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UDC 621.793/.795
DOI: 10.15587/1729-4061.2017.97534

RESEARCH OF WEAR RESISTANCE OF BRONZE BUSHINGS DURING PLASTIC VIBRATION DEFORMATION

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Досліджено технологічний процес пластичної обробки бронзових втулок методом вібраційного деформування. Отримано параметри процесу вібраційного деформування бронзових втулок сільськогосподарської техніки. Досліджені механічні властивості відновлених деталей і їх вплив на експлуатаційні показники робочих поверхонь. Визначено механізм підвищення зносостійкості оброблених вібраційним деформуванням деталей

Ключові слова: вібраційне деформування, пластичність, бронзова втулка, зносостійкість, механічні властивості, відновлення, зміцнення

Исследован технологический процесс пластической обработки бронзовых втулок методом вибрационного деформирования. Получены параметры процесса вибрационного деформирования бронзовых втулок сельскохозяйственной техники. Исследованы механические свойства восстановленных деталей и их влияние на эксплуатационные показатели рабочих поверхностей. Определен механизм повышения износостойкости обработанных вибрационным деформированием деталей

Ключевые слова: вибрационное деформирование, пластичность, бронзовая втулка, износостойкость, механические свойства, восстановление, упрочнение

1. Introduction

Equipment performance is the ability to perform preset functions in the process of operation. It is estimated by comparing the actual values of parameters with the specifications. The use of new technological processes in the manufacture and reconditioning of parts contributes to the reliability of agricultural machines and units. Insufficient reliability leads to a significant increase in reconditioning and operating costs [1].

A large number of parts made of non-ferrous metals and alloys are used in agricultural machinery. These materials have high antifriction properties and corrosion resistance. They also withstand considerable specific loads and high speeds. Most often these are bronze "bushing" type plain bearings [2].

In practice, vibration treatment is a highly effective method of increasing the wear resistance of machine parts. Thus, the urgency of the work lies in a comprehensive study of vibration treatment of bushings of agricultural machinery. However, this requires determining the optimum values of process parameters.

2. Literature review and problem statement

The use of vibrations has some advantages over conventional treatment methods. This is due to the harmonic vibrations of a workpiece or tool [3]. In [4], the authors note an increase in the metal fatigue resistance under vibro-impact loading. Also, the mechanical properties of a working surface during vibration centrifugal hardening are improved [5]. According to the author [6], application of vibration technologies contributes to resource saving. The authors of [7, 8] also indicate a change in physicomechanical properties of the processed material and the intensifying effect of vibrations. However, there is a lack of data on certain types of parts.

Vibration treatment is characterized by a periodic separation of the surface of the active part of the tool from the treated surface of the part, which leads to a microprocess of unloading of these surfaces. The dynamic effect increases with increasing parameters such as vibration amplitude and frequency [9]. These parameters, as the authors [10] note, have a significant impact on the surface hardening of workpieces.

The wear resistance of the parts subjected to vibration treatment is largely determined by the depth of the hardened layer. However, the authors [11] indicate the lack of specific recommendations for determining its values in the literature.

Therefore, a comprehensive research on vibration deformation of parts is needed.

3. Goals and objectives

The goal of the experimental research was to increase the wear resistance of bronze bushings of agricultural machinery through reconditioning by the method of vibration deformation.

To achieve this goal, it is necessary to accomplish the following objectives:

– to justify the process parameters of vibration deformation of bronze bushings of agricultural machinery, providing an increase in their wear resistance;

– to analyze the mechanical properties of the parts subjected to vibration deformation.

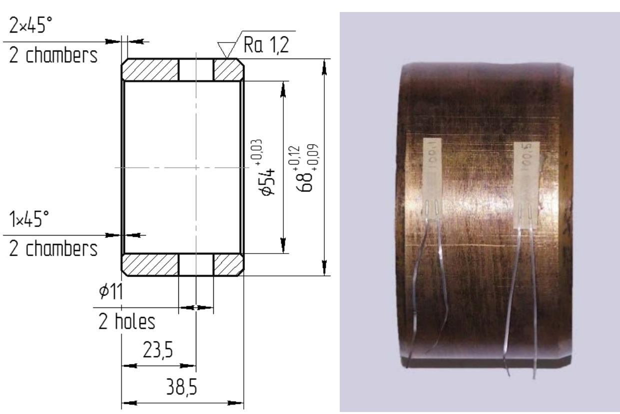
4. Materials and methods of experimental research on increasing the wear resistance of bronze bushings under vibration deformation

4. 1. Experimental materials and equipment

To get the results of the research of the parameters and characteristics of materials under vibration deformation, the experiments were carried out on specimens and on natural worn-out parts.

The specimens are made of BrOTsS 5-5-5 bronze (Fig. 1) of two dimensional groups: the first – L=38.5 mm; d==68 mm; d_0=54 mm; the second – L=30 mm; d=68 mm; d_0=54 mm.

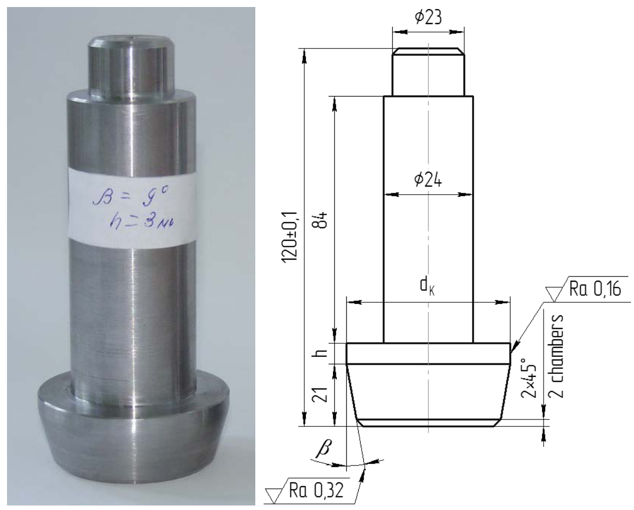
The inner surface of the specimens was treated with the U7 tool steel punch.



a *b*

Fig. 1. Test specimens: *a* — specimen designs; *b* — specimens of camshaft bushings of YaMZ-236 engines with strain gauges

The punches (Fig. 2) were subjected to oil quenching to a temperature of 780–800 °C, tempering at a temperature of 400–420 °C, ageing for 15–20 min, and cooling. The hardness of the working part of the punch was 55–58 HRC, and of the shank – 40–45 HRC. For determining the optimum angle of the treatment tool (punch) during normal and vibration deformation of bronze bushing specimens, the experimental research was conducted with the following angles β: 8°, 9°, 10°.



a *b*

Fig. 2. Hole punches:
a — a general view; *b* — a structural diagram

Deformation of the bushings was carried out both with lubrication and with no lubrication. Grease A and engine oil were used as lubricants.

The experimental research of deformation of bushing specimens and parts by the method of vibration deformation was carried out on an installation, whose general view is shown in Fig. 3. The main units of the installation are a vibration exciter (1), a base (2) and a hydraulic lifting system (3). The bed and auxiliaries provide attachment of the vibration unit, and also create reliable isolation of the entire installation from the floor.

Fig. 3. The general view of vibration installation:
1 — a vibration exciter; 2 — a base;
3 — a hydraulic lifting system

Vibration installation allows performing such operations as distribution, compression and hardening. The required operating parameters are set on the installation using the vibration unit. The operating parameters include the vibration amplitude and frequency, as well as the speed of the treatment tool.

4. 2. Methods for determining the mechanical properties of treated parts

The metallographic research was carried out on grinding plates made of camshaft bushings, treated by conventional and vibration deformation. For a research of the revealed structure at 100–400 magnification, the MIM-8M microscope was used.

The roughness of the treated surfaces was measured by the portable profilometer 253 by the R_a parameter.

The research of the surface wear of the reconditioned parts was carried out by the MI-1M machine. The test modes were chosen from the operating conditions of the conjugate pair: the roller speed was 550 min^{-1}, the load – 460 N.

5. The results of the research on increasing the wear resistance of bronze bushings under vibration deformation

It was experimentally revealed that the amount of the metal shifted to the bushing end depends on the angle β, machining allowance and deformation rate. With an increase in the punch speed, the mass of the metal shifted to the bushing specimen end increases. The machining allowance was within 0.1–0.4 mm.

The values of the metal shifted to the specimen ends at different punch angles and deformation rate of 0.03 m/s are shown in Fig. 4.

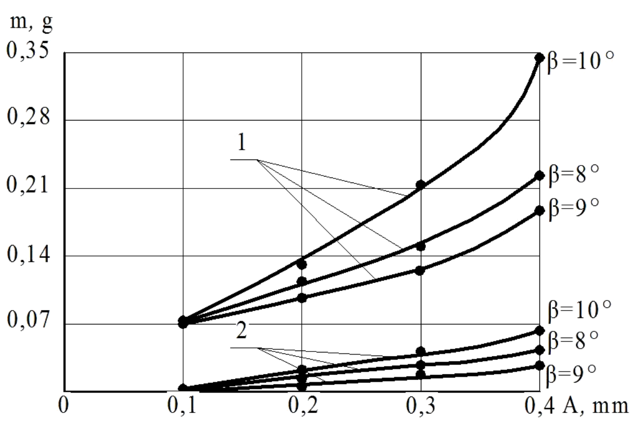


Fig. 4. Variation of the mass m of the metal shifted to the bushing end at different punch angles β: 1 — normal deformation; 2 — vibration deformation

The research found that the smallest amount of the shifted metal was at the punch angle β=9°. Under vibration deformation, the intensity of the metal shifting to the end of the bronze bushing with a length L=38.5 mm is much lower compared to normal distribution. Thus, at the punch angle β=9° and allowance A=0.4 mm, the mass of the shifted metal under vibration deformation is 6.5 times smaller in comparison with normal distribution.

For determining the impact of the height of a *gauge* part of the tool on the quality of the treated surface of parts, the punches were made with the *gauge* part height of 3, 4, 5, 6 and 7 mm. The research was carried out on specimens with a length of 38.5 mm and allowance of A=0.4 mm under normal and vibration deformation.

Table 1 gives experimental data on variation in the roughness of the specimen surface at different heights of the punch *gauge* surface.

Table 1

Variation of the R_a parameter of the specimen surface

Gauge part height h, mm	R_a values, μm	
	Vibration deformation	Normal deformation
3	2.2	3.8
4	0.8	2.6
5	0.9	2.9
6	1.5	3.6
7	1.7	6.2

The data in the table show that the lowest roughness value of 0.8–0.9 μm for vibration deformation was obtained at a height of the punch *gauge* part of 4–5 mm. Under normal deformation, the smallest roughness was 2.6–2.9 μm.

For the deformation process assessment, it is necessary to know the values of the specimen treatment forces under normal and vibration deformation.

In the course of the research, the deformation forces were determined by means of a pressure gauge and strain gauges. Fig. 5 shows the graphical dependencies of variation in deformation forces of specimens for different allowances under normal and vibration deformation.

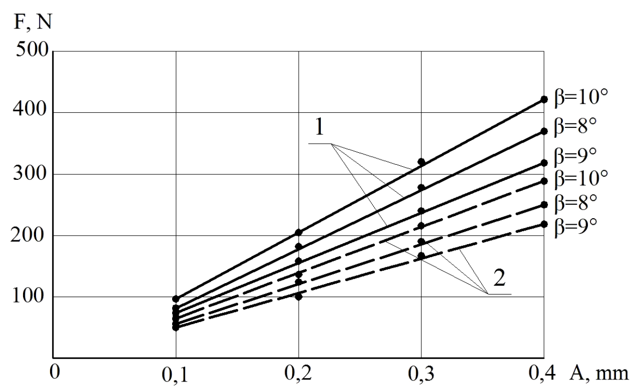


Fig. 5. Variation of deformation forces F from the punch angle β: 1 — normal deformation; 2 — vibration deformation

As can be seen from Fig. 5, with increasing the machining allowance and the punch angle, deformation forces increase both under normal and vibration loading. The nature of the curves is identical. The variation of the deformation force of the BrOTsS 5-5-5 bronze specimens with the machining allowance A=0.4 mm and the punch angle β=9° is 1.15 and 1.33 times lower than at the angles β=8° and β=9°, respectively.

The research shows that the treatment force depends on the vibration amplitude of the treatment tool – punch. The research was carried out at the following amplitudes: 0.5; 1.0 and 1.5 mm (Table 2).

In Table 2, the lowest deformation force is observed at the vibration amplitude of the treatment tool A=1.0 mm. Such values provide optimum deformation conditions. With an allowance A=0.4 mm and amplitude A=0.5 mm, the treatment force is 1.19 times lower than at an amplitude

A=1.5 mm. This is due to the joint action of static and cyclic (dynamic) stresses, which facilitates the movement of slip lines and, consequently, reduces the deformation force.

Table 2

Variation of the vibration deformation force at different amplitudes A, β=9°

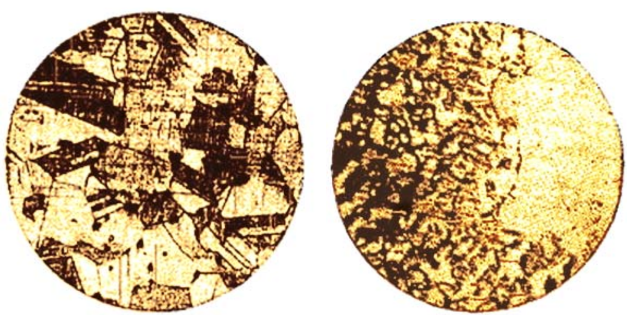
A=0.5 mm		A=1.0 mm		A=1.5 mm	
Allowance A, mm	Force F, N/m^2	Allowance A, mm	Force F, N/m^2	Allowance A, mm	Force F, N/m^2
0.1	56	0.1	50	0.1	67
0.2	116	0.2	102	0.2	128
0.3	182	0.3	161	0.3	195
0.4	240	0.4	217	0.4	258

For a comparison of the material quality of the bushing specimens subjected to normal and vibration deformation, the metallographic research was carried out on polished sections made of camshaft bushings.

The properties of bronze are determined by its microstructure, i.e. the type and composition of structural components, which, in turn, are determined by the phase composition [12].

Fig. 6 shows the microstructure of specimens after normal and vibration deformation.

The microstructure examination showed that vibration deformation provides a more fine-grained and uniform structure in comparison with normal treatment.



a *b*

Fig. 6. Microstructure of BrOTsS 5-5-5 bronze specimens at ×100 magnification: *a* — normal deformation; *b* — vibration deformation

The depth of the deformed layer was determined using the reticle eyepiece. The eyepiece interval was 650 μm under normal deformation, and 950 μm under vibration deformation.

An increase in the deformation depth induces hardening of the layers of the specimens that are in contact with the treatment tool. Hardening under vibration loading occurs more vigorously.

The wear resistance tests were performed for 18 pairs of specimens (6 pairs of specimens made of new parts, 6 pairs of specimens after normal distribution and 6 pairs after vibration deformation).

The wear rate of the friction pair parts was estimated by the average mass loss as a result of the tests. Duration of tests made up 2 hours.

The research results showed that the average wear rate of rollers was 0.0673 g for those made of new parts, 0.0772 g – after normal deformation, and 0.0682 g – after vibration deformation. The average wear rate of pads was 0.0904 g, 0.1106 g and 0.0920 g, respectively (Table 3).

Table 3

Results of the research on wear resistance of specimens

Friction pair number	Parts	Pad wear rate, g	Roller wear rate, g	Average pad wear rate, g	Average roller wear rate, g
1	New	0.0904	0.0691	0.0904	0.0673
2		0.0920	0.0679		
3		0.0908	0.0652		
4		0.0913	0.0686		
5		0.0905	0.0690		
6		0.0903	0.0642		
7	After normal deformation	0.1140	0.0765	0.1106	0.0772
8		0.1111	0.0776		
9		0.1065	0.0770		
10		0.1113	0.0795		
11		0.1085	0.0783		
12		0.1121	0.0743		
13	After vibration deformation	0.0972	0.0683	0.0910	0.0682
14		0.0951	0.0676		
15		0.0902	0.0689		
16		0.0907	0.0680		
17		0.0856	0.0673		
18		0.0944	0.0691		

Table 3 shows that the wear rate of pads and rollers under vibration deformation is respectively 1.2 and 1.13 times lower than under normal distribution.

6. Discussion of the results of the research on increasing the wear resistance of bronze bushings under vibration deformation

Under normal deformation, the variation of the amount of the metal shifted to the bushing end is non-linear within the allowances P=0.1...0.4 mm, and under vibration deformation – almost rectilinear. The smallest amount of the material shifted to the specimen end during deformation was at the punch angle β=9°. This is due to the fact that at smaller angles, the contacting surface of the punch with the treated bushing increases. Consequently, the number of contact points increases, thereby increasing the material adhesion. With an increase in the punch angle, the contact surface decreases, thus increasing the specific pressure and the amount of the adhered material.

Under vibration deformation of a hollow specimen, repeated separations of the treatment tool decrease the friction force, which reduces the material shift along the specimen (to its end) and increases the radial deformation rate. The emerging additional circumferential tensile stresses facilitate the metal movement in the layers adjacent to the punch. As a result, the central layers get a greater elongation, which contributes to the appearance of additional longitudinal and tangential tensile stresses in outer layers and compressive stresses in central layers.

The research has shown that vibration loading leads to an alignment of the structure. It becomes more uniform and fine-grained. Under deformation, more fine grains are formed and favorable conditions for dislocation generation are created. Dislocations promote an increase in the radial deformation rate. The obtained data confirm the earlier theoretical research [13].

Under vibration deformation, grains are also crushed and directed towards the treatment force. The number of grains, whose slip planes are located at 45° to the applied force increases. First of all, the conditions for plastic slip deformation are created in them, since shear stresses in these planes reach the maximum values. This creates conditions for free movement of dislocations and formation of new ones. When the treatment tool comes in contact with the bushing, the deformation rate increases, along with the number of defects in the crystal structure. This complicates the dislocation movement and leads to hardening, which helps to reduce the wear rate of the working surface of parts.

Under normal deformation, the trajectories of the maximum shear stresses will be at 90° to the specimen surface, under vibration deformation – at 45°. This is due to cyclic separation of the punch from the treated surface. Consequently, under vibration deformation, the slip lines will intersect the treated surface at an angle varying from 45° to 90°. Therefore, the force and rate of radial deformation under vibration deformation will be greater compared to normal distribution. This promotes greater compaction (hardening) of the workpiece surface.

7. Conclusions

1. The analysis of the experimental research has revealed the technical possibility of using vibrations for reconditioning and hardening of "bushing" type parts.

2. Based on the results of the experimental research, the process parameters of vibration deformation of bronze bushings: vibration amplitude A=1.0 mm; machining allowance A=0.4 mm; the punch angle β=9°; the height of the punch gauge part h=4–5 mm are obtained. These parameters allow reconditioning of worn-out surfaces. Also, they can be used for treatment of new parts. Vibration treatment allows reducing the operational wear by 1.2 times. This indicates a higher wear resistance of the parts reconditioned by vibration deformation, compared with non-vibration deformation.

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Досліджено загасання інфразвуку в сталях Х18Н9Т і 12Х18Н10Т із плазмовими покриттями на основі ($NiAl-SiO_2 \cdot Al_2O_3$). Встановлений вплив покриттів складної мікроструктури з наноскладовими у вигляді аеросилів на параметри внутрішнього тертя досліджуваних композицій. На температурному спектрі за наявності покриттів виявлені аномалії у вигляді піків різної фізичної природи. Запропонований критерій демпфування покриттів із наноскладовими

Ключові слова: плазмове покриття, внутрішнє тертя, демпфування, наноскладові, аномальні властивості, модуль пружності

Исследовано затухание инфразвука в сталях Х18Н9Т и 12Х18Н10Т с плазменными покрытиями на основе ($NiAl-SiO_2 \cdot Al_2O_3$). Установлено влияние покрытий сложной микроструктуры с наносоставляющими в виде аэросилов на параметры внутренего трения исследуемых композиций. На температурном спектре при наличии покрытий выявлены аномалии в виде пиков различной физической природы. Предложен критерий демпфирования покрытий с наносоставляющими

Ключевые слова: плазменное покрытие, внутреннее трение, демпфирование, наносоставляющие, аномальные свойства, модуль упругости

UDC 539.375.5:621.793.74
DOI: 10.15587/1729-4061.2017.97343

A STUDY OF INTERNAL FRICTION ANOMALIES IN STAINLESS STEEL WITH NANOSTRUCTURED PLASMA COATING

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1. Introduction

In conditions of exposure to temperature fields and deformations, it is important to ensure dynamic strength and vibration reliability of structural elements, which can be achieved by increasing of their damping capacity. Damping, along with other properties, is an independent physico-mechanical property of metals and alloys [1, 2]. The damping capacity of structural materials can be increased by applying an appropriate functional metal coating [3, 4], in particular, by plasma sputtering [5, 6]. Coating materials include powders of different compositions – metallic [4, 7], ceramic [8], nanostructured [9, 10], and plated [11]. The damping capacity of materials can be characterized by means of the parameters of their internal friction (IF) [2, 7, 12].

Analysis of the IF measurements reveals additional information on structural and phase features of various zones along the composition cross section [5, 13, 14]. Research on the temperature and the amplitude dependences of internal friction (TDIF and ADIF) allows formulating the basic provisions of the mechanism of high damping, depending on the composition and structure of the coatings [5, 14, 15]. At the same time, research on the energy dissipation on TDIF and ADIF in coated structural materials reveals a change in the general background and the appearance of new anomalies [13, 14]. Such circumstances necessitate additional research to better understand these phenomena.

In such conditions, the issue of the damping capacity of coatings (DC), that is the issue of the damping criterion, is topical. The issue of compatibility of the damping capacity with other physico-mechanical properties of the “base-coating” system as a whole remains important.

2. Literature review and problem statement

The problem of increasing the dynamic strength and the related damping properties involves various areas of engineering, aerospace engineering, turbine construction, and transportation.

An effective means of combating vibration is the use of damping materials such as cast iron, composite materials, as well as steel based on Fe–Cr and Fe–Cr–V. However, with the exception of cast iron, they all find little use, which is due to low mechanical properties, high cost, or low heat resistance. The application of damping materials such as coatings on structural steel rationally combines the mechanical strength of the base and the damping capacity of the coating. There exist metal antifriction plasma coatings [4] as well as coatings of polymeric materials and composites [7] that are applied to steel to reduce vibrations by means of electroplating [16].

The effect of plasma single and multicomponent coatings on the parameters of IF has been tested on a number of systems, where iron [17] and high-alloy steels [4, 15] were chosen as bases. At the same time, the research has revealed that it is possible to increase the damping properties of the matrix due to coatings, both without treatment and after thermal diffusion treatment.

In aviation turbine construction, for example, the damping capacity of turbine blades that are made of special alloys is commonly increased due to vacuum condensates, including reinforcing nanocomponents [9, 18]. It was found that the damping capacity of coatings alongside the physical and mechanical properties of coated materials depend on the production parameters and the structure of these coatings [18]. At the same time, the available data reveal the fact of