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*Проведений аналіз зносу деталей дозволив встановити характерні вимоги технологічного процесу відновлення зношених поверхонь. Експериментальні дослідження по зміцненню робочих поверхонь плужних лемешів дозволили визначити параметри обробки: частота коливань обробного інструменту  $1400 \text{ хв}^{-1}$ , амплітуда коливань  $0,5 \text{ мм}$ , час обробки  $20 \text{ с}$ . Дослідження впливу звичайного і вібраційного деформування на характеристики міцності попередньо проводилися на моделях, а потім на деталях. Моделями слугували нові лемеші, експериментальні дослідження на яких забезпечували ідентичність характеру зношування різьблених елементів. Забезпеченням однакових умов протікання процесів зміцнення дотримувалося однаковість ступеня деформації моделі і деталі.*

*Достовірність результатів експериментальних досліджень оцінювали відповідно до прийнятого теоретичного закону розподілу при заданій величині ймовірності  $\alpha=0,95$ . Дослідженнями встановлено, що найбільшій ймовірності  $0,39$  відповідає ширина лемешу  $116-117,5 \text{ мм}$ , яка має певний вплив на працездатність лемешу.*

*Експериментально встановлено, що ступінь зміцнення лемешів зі сталі Л-53 з подальшим наплавленням сормайтотом і вібраційним зміцненням в  $1,85$  рази більше, ніж при звичайній обробці. Проведені дослідження дозволили визначити характер зміни форми лемешу і товщини різальної кромки, а також відрізняються більш ефективний технологічний процес його відновлення методом вібраційного зміцнення. Запропоновано метод відновлення лемешів приварюванням шин зі сталі 45 з автоматичним наплавленням сормайтотом і подальшим вібраційним зміцненням*

*Ключові слова: деформування, динаміка зношування, вібраційна обробка, зносостійкість поверхні*

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## IMPROVING THE TECHNOLOGICAL PROCESS OF RESTORING THE TILLAGE MACHINE WORKING PARTS

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### 1. Introduction

One of the problems of repair activities is to increase the durability of working parts of tillage machines during their restoration. A solution to this problem will allow repair enterprises to reduce downtime, improve the quality of maintenance and repair and improve indicators of equipment reliability and utilization [1].

A significant role in ensuring the long service life of tillage machines is assigned to the development and application

of progressive technological processes which will significantly improve indicators of restoration quality.

The feasibility of the restoration of working parts of these machines is to reduce repair costs by cutting expenses on new spare parts and operation costs [2].

In this regard, the technical condition of working parts of the tillage machines significantly affecting the yield of agricultural crops is of particular interest.

When restoring parts, it is necessary to ensure their quality at a level of new parts or even higher. Wear resistance of

working surfaces can be improved by the development and application of advanced technologies that can significantly improve quality indicators of restored parts. However, this requires additional studies.

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## 2. Literature review and problem statement

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In most cases, the destruction of the material of machine parts begins with the surface (wear, fatigue, contact destruction, etc.). In many cases, it is difficult to ensure the reliability and durability of products in view of changes in strength and structurally stressed state of the metal surface layers resulting from the effect of hardening processes [3].

There are a number of methods for restoration and hardening of tillage machine working parts: sharpening, hardening, sormite surfacing, gas-plasma surfacing with wear-resistant powders or brazing cermet plates [4]. However, these methods did not find proper application in agricultural production in view of insufficiently high quality of restoration of working parts of tillage machines, high processing complexity and costs.

Restoration of tillage working parts using the electro-physical method of welding special wedge-shaped rolled products instead of worn blades is hampered by the high cost of special rolled products [5]. Induction surfacing with carbide powders is an expensive and energy-intensive process as well [6].

Use of Elkefem hard alloy in the restoration of working parts of tillage machines ensures a two to three times increase in their wear resistance. However, costs are much higher [7].

Restoration of parts by welding plates with their subsequent surfacing by wear-resistant metal powders from below provides, to a certain extent, effect of blade self-sharpening. However, this method is of significant complexity and does not provide high wear resistance. In addition, the level of the stress-strain state of the restored part increases [8].

The method of restoring working parts of tillage machines by flux-cored wire surfacing provides a rather high surface hardness (56–58 HRC). However, the impact resistance of the restored part material reduces because of the features of the material and the deposited layer properties [9].

What concerns restoring parts of tillage machines, there are data in the literature on their restoration by freezing surfacing which ensures the formation of a wear-resistant layer of required dimensions and shape [10]. However, the method is highly labor-intensive, requires expensive equipment and eventually did not find application in repair activities.

The use of laser technology for hardening cutting surfaces of tillage machine parts is promising as it enables continuous pulsed processing [11]. However, the authors note that the application of this technology to working surfaces of the tillage machine parts features a local nature of processing and therefore requires substantial theoretical and experimental studies.

There are other recovery methods mainly used in mechanical engineering. Such methods are at a stage of experimental studies and require expensive equipment.

Hardening ensures the creation of a reserve of reliability of the recovery process since the introduction of special operations imparts higher in-service properties to the restored parts of agricultural machines. In this regard, solutions in the field of hardening by vibrational deformation are of particular interest.

Processing of materials using mechanical oscillations or vibrations [12] is among the new promising methods of plastic surface deformation.

The vibrational process of working machined surfaces implies applying a large number of micro-impacts to the processed material to harden it. Hardening entails mutual displacement of the processed metal layers. All characteristics of deformation resistance (tensile strength, yield strength, elasticity, fatigue strength, hardness, etc.) get higher during processing [13].

Thus, conducting a study on vibration hardening of machine parts operating in conditions of extremely high loads is of practical interest when finding ways for raising durability and reliability.

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## 3. The aim and objectives of the study

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This study's objective is to improve the technological process of restoration of working parts of tillage machines using the vibration of the processing tool. This will provide an increase in the reliability of recovered parts.

To achieve the objective, the following tasks were set:

- to study the nature of change in parameters of plow-share processing;
- to study hardening of the surface layer during processing;
- to assess wear resistance of the share blades.

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## 4. The procedure used in defining quality indicators

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The choice of the recovery process was substantiated taking into account the nature of defects and degree of wear of working surfaces of cutting elements, their hardness, material, geometric dimensions, processing accuracy and repair costs.

Analysis of wear of these parts has made it possible to establish characteristic requirements of the technological process of restoring worn surfaces.

When assessing reliability, formulas from the theory of reliability were used as estimation dependences.

Quantitative and qualitative assessment of the reliability of the share cutting elements as working parts of tillage machines restored by various methods was carried out by comparison with the same indicators of new parts.

State of restored and new shares was assessed by their wear in the tests.

Micrometry of the thickness of the share cutting edge was carried out by means of the MKC-25 micrometer with a gage indicating unit having an accuracy of 0.001 mm and design parameters were determined using the ShCC-500 caliper with a gage indicating unit having an accuracy of 0.01 mm.

Oscillations of the working part (of the tool) cause a change in physical-mechanical properties (hardness, microhardness) of the processed material. TK-2M hardness tester was used to measure hardness along the entire length of the share cutting edge and the PMT-3 instrument was used in measuring microhardness.

Determination of the processing parameters that reduce the wear of cutting edges of working parts of tillage machines is an important factor in the selection of a restoration process.

Experimental studies were carried out on the vibration unit manufactured for hardening working surfaces of the parts with necessary processing parameters: perturbing force,

amplitude, and frequency of oscillations and speed of movement of the processing tool.

The value of the processing force was fixed using a manometer and a device that stabilize this force level.

To study the influence of conventional and vibrational types of loading on strength characteristics of the processed material, studies were carried out on model samples and then on the actual parts.

New shares were used as experimental study samples on which identity of history of the cutting element wear was provided.

In order that the laws and quantitative data obtained in laboratory conditions could be extended to concrete parts, the law of similarity (the Kirpichov-Kik law) was observed according to which the models should be geometrically similar and physically identical, that is:

$$\frac{l_{\partial}}{l_M} = \frac{h_{\partial}}{h_M} = n, \tag{1}$$

where  $n$  is the modeling scale;  $\partial$  and  $M$  are indices of the part and model, respectively.

To ensure the same conditions for the hardening processes, the similarity of the degree of deformation of the model and the part was observed, that is,  $\epsilon_M = \epsilon \partial$ .

Studies of wear dynamics for the working parts of tillage machines were carried out on experimental lots of shares. To assess changes in microgeometry of the share blades along their generatrix, a planimetric method was used. It implies recording the blade geometry at various wear stages depending on operating time. Analysis of the obtained wear data has made it possible to evaluate the process intensity with different recovery methods and choose a more effective one.

To confirm prerequisites for appropriateness of using the vibration technology, five geometric parameters of share hardening were determined (Fig. 1). These parameters include width in planes ( $h_1, h_2, h_3$ ); change in the point size ( $\Delta h$ ); width ( $l_1, l_2, l_3$ ) and depth ( $a_1, a_2, a_3$ ) of wear and bend ( $u$ ).

Shares of three options were taken for the tests:

- new shares of L-53 steel;
- new shares of L-53 steel subjected to vibration hardening;
- shares restored by welding strips of ‘45’ steel, sormite surfacing and vibration hardening.

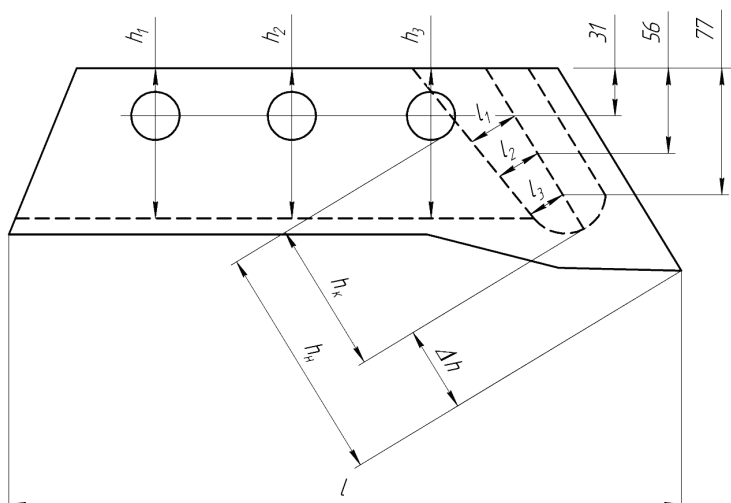


Fig. 1. Places of measurement of share wear after tests

The reliability of the results obtained in experimental studies was assessed in accordance with the theoretical law of distribution for a given value of confidence probability  $\alpha=0.95$  [14].

Studies of wear of the share cutting elements were carried out along the cutting element generatrix using the planimetric method. Using the registered wear lines, diagrams (contours) of geometry change depending on wear time were obtained.

Change of the blade shape in the sections perpendicular to the blade generatrix was determined by the method of taking impressions (replicas) in three characteristic sections (opposite the mounting holes) in equal operating time steps.

Relative experiment error at the specified confidence level was determined:

$$\delta = \frac{\bar{t}_{\alpha}^b - \bar{t}}{\bar{t} - t_{cm}}, \tag{2}$$

where  $t_{\alpha}^b$  is the upper confidence limit of mean value scatter;  $t_{cm}$  is the magnitude of the scatter onset shift;  $\bar{t}$  is the mean value of the indicator:

$$\bar{t} = \frac{1}{N} \sum_{i=1}^N t_i, \tag{3}$$

where  $t_i$  is the value of the  $i$ -th indicator.

The empirical mean square value of  $S$  was found:

$$S = \sqrt{\frac{\sum_{i=1}^N (t_i - \bar{t})^2}{N}}, \tag{4}$$

where  $t_i - \bar{t}$  is the residual error.

Using the Irwin criterion, the experiment results were assessed:

$$\lambda_{opt} = \frac{1}{S} (t_i - \bar{t}_{i-1}), \tag{5}$$

where  $t_i$  and  $t_{i-1}$  are the adjacent points of information.

## 5. The results of studying the share hardening

### 5. 1. The study of nature of change in parameters of share processing

The results of experimental share studies are given in Table 1.

The data presented in the Table allow us to state that in order to raise wear resistance of the restored shares, vibration hardening should be carried out at tool oscillation frequency of  $1,400 \text{ min}^{-1}$ , the oscillation amplitude of 0.5 mm and hardening time of 20 s. With these processing parameters, the smallest wall wear of 0.4 mm and the point wear of 0.5 mm is provided in shares of L-53 steel (experiment 14, Table 1).

**Table 1**  
The results of experimental studies of shares restored by vibration hardening

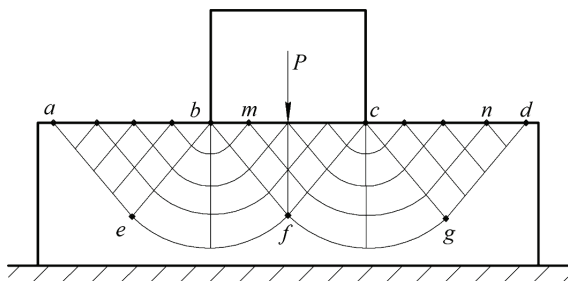
Experiment No.	Oscillation frequency, min <sup>-1</sup>	Oscillation amplitude, mm	Hardening time, s	Wear magnitude W, mm			
				Share option			
				L-53 steel		65G steel	
				wall	point	wall	point
1	700	0.25	10	1.5	1.45	1.65	1.4
2	700	0.25	20	1.2	1.2	1.7	1.3
3	700	0.25	30	1.6	1.6	1.4	1.5
4	700	0.50	10	1.35	1.3	1.3	1.25
5	700	0.50	20	1.3	1.0	1.2	0.9
6	700	0.50	30	1.3	1.2	1.2	1.0
7	700	0.75	10	1.55	1.5	1.65	1.4
8	700	0.75	20	1.4	1.35	1.55	1.3
9	700	0.75	30	1.4	1.5	1.6	1.45
10	1400	0.25	10	1.5	1.4	1.3	0.8
11	1,400	0.25	20	0.4	1.2	0.7	1.4
12	1,400	0.25	30	1.2	1.0	1.6	1.3
13	1,400	0.50	10	1.1	0.9	1.1	1.1
14	1,400	0.50	20	0.4	0.5	0.4	0.4
15	1,400	0.50	30	0.5	0.7	0.6	1.0
16	1,400	0.75	10	1.1	1.25	1.5	1.3
17	1,400	0.75	20	0.9	1.0	1.2	1.2
18	1,400	0.75	30	1.0	1.1	1.3	1.3
19	2,100	0.25	10	1.0	1.2	1.5	1.4
20	2,100	0.25	20	1.3	1.25	1.4	1.0
21	2,100	0.25	30	1.2	1.3	1.4	1.2
22	2,100	0.50	10	1.3	1.4	1.3	1.1
23	2,100	0.50	20	1.2	1.1	1.0	0.8
24	2,100	0.50	30	1.1	1.5	1.5	1.0
25	2,100	0.75	10	1.5	1.5	0.6	1.5
26	2,100	0.75	20	1.0	1.0	1.3	1.2
27	2,100	0.75	30	1.4	1.5	1.6	1.5

**5. 2. The study of hardening of the surface layer during processing**

It has been established that the increase in strength characteristics is largely explained by an increase in resistance to displacement of dislocations and their ordering in the course of deformation [15].

During deformation (Fig. 2), the Luder's lines intersect free (*ab* and *cd*) and contact (*bc*) surfaces at an angle of 45°.

Friction stress arises in surface *bc* during conventional working. At its limit value, one family of Luder's lines reaches the contact surface at an angle of 90° and the other family is tangent to it.



**Fig. 2.** Diagram of Luder's lines in the plastic working of material

Under vibration loading when the processing tool is taken off, this angle will be equal to 45° and the angle of intersection of the Luder's lines with the processed surface will vary from 45° to 90°. Thus, at the moment when the tool is taken off, the processing force will be directed to the movement direction at a large angle. The force, the degree of compaction, and the magnitude of deformation in radial direction will be of greater importance than in conventional working.

Stress  $\sigma_z$  normal to the surface is equal to zero and normal compression stresses  $\sigma_x$  along the *X* axis act on free surfaces *ab* and *cd*. Based on the equation of plasticity, we can write:

$$0 - \sigma_{xn} = 2k; \quad \sigma_{xn} = -2k, \tag{6}$$

where

$$k = \frac{\sigma_s}{\sqrt{3}}.$$

On free surfaces, the mean stress will be:

$$\bar{\sigma}_n = \frac{0 + \sigma_{xn}}{2} = \frac{\sigma_{xn}}{2} = -k. \tag{7}$$

When moving from point *n* to point *m* on the contact surface, the Luder's lines turn by an angle of 90°. Therefore:

$$\bar{\sigma}_{xn} - \bar{\sigma}_{xm} = 2k \frac{\pi}{2} = k\pi. \tag{8}$$

Hence:

$$\bar{\sigma}_{xn} - \bar{\sigma}_{xm} - k\pi = -k(1 + \pi) = \frac{\sigma_x^m + \sigma_z^n}{2}. \tag{9}$$

Compressive stresses  $\sigma_z$  and  $\sigma_x$  act throughout the *bfc* region. According to the equation of plasticity:

$$\sigma_{xm} - \sigma_{zm} = 2k. \tag{10}$$

The following is found from equation (1):

$$\sigma_{xm} + \sigma_{zm} = -2k(1 + \pi). \tag{11}$$

Then the compressive stress will be:

$$\sigma_{zm} = -k \cdot (2 + \pi) = 5.14k. \tag{12}$$

After substituting the value of *k* into equation (13):

$$\sigma_{zm} = \frac{5.14}{\sqrt{3}} \sigma_s = -2.97\sigma_s. \tag{13}$$

Specific *p* and complete force *P*, respectively, will be:

$$p = 2.97\sigma_s; \quad P = p \cdot bc. \tag{14}$$

Since there is no friction between the processing tool and the surface at the moment when the processing tool backs off the surface during vibrational working, then based on the plasticity theory [16], normal stress will be 1.15 $\sigma_s$ . Hence, 2.57 times rise of stress occurs during conventional working.

With plastic deformation, a change in the part dimensions occurs which contributes to the hardening of the processed surface material.

The degree of hardening of the processed material was determined:

$$\eta = \frac{F_0}{F_1}, \tag{15}$$

where  $F_0$  and  $F_1$  are the areas of the processed surface before and after working.

Calculated values of the degree of hardening of the processed share material are given in Table 2.

Table 2  
Values of hardening degree

Processed material	Hardening degree	
	Conventional working	Vibrational working
L-53 steel	0.045	0.067
L-53 steel, sormite surfaced	0.034	0.063

The degree of hardening the material of L-53 steel samples subjected to sormite surfacing and vibration hardening was 0.063 that is, 1.85 times more than in conventional processing (0.34).

**5. 3. The study of wear resistance of plowshares**

Studies of wear dynamics in cutting elements were conducted for the following shares:

- shares restored by welding strips of 45 steel, sormite surfacing, and vibration hardening;
- new shares of L-53 steel with no hardening applied;
- new shares of L-53 steel subjected to vibration hardening.

Service reliability of shares of the above options was assessed by the rate of wear of width, point, and thickness of the share (Table 3).

Table 3  
Change in the rate of share wear

Share option	Mean rate of share wear, mm/ha		
	width	point	thickness
1. New shares of L-53 steel	0.035	0.140	0.024
2. Shares restored by welding strips of 45 steel, sormite surfacing, and vibration hardening	0.027	0.122	0.013
3. New shares of L-53 steel subjected to vibration hardening	0.029	0.128	0.016

As can be seen from the data in Table 3, wear rates of the above parameters of the shares restored according to the developed technology were respectively 1.3, 1.4 and 1.85 times less than those observed in new shares.

The utilization factor characterizing reliability, maintainability and repair time is an important indicator of tillage machine reliability. It also takes into account maintenance and repair time. The utilization factor was determined from the following relationship:

$$K_{II} = \frac{T_p}{T_p + T_B + T_{TO}}, \tag{16}$$

where  $T_p$  is the mean time between failures,  $T_B$  and  $T_{TO}$  are the mean time during which the object could work during the

restoration of its working condition and the time determined by maintenance.

Table 4 shows the mean values of the utilization factor for the plow units working with shares of the above options.

Table 4  
Values of the utilization factor

Share option	Mean production capacity between failures, ha	Utilization factor, $K_U$
1. New shares of L-53 steel	422	0.949
2. Shares restored by welding strips of 45 steel, sormite surfacing, and vibration hardening	439	0.991
3. New shares of L-53 steel subjected to vibration hardening	427	0.973

The plow units working with shares restored by welding strips of 45 steel, sormite surfacing, and vibration hardening had the highest value of  $K_U=0.991$ . The presented data make it possible to prognosticate higher reliability of the entire technological complex and plan the number of modes in a certain time period to ensure smooth operation.

**6. Discussion of the results obtained in improving the wear resistance of shares using vibration hardening**

When determining the nature of change in parameters of processing shares restored by vibration hardening, optimal values of frequency and amplitude of the processing tool oscillation and hardening time were obtained on the basis of experimental data. The established numerical values of the above parameters of processing the cutting parts of plowshares contribute to an increase in their wear resistance during recovery.

The established nature of change in the degree of share wear during vibration working with an amplitude  $A=0.25$  mm can be explained by a weak manifestation of properties of the processing tool oscillation. With an amplitude  $A=0.75$  mm, there is smaller contact between the processing tool and the surface being worked as a result of greater tool withdrawal from the surface being hardened. In this case, load on the part material is shock-like which contributes to the reduction of material deformation. This fact was confirmed by previous studies [17].

The decrease in the wear of the share cutting elements subjected to vibration hardening can be explained by metal hardening due to a change in its structure under vibration loading, a decrease in residual stresses and an improvement in the hardened material properties.

The obtained tabular data indicate that the degree of hardening of the material of the shares restored by sormite surfacing and vibration processing is 1.85 times more than in conventional processing.

Wear dynamics has shown that the rates of wear of the blade width, point and thickness of the shares restored according to the developed technology are respectively 1.3, 1.14 and 1.85 times less than those of the new shares.

Analysis of the data obtained makes it possible to state that wear resistance of the share depends to a large extent on the type of recovery processing and combination of the main and deposited materials.

As a result of bench tests and property studies, an option of share restoration by welding strips of 45 steel, automatic hard surfacing, and subsequent vibration hardening was proposed. In terms of carbon content, 45 steel is close to L-53 steel and provides good fusion quality.

Calculations of the utilization factor indicate that the highest value of 0.991 was observed in plow units working with shares restored by welding strips of 45 steel, sormite surfacing, and vibration hardening.

The obtained study data make it possible to predict the greater reliability of the entire technological complex.

Disadvantages of using vibration oscillations in metal part recovery relate to the increased noise level during the operation of the vibration unit. To reduce noise, it is necessary to provide proper insulation of the unit from the floor of the workshop where it is mounted.

These studies were conducted for the areas characterized by certain climatic and soil conditions. The studies have to

be further developed for the areas with other climatic and soil conditions.

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## 7. Conclusions

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1. The main parameters of share processing that improve wear resistance were established: the processing tool oscillation frequency of  $140 \text{ min}^{-1}$ , oscillation amplitude of 0.5 mm and hardening time of 20 s.

2. It was found that the degree of hardening of the material of the shares made of Л-53 steel by sormite surfacing and vibration hardening is 1.85 times more than that obtained by conventional processing.

3. An option of restoring shares by welding strips of 45 steel with automatic hard surfacing and subsequent vibration hardening that provides maximum wear resistance with a shape factor of 0.956 was proposed.

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