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EFFECT OF VIBRATION TREATMENT ON INCREASING THE DURABILITY OF TILLAGE EQUIPMENT WORKING BODIES

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This paper reports a study into the durability of tillage equipment working bodies. It has been established that the quality of surface layers during plastic deformation depends on a series of factors. These factors include the degree of hardening, the thickness of the hardened layer, the size and nature of the distribution of residual stresses.

The study has shown that the technology to restore working bodies that involves vibration oscillations provides for higher durability.

Investigation of deformed samples demonstrates that when exposed to vibration treatment, the microstructure is more fine-grained and even; the hardness of the treated surface of a ploughshare blade increases by 22–35 %. This contributes to hardening the machined surface.

It has been established that the tillage equipment working body wear is a random process, which is predetermined by changes in the structural dimensions and shape of cutting elements. An analysis of the wear distribution density of cutting elements has revealed its compliance with the law of normal distribution.

It should be noted that the most influential geometric parameter of a working body affecting the part's resource is the wear depth. This parameter determines the residual thickness of the ploughshare wall.

Data from surface-layer studies at hardening make it possible to note a decrease in the limiting state of the examined parameters. In particular, the wear of a ploughshare tip was 17 % less than the limiting state.

The study of durability has shown that the amount of tillage equipment working body wear is 1.28 times less when using vibrational plastic deformation. Accordingly, when restoring ploughshares, in order to increase the working bodies' resource, it is more expedient to use a method that implies the welding of tires made from steel 45 involving sormite surfacing and vibration treatment

Keywords: increased durability, tillage equipment working bodies, surface hardening, plastic deformation

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1. Introduction

Improving the durability of tillage equipment working bodies is an urgent task. Their insufficient reliability leads to significant expenditures for spare parts, which contributes to higher operating and repair costs.

In improving the resource of tillage machines, the development and application of effective hardening technologies play a significant role, which can significantly improve the quality of restoring their working bodies [1].

There are several methods of hardening by surface plastic deformation, based on the static and dynamic influence on the surface layer material, causing plastic deformation in it.

The issue related to prolonging the durability of parts is a complex problem, which implies the application of effective technologies in their manufacture and restoration, as well as the use of materials with the required physical-mechanical properties [2].

The durability of agricultural machinery working bodies is typically determined by their resource. In this regard, one of the important challenges is research aimed at finding effective technologies for hardening the surface layers of the material of contacted parts.

It should be noted that the possibility to obtain a surface layer with the required indicators of hardening remains to be implemented in full.

Therefore, it is a relevant task to manufacture a hardened surface layer with a greater degree and depth of hardening when using SPD (surface-plastic deformation) techniques based on the vibration oscillations of the machining tool. More research is needed to obtain the required data.

2. Literature review and problem statement

Strengthening the surface layer of tillage equipment working bodies by an effective manufacturing process makes it possible to restore not only the specified geometric parameters but also ensure their high durability. During operation, the working bodies of tillage machines are exposed to a series of factors (stresses in their material; the environment; the soil composition and humidity; damage accumulation, etc.), which impair their technical characteristics and performance. When restoring the tillage equipment working bodies, it is necessary to choose an effective manufacturing process that could restore the specified geometric parameters and ensure high durability. Existing ways to restore tillage equipment working bodies are described in detail in work [3]. Given the unsatisfactory quality of the tillage equipment working bodies restoration and the high cost of machining, these techniques have not yet been properly used in agriculture.

The results of a study reported in [4] showed that the use of effective hardening technology ensures the creation of a safety margin for the recovery process. That is provided by the introduction of specialized operations; higher operational properties of the parts recovered are achieved. In this regard, developments on hardening by the vibration deformation method are of interest.

Chemical-thermal treatment, deformation, and some specialized techniques [5, 6] can be attributed to methods for increasing corrosion resistance. However, the use of such methods may prove to be inexpedient due to the complexity of the manufacturing process for small service enterprises.

There are studies on treating the parts by surfacing with a powder wire [7, 8]. This technique ensures a high enough surface hardness but the resistance of the material of the restored part to impacts is reduced due to the properties of the part's material and the surfaced layer.

Promising methods in terms of their further advancement likely include the machining of parts' materials by mechanical oscillations (vibrations) [9]. The use of vibrations shows its effectiveness in various manufacturing processes [10].

The vibrational hardening of a surface is implemented in two ways: in one case, vibrations are applied to a machining tool, and, in the other case, to a machined part.

Vibration treatment contributes to the intensification of a larger number of manufacturing processes; it is an advanced direction in the technologies of machine building, whose possibilities and the scope of application are not yet fully defined.

The intensity of vibration treatment is determined by the following factors: machining modes (perturbing force, amplitude, the oscillation frequency of a machining tool, its movement speed); the mechanical properties of the material of parts being machined, their geometry, etc.

The theory of dislocations [11] elucidates deformational hardening, the formation of internal stresses, and their role in plastic deformation [12]. As the deformation increases, the density of dislocations in the surface layer increases, which contributes to the increase in its strained state, as a result of which the material of the part's machined surface is strengthened.

Ultimately, hardening implies the reciprocal movement of the layers of the metal being machined [13]. In this case, all characteristics of resistance to deformation increase: the limit of strength, fluidity, elasticity, hardness, fatigue, etc.

The method of vibration treatment that is being used in industry has not yet been widely applied in agricultural machinery when restoring machine parts, in particular, the hardening of the working bodies exposed to an abrasive environment, due to the lack of detailed studies of this manufacturing process. The lack of research and practical recommendations in the field of vibration treatment inhibits its use in the restoration of parts of agricultural machinery.

It should be noted that the dynamics of tillage equipment working body wear have not yet been fully revealed. There is no mathematical dependence that would take into consideration the physical-mechanical characteristics of the abrasive environment, the material of the cutting elements of tillage equipment working bodies, as well as the conditions of operation. There is no physical-mathematical model of the abrasive wear and the formation of structural parameters of cutting elements.

The problem's essence is to identify the impact of regime parameters of machining the working bodies of tillage machines on the increase in durability.

3. The aim and objectives of the study

The aim of this work is to identify the impact of manufacturing parameters in the vibrational hardening of tillage equipment working bodies on an increase in durability.

To accomplish the aim, the following tasks have been set:

– to investigate the impact of machining mode parameters on the hardening of the machined surface;

– to assess the durability of the material of parts that are restored by various technologies.

4. Procedure to determine quality indicators

Since the tillage equipment working bodies operate under conditions of abrasive wear, the choice of technology to restore them was justified taking into consideration the nature of defects in their cutting elements, the precision of machining, the material's properties. The amount of wear in our laboratory and operational tests was one of the basic criteria for analyzing the condition of the recovered and new specified parts [14].

We studied the hardening of tillage equipment working bodies at an installation (Fig. 1) fabricated at the Department of Technologies and Means of Mechanization of Agricultural Production, the Poltava State Agricultural University.

The installation enables hardening the surfaces of various parts with the required machining parameters such as perturbing force, the amplitude and frequency of oscillations [15].

The vibration installation includes a base (1) hosting support equipment; a hydraulic system (2) to lift and lower a vibration exciter (3) with a fixed machining tool.

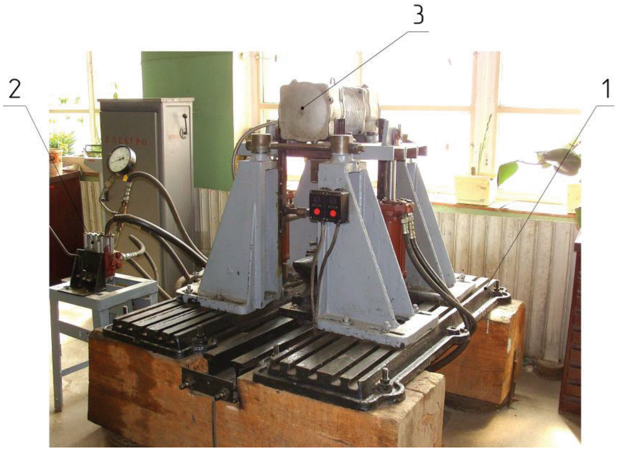

Fig. 1. Installation overview

We registered the magnitude of the machining effort using a manometer and a device to stabilize its readings, that is, a device to automatically maintain the predefined value of adjustable magnitude at a certain accuracy under varying perturbing influences: a stabilizer of the machining tool speed on the amplitude of its oscillation.

The experimental (bench) study into the durability of the specified parts was carried out on a soil channel shown in Fig. 2.

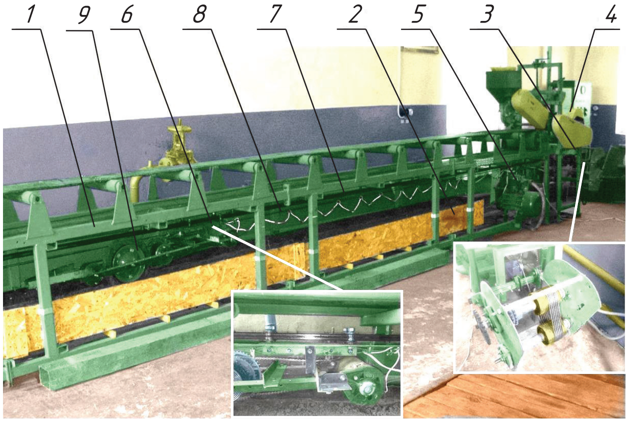

Fig. 2. Test bench for tillage equipment working bodies: 1 – frame; 2 – soil channel; 3 – traction winch; 4 – gearbox; 5 – electric motor; 6 – a universal traction device; 7 – guide; 8 – tether; 9 – roller

Bench tests allowed us in a relatively short time to evaluate the options for the restoration of parts and determine the most effective one.

In order to assess the influence of the composition of the abrasive mixture in the soil channel on the nature and magnitude of the wear of the specified parts, its composition included 75 % of sand, 25 % of clay with a lump structure.

To study the effect of regular and vibrational deformation on the strength characteristics of the machined material, our studies involved model samples followed by actual parts. The samples were new ploughshares; experimental studies involving them provided the identity of the nature of the wear of cutting elements.

The study involving worn-out ploughshares has made it possible to adjust the basic parameters of the manufacturing process of hardening required for the development and implementation of their recovery technology.

The thickness of the ploughshare blades varied within 2.0±0.5 mm; the sharpening angle was 25°, 30°, and 35°.

The oscillation amplitude of the machining tool was 0.25–0.75 mm, the oscillation frequency was 700–2,100 min^{-1}, the time of hardening was 10–30 s. The microstructural study was conducted using the microscope MIM-8 (Ukraine), the microhardness tester PMT-3M (RF), and the hardness tester TM-2M (Ukraine).

The degree of hardening η was determined from the following dependence:

$$\eta = \log \varepsilon \frac{\delta_S}{\delta_T}, \qquad (1)$$

where ε is the logarithmic degree of deformation; Δ_S is the tension of metal current; Δ_T is the fluidity limit.

We determined stresses in the material of the restored ploughshares using a tensometry method.

5. Results of studying the hardening of the ploughshare working bodies' material

5. 1. Studying the hardening of a surface layer during its machining

The following criteria for the limit condition of working bodies were examined: the width in planes (h_1, h_2, h_3); the loss of a tip size (Δh); wear width (l_1, l_2, l_3); wear depth (a_1, a_2, a_3).

Experimental studies were conducted in accordance with the chosen plan to test the feasibility of applying a recovery technology. The parameters of optimization chosen for a multifactorial experiment were the amount of wear of a ploughshare tip Δh and the residual thickness of a ploughshare wall Δa in three variants (trapezoidal, chisel-type, with a cut-off tip).

The results of our experimental study of the dependence of wear amount on machining parameters are given in Table 1.

Table 1

Results of studying the dependence of wear amount on machining parameters

Experiment number	Oscillation frequency n, min^{-1}	Oscillation amplitude A, mm	Hardening time t, s	Wear amount W, mm					
				Ploughshare variant					
				Δa_1	Δh_1	Δa_2	Δh_2	Δa_3	Δh_3
1	700	0.25	10	1.2	1.7	1.4	1.4	1.5	1.4
2	700	0.25	20	1.0	1.2	1.0	1.1	1.6	1.3
3	700	0.25	30	1.2	1.7	1.4	1.5	1.5	1.1
4	700	0.50	10	1.1	1.4	1.3	1.4	1.3	1.2
5	700	0.50	20	0.7	1.0	1.2	1.1	1	0.9
6	700	0.50	30	0.9	1.3	1.3	1.1	1.1	1.0
7	700	0.75	10	1.3	1.6	1.5	1.4	1.6	1.4
8	700	0.75	20	1.0	1.1	1.4	1.3	1.5	1.2
9	700	0.75	30	1.2	1.3	1.4	1.4	1.6	1.4
10	1,400	0.25	10	1.1	1.5	1.5	1.3	1.4	0.8
11	1,400	0.25	20	0.5	0.7	0.5	1.2	0.6	1.2
12	1,400	0.25	30	0.7	1.1	1.1	1.0	1.4	1.3
13	1,400	0.50	10	0.8	1.2	1.0	0.9	1	1.1
14	1,400	0.50	20	0.4	0.5	0.4	0.5	0.5	0.6
15	1,400	0.50	30	0.4	0.6	0.5	0.7	0.6	1.0
16	1,400	0.75	10	1.0	1.2	1.1	1.2	1.5	1.3
17	1,400	0.75	20	0.6	1.1	0.9	1.1	1.3	1.2
18	1,400	0.75	30	0.6	1.2	1.1	1.1	1.2	1.2
19	2,100	0.25	10	0.9	1.8	1.1	1.9	1.4	1.4
20	2,100	0.25	20	1.0	1.3	1.2	1.3	1.3	1.1
21	2,100	0.25	30	1.2	1.4	1.3	1.2	1.4	1.3
22	2,100	0.50	10	1.1	1.3	1.4	1.4	1.3	1.2
23	2,100	0.50	20	1.2	1.2	1.0	1.0	1.1	0.9
24	2,100	0.50	30	1.3	1.6	1.5	1.4	1.6	1.5
25	2,100	0.75	10	0.9	1	0.9	1	1.3	1.3
26	2,100	0.75	20	0.9	1	0.9	1	1.3	1.3
27	2,100	0.75	30	1.2	1.5	1.4	1.4	1.6	1.5

The analysis of our results makes it possible to confirm the parameters of the vibrational hardening of ploughshares [3]. For better efficiency, the manufacturing process parameters should be taken as follows: oscillation amplitude, $A=0.5$ mm; the tool oscillation frequency $n=1{,}400$ min^{-1}; machining duration, $t=20$ s.

A sample of the restored ploughshare is shown in Fig. 3.

The study of deformed samples shows that at vibration treatment the microstructure is more fine-grained and even; there is a 22...35 % increase in the hardness of the machined surface of a ploughshare blade, which contributes to the hardening of the machined surface (Fig. 4, 5).

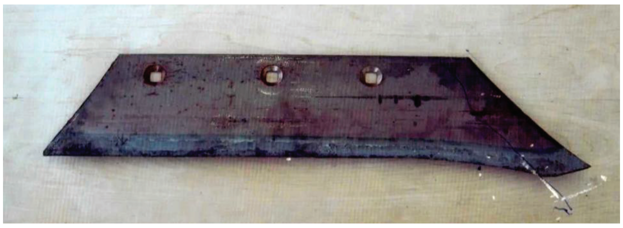

Fig. 3. Sample of the restored ploughshare

Fig. 4. The microstructure of steel 45 with sormite surfacing without hardening, ×500 [16]

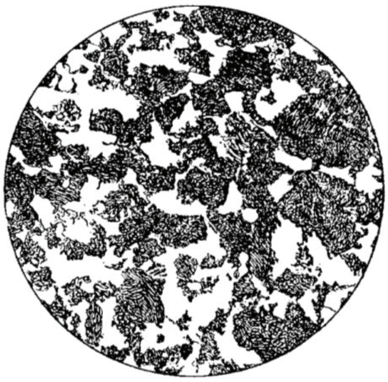

Fig. 5. The microstructure of steel 45 with sormite surfacing after vibrational hardening, ×500 [16]

When the specified ploughshares are restored, there are the residual stresses in the material of their cutting elements that are re-distributed due to the thermal impact on the main metal during surfacing, as well as subsequent hardening.

In the material of the cutting element of cultivating paws, the compression stresses amounted, at a depth of 80–150 μm, when the trapezoidal paws were restored by welding the steel 45 tires with sormite surfacing and vibrational hardening, to 380–398 MPa. For chisel-shaped paws and paws with a cut-off tip, the compression stresses were 340–355 MPa and 300–320 MPa, respectively.

5. 2. Assessment of the durability of tillage machine parts

Our findings (Table 2) demonstrate that the amount of wear across the width of a working element depends on the following basic factors: the type of machining, material, and the technological modes.

Table 2

Change in wear along the width of a cutting element depending on the method of hardening, the type of ploughshare, and the time of operation

Ploughshare variant	Wear amount value, mm			
	6 h	12 h	18 h	24 h
Restored by welding steel 45 tires with sormite surfacing and vibrational hardening:				
– trapezoidal ploughshares;	0.36	0.62	0.71	0.82
– chisel-type ploughshares;	0.33	0.59	0.69	0.84
– ploughshares with cut-off tip	0.39	0.65	0.79	1.05

The data from Table 2 show that the least amount of wear was demonstrated by trapezoidal ploughshares at the longest operation time. The amount of wear of these ploughshares, restored by the welding of steel 45 tires with sormite surfacing and vibrational hardening, is 1.28 times less than that of ploughshares with a cut-off tip.

6. Discussion of results of studying the improvement in the durability of tillage machine parts by vibrational hardening

The analysis of our data (Table 2) reveals that the wear of the cutting elements of tillage bodies at different hardening methods depends, first of all, on the type of machining, material, technological regimes, and working time.

Thus, for ploughshares subjected to vibrational hardening, the amount of wear after 6 hours of operation is 1.82 less than that of new samples made of steel 65G.

Experimental studies have shown that for cultivated paws, restored by welding angular plates made of steel 45, with sormite surfacing and vibrational hardening, the value of linear wear is 1.21...1.23 times less compared to that of new samples.

The increase in durability is due to the emergence in the surface layers of the material of the machined parts of the favorable compressing residual stresses, which contribute to greater hardening (compaction) of the material being machined [3].

The dynamics of wear (Table 2) showed that the amount of wear of the working bodies of tillage equipment is 1.28 times less when using vibrational plastic deformation.

As a result of our bench tests and property research, the option for restoring the ploughshare has been proposed, in order to increase the resource by welding steel 45 tires with an automatic surfacing of sormite and subsequent vibration treatment. Steel 45 is close to L-53 steel in terms of carbon content and provides good fusion quality.

The disadvantage of using vibration oscillations in recovery is the increased noise level of the installation during its operation. To reduce noise, it is necessary to provide for a good insulation of the installation from the floor of the shop where it is installed.

Our study has found that the vibrational hardening makes the structure of the metal more fine-grained, there is a greater fragmentation of the grains of the machined material and an increase in their number (Fig. 5). This, in turn, causes the activation of dislocations in all grains adjacent to the surface, and, in the process of sliding, their structure becomes more homogeneous. During vibration deformation, as a result of the crushing of grains, the length of their boundaries increases and thus more zones of accumulation of dislocations are formed. This can explain the mechanism of hardening.

Based on the results of our study and experiments, a comprehensive technological instruction on the process of hardening and restoration of arrow cultivated paws has been developed and implemented. The research carried out in cooperation with PAO Spetlesmash (Lubny, Poltava region) allowed this enterprise to adopt the developed technology using the vibrational hardening of the blades of cultivating paws during their manufacture.

Further research should be undertaken to establish the impact of treatment parameters on durability for different regions with different soil structure.

7. Conclusions

1. The wear of the cutting elements of tillage bodies under different hardening methods depends on the type of machining, material, technological modes, and working time. For ploughshare subjected to vibrational hardening, the amount of wear after 6 hours of operation is 1.82 less than that of new samples made of steel 65G.

2. Our study of durability has shown that the amount of wear of the working bodies of tillage equipment is 1.28 times less when using vibrational plastic deformation. Accordingly, when restoring ploughshares, in order to increase the resource of working bodies, it is more expedient to use the method whose essence is the welding of steel 45 tires with sormite surfacing and vibration treatment.

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