IMPROVING THE EFFICIENCY OF MACHINING OPPOSITELY DIRECTED CONICAL SURFACES BY MANAGING DYNAMIC TECHNOLOGICAL RELATIONSHIPS

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Abstract

This paper presents a technology for sequential-parallel machining of internal cylindrical and conical surfaces of oil field couplings, identifies a unique system of forces acting on the boring bar during parallel machining, and since all three corresponding components of the cutting forces are directed in opposite directions, a sharp decrease in the elastic deformations of the elements occurs in the technological system, due to the control of dynamic technological relationships and main angles in plan of the cutters during parallel machining, the values of the cutting force components change in a favorable direction, ensuring a decrease in the range of elastic deformations of the elements of the technological system, reducing their impact on the accuracy of machining, provides the results of studies of elastic deformations by modeling in ANSYS, it was recommended to apply the developed technology and technological measures that ensure the processing of responsible surfaces of couplings with high accuracy and productivity.

Keywords: internal, multidirectional, surface, coaxiality, boring bar, parallelism, machining, tool, dynamic, technological, relationships, deformation, accuracy.

I. Introduction

The multi-tool parallel machining of surfaces is widely used in solving various technological tasks and including for ensuring high processing efficiency. The application of similar technologies on modern CNC machines, as well as the execution of auxiliary tasks related to material removal with high precision and speed, further enhances the efficiency of the technological process [1-5]. The parallel machining of various internally multi-directional threaded and conical surfaces is recommended for a range of couplings in the oil and gas industry [3, 6]. The primary technological challenge is ensuring the precision of the machined conical surfaces, including coaxiality accuracy, as well as increasing productivity.

The accuracy of shape formation is primarily determined by dynamic technological relationships. This is because static interactions are relatively easier to ensure, and their impact on machining accuracy can even be reduced to zero through them control (e.g., errors in basing, clamping-fixing errors, etc.) [2, 7-11]. However, dynamic relationships, due to the variability of cutting forces inherent to the machining process during material removal, induce elastic deformations of varying magnitude in the elements of the technological system (TS), which cannot be entirely eliminated.

Nevertheless, by controlling dynamic technological interactions, it is possible to reduce the range of elastic deformations in TS elements and include their expected minimum values within adjustment parameters, thereby ensuring high machining accuracy [4, 7, 12-14].

II. Statement of the Problem

Humanity's continuously growing demand for hydrocarbons necessitates drilling wells to greater depths. The conical threads of couplings, used to connect parts of drilling, pump-compressor, and casing pipes, as well as other equipment serving the transportation of extracted oil, are among the elements that bear the weight of downhole tools and equipment while ensuring the tightness of the connection [15-18]. Improving the parameters and coaxiality precision of multi-directional conical threads in couplings enhances their load-bearing and sealing capabilities, thereby ensuring better operational performance [3, 6, 18]. Increasing the load-bearing capacity of couplings, in turn, facilitates the efficient drilling of deeper wells. The high precision of the smooth conical surfaces between threads creates a foundation for improving both the parametric and coaxiality precision of the threads to be cut, through inherited accuracy. Additionally, the results obtained from the parallel machining of these surfaces serve as fundamental data and materials of high importance for developing parallel machining technologies for multi-directional conical threads.

Various machining technologies, implementation methods, and features of auxiliary equipment have been developed for the parallel machining of multi-directional internal conical surfaces and threads in couplings [3, 6]. To implement the proposed innovative technological process in practice, it is necessary to test it through simulation, theoretically determine the impact of the elastic deformations of TS (technological system) elements on machining accuracy, and ensure high machining precision by managing technological interactions.

The aim of the work is to analyze the influence of elastic deformations of TS elements on the accuracy of processing during parallel processing of internal conical surfaces in oil field grade couplings, using the control of dynamic technological relationships, to determine the directions for increasing accuracy and to test the process using simulation.

III. Methodology

The accuracy of parallel machining of surfaces in holes depends not only on the elastic deformations of the cantilever boring bar, but also on the accuracy of the mutual arrangement of the tools on it. During mechanical processing, the elastic deformations of the boring bar sections where the tool is located are different due to the effect of dynamic cutting forces. Although the tools are designed for the same cutting depth, their stability during machining is not guaranteed. Taking these different deformations into account in the dimensions of the tool positions on the boring bar ensures a reduction in the errors of sizes and shapes that occur on the under-thread surfaces and their negative impact on accuracy due to heredity in the threads.

The features of parallel machining developed for internal surfaces differ fundamentally from the features of parallel machining used in production for external surfaces. Since, machining of internal surfaces of the coupling in the last pass of the tool occurs as follows: first, the second tool sequentially machines the cylindrical and conical surfaces at the end of the coupling (Figure 1.1; in the figure: Lm- is the length of the coupling; φ- is the angle of inclination of the threaded conical surfaces; φ_A and φ_B - are the main angles in plan of the cutting edges of the tools, in the middle and end of the boring bar, respectively; b- is the length of the cylindrical and conical surfaces at the end; a-is the length of the conical surfaces under the threads, taking into account the tool outlet;

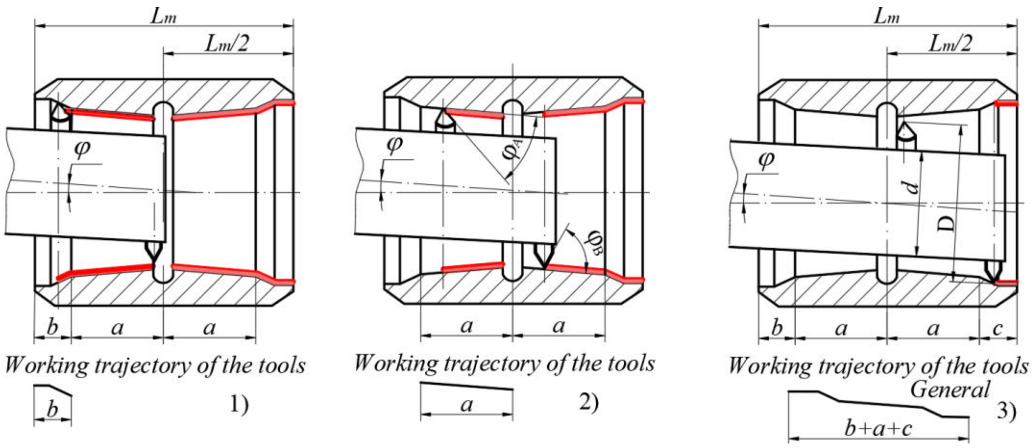

Figure 1: *Schemes of serial-parallel machining of internal surfaces of a coupling in one pass*

c - is the length of the conical and cylindrical surfaces of the coupling, taking into account the tool outlet; d- is the diameter of the boring bar; D- is the distance between the tools, in the direction perpendicular to the boring bar axis), then both cutting tools parallel machine differently directed conical surfaces under the threads (Figure 1.2). Finally, the first cutting tool is used to successively machine the transition conical and cylindrical surfaces in the inner part of the coupling (Figure 1.3). Thus, in this case, the cutting tools remove material from opposite, and from different sides, coaxial multidirectional conical and cylindrical surfaces. Therefore, the cutting force components acting on the cutting tool are directed opposite to each other, unlike traditional parallel processing schemes, and with well-organized operations even take the same values (Figure 2; the figure shows: P_z, P_y and P_x - vertical, radial and axial components of the cutting forces, respectively; Aa and Ba - installation dimensions of the second and first tools, respectively; l1 - axial distance between the

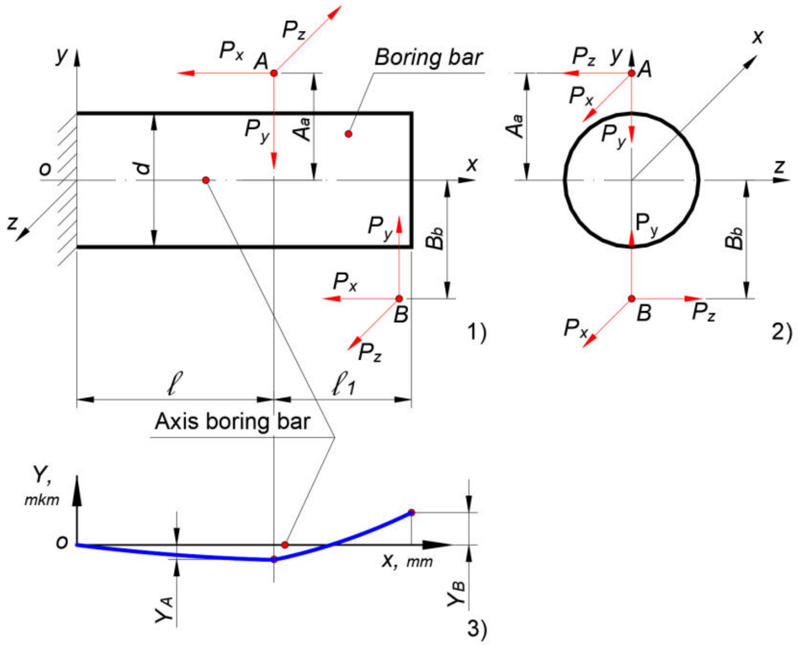

Figure 2: *Scheme of the system of cutting forces acting on the boring bar*

tools; l - distance from the second tool to the boring bar support). As a result, during processing, elastic deformations caused by different cutting force components on different sections of the second section of the boring bar occur in opposite directions, compared to the first section, and they compensate each other (Fig. 2.3). This ensures high processing accuracy.

The boring bar, and consequently the similar workpiece-workpiece system and the system of forces acting on the machine, is technologically very advantageous (Figures 2; 1 and 2). By controlling the geometric parameters of the cutting tools under given cutting conditions, in particular the main angles in the plan (φ_A and φ_B), it ensures both the optimal value of the cutting force components and favorable elastic deformations arising in different sections of the boring bar. This also facilitates self-adjustment of the boring bar to the most favorable cutting conditions.

To solve the stated problem, a coupling conforming to НКМ-60-ГОСТ 633-80 (according to the ANI standard) was selected as the research object. The choice of this size coupling is also related to the convenience of conducting experiments on natural samples under laboratory conditions. The cutting forces generated during the machining of conical surfaces and their components were determined analytically using a known methodology [2, 4, 7]. In this case, the cutting part of the tool is made of T15K6-grade hard alloy, while the boring bar material is 40XH steel with a hardness of HRCЭ 48-52. The cutting depth was set to t=3 mm, the feed rate to S=0.2 mm/rev, and the cutting speed to V=200 rev/min. Considering the special role of the principal cutting edge angles (φ_A and φ_B) in the formation of cutting forces, the components of the cutting force were determined and analyzed at various values of these angles ($\varphi_A=\varphi_B \Rightarrow 45^0$; 60^0; 90^0). The system of forces specific to the machining processes was determined (Figures 2.1 and 2), and based on the theories of "Material Strength" [18-21], the deformations ($\Delta=f(\varphi, P_z, P_y, P_x)$) of the boring bar along the direction of the machining dimensions of the tool's principal cutting edge angles (45^0; 60^0; 90^0) were determined, taking into account the mechanisms of their influence on the boring bar. The results were analyzed and generalized (Figure 2.3). According to the coupling design, the dimensions of the designed boring bar are as follows: A_a=30 mm; B_a=30 mm; ℓ_1=56 mm; ℓ=84 mm; d=45 mm; D=60 mm.

The deformations of the boring bar along the axis of its dimension were determined along the working length of the boring bar using the "EXCEL" software.

The technological operation, including the investigation of the elastic deformations of the boring bar and the stress state of its material, was simulated using the ANSYS software for all three variants provided in Figure 1. In the variant where the second cutter processes the cylindrical and conical surfaces at the output end of the coupling (Figure 1.1), the elastic deformation state of the boring bar is shown in Figure 3.

IV. Discussion

The system of forces affecting the boring bar during the parallel machining of surfaces in the processed machining scheme differs significantly from the force system formed during traditional multi-tool parallel machining, as described in the literature. This difference makes the process highly favorable for ensuring machining accuracy (Figure 1). Specifically, the fact that the cutting forces' three components acting on the boring bar and other elements of the technological system (TS) are

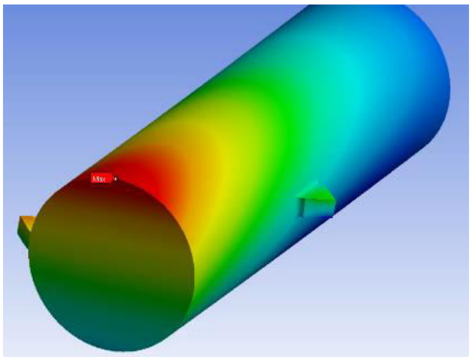

Figure 3: *Simulation of the elastic deformations of the boring bar*

oriented in opposite directions ensures a sharp reduction in elastic deformations on the XOY plane in various workpiece cross-sections, especially in the sections where the machining dimensions are formed (Figure 2).

It should be noted that, based on initial reports and studies, although the elastic deformations of the boring bar's axis under the influence of P_z forces may take relatively large values, their effect on machining accuracy is not technologically significant in this case, since they are oriented perpendicular to the machining dimensions.

The ratio of the forces P_z, P_y, and P_x in the system of forces during the parallel machining of surfaces, and consequently the bending behavior of the boring bar's axis, depends on the geometric parameters of the cutting tools, including the main angles in plan of the cutting edges of the tools (φ_A and φ_B). It is clear that from a technological point of view, the elastic deformations of the boring bar are important in the cross-sections where the vertices of the cutting tools are located.

Thus, the control of dynamic technological connections and the main angles in plan of the cutting edges of the tools during parallel processing of the internal surfaces of the coupling makes it possible to achieve a change in a favorable direction of the magnitude of the cutting force components and to ensure a reduction in the range of elastic deformations of the elements of the technological system and a reduction in their influence on the processing accuracy.

The dimensions of adjustment the tool setup determined taking into account the elastic deformations of axis of the boring bar in its sections, where the tool tips that form the machined surfaces are located (A_a and B_a). That is:

$$A_{af}=30+Y_a \text{ mm}; \qquad B_{af}=30+Y_b \text{ mm},$$

Here, A_{af} and B_{af} are the adjustment dimensions for the position of the cutters in the boring bar.

- Y_a and Y_b are the elastic deformations of the boring bar's axis in the cross-sections where the cutters are located, respectively.

The adjustment tolerance is determined based on the required machining accuracy and technological capabilities.

The simulation of the elastic deformations of the boring bar using ANSYS software has confirmed the above-mentioned results.

V. Conclusions

1. The technology and technological measures for processing internal cylindrical and conical surfaces of oil field couplings are presented, providing sequential-parallel processing of its responsible surfaces with high accuracy and productivity,

2. A unique system of forces acting on the boring bar during parallel processing has been identified, in which all three corresponding components of the cutting forces are directed oppositely, which leads to a sharp decrease in the elastic deformations of the elements of the technological system,

3. By controlling the dynamic technological connections and the main angles in the plan of the

cutters during parallel processing, a change in the favorable direction of the magnitude of the components of the cutting forces is achieved, a decrease in the range of elastic deformations of the elements of the technological system and a decrease in their impact on the accuracy of processing are ensured.

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