Обговорюється проблема підвищення ресурсу машин та деталей за рахунок більш ефективних технологій в машинобудуванні, як при виготовленні, так і в ремонтному виробництві при відновленні. Основною метою дослідження є обґрунтування і вибір більш ефективного методу підвищення довговічності та надійності деталей поршневої групи двигунів внутрішнього згоряння з урахуванням конструктивних і матеріалознавчих факторів. Розроблено технологічний процес відновлення деталей вібраційним деформуванням, особливостями якого є періодична дія робочого органу на оброблювану поверхню. Визначені параметри технологічного процесу вібраційного зміцнення: швидкість деформування υ=0,030 м/с, припуск на обробку П=2,0 мм, робочий орган – пуансон з кутом нахилу β=11°, висотою калібруючого пояска h=4 мм. Проаналізовано умови і тривалість експлуатації досліджуваних деталей, методи попередньої обробки, способи відновлення та матеріал. Аналіз чинників, що визначають інтенсивність зношування робочих поверхонь деталей, дозволив розробити технологічний процес зміцнення як при виготовленні в машинобудуванні, так і відновленні в ремонтному виробництві. Досліджено схеми конструктивного рішення вібраційної установки для вибору більш високої ефективності технологічного процесу. Виявлено підвищення пластичності деталей на 21...27 % при використанні вібраційних коливань. В результаті проведення комплексу досліджень і експериментів запропонована технологія відновлення втулок верхніх головок шатунів методом вібраційного зміцнення. Суть та особливості її полягають в компенсації зношеного робочого шару пластичним вібраційним деформуванням, при роздачі пуансоном неробочого шару. Використання даної технології дозволяє отримати поверхню з підвищеною зносостійкістю. Результати отриманих досліджень можуть бути використані в машинобудівному виробництві для зміцнення зазначених деталей при виготовленні

Ключові слова: пластичне деформування, вібраційна обробка, зносостійкість, шорсткість поверхні, інтенсивність і швидкість деформування

UDC 621.793/.795
DOI: 10.15587/1729-4061.2018.130999

INFLUENCE OF THE HARDENING TREATMENT OF A MACHINE PARTS' MATERIAL ON WEAR-RESISTANCE

A. Dudnikov
PhD, Professor, Head of Department*
E-mail: anatolii.dudnikov@pdaa.edu.ua
I. Dudnikov
PhD, Associate Professor
Department of Industry Mechanical Engineering**
E-mail: mech@pdaa.edu.ua
A. Kelemesh
PhD*
E-mail: antonkelemesh@gmail.com
O. Gorbenko
PhD, Associate Professor*
E-mail: gorben@ukr.net
*Department of Technologies and Means of Mechanization of Agricultural Production**
**Poltava State Agrarian Academy
Skovorody str., 1/3,
Poltava, Ukraine, 36003

1. Introduction

Plastic deformation at machining should be regarded not only as a method for obtaining the required shape and size of parts but also as a material strengthening technique, which has a significant influence on operational performance. Using effective methods of machining helps in turn improve the durability of machine components.

The problem of durability improvement has acquired relevance in connection with the creation of the newest high-performance machines operating under heavy loads and speeds. Enhanced machine resource is largely achieved through the restoration of parts, which produces a positive effect on improving the indicators of reliability and utilization of equipment [1].

Enhancing wear resistance of surfaces of machine parts necessitates development and implementation of effective methods of strengthening. The application of a comprehensive technology for the restoration and strengthening of machining tools based on vibratory oscillations could prove to be an important and relevant direction for the agroindustry in Ukraine.

The practice of repairing production quite often employs restoration of worn-out parts of the bushing type: a piston pin, a bushing of the conrod upper head, a bushing of the oil gear, a rocker arm bushing, etc. The amount of wear depends on several factors: conditions, duration of operation, methods of pretreatment, material, restoration options, etc.

Restoration of the worn-out parts using plastic deformation and reuse could greatly reduce repair costs and relieve the industry of manufacturing spare parts for machines.

The essence of restoration implies that worn-out parts regain the size and shape to ensure standard performance, specified by technical specifications. The practice of repairing production employs various techniques of restoration.

The most common one is a technique of plastic deformation, based on the properties of metals and alloys (dispensing, crimping). The essence of both processes implies the displacement, under pressure, of a material of parts brought to the plastic state.

In the practice of repairing production the most common restoration method is the restoration of specified parts using dispensing. It should be noted that the process of shape formation is largely influenced by the inclination angle of a machining working body (punch) and the tolerance magnitude (tightness) for processing.

The existing pressure metal processing theory mainly describes data on such technological machining processes as free forging, bulk punching, rolling.

When machining parts of the bushing type, there are no guidelines for determining the magnitude of deformation, the inclination angle of a punch, its roughness, and the magnitude of a calibration belt.

Improving the plasticity of a components' material enhances efficiency of the deformation process. Therefore, it is an important task is to obtain such a state of the parts' material that would enable machining under pressure without preheating.

2. Literature review and problem statement

The application of mechanical oscillations of various spectrum in technological processes (finishing and hardening treatment, vibratory-stabilizing treatment, change in the parameters of a process and material condition, etc.) has good prospects. The interest from specialists in various fields to this issue will definitely grow [2]. At the same time, the application of vibratory oscillations is considered only in terms of reducing an abrasive wear.

The longest durability of parts and assembly units is achieved when implementing advanced technologies in order to improve the properties of materials, in particular using vibratory oscillations. That can be achieved by employing different structural designs during a deformation process under pressure, as well as mechanical machining [3]. However, the scheme proposed in a given paper does not make it possible to use it for the restoration of components.

Maintaining strength characteristics and durability indicators of treated surfaces is achieved by the formation of optimal structure of surface layers [4]. Specifically, that involves using the direction of oscillations. However, the issue was not fully investigated in a given work, which imposes certain limitations on the applicability of the proposed solutions.

Technological processes based on vibratory oscillations enable the following: to intensify the existing technological processes; to develop new materials treatment techniques; to reduce energy costs and significantly improve the quality of treatment [5]. This study confirmed the improvement of efficiency of a technological process when using vibratory oscillations. However, despite the advantages, still unresolved is the task on finding the optimal parameters at plastic deformation.

Analysis of paper [6] reveals that most worn-out machine parts and assembly units have a high residual value. When restoring, they use 20...30 times less material than at manufacturing new ones. Over 90 % of defective parts have a wear of 0.1...0.3 mm, that is, they lost 0.05...0.10 % of their mass. About 65...75 % of the specified parts can be restored [7]. The authors of studies consider the issue only conceptually, there is therefore a need to examine this issue in more detail.

Work [8] reports research into durability improvement of carbon steel at different ways of treatment. However, the author does not reveal the possibilities of application of plastic treatment of products made of non-ferrous metals for the components of agricultural machinery. The study has shown that upsetting reduces the volume of bushings at the expense of material compaction. The bronze bushings volume was reduced by 1.035 % at a compression pressure of 1,300 MPa compression [9].

A systematization of the results of cited research suggests that there are no optimum parameters for the technological process of vibratory deformation. Therefore, it is necessary to examine the relationships in order to obtain such quality of strengthening surface of parts (piston pins, bushings of engine crankshafts upper heads, etc.) that would ensure increased wear resistance.

3. The aim and objectives of the study

The aim of present work is to study wear resistance of machine elements of the «bushing» type when restoring using a method of vibratory hardening.

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

– to investigate the effect of parameters of machining and the working tool at a standard deformation and a vibratory deformation;

– to assess the wear resistance of parts at different methods of restoration.

4. Materials and methods for experimental study into the influence of hardening treatment of bushings at a vibratory deformation

An important role belongs to the schematic design of a vibratory machine, which greatly influences the accuracy of centering the machining tool (punch) and the restored part. To this end, a vibratory installation was built based on two structural schemes.

The first variant (Fig. 1, *a*) implies that the part to be restored is stationary while a vibrating punch is moved using a hydraulic system thereby performing the process of deformation (dispensing).

For the second variant (Fig. 1, *b*) vibrator (7) is mounted on the plate (10) with four rollers (9) fixed at its edges. The rollers move along guide plates (8) with a certain curvature, fixed to racks (12).

For the second design of a vibratory installation, the vibrator, along with a plate and a punch, perform oscillations around neutral position. A matrix holding the part displaces towards a vibrating punch. This is the way a technological process of the deformation of a material of the part is carried out. Such a design of the installation has two drawbacks. First, the displacement of rollers of the vibrator plates along a certain curvature of plates creates additional noise during operation. Second, it is more difficult to enable the centering between a punch and a part.

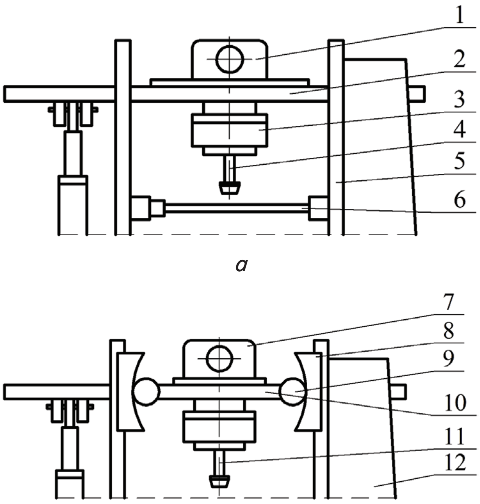

Fig. 1. Designs of various variants of the vibratory node of the vibration installation: *a* – first variant; *b* – second variant; 1, 7 – vibratory exciter; 2, 10 – plate of the vibratory exciter; 3 – chuck; 4, 11 – punch; 5 – guide; 6 – tie; 8 – guide plate; 9 – roller; 12 – rack

The studies were carried out using the installations built in line with the shown structural designs. The data obtained demonstrated a higher efficiency of the deformation process for the installation whose diagram is shown in Fig. 1, *a*. The hardness of the material at the inner surface of the part is 1.35...1.42 times larger than that of parts machined in line with the second structural scheme. That relates to the higher sub-structural hardening of the machined part's material at which the stressed state at all points of the treated material is the same. A significant influence is exerted by the following: a shape of the machining tool, heterogeneity of the physical properties of a material and the shape of a deformed part, external friction, etc.

To identify the rational shape of the working tool at a standard deformation and a vibratory deformation, the punches were made in the form of a ball and a cone (Fig. 2).

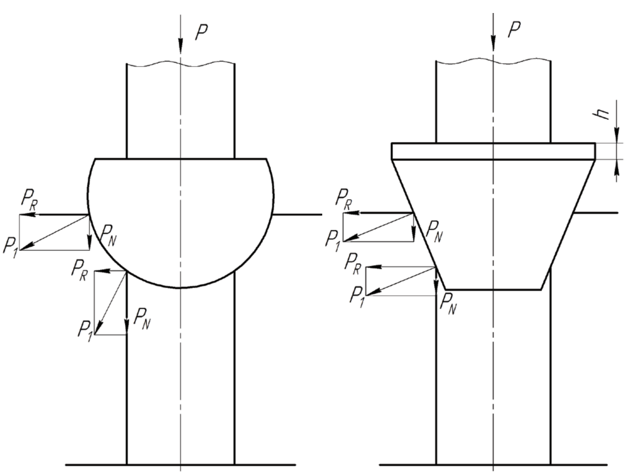

Fig. 2. Bushing dispensing diagram by a punch: *a* – ball shape; *b* – conical shape

Force *P* that acts on the punch is decomposed into two components, one of which is tangential to the point of a ball-shaped punch and forming a cone shape. The second component P_1 acts perpendicular to the tangent line at the point on the surface of the ball shape and to the forming conical surface of the punch. In turn, the component P_1 is decomposed into force P_R, directed along a radius of the bushing, and force P_N, acting in the direction of punch movement.

The dispensing diagram shows that effort P_R is spent on the deformation of the bushing in radial direction, and effort P_N – on the displacement of the material along the length of the bushing.

Upon deformation, a mass of the metal displaced to the end of the sample was determined by weighing at the analytical scale VLA-200M with a measuring accuracy of 0.0001 g.

5. Results of studying wear resistance of bushings in engine connecting rods upper heads

5. 1. The influence of machining parameters, as well as parameters of a working tool, at a standard deformation and a vibratory deformation

To determine optimal machining parameters, as well as parameters of a working tool, at a standard deformation and a vibratory deformation, we studied deformation rates, machining tolerance, the magnitude of punch inclination angle, the height of a calibration belt.

We investigated the influence of punch motion speed on the magnitude of machined material sticking on the surface using the samples with a length of 110 mm. The rate of deformation was 0.015; 0.030; and 0.045 m/s.

Results of the studies conducted (Table 1) showed that both at a standard deformation and a vibratory deformation an increase in the deformation rate leads to an increase in the amount of metal that sticks resulting to a decrease in the quality of the machined surface.

Table 1

Amount of the metal that sticks depending on the deformation rate

Tolerance magnitude *A*, mm	Deformation rate υ, m/s	Amount of the metal that sticks, g	
		St.3	Bronze BrTZL 5-5-5
Vibratory deformation			
2.0	0.15	0.023	0.044
	0.30	0.025	0.049
	0.45	0.030	0.058
2.5	0.15	0.036	0.063
	0.30	0.040	0.072
	0.45	0.048	0.087
Standard deformation			
2.0	0.15	0.064	0.113
	0.30	0.080	0.144
	0.45	0.107	0.197
2.5	0.15	0.087	0.156
	0.30	0.104	0.197
	0.45	0.140	0.251

At a vibration loading, an increase in the deformation rate leads to a slight increase in the amount of the metal that sticks. During standard machining the intensity of sticking to the surface of a punch is considerably greater than that at a vibratory deformation.

Thus, at a deformation rate of $\upsilon=0.030$ m/s, a machining tolerance of $A=2.5$ mm, and a length of the steel sample of $l=110$ mm, the amount of metal that sticks under a normal loading is 2.6 times larger than that at a standard machining.

At a deformation rate of 0.045 m/s the amount of metal that sticks increases under a normal loading by 1.37 times, and at a vibratory loading – by 1.2 times compared to the amount of metal that sticks at a deformation rate of 0.030 m/s.

That can be explained by the fact that an increase in the punch motion speed leads to a decrease in the deformation duration while a temperature in the contact area increases. This creates more favorable conditions for setting a material and its sticking to the punch surface.

Based on the research conducted, it was established that plasticity increases by 21...27 % at a vibratory deformation.

The study revealed that at a machining tolerance $A=2$ mm under conditions of standard deformation with a punch inclination angle of $\beta=11°$ and a deformation rate of 0.03 m/s the mass of the displaced metal amounted to 1.148 g, and at a vibratory deformation reached 0.562 g, which is 2.04 times greater.

Height of the punch calibrating part h exerts a significant effect on the roughness of the machined surface of a part. We fabricated punches in line with a height of the calibrating part of 3, 4, and 5 mm. The study was carried out using the punches with inclination angle $\beta=11°$ at machining tolerance $A=1.5$ mm and length $l=110$ mm under conditions of a standard deformation and a vibratory deformation (Table 2).

Table 2

Changes in the surface roughness of machined samples

Height h of the punch calibrating part, mm	Vibratory deformation	Standard deformation
	Parameter R_z, μm	Parameter R_z, μm
3	6	9
4	4	8
5	5	11

An analysis of Table 2 indicates that the lowest machined surface roughness was demonstrated at height $h=4$ mm of the punch calibrating surface both at a standard deformation and a vibratory deformation.

A deformation effort was estimated by the magnitude of its intensity.

Table 3 gives data on a change in this magnitude depending on the tolerance, punch inclination angle, and the deformation method.

The magnitude of the deformation effort intensity at tolerance values of 0.5...1.5 mm and 2.0...2.5 mm during vibratory machining was, respectively, 1.6...2 and 3...4.5 times less. That was also confirmed by earlier studies undertaken when machining other parts [10].

Table 3

Deformation intensity values

Inclination angle, β	Intensity value									
	Vibratory deformation					Standard deformation				
	Machining tolerance, mm									
	0.5	1.0	1.5	2.0	2.5	0.5	1.0	1.5	2.0	2.5
10°	0.22	0.24	0.19	0.10	0.17	0.39	0.41	0.38	0.42	0.49
11°	0.23	0.24	0.20	0.10	0.18	0.39	0.41	0.39	0.43	0.48
12°	0.24	0.25	0.22	0.11	0.20	0.42	0.42	0.40	0.43	0.50

5. 2. Estimation of wear resistance of parts at different restoration methods

In order to conduct comparative studies of bushings in the tractor MTZ-82.1 connecting rods upper heads using the methods of standard deformation and vibratory deformation, the latter were machined by punches made of steel U9 with inclination angle $\beta=11°$. A punch head (working part) was tempered to a hardness of 60...65 HRC; a shank – 48...50 HRC. The bushings were machined at punch motion speed $\upsilon=0.030$ m/s. Bushings' internal diameter was measured in three sections for length and in four planes A–A, B–B, C–C, D–D (Fig. 3).

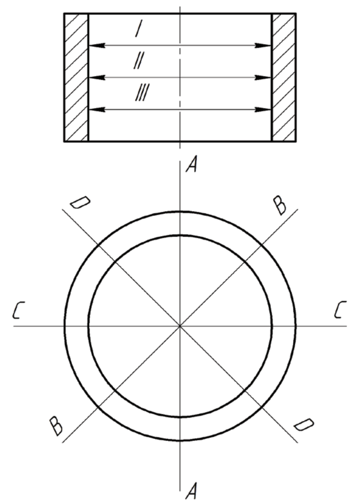

Fig. 3. Micromeasurement diagram of the connecting rod upper head bushing

Data on the micromeasurement of the connecting rods upper heads bushings, restored using a standard deformation and a vibratory deformation, are given in Tables 4, 5.

The magnitude of linear wear of bushings, restored using a vibratory deformation, is 1.81...1.95 times less than that at a standard dispensing.

The data obtained in the course of research into dispensing of samples-bushings using a standard deformation and a vibratory deformation demonstrated a higher effectiveness of the vibratory machining method. The magnitude of deformation in radial direction increased by 1.2 times, and for the length of the sample decreased by 2.2 times. A deformation effort reduced by 2.32 times while improving the structure of the material (which became more fine-grained). The amount of metal displaced at the end of the sample also decreased; the amount of metal that sticks on the punch working surface reduced as well [10].

The study into vibratory deformation of samples-bushings allowed us to argue about the feasibility of application of a vibratory method to restore such parts as piston pins, etc.

Table 4

Data on the micromeasurement of the connecting rods upper heads bushings, restored using a vibratory deformation

Cross-section number	Measurement plane			
	A–A	B–B	C–C	D–D
	Wear amount, mm	Wear amount, mm	Wear amount, mm	Wear amount, mm
Bushing 1				
1	0.039	0.038	0.041	0.040
2	0.035	0.033	0.034	0.032
3	0.038	0.040	0.039	0.038
Bushing 2				
1	0.040	0.041	0.039	0.039
2	0.031	0.034	0.033	0.032
3	0.039	0.040	0.038	0.038
Bushing 3				
1	0.038	0.039	0.038	0.040
2	0.032	0.031	0.033	0.032
3	0.037	0.038	0.039	0.039
Bushing 4				
1	0.037	0.038	0.039	0.040
2	0.031	0.032	0.033	0.032
3	0.035	0.036	0.037	0.038
Bushing 5				
1	0.039	0.040	0.038	0.039
2	0.032	0.032	0.033	0.033
3	0.038	0.038	0.039	0.039
Bushing 6				
1	0.041	0.040	0.041	0.039
2	0.032	0.030	0.033	0.031
3	0.039	0.038	0.039	0.038

Table 5

Data on the micromeasurement of the connecting rods upper heads bushings, restored using a standard dispensing

Cross-section number	Measurement plane			
	A–A	B–B	C–C	D–D
	Wear amount, mm	Wear amount, mm	Wear amount, mm	Wear amount, mm
Bushing 1				
1	0.076	0.073	0.075	0.074
2	0.065	0.061	0.063	0.056
3	0.072	0.070	0.071	0.068
Bushing 2				
1	0.074	0.080	0.77	0.74
2	0.061	0.062	0.58	0.58
3				
Bushing 3				
1	0.072	0.073	0.074	0.075
2	0.059	0.057	0.060	0.061
3	0.069	0.073	0.071	0.070
Bushing 4				
1	0.073	0.074	0.076	0.073
2	0.063	0.060	0.057	0.058
3	0.071	0.070	0.074	0.070
Bushing 5				
1	0.076	0.078	0.072	0.074
2	0.061	0.060	0.059	0.062
3	0.073	0.070	0.071	0.072
Bushing 6				
1	0.075	0.076	0.078	0.077
2	0.063	0.066	0.065	0.065
3	0.072	0.076	0.075	0.073

6. Discussion of results of studying the improvement of parts' wear resistance at a vibratory deformation

The study conducted has allowed us to develop a technology for the vibratory restoration of bushings of connecting rods upper heads in automobile and tractor engines.

A special feature of the technology is the use of vibratory oscillations during plastic deformation. Vibratory oscillations are initiated by the working body – a punch, which compensates for the worn-out layer a part's working surface. The chosen optimal parameters of a working tool make it possible to reduce the magnitude of deformation intensity. The advantage of a given technology is providing for a higher wear resistance compared to other existing techniques. The application of a given parts restoration process based on the proposed scheme eliminates a thermal influence on the structure of the surface layer. Enhanced wear resistance is a consequence of the uniform distribution of load between the microscopic volumes of parts. That results in a more fine-grained and uniform structure.

One should pay attention to the shortcomings that include a decreased machining tolerance, which could compromise performance efficiency. This notion might be considered when designing, as well as improving, pressure treatment technologies in mechanical engineering and repair production.

Present work is continuation of earlier studies that were based on the application of vibratory oscillations in technological processes.

7. Conclusions

1. We have investigated the influence of machining parameters, as well as parameters of working tools, at a standard deformation and a vibratory deformation. At deformation rate $\upsilon=0.030$ m/s, machining tolerance $A=2.0$ mm, punch inclination angle $\beta=11°$, calibration belt height $h=4$ mm, the magnitude of deformation effort intensity when using vibratory oscillations is 3...4.5 times less.

2. The proposed method for restoring the bushings of connecting rods upper heads makes it possible to reduce wear by 1.81...1.95 times compared to a standard dispensing. That becomes possible due to the uniform distribution of load between the microscopic volumes of parts, resulting in a more fine-grained and uniform structure.

References

1. Babichev A., Motrenko P. Vibration engineering technologies: experience in the application and development prospects // Strengthening Technologies and Coatings. 2015. Issue 8 (128). P. 3–5.
2. Dynamics of wear of the cutting elements of tillers / Dudnikov A., Belovod A., Pasyuta A., Gorbenko A., Kelemesh A. // Annals of Warsaw University of Life Sciences. SGGW: Agriculture (Agriculture and Forest Engeneering). 2015. Issue 65. P. 15–19.
3. Nikolaenko A., Hussein A. T. Modeling of vibrating machine-tool with improved construction // TEKA. Commission of motorization and energetics in agriculture. 2014. Vol. 14, Issue 1. P. 174–181. URL: http://www.pan-ol.lublin.pl/wydawnictwa/TMot14_1/Teka_14_1.pdf
4. Surface Modification of Products by Plastic Deformation and the Application of Functional Coatings / Belevskii L. S., Belevskaya I. V., Belov V. K., Gubarev E. V., Efimova Y. Y. // Metallurgist. 2016. Vol. 60, Issue 3-4. P. 434–439. doi: 10.1007/s11015-016-0310-y
5. Effects of vibration amplitude and relative grain size on the rheological behavior of copper during ultrasonic-assisted micro-extrusion / Lou Y., He J. S., Chen H., Long M. // The International Journal of Advanced Manufacturing Technology. 2016. Vol. 89, Issue 5-8. P. 2421–2433. doi: 10.1007/s00170-016-9288-7
6. Świercz R., Oniszczuk-Świercz D. Experimental Investigation of Surface Layer Properties of High Thermal Conductivity Tool Steel after Electrical Discharge Machining // Metals. 2017. Vol. 7, Issue 12. P. 550. doi: 10.3390/met7120550
7. Stotsko Z., Kusyj J., Topilnytskyj V. Research of vibratory-centrifugal strain hardening on surface quality of cylindric long-sized machine parts // Journal of Manufacturing and Industrial Engineering. 2012. Vol. 11, Issue 1. P. 15–17.
8. Korotkov V. A. Wear resistance of carbon steel with different types of hardening // Journal of Friction and Wear. 2015. Vol. 36, Issue 2. P. 149–152. doi: 10.3103/s1068366615020105
9. Povyshenie nadezhnosti detaley mashin poverhnostnym plasticheskim deformirovaniem / Dudnikov A. A., Dudnik V. V., Kelemesh A. A., Gorbenko A. V., Lapenko T. G. // Vibratsiyi v tekhnitsi ta tekhnolohiyakh. 2017. Issue 3 (86). P. 74–78.
10. Research of wear resistance of bronze bushings during plastic vibration deformation / Kelemesh A., Gorbenko O., Dudnikov A., Dudnikov I. // Eastern-European Journal of Enterprise Technologies. 2017. Vol. 2, Issue 11 (86). P. 16–21. doi: 10.15587/1729-4061.2017.97534