Improving the efficiency of the process of burnishing splined holes under the influence of an ultrasonic field

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Abstract. The essence of finishing and hardening processing of slotted holes with shaped mandrels is described. The analysis of the technological parameters of the mandrel process has been carried out. It is shown that the main technological parameter that determines the efficiency of processing is the tractive effort. A technological scheme is proposed for mandrel drilling of spline holes of gear wheels, which provides by imposing an ultrasonic field on the workpiece. reduction of it by 40%, creation of favorable compressive stresses in the surface layer.

1. Introduction

Mandrel is one of the most effective methods of finishing and strengthening processing of splined holes for machine parts by plastic deformation, which is carried out by shaped mandrels by pushing or pulling them through the splined hole or on a press, or on a broaching machine [1]. This method increases processing productivity, improves hole accuracy, frees up expensive cutting tools, eliminates defects, and improves the performance of parts.

To date, as a research result in the field of mandrel processing, a whole range of tasks has been solved that determine its practical application [2, 3]. The design of the splined mandrel (Figure 1) has been developed, which provides effective implementation of the mandrel process with the help of working bodies in the form of hard-alloy plates 2, which have: intake and return cones along the outer diameter and side surfaces of the slot and calibration tapes.

Figure 1. Shaped mandrel for splined hole calibration: 1 - mandrel, 2 - carbide plates, 3 - body, 4 - sleeve, 5 - nut, 6 - washer, 7 - cracker, 8 - screw
The geometric parameters of the working surfaces of shaped mandrels are determined, which play a very important role in the mandrel process, because they have a significant impact on the deformation conditions of the metal surface layer, changes in traction forces, the quality of the treated surface and the wear resistance of the mandrels. The main technological parameters of the mandrel process that determine the mechanism of surface plastic deformation and the formation of geometric and physical - mechanical characteristics of the surface layer quality are established.

The purpose of this research was to analyze the influence regularities of technological parameters on the mandrel process and develop proposals to improve its technological efficiency.

2. Technological parameters of the mandrel process

When splined holes are processed with mandrel, the main technological parameters of the process are the tool geometry, pulling forces, tension and mandrel speed. Summarizing the results of theoretical and experimental studies, we can state the following [2, 3].

One of the most important elements that determine the shape of the mandrel working surface are the angles of the intake cone. The chamfer is the main deformation of processed metal and it influences on a mandrel force RT and surface quality (Figure 2). With proper selection of the angles of the intake cones splined mandrels traction will be minimal, the height of surface roughness of machined holes will be the smallest, due to the preferential radial flow of the metal. It is established that the optimal geometry of the mandrel tool α=4°-5° provides the highest quality of the processed surface of the splined hole and the smallest amount of the mandrel pulling force.

![Figure. 2 Change in traction forces P depending on the value of the intake angle α; processed materials-steel grades: 20X-cemented and hardened to a hardness of HRC 58-62 (upper arc); 40X hardened to a hardness of HRC 48-52 (dotted graph); 40X hardened to a hardness of HRC 48-52 (lower graph)](image)

In the process of calibration with shaped mandrels, elastic and plastic deformations occur along the profile in the splined hole surface layer of the processed part, which lead to a change in its stress state and, as a result, have a significant impact on the accuracy of the splined hole size. The amount of residual deformation of the splined hole surface during calibration depends on: the values of tension along the outer diameter-\(iD\) and the side surface of the splines-\(iB\); physical and mechanical properties of the processed material, the thickness of the sleeve wall, the scheme of deformation of the hole surfaces. As shown in Fig.6 the dependence of the values of residual metal deformations on the surface of the outer diameter of the splined hole (\(δD1\)) OST on the tension of the mandrel \(iD\) is approximately rectilinear in nature and a small angle of inclination to the axis of the abscess. This indicates that the residual...
deformation along the outer diameter of the splined hole during the mandrel is much less than the mandrel tension. Therefore, the value of the inverse elastic deformations in this case the total sum of the absolute deformation (the tension of the mandrel $iD$) has the greatest value. The straight line originates on the abscess axis from a certain positive value of the tension, because at lower tension the processed sleeve is in the mode of pure elastic deformations and does not have any residual deformations.

![Image of graph showing change in residual deformations](image)

**Figure. 3.** Change in residual deformations ($\delta D1$) of the metal on the surface of the splined outer diameter from the amount of tension $iD$: 1-steel 40X, volume-hardened to a hardness of HRC 48-52; 2-steel 20X, cemented to a depth of 0.8-1.1 mm and hardened to a hardness of HRC 58-62

Thus, based on the amount of residual deformations along the profile of the splineds, it is possible to correctly select rational mandrel tension and ensure that the splined holes and parts are obtained within the required accuracy.

Determination of the tractive effort during the mandrel of splined holes is of great practical importance, since knowing the force amount in advance, you can correctly choose the design dimensions of the broaching machine or press, calculate tools, fixtures and the workpiece for strength and stability. Taking into account the tractive effort, you can correctly assign the optimal geometry of the mandrel tools, which all other things being equal, provides the lowest value of the tractive effort. Figure 4 is a graph of the dependencies of tractive effort $P$ preload $iD$ which shows that during processing space-hardened steel 40KH and steel 45 with increasing tightness of mandrel $iD$ the traction is considerably increasing on a straight-line law.

![Image of graph showing dependence of traction forces](image)

**Figure 4.** Dependence of the traction forces $P$ on the value of the mandrel tension for the samples from: 1-steel 40X, volume-hardened to a hardness of HRC48-52; 2-steel 20X, cemented to a depth of 0.8-1.1 mm, and hardened to a hardness of HRC 40-45
During the sample mandrel of cemented and hardened steel 20X the traction forces increase significantly with increasing of mandrel tension along the outer diameter of the slot iD, approximately according to the rectilinear law only to the value of the tension iD=0.13 mm, indicating that only the surface layers of the metal are deformed. After exceeding this tension, the growth of traction forces becomes less intense, and the curve bends smoothly, since at strains greater than iD=0.13, the plastic deformation of the metal lying below the cemented layer and having less hardness occurs, and therefore the metal has less resistance to deformation. Starting from the tension iD=20mm, the traction forces continue to increase approximately according to the rectilinear law, indicating that during these strains, not only the layers of metal lying under the cemented layer are subjected to plastic deformations, but also the cemented layer itself.

3. The influence of ultrasonic vibrations on the mandrel process

The main technological parameter of the mandrel process, which determines the technical and economic efficiency of finishing and strengthening treatment of splined holes, as shown, is the traction force. Knowing in advance the amount of effort, you can correctly choose the design dimensions of the broaching machine or press, calculate tools, fixtures and the workpiece for strength and stability. Taking into account the tractive effort, you can correctly assign the optimal geometry of the mandrel tools, which, all other things being equal, provides the lowest value of the tractive effort.

Along with the above factors that affect the pulling force of the mandrel process, determining the justification of its value are the mechanical properties of the material being processed and the physical and mechanical characteristics of the quality of the splined hole surface layer formed during operations preceding the mandrel, as well as the geometric dimensions of the splined hole. It has been experimentally established [2] that during the mandrel of parts made of materials with a high yield strength, large tractive forces are required, and, conversely, the lower the yield strength, the lower the tractive forces. The use of high traction forces is required for the mandrel of thermally treated splined holes that have a surface hardness after quenching of 50...55NRS. When selecting traction forces, the nominal size of the splined hole must also be taken into account. Slotted holes with a large nominal size correspond to a large tractive effort, since the volume and work of deformation are obtained more.

It follows that the technical and economic efficiency of the mandrel process of splined holes depends on the rational choice of traction force. To solve this problem, it is necessary to control the stress state of the surface layer in the zone of contact interaction of the tool with the treated surface.

As one of the ways to control the stress state of the surface layer, it is proposed to apply ultrasonic effects on the mandrel process. In [4], it is shown that ultrasonic vibrations reduce internal friction in the material, resulting in more effective conditions for the tool to act on it.

Figure 5 shows a schematic diagram of the mandrel process of splined holes with the imposition of an ultrasonic field on it.

The proposed scheme consists of two blocks: the technological one, which implements the mandrel process of a splined hole with a shaped mandrel, and the acoustic one, which creates a complex acoustic field in the part material (or tool). The main elements of the acoustic unit are: an ultrasonic generator designed to convert an electric current of industrial frequency 50 Hz to electrical vibrations of 22 kHz magnetic-friction converter that converts an electrical frequency in the range of 22 kHz to mechanical movements; a waveguide that forms a complex acoustic field in a part by transforming longitudinal vibrations into longitudinal-torsional ones.
Figure 5. Diagram of the mandrel process of the splined hole of a gear wheel using an ultrasonic field: 1 – power rod, 2 – shaped mandrel, 3 – gear wheel, 4 – mounting table, 5 – magnetostrictive converter, 6 – acoustic feedback sensor, 7 – waveguide, 8 – generator (APF-frequency auto-tuning system, INV-inventory)

Applying an acoustic field to the part increases the efficiency of the entire technological system due to alternating changes in the geometric dimensions of the part in the radial and tangential directions, due to the flow of high-speed wave processes in the material of the part that lead to a decrease in its stress state.

4. Conclusion
The usage of PPAs with the energy of ultrasonic vibrations, which have a significant effect on the character of contact interaction of tool and workpiece surface allows to achieve an efficient calibration of the workpiece splined hole with shaped mandrel while reducing traction. The use of ultrasonic action in the mandrel process, as shown by preliminary experimental studies, allows a 40% decrease in traction force due to a decrease in friction and an increase in plasticity in the deformation zone, promotes deep plastic and elastoplastic processing of the surface layer, and the creation of favorable compressive stresses.

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