Thermal strengthening treatment of low-rigid lead screws

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Abstract. The article deals with the design of equipment for thermal strengthening operations (hardening, tempering and normalization) of low-rigid long-length lead screws of high accuracy. The technology of thermal strengthening processing is given. In this paper, a new approach is proposed to the processing of lead screws and their treatment technology to obtain high geometric accuracy. Relatively long and thin products are characterized by common deviations of shapes from the straightness of the axis and the uneven pitch of the helix. The technological process of their production should include bending operations and multiple tempering to stabilize residual stresses. This ensures the straightness of the part and the stability of the thread pitch. As an effective method and promising direction, a thermal strengthening processing is proposed. Recommendations are given on technical methods of axial deformation and determination of the optimal modes of thermal strengthening. The principle of operation of the installation and algorithms of the technological process are described.

1. Introduction
Thousands of lead screws (LS) are produced annually, a significant part of which belongs to low-rigidity products. In the manufacture of such parts, the requirements for their quality, reliability and durability are constantly increasing, since the performance of machines and mechanisms, as a whole, depends on them.

In the process of manufacturing of lead screws (mechanical processing, heat treatment, etc.), as well as during assembly and installation, residual stresses occur, which negatively affect the performance of processing machines and mechanisms in mechanical engineering.

Analysis of the reasons for the loss of accuracy of low-rigid long-length lead screws showed that, when they are manufactured, there are residual deformations that exceed the specified tolerances for geometric dimensions. The most common deformations are deviations from the straightness of the axis and uneven pitch of the helix along the length of the product. To ensure straightness and stability of the pitch, bending operations and multiple tempering are introduced into the manufacturing process to stabilize the residual stresses.

Traditional methods of manufacturing the high-precision lead screws are time-consuming and costly. In this paper, a new approach is proposed to the treatment of LS and the technology of their production with high operating precision [1-5].

2. Relevance and purpose of the study
Low-rigidity long-length lead screws are widely used in many industries, from agricultural to household appliances. One of the problems that arises in the manufacture of such parts is the loss of their axis straightness and geometric error in the pitch of the helix along the entire length. Loss of geometric
operational accuracy of low-rigid lead screws occurs at all stages of the process due to incompatibility of residual stresses. The traditional way to restore a geometric shape is to correct it by bending or stretching. However, these methods are not acceptable for LS of class 0 and class 1 due to the complexity of their implementation.

It is not advisable to deviate from traditional processing schemes for restoration of low-rigid LS. As a promising direction, it is possible to consider the thermal strengthening treatment as an effective method, to a large extent superior as compared with the above methods. For the practical implementation of the new processing method, it became necessary to study this process in depth [6-9]. The purpose of the development is to improve the operational accuracy of the LS by introducing thermal strengthening processing technology (TSP) and development of equipment for its implementation.

3. Presentation of the main material
The peculiarity of the proposed technology for heat treatment of lead screws of the 0-th and 1-st accuracy classes is not only changing the treatment method itself, but also changing the machining method during turning and grinding. These processes are carried out with the use of self-aligning collars (SAC), a feature of which is the combination of design, technological and measuring base for mechanical processing [3]. The latter eliminates the processing of LS in the center holes-bases, allows them to be processed without remounting. And also to get the accuracy of external surfaces less than 10 microns in diameter and 10-15 microns per meter of LS length. Cold bending is allowed with an accuracy of 1 mm per 1 meter of length, since the axial residual stresses after TSP have a uniform distribution over the cross section of the LS workpiece. After the TSP, the unevenness of plastic deformation along the length of the workpiece is evaluated. The unevenness ratio \( \text{Kav} \) characterizes the average unevenness of plastic deformation as the ratio of \( \text{Kav}=\varepsilon_{\text{max}}/\varepsilon_{\text{av}} \). Measurements are made along the thread pitch as a function of the total deformation value and the heating temperature.

The essence of the new TSP technology is as follows. The workpiece 1 (Fig. 1) is pre-processed on a lathe using SAC [3] and a working profile of two types is formed: a) threaded with a profile for LS; b) threaded metric profile for stepped parts of LS. The difference between the outer and inner diameters of smooth surfaces is determined by the ultimate strength of the material and the size of the cross-section of the LS workpiece; it should not exceed the allowance for finishing machining. When processing the LS step blanks, the spacer bushings 2 are screwed or superimposed on the threaded surfaces 3 on the principle of sliding bearing inserts (the bushing consists of two parts). Bushings are made of a material whose linear expansion coefficient \( \alpha_{\text{bush}} \) is less than the linear expansion coefficient of the LS workpiece material \( \alpha_{\text{part}} \). The length of the bushings is calculated from the condition of equal strength of the part of the product on which the bushing is installed, as well as from the condition of minimizing the deflection deformation. Moreover, to ensure uniformity of compression along the axis of the part, we take the ratio of lengths \( l_1 = l_2, l/d \leq 10 \) to ensure the longitudinal stiffness of the compressed part of the workpiece. In the bushings 2, the holes 9 are made, and their shape and location are made so that, at any mutual arrangement of the two connections of the bushings, the passage of the cooling liquid is provided.

![Figure 1. General view of the structure.](image-url)
The assembled workpiece 1 with spacer bushings 2 is inserted, with a pre-calculated thermal gap, into the multi-layer bench 4 and fixed at the lower end of the bench. The bench is made of a material whose linear expansion coefficient is equal to the linear expansion coefficient of the bushings (to avoid jamming due to temperature deformations), with a filler 5, which may have a different coefficient of thermal conductivity. The body of the bench 4 is made multi-layer, each layer of which has an additional volume filled with a material with a lower coefficient of thermal conductivity. In the multi-layer body 4, through holes are made in the longitudinal and transverse directions, in which bushings made of the same material as the bench are mounted. There are two ways to fix a workpiece:

a) Workpiece is fixed on the lower end by means of a sphere 7 rigidly fixed with a cover 6 on the lower end, so that the workpiece rests by its lower end on a spherical surface and, thus, provides point contact with the bench;

b) Fixation of the workpiece occurs on two ends by means of two spheres 7, rigidly fixed with covers 6 on the lower and upper ends. With this method of fixing, the workpiece is rigidly connected to the bench along the axis.

Fixation of the workpiece 1 occurs on two ends by means of two spheres 7, rigidly fixed with covers 6 on the lower and upper ends. Four eyelets 8 are welded to the upper part of the bench 4 for suspension of the entire structure. The assembled structure is lowered into the shaft furnace and heated according to the heat treatment technology to the quenching or tempering temperature, etc. and kept at this temperature until it is completely warmed up. When heated, the workpiece is lengthened more than the bushings and the bench, due to the difference in the coefficients of linear thermal expansion. Selecting the numerical values of the positive difference between the coefficients of linear thermal expansion of the workpiece and the bushings, we get the amount of plastic deformation of the part that exceeds the limit of proportionality. Axial plastic deformation beyond the proportionality during heating eliminates technological inheritance from previous operations. In addition, under the effect of axial loads, the deformation hardening of the part material (peening) occurs, and internal microcracks are smoothed.

When cooling the bench, its cooling rate is at least five times less than the cooling rate of the workpiece (the workpiece must be cooled at a higher rate than the bench, at least five times, depending on the cooling medium: oil, water, air). In the workpiece, when cooling it with axial loading, residual stresses are formed, sign-alternating along the length and uniform across the cross section of the part, which eliminates warping of the finished parts during operation.

To expand the technological capabilities of the TSP, a multi-layer bench can be made of prefabricated sections, if there is a need to increase the lengths of the workpieces and the values of their plastic deformation. The length of the bench is increased by increasing the number of sections.

**Figure 2.** Variation of residual stresses in the part before and after thermal strengthening treatment: a) – variant of the fastening of the lead screw workpiece to the lower end by means of a sphere, b) - variant of the part fastening at the two ends by two spheres.
4. Experimental result. Conclusion

Fig. 2 shows a comparison of internal stresses in the part before and after the TSP application. In addition, the strength characteristics of the finished product are increased. The use of new TSP processing technology allows to minimize the amount of deflection of the workpiece and to stabilize the level of residual stresses along its length, which allows to improve the operational accuracy of low-rigid long-length lead screws.

Warping of finished products after applying the developed method does not exceed the accuracy requirements set by the drawing.

The technical result of the developed TSP technology for low-rigid LS is the increased accuracy and stability of geometric parameters, increased operational accuracy of finished products by creating uniform sign-alternating residual stresses along the entire length of the workpiece.

The experiments were carried out on workpieces with a diameter of 28 mm and a length of 2 100 mm made of 40HG steel. Tolerances for outer, middle and inner diameters, threads of trapezoidal screws are made in accordance with GOST 9484-81. All operations for the production of LS were performed according to the factory technology, except for heat treatment operations (changes related to TSP) and mechanical processing in the SAC. Finished products were suspended, and every 30 days measurements were made on the thread geometry and deflection of the LS axes and so on for 180 days. As a result, during the whole period of monitoring, for the entire length of LS, unevenness in pitch did not exceed 3-5 µm, the allowable accumulated error of the screw pitch for the entire length of the screw was not more than 15 µm, the allowable runout of the outer diameter - 40 microns on the entire length, and the deflection of the axis of the shaft was not more than 5 microns per meter.

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