DETERMINATION OF THE BENDING STIFFNESS OF THIN-WALLED SHAFTS BY THE EXPERIMENTAL METHODOLOGICAL METHOD DUE TO THE FORMATION OF INTERNAL STRESSES

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ABSTRACT
This article presents the results of computer simulation of the flexural stiffness of thin-walled shafts. Influence of residual stresses on the maximum bending value of shaft-type parts. During the experimental and methodological work, it was found that the formation of residual stresses in the surface layers of a certain thickness have a positive effect on increasing the stiffness of the shafts. The results obtained make it possible to explain a number of experiments on the hardening of shafts by surface plastic deformation. Determination of the bending stiffness of low-stiff shafts due to the formation of residual stresses is allowed only when it is possible to create deeper fields of their distribution.

Keywords: thin-walled shaft; maximum bend; surface layer; wear resistance, bending stiffness.

INTRODUCTION

The service purpose of thin-walled shafts is the transmission of torque over a sufficiently large distance within the shaft structure. The efficiency of the production of metal products is the saving of metal and the production of products with a lower weight. The reduction in material consumption is carried out mainly due to the size of the cross-section of the part. At the same time, a thin and long rod has a low stability under the action of a longitudinal force and a low stiffness of a transverse load. Technological requirements for increasing the rigidity and stability of rod parts is relevant. Thin-walled parts include shafts whose length is ten or more times their diameter. Thin-walled shafts are widely used in various fields of transport and agricultural machinery, in watercraft and metal-cutting machines, in various mechanisms of mining and textile machinery.

The stiffness of thin-walled shafts depends on loading conditions, product design and physical and mechanical properties of the material. The main problem in the manufacture of low-rigidity parts such as a shaft is the presence in the material of a significant level and uneven distribution of residual stresses, the appearance of which is largely due to technological processes. Residual stresses arise in almost all technological operations of material processing, and persist over time.

The reasons for the formation of residual stresses are manifold: non-uniformity of plastic deformation, non-uniformity of the temperature field, phase transformations, etc. In the studies carried out, the effect of residual stresses on the performance properties of parts, such as wear resistance, corrosion resistance, fracture, static and cyclic strength, and shape stability of parts. Usually, the presence of residual stresses in parts is considered a negative phenomenon, but in some cases these stresses can also be useful (they increase the elasticity and endurance limits, corrosion-mechanical and corrosion resistance, etc.).

The experimental methodological method is used to study the influence of residual stiffness stresses on bending of hardened shafts. The work uses residual stresses of the first kind, which are balanced in the volume of the body and can exert a compressive or tensile effect on the inner layers of the metal.

Let us investigate the deformation of a smooth steel low-rigidity shaft of length L and diameter d under the action of a transverse load P (Fig. 1). For consideration of bending stiffness shafts, depending on the magnitude and distribution of residual stresses, it is shown in two sketches: 1 - residual compressive stresses in the surface layers and tensile stresses in the inner layers (Fig. 1, a); 2 - residual tensile stresses in the surface layers and compressive stresses in the inner layers (Fig. 1, b).

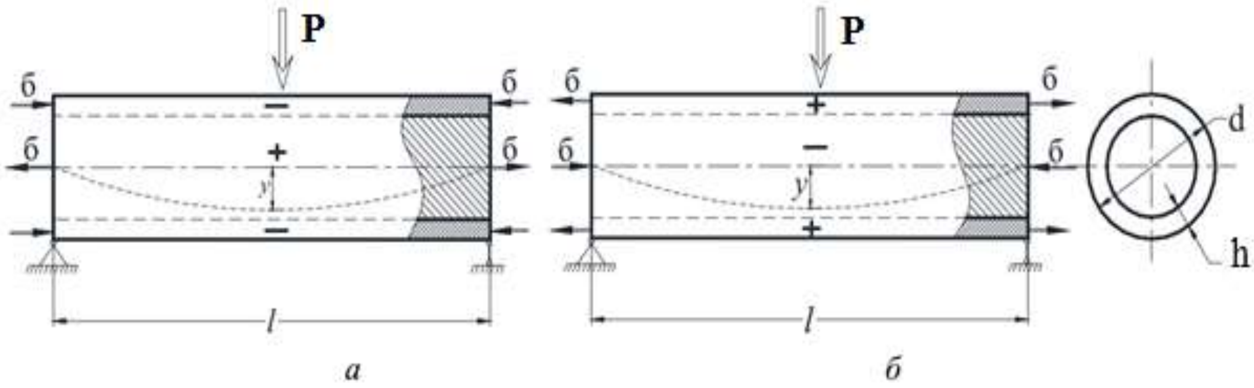

Fig. 1. - Sketch to determine the effect of residual stresses on the stiffness of thin-walled shafts: a - sketch of tension; b - a sketch of the compression;
h - surface layer size

When carrying out an experimental determination of the residual stresses of bending stiffness in the workpieces of low-stiffness shafts, which are often made from rolled stock, it was found that the residual stresses on the surface and in the central zone in the first approximation are equal in magnitude and opposite in sign. In this method, according to the results of experimental studies, it was found that the enveloping hardening of rolled products makes it possible to form an opposite distribution of residual stresses over the section of round bars. Based on this, the shaft model is presented in the form of a cylinder consisting of a core and a shell (sleeve of size h).

Calculation-analytical method of bending stiffness of thin-walled shafts was carried out by the *Koshi-Krilova* method. At h = 0, solving the differential equation of the curved axis of the bar:

$$\frac{1}{\rho} = \pm \frac{d^2y/dz^2}{\sqrt{\left[1+\left\{dy/dz\right\}^2\right]^3}}$$

we get the maximum bend of the shaft:

$$y_{max} = -\frac{Fl^3}{48EI_x + 4\pi\sigma_z R^2 l^2} \qquad (1)$$

$$y_{max} = -\frac{Fl^3}{48EI_x - 4\pi\sigma_z R^2 l^2} \qquad (2)$$

Formula (1) allows you to determine the maximum deflection of the shaft under the action of a shear force P under axial tension, and formula (2) under axial compression. It is seen that the value of the maximum deflection in the case of tensile stresses is less than that under the action of compressive stresses. Equations 1 and 2 allow you to mathematically prove the action of axial loads on the transverse bending of the bar. For example, if the string is pulled, the deflection from the lateral force will depend on the magnitude of the tensile force.

The results of changes in the maximum bending of a low-stiffness shaft depending on the size of the surface layer and the distribution of residual stresses are shown in Fig. 2.

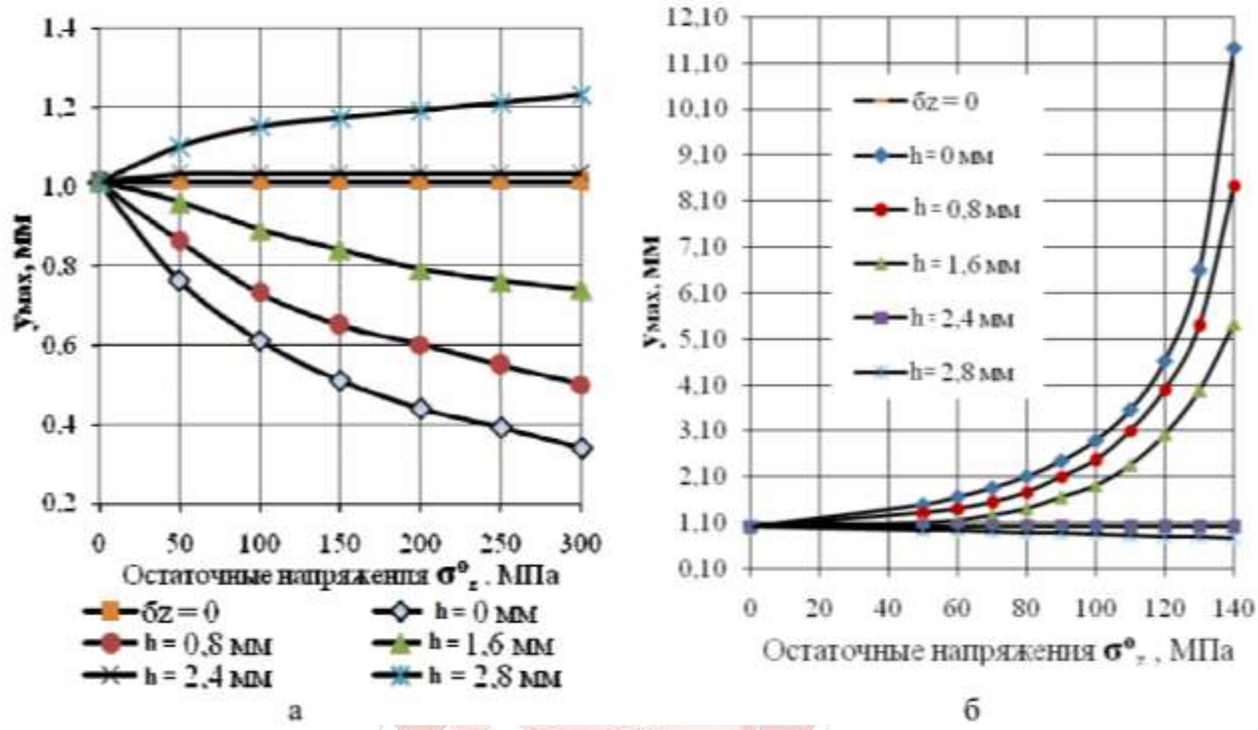

Fig. 2. - Conversion of the maximum bending of low-stiffness shafts depending on the size of the surface layer and the distribution of residual stresses in the material steel 40X: a - tension graph; b - compression graph.

In fig. 2 shows the results in the form of a graph of the transverse deflection of the shaft under the action of axial stresses of different signs and different thicknesses of the layers in which they are distributed. As expected, if the shaft is fully (over the entire section) stretched by the axial force (Fig. 2, a), then the deflection will be minimal (h = 0). With the formation of surface layers with compressive stresses, the deflection of the shaft increases. At a certain layer thickness (h / R <0.3), the deflection increases sharply, since the shaft loses its stability under the action of compressive stresses.

When carrying out research work, we come to the conclusion that the effect of residual stresses on the stiffness of hardened shafts. Depends on the most favorable residual stress distribution scheme. The maximum section of the shaft is under tensile stresses. The residual compressive stresses formed during hardening treatment in thin surface layers, although slightly reduce the rigidity, are generally the best option for hardening treatment.

Thus, to increase the stiffness of the shafts, it is advisable to form compressive stresses in the surface layers, and tensile stresses in the central zone. In this case, the deflection of the shafts can be reduced by 2-3 times, depending on the magnitude of the acting stresses and the size of the layers in which they are distributed.

CONCLUSIONS

1. The possibility of increasing the rigidity of low-stiff shafts and axles due to the formation of residual stresses has been established.

2. Axial residual stresses according to the tension sketch (see Fig. 1, a) in the presence of thin surface layers (h / R <0.3) increase the rigidity and reduce the bending of low-stiff shafts, and the stresses according to the tension sketch have the opposite effect.
3. The thickness of the surface layer, in which the residual stresses act, has a significant effect on the bending of low-stiffness shafts. With a large size of this layer, the role of residual stresses in the formation of rigidity can be reversed.

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