Use of pulsed roller rolling to increase the wear resistance of a bronze nut

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The paper presents the results of analysis of literature data and an assessment of the state of friction pairs after operation. It was established that long-term operation of screw mechanisms of metallurgical machines under conditions of high power loads and intense wear leads to loss of their performance due to wear or destruction. Analyzing the methods for increasing the performance of screw mechanisms, we can conclude that use of surface plastic deformation (SPD) methods to increase durability of friction pairs of large-sized screw-nut transmission parts is promising. Computer simulation of the process of final thread profile formation via pulsed roller rolling (PRR) was carried out. It was established that the maximal values of σ_i = 880 MPa, ε_i = 4.69 mm and a_y = 0.092 are achieved for a preformed profile by mechanical processing with concaveness in the form of a trapezoid with a triangle and subsequent PRR of samples made of BrO10F1 bronze. This technology allows maximal hardening of the zones adjacent to the thread concaveness, which ensures increased fatigue strength. The new technical solution, aimed at improving the combined method of forming trapezoidal threads (RF patent No. 2731949) for large-sized parts of the screw mechanism of a roasting machine of the OK-306 type, was developed. The research results showed that use of PRR for trapezoidal thread samples makes it possible to: increase surface microhardness of the samples made of bronze grade BrO10F1 by 2.6 times; provide thickness of the hardened layer up to 2.8 mm; reduce the surface wear rate for the samples by more than 12 times compared to the initial state. The tests on nuts made of bronze grade BrO10F1 were carried out in the conditions of JSC "Stoilensky Mining and Concentrating Plant" as a part of the tension device in the trolley conveyor of the OK-306 roasting machine. Hardening the working surfaces of PRR trapezoidal threads made it possible to increase the service life of the nuts by at least 2 times.
Key words: bronze, trapezoidal thread, nuts, pulsed roller rolling, microhardness, wear rate, friction pairs, surface plastic deformation.
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Introduction

Efficiency of metallurgical industry, one of the most important industries in RF economics, depends substantially on service life of applying machines and equipment. Many components of metallurgical machines consist of large-size screw mechanisms, such as screw mechanisms of rolling mill stands, tension devices of conveyors at concentrate pelletizing plants etc. [1, 2].

Screw mechanisms in metallurgical machines take up high forces arising during operation of an executive mechanism and operate often in the conditions of intensive wearing of the contact surfaces. Wear of screw mechanisms and, as a result, their destruction can cause unplanned downtimes of production processes and additional repair and maintenance expenses. Wear resistance is considered as a main workability criterion of screw mechanisms; it depends on the forces at the contact surfaces, geometric parameters of thread profile, screwing / unscrewing rates, presence of lubrication etc.

Despite use of high-strength and antifriction materials, long-time operation of screw mechanisms in metallurgical machines, in the conditions of high force loads and intensive wearing, leads their workability loss due to wear or destruction.

Bronze nuts in screw mechanisms of metallurgical machines and units should be replaced owing to wear unacceptability. Nuts are worn rather more quickly than screws, because hardness of screw surfaces on bronze nuts is principally lower than hardness of such surfaces on steel screws.

Analysis of worn surfaces in worked-out nuts allows to conclude that their wear is caused by tie effect of abrasive particles with irregular shape and high hardness. It is testified on the base of multiple scratches (traces of abrasive particles) on friction surfaces. Abrasive particles enter in the contact area "screw-nut" from outer medium due to insufficiently reliable friction pair protection. Abrasive particles are subjected to additional comminution as a result of their entering a friction area, and they are introducing in a nut working surface owing to low bronze hardness; it ensures largwe wear of an expensive screw component.

These parameters should be taken into account during engineering, fabrication and improvement of screw mechanisms in metallurgical machines. Thus, the researches directed on improvement of the processes for increase of operating resource and wear resistance of screw mechanisms nuts are rather actual.

Improvement of processing of internal trapezoid thread in a screw mechanism nut is the aim of this research. It is achieved by search and introduction of rational technological routes for surface plastic deformation, which provide increase of operating resource of a friction pair, rise of microhardness, improvement of roughness of working surfaces and decrease of destruction possibility on the base of practical realization of the method of hardening of contact surfaces in thread profile.

Materials and methods of the research

Large-size bronze nuts (BrO10F1 material) with trapezoid thread are the objects of the research. Their chemical composition and mechanical properties correspond to the requirements of GOST 613.

Microhardness measurement was carried out on a polished micro-sample using hardness meter Durascan 20 with load 100 g in correspondence with the GOST 9450.

Bronze samples of BrO10F1 material for wear in initial state and after PRR were tested according to the technique published in the work [3].

Results and discussion

JSC “Stoilensky Mining and Concentrating Plant” uses roasting machines OK-306. The screw mechanism of a tension device in the trolley conveyor of the OK-306 roasting machine is characterized by trapezoid thread according to the GOST 24737.

Fatigue destruction of trapezoid threads during cyclic load occurs as a result of appearance and propagation of cracks, which originate in the areas adjacent to thread concaveness. Thereby it is necessary to strengthen threads of screw mechanisms in the adjacent areas to increase fatigue strength.

The problems of wear resistance increase can be solved via different methods of hardening of thread working surfaces [4–8]. Surface plastic deformation (SPD) is one of the most simple and effective methods for surface hardening of metallic components, i.e. the components of screw mechanisms [9]. Use of SPD ensures increase of hardness and wear resistance of working surfaces as well as decrease of their roughness.

To form threads of large-size components, it is efficient to use the combined method including preliminary forming of thread profile via cutting and final forming via pulsed roller rolling (PRR) [10–14].

PRR process is realized in the following way. A billet with a longitudinal groove on its top plane is mounted horizontally and motionless. Roller working surface is introduced in a groove and a roller is subjected to motion and oscillation, when roller rotating axle moves straightly and in parallel direction to a top billet plane. A roller deforms preliminarily cu groove and forms a final thread concaveness.

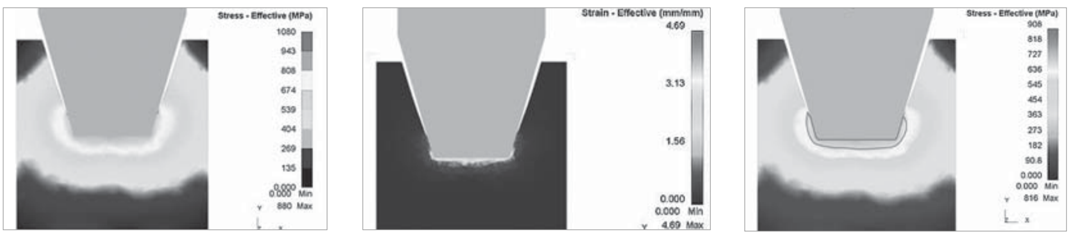
Three variants for thread concave profile, which was preliminarily formed by mechanical processing, were considered: trapezoid, similar to finally formed profile (1); trapezoid, with end triangle area (2); trapezoid, with end parabolic area (3).

Search of the most rational method of final thread forming via PRR process from the above-mentioned methods was implemented on the base of the results of FEM simulation analysis; this simulation was carried out using the “DEFORM” software complex [15, 16]. In this case, the “DEFORM” data for bronze were used as a billet material, while a roller was considered as a perfectly rigid body. Based on the results of these calculations, stress intensity σ_i, deformation intensity ε_i and relatively square a_y of deformation area cross-section with maximal hardening were determined (**Fig. 1**).

The results of calculation are presented in the **Table 1**.

Table 1. The results of calculation of stresses, deformations and relative cross-section squares

Parameters	Shapes of preliminarily formed profile		
	Trapezoid	With end triangle section	With end parabolic section
Stress intensity σ_i, MPa	816	880	833
Deformation intensity ε_i, mm	3.08	4.69	3.63
Relative square of cross-section in the area of maximal hardening a_y	0.071	0.092	0.078



a *b* *c*

Fig. 1. Intensity distribution fields for stress σ_i (*a*), deformation ε_i (*b*) and cross-section square with maximal hardening a_y (*c*)

When analyzing the obtained results, it was established that the combined method, including preliminary trapezoid-triangle groove forming via cutting (variant 2) and consequent PRR, is the most rational process for hardening of trapezoid thread. Such technology allows maximal hardening of the areas adjacent to thread concaveness, what provides maximal increase of fatigue strength.

The new technical solution, which is directed on improvement of the combined method of forming trapezoid threads, was developed for hardening of internal working surfaces of trapezoid threads and conduction of researches [17]. This research was carried out using the unit with its construction presented in the **Fig. 2**.

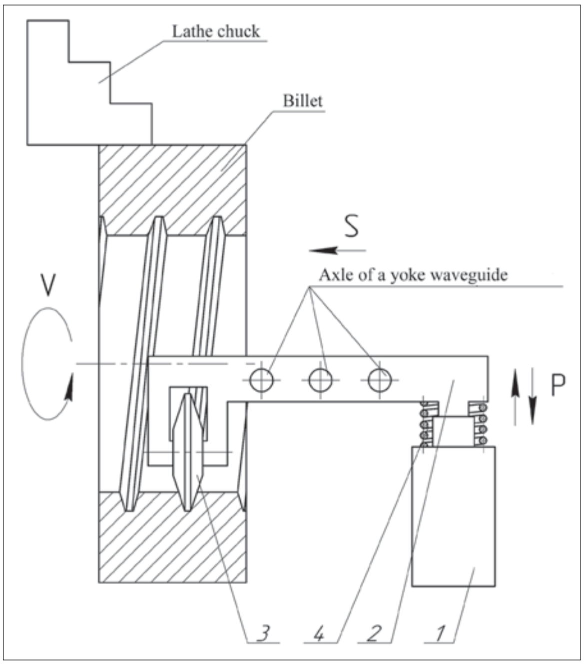


Fig. 2. The scheme of the unit for hardening on internal surfaces of trapezoid threads: *1* – generator of impulses; *2* – yoke waveguide; *3* – deforming roller; *4* – spring

This unit operates in the following way. A generator of mechanical impulses *1* transmits impulses through a yoke waveguide *2* to a roller *3*. This roller *3*, which is mounted at the other end of a yoke waveguide *2*, is pressed to a billet located in a lathe chuck by a spring *4*. In this case and axle of a yoke waveguide *2* is fixed on a lathe support with reset option.

Use of the developed technical solution allows adjusting and managing the procedures of the effect of deforming roller on processed surface. It is achieved via varying generator frequency and energy. Additionally, use of the developed device allows adjusting the effect force of a rolling roller on processed billet for the constant force of generator; it is achieved via varying location of a turning axle of a yoke waveguide.

Experimental samples with outer diameter 122 mm made of bronze BrO10F1 grade were manufactured for the researches.

To determine thickness of hardened layer after PRR of preliminarily cut groove (variant 2) of trapezoid thread made of bronze BrO10F1 grade, polished micro-samples manufactured of transversal templates of thread samples were examined (**Fig. 3**).

Surface microhardness (average values) makes 215 HV, core microhardness – 82 HV, while thickness of hardened layer in the sample of trapezoid thread made of bronze BrO10F1 after PRR is 1.2 mm (surface 1), 2.8 mm (surface 2) and 1.6 mm (surface 3).

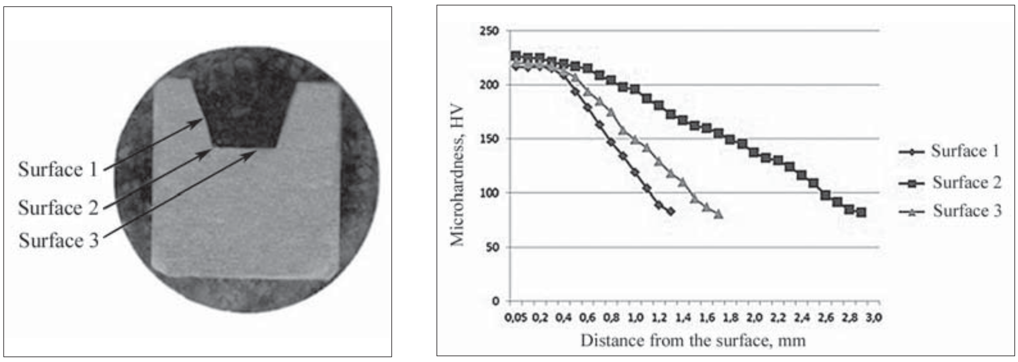
Testing of the samples for wear was carried out using tribometer Nanovea T-50 during this research.

Examination of tribotechnical parameters in the samples made of bronze BrO10F1, in the initial state and after PRR, was conducted in dry sliding friction conditions according to the scheme "ball-disc", with linear speed about 0.1 m/s and load 5 N, using tribometer Nanovea T-50. A ball of ShKh14 chromium steel (analogue of the steel AISI 52100) with diameter 5 mm and hardness 61–63 HRC (760–830 HV) is considered as a counterbody. To assess wear features, the diagram obtained from a sensor of LVDT tribometer, was used; motion of this sensor displays summarized wear of the sample and counterbody materials.

Wearing intensity W ($mm^3 \cdot N^{-1} \cdot m^{-1}$) was calculated via the formula:

$$W = \frac{l \cdot s}{P \cdot L'}$$

where l – circumference length, mm;
s – cross-section square of wear path, mm2;
P – load, N;
L – friction path, m.



a *b*

Fig. 3. Template of the sample (*a*) and graphs of microhardness distribution along thickness of a hardened layer in the sample of trapezoid thread made of bronze BrO10F1 after PRR (*b*)

Surface volumetric wear of a counterbody ΔV_{ball} (mm^3) was calculated via the formula:

$$\Delta V_{ball} = \pi \cdot h^2 \left(r - \frac{1}{3} h \right)$$

where $h = r - \left(r^2 - \left[\frac{d}{2} \right]^2 \right)^{\frac{1}{2}}$ – thickness of a worn segment, mm;

d – diameter of wear spot, mm;

r – ball radius, mm.

Wearing testing of the samples showed that adhesion wearing with mass transfer of wear products in the contact area and consequent bronze BrO10F1 drag to a sliding path occur in all cases. Wearing testing for bronze BrO10F1 in the initial state is accompanied by observing rather low friction coefficient 0.25–0.35 in the stationary area, what is connected with forming of oxide films in the contact area (**Fig. 4**).

Use of pulsed roller rolling led to increase of surface microhardness of the samples from 82 HV to 215 HV (after PRR) and to increase of the friction coefficient in the stationary area to 0.6 during wearing testing. Wearing intensity calculation displayed that surface processing of the samples allowed decreasing surface wearing intensity more than by 12 times after pulsed roller rolling in comparison with the initial state.

The results of wearing intensity measurements of the samples are presented in the **Table 2**.

The results of these researches displayed that use of pulsed roller rolling for the samples of trapezoid thread of bronze BrO10F1 allows increasing surface microhardness of the samples by 2.6 times, providing thickness of a hardened layer up to 2.8 mm and decreasing of surface wearing intensity of the samples by more than 12 times in comparison with the initial state.

Conclusions

It was established on the base of literature data analysis and assessment results of friction pairs state after their operation that long-term operation of screw mechanisms of metallurgical machines under conditions of high power loads and intense wear leads to loss of their performance due to wear or destruction.

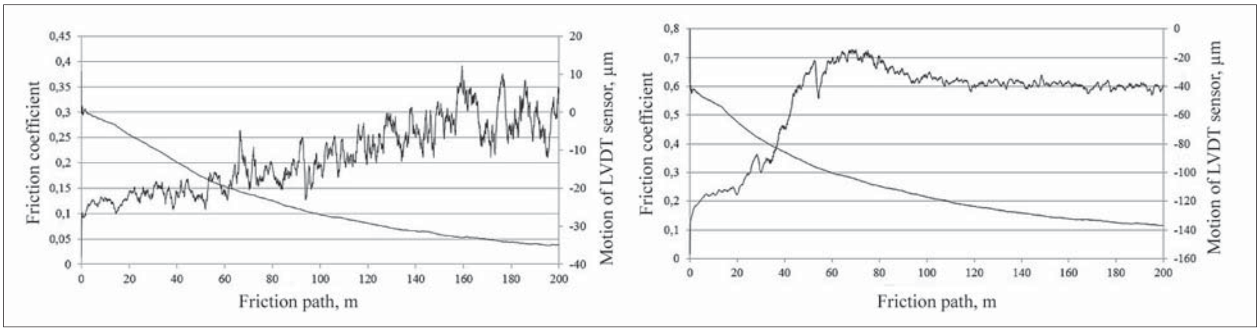
Analyzing the methods for increasing the performance of screw mechanisms, we can conclude that use of surface plastic deformation (SPD) methods to increase durability of friction pairs and thread resources of large-sized screw-nut transmission parts is promising.

Computer simulation of the process of final thread profile formation via pulsed roller rolling (PRR) was carried out. It was established that the maximal values of i = 880 MPa, i = 4.69 mm and ay = 0.092 are achieved for a pre-formed profile by mechanical processing with concaveness in the form of a trapezoid with a triangle and subsequent PRR of samples made of BrO10F1 bronze. This technology allows maximal hardening of the zones adjacent to the thread concaveness, which ensures increased fatigue strength.

The new technical solution, aimed at improving the combined method of forming trapezoidal threads (RF patent No. 2731949) for large-sized parts of the screw mechanism of a roasting machine of the OK-306 type, was developed.

The research results showed that use of PRR for trapezoidal thread samples makes it possible to: increase surface microhardness of the samples made of bronze grade BrO10F1 by 2.6 times; provide thickness of the hardened layer up to 2.8 mm; reduce the surface wear rate for the samples by more than 12 times compared to the initial state.

The tests on nuts made of bronze grade BrO10F1 were carried out in the conditions of JSC "Stoilensky Mining



a *b*

Fig. 4. Kinetics of varying the friction coefficient and LVDT sensor location, depending on friction path during wearing testing of bronze BrO10F1 in the initial state (*a*) and after PRR (*b*)

Table 2. The results of wearing intensity measurements of the samples of trapezoid thread made of bronze BrO10F1 after PRR

Hardening method	Microhardness average value, HV	Layer thickness, mm	W, mm$^3\cdot$N$^{-1}\cdot$m^{-1}
Initial state	82	–	6.5×10^{-4}
Pulsed roller rolling	215	1.2–2.8	5.39×10^{-5}

and Concentrating Plant" as a part of the tension device in the trolley conveyor of the OK-306 roasting machine. Hardening the working surfaces of PRR trapezoidal threads made it possible to increase the service life of the nuts by at least 2 times.

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