possible to clarify the main parameters of the technological process.

The recovery process is carried out by the vibration-arc method on a universal surfacing installation (Fig. 2).

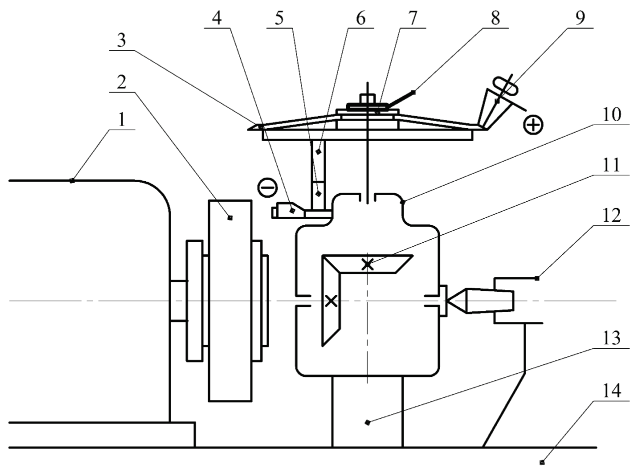

Fig. 2. The surfacing scheme:
1 – headstock; 2 – cartridge; 3 – surfacing detail; 4 – electric wire; 5 – brush; 6 – contact plate; 7 – clamping washer; 8 – clamp; 9 – surfacing head; 10 – gearbox housing; 11 – bevel gear; 12 – tailstock; 13 – bracket; 14 – bed

The surfacing process is carried out as follows. The horizontal shaft of the bevel gearbox was fixed in the cartridge (2) of the surfacing unit. A part is installed in the clamping device, which transmits the rotational movement from the gearbox spindle (10). To the worn surface is fed the mouthpiece of the surfacing head (9). Submission is carried out using the installation screw.

Restoration of the working surface of the disk is carried out by welding the segments according to its outer diameter.

Segments made of steel 45 with a thickness of 2 mm and a width of 15 mm on a forty-ton press are welded with a wire of 2 mm in diameter from steel 08GS followed by surfacing with smite.

The oscillation amplitude of the machining tool was varied within 0.25–0.75 mm, and the oscillation frequency was 700–2100 min^{-1}.

To assess the effect of the processing method on the material properties of the disks, microstructural studies are carried out, which are necessary to select the optimal parameters of the technological recovery process. The hardness of the material was determined by the Rockwell method on the TK-2M device (Russia, GOST 23677). Microhardness is measured on a ПМТ-3 microhardness meter (Ukraine) in accordance with GOST 9450-76.

6. Research results

The hardening of the disk surface depends on numerous factors, the study of the influence of which is important for the development of the technological process of their restoration.

Three main hardening parameters are determined and substantiated: amplitude A, oscillation frequency of the processing tool n and hardening time t.

As optimization criteria for a multifactorial experiment, disk wears are chosen in diameter ΔD and thickness Δa. Investigations are carried out for ploughshare disks of 65G steel, new with vibro-hardening of the working surface and welding segments of steel 45 restored with welding, with sormite surfacing and vibratory hardening.

As a result of experimental studies, the following equations of the relationship of the main parameters of vibration hardening are obtained:

– wear ΔD_1 of a new 65G steel disc:

$$\Delta D_1 = 1.3076 - 1.2709x_1 - 0.0005x_2 - 0.0341x_3 + 1.5729x_1^2 + 1.9\cdot 10^{-7}x_2^2 + 0.0007x_3^2; \quad (1)$$

– wear Δa_1 a new 65G steel disc:

$$\Delta a_1 = 1.3941 - 1.484864x_1 - 0.0048x_2 - 0.0451x_3 + 1.5019x_1^2 + 1.64\cdot 10^{-7}x_2^2 + 0.001x_3^2; \quad (2)$$

– wear ΔD_2 of a restored disk made of steel 45 with sormite surfacing:

$$\Delta D_2 = 1.3819 - 1.6527x_1 - 0.0049x_2 - 0.0392x_3 + 1.6535x_1^2 + 1.77\cdot 10^{-7}x_2^2 + 0.0088x_3^2; \quad (3)$$

– wear Δa_2 of the restored disk made of steel 45 with sormite surfacing:

$$\Delta a_2 = 1.4889 - 1.9108x_1 - 0.00065x_2 - 0.0343x_3 + 1.9202x_1^2 + 2.18\cdot 10^{-7}x_2^2 + 0.0002x_3^2, \quad (4)$$

where x_1 – the amplitude factor of the processing working body; x_2 – factor of the oscillation frequency of the working body; x_3 – processing time factor.

Substituting into the system of equations (1)–(4) the real values of the parameters, let's obtain mathematical models of changes in wear in diameter ΔD and thickness Δa:

– wear ΔD_1 and Δa_1 of new disk of steel 65G with vibration reinforcement:

$$\Delta D_1 = 1.3076 - 1.2709A - 0.0005n - 0.0341t + 1.5729A^2 + 1.9\cdot 10^{-7}n^2 + 0.0007t^2; \quad (5)$$

$$\Delta a_1 = 1.3941 - 1.484864A - 0.0048n - 0.0451t + 1.5019A^2 + 1.64\cdot 10^{-7}n^2 + 0.001t^2; \quad (6)$$

– wear ΔD_2 and Δa_2 of restored disk by welding of segments from steel 45 with surfacing by welding with vibration deformation:

$$\Delta D_2 = 1.3819 - 1.6527A - 0.0049n - 0.0392t + 1.6535A^2 + 1.77\cdot 10^{-7}n^2 + 0.0088t^2; \quad (7)$$

$$\Delta a_2 = 1.4889 - 1.9108A - 0.00665n - 0.0343t + 1.9202A^2 + 2.18\cdot 10^{-7}n^2 + 0.0002t^2. \quad (8)$$

The regression equations (5)–(8) make it possible to determine the change in the amount of wear of the disks depending on the amplitude A, the oscillation frequency of the processing tool n and the processing time (hardening) t.

Based on a study on the extremes of the surfaces obtained using these equations, it has been established that the optimal modes of vibration hardening are:

– frequency of oscillation of the working body $n = 1400$ min^{-1};
– amplitude of the working body $A = 0.5$ mm;
– hardening time $t = 20$ s.

The repeatability of the experiments and measurements of the parameters of the disks at the marked points is taken three times (Table 1).

Table 1

Change of parameters of disks with a diameter of 350 mm

Disk option	Hardening time, s	Increasing the disc diameter, mm	Reducing the thickness of the cutting edge, mm
1. New 65G steel disks	10	1.79	0.11
	20	2.02	0.12
	30	2.18	0.14
2. Restored by welding segments made of steel 45 with sormite surfacing	10	2.78	0.15
	20	3.17	0.17
	30	3.48	0.19
3. Restored by welding segments made of steel 65G with sormite surfacing	10	1.82	0.07
	20	1.95	0.09
	30	2.08	0.11

The obtained data indicate that the largest increase in the disk diameter of 3.48 mm occurred when restoring the segments of steel 45 with sormite welding. The greatest reduction in the thickness of the cutting edge of 0.19 mm is also observed in the disks of the second variant.

An identity of the increase of the disk diameter and decrease of its blade thickness during vibration hardening are experimentally revealed.

The nature of the change in the intensity of the increment of the diameter of the disks with amplitude $A = 0.5$ mm is shown in Fig. 3.

Studies have established that with the hardening time $t = 20$ s, the greatest intensity of the disk diameter increment of 0.158 mm/s is observed in the weld-backed segments made of steel 45 with sormite welding. The smallest increment intensity is 0.097 mm/s for discs restored by welding of segments made of 65G steel with sormite surfacing.

The greatest intensity of the blade thickness decrease of 0.009 mm/s is observed for the disks restored by welding segments made of steel 65G, and the smallest – 0.004 mm/s for disks restored by welding of segments made of steel 65G with surfacing.

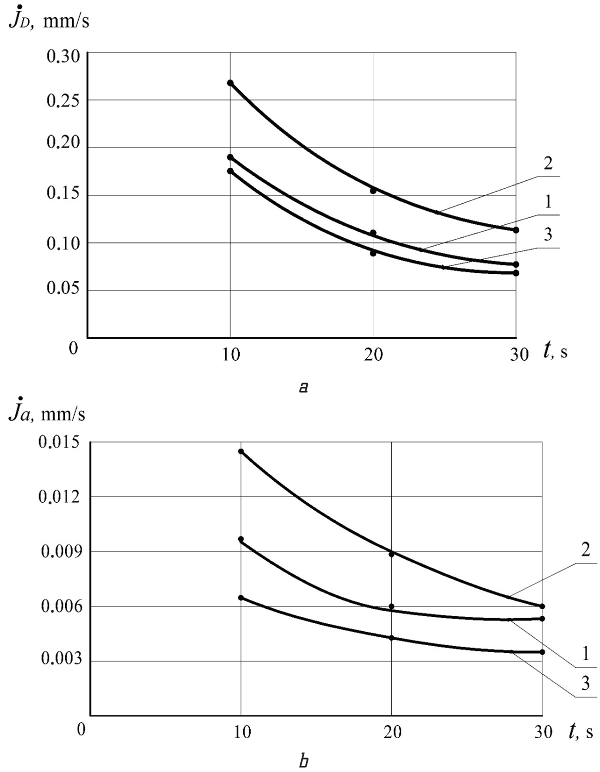

Fig. 3. The intensity of the change in the parameters of the disk as a function of time at A=0.5 mm: *a* – an increase in diameter; *b* – decrease in the blade thickness

The obtained experimental data allow to confirm the following:

– the optimal value of the amplitude of the processing working body (tool) is A=0.5 mm. An increase in the amplitude value causes an uneven increment in the diameter of the disks around the circumference, and a decrease in the magnitude of the deformation in the radial direction is observed;

– the largest value equal to 3.48 mm of the strain value at t=30 s in the radial direction took place on the disks restored by welding segments made of steel 45 with sormite surfacing.

When surfacing and hardening by vibration deformation of the restored surface, there is a change in its mechanical and technological properties. Microstructural studies are carried out on microsections made from the blade of ploughshare discs of the options listed in Table 1.

During vibration deformation, the structure is more fine-grained and uniform compared to the material structure of samples that have not been subjected to vibration hardening.

The depth of hardening of the material of discs restored by welding segments made of steel 45 with sormite surfacing is 2.45 times greater than that of discs restored by welding segments of steel 65G.

Studies allow to conclude that during vibration hardening, the metal structure is more uniform, fine-grained and is characterized by a uniform phase distribution to a depth of 170–300 μm.

When using disks as a result of the abrasive, their blades wear out, which causes blunting (increase in thickness) of the cutting edge. This leads to a deterioration of the sowing process.

The speed of the seeders during field tests with the indicated disk options is 10...12 km/h. Data on their operating time are given in Table 2.

Table 2

Test results

Disk option	Sown area, ha	Disk wear by diameter, mm	Increase of blade thickness, mm
1. New 65G steel disks	190	1.40	0.94
2. Restored by welding segments made of steel 45 with sormite surfacing	256	0.86	0.49
3. Restored by welding segments made of steel 65G with sormite surfacing	232	0.84	0.53

The data in Table 2 show that the seeder with the ploughshare disks restored by welding of segments from steel 45 with subsequent surfacing with sormite and vibration deformation has the greatest value of 256 ha. The increase in operating time even in comparison with new disks is 1.34 times.

Operational tests have shown that for all disk options, the speed of blade thickness blunting is 1.49...1.70 times less than the wear rate of diameter.

Evaluation of the operational reliability of the disk working bodies of the planters is carried out on the following indicators:

– working hours for the seas on;

– coefficient of technical use, which quantitatively characterizes the properties as the reliability of the object, and also takes into account the time the object is in working condition and the time for maintenance and repair.

The average values of the coefficient of technical use of grain seeders, working with ploughshare disks of these options, are given in Table 3.

Table 3

The values of the coefficient of technical use

Disk option	Operation time, h	Coefficient of technical use, C_{TU}
1. New 65G steel disks	62	0.936
2. Restored by welding segments made of steel 45 with sormite surfacing	78	0.986
3. Restored by welding segments made of steel 65G with sormite surfacing	70	0.948

The greatest value C_{TU} =0.986 had seeders working with ploughshare disks, restored by welding of segments made of steel 45 with sormite surfacing and vibratory hardening, which is 1.053 times higher than the seeders with new opener disks.

Conducted operational studies allow to predict the greater reliability of the entire technological complex when sowing crops and plan the number of maintenance and repairs in a certain period of time to ensure its uninterrupted operation.

Table 4 shows the prices of the ploughshare disc of grain seeders of Ukrainian production.

The cost of the ploughshare disc restored by welding of segments made of steel 45 with surfacing with surfacing and vibration hardening is 1.50...1.55 times less than the cost of new ploughshare disks of Ukrainian production.

Table 4

The cost of the ploughshare disc ∅350 mm grain seeders of Ukrainian and foreign production

Manufacturing firm	Cost, UAH/USD
Agroservice LLC, Orekhov, Ukraine	187/6.93
Agrosoiuz PC, Poltava, Ukraine	258/9.55
«Chervona Zirka» PJSC, Kropyvnytskyi, Ukraine	150/5.56
Agrotransit LLC, Minsk, Belarus	240/8.89

7. SWOT analysis of research results

Strengths. The use of the developed technology of restoration of the ploughshare discs of grain seeders contributes to an increase in the coefficient of technical use of 1.053 times, compared with the seeders with new ploughshares. This helps to increase their resource.

The cost of one disc recovered after the developed technology is 1.50–1.55 times lower than the cost of a new one.

Weaknesses. It should be noted that the average installed power of electric motors (kW) at the installation for the restoration of ploughshare disks is 1.34 times higher.

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 the study of the problem of increasing the durability of machine parts, both in the manufacture and restoration with the aim of increasing their reliability and service life.

Threats. The economic effect of the introduction of the developed technology amounted to 88492 UAH/3277.17 USD with an annual volume of implementation of 2400 units [18].

8. Conclusions

1. The analysis of the working conditions and the reasons for the loss of performance of the ploughshares of grain seeders is made. It is established that in the course of their operation, as a result of friction, the parameters of cutting elements undergo a change (diameter reduction and blunting of the cutting edge), which reduces the quality of sowing grain.

2. The effect of vibration processing on the character of the hardening of the blade material is investigated. The basic parameters of vibration hardening are established: amplitude, oscillation frequency of the machining tool and hardening time. The optimal values of these parameters, providing the greatest hardening, are determined: amplitude A=0.5 mm; oscillation frequency n=1400 min^{-1}; hardening time t=20 s.

3. The reliability assessment of the disk ploughshares of grain seeders, determined by the coefficient of technical use (CTU), is performed. The C3-3.6 grain seeders with the ploughshares, restored by welding made of steel 45 segments with automatic surfacing with sormite and vibration hardening, have the highest value of CTU=0.986. This is 1.053 times higher than with new discs.

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