Improving the accuracy of threading by optimizing the design of the tool

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Abstract. The paper presents the original design of a special tap for cutting precise threads. Distinctive design features of the tap are: the presence of the rear threaded guide, which together with the copier threaded sleeve of appliance perceives the axial forces and provides the tap axial feed strictly corresponding to the step of the thread being cut, excluding its breaking under the action of axial forces; the presence of a smooth front guide part with the direction on the cut hole, to reduce the influence of radial forces that lead to an increase in the diameter of the thread due to the radial vibrations of the tap; the presence of the chamfer that implements the most technological cutting scheme such as flank infeed. A prototype of a special tap made on a turning and milling machine tool is presented, confirming the manufacturability of the proposed tool design. Research conducted in the field of engineering analysis with the CAE-system Ansys showed a significant increase in structural rigidity, as well as a significant increase in natural frequencies.

1. Introduction

Machining of threaded surfaces is currently implemented in various ways. For example, external threads are formed by a cutter, a rack-type tool, a threading heads, multiple thread cutters, rolling flat or round dies [1]. Today, traditional methods of threading are replaced by the most productive and reliable [1–6].

The machining of internal threads of small sizes is performed with taps [2]. For example, according to GOST 1336-77, the minimum diameter of the threaded multiple thread cutter is 10 mm. According to this GOST, it is also impossible to cut a large diameter thread with the low lead. However, machine taps are one of the least reliable tools for threading. Therefore, much attention is paid to the study of forces and torques arising when threading not only cutters and cutters, but taps [5–8].

Long-term production observations show that despite the apparent simplicity of thread cutting processes, it is not always possible to obtain the expected effect when machining a precise threads [9]. Sometimes, after machining on a high-performance automated machine, "manual" thread calibration is performed, since without it is not possible to perform accurate and high-quality threaded hole, or very often breakage of taps occur with single-pass threading.

When working with conventional equipment, precision threading is performed mainly with a set of taps, with the final finishing pass usually performed manually.

Factors that reduce the performance of taps, mainly are: edge chipping on the on the chamfer; breakage taps (especially up to 18 mm); failure to meet the sizes and technical requirements for the thread in the part [3, 8, 9].
The main reasons for the inaccuracy of the cut thread parameters are axial and radial forces acting on the tap [5-10]. Therefore, to improve accuracy, it is necessary to reduce the operational damage to the thread primarily from the impact of both axial and radial forces.

Approximately for different parameters of threads, the values of increasing the thread diameter due to the operation processes are given in the Table 1.

Table 1. The values of increasing the thread diameter.

| Thread pitch | mm   |
|--------------|------|
| M6–M12       | 0,04–0,16 |
| M14–M22      | 0,05–0,24 |
| M24–M36      | 0,05–0,4  |

If these areas of variation to compare with fields tolerances on the thread, about the accuracy of the thread ranges from the second to the ninth degree of accuracy. This explains the use of notes to the recommendations for the purpose of the class of taps depending on the tolerance fields of cut metric threads according to GOST 16925-71 (Table 2).

Table 2. Assignment of the accuracy class of the tap depending on the tolerance fields of the cut metric threads.

| The accuracy class of the tap | Tolerance fields of the thread |
|------------------------------|--------------------------------|
| 1                            | 4H, 4H5H, 5H                  |
| 2                            | 6H, 5H6H, 5G                  |
| 3                            | 6H, 7H, 8H, 6G                |
| 4                            | 6H, 7H, 8H                    |

Analysis of the design features of standard and special taps, as well as recommendations presented in the scientific and reference literature, determined the design of a special machine-hand tap for single-pass cutting accurate through metric thread. The design of the tap features:

– the presence of a rear threaded guide, which, together with the copier threaded sleeve of device perceives the axial forces and provides a tap axial feed strictly corresponding to the machined thread pitch, excluding increasing the diameter of the thread under the action of axial forces;

– the presence of a smooth front guide part with a direction along the cut hole, made to reduce the influence of radial forces that lead to an increase in the diameter of the threaded hole due to the radial vibrations of the tap, while the radial vibrations of the tap should remain within the gap between the guide surfaces;

– the presence of chamfer part that implements standard cutting scheme such as flank infeed , as the most technologically advanced scheme.

It should be noted that:

– thread with tolerance fields 6H, 7H and 8H can be cut with taps of accuracy classes 1 and 2;

– the tolerance fields of the cut threads given in the table can be obtained by taps only on machines of the corresponding accuracy class, and with the use of mandrels that provide centering of taps in the hole;
thread cutting accuracy depends on the material to be machined, the cutting speed and the properties of the cutting fluid (coolant), which may result in slightly different combinations of tap accuracy class and tolerance fields of the cut metric threads given in Table 2.

The guide parts of the tap are designed in one piece with the working part of the tap, as this ensures their most accurate location. Tool material is high-speed steel R6M5 GOST 19256-73, shank material is steel 40Kh GOST 4543-71.

2. Method
The calculation of the geometric parameters of the tap was made by the method proposed by SHagun V.I. [12]. Determination of the main sizes of the cut thread of external, internal and average diameters and a step is made according to the state standard GOST 9150-81. Technical requirements are accepted according to the state standard GOST 3449-84E for the tap of the first class of accuracy.

Designing of machine tool positioning devices for through thread bore by a special machine-hand taps M16x2-1cl. produced for the part of "Sleeve" M16x2-4H, corresponding to the micrometer sleeve with internal thread of measuring tool.

CAD-system COMPAS 3D and CAE-system Ansys were used when designing the tap. Static and modal characteristics of two design variants of taps were calculated using the CAE-system Ansys: standard and special with two guide parts.

3. Main part
A working drawing of the tap and its prototype of composite construction, machined on the machine tool HAAS ST-10Y, are shown in Figure 1 and Figure 2. The designed device for fixing the part with guide bushings for the tap of a special design is shown in Figure 3.

Figure 1. A working drawing of the tap

Figure 2. The tap prototype
For further research, a three-dimensional model of the tap was developed (Figure 4 a). The results of the calculation of static and modal characteristics in the Ansys system made it possible to refine the geometric parameters of the designed tap.

Two types of calculation models were used in the calculations: solid-state and beam models. The solid model was constructed using typical solid185 finite elements (Figure 4 b) and the beam model using Beam188 elements.

The advantage of the beam model is the possibility of the most accurate reproduction of the tool geometry in the calculation model. The disadvantage of the model is the complexity of the task load, as in this case is strongly affected by the edge effect, leading to distortion of the results of the static problem.

Although the rod model has obvious limitations on the accuracy of the representation of tap geometry, it is easier to specify boundary conditions such as load and anchorage conditions. Regardless of the design of the taps, the load from the cutting forces was represented by the axial and radial components of the cutting forces, as well as torque.
The presence of guide parts in a special tap allowed to set additional restrictions on the degrees of freedom.

Analysis of the results of the static calculation showed that the tap of the standard design under the action of the components of the cutting forces receives significant displacement, significantly exceeding the required value equal to 34 microns (Figure 5).

For a special tap, the maximum displacements did not exceed 30 µm (Figure 6). Taking into account the static displacements introduced by the bearing system of the machine, as well as displacements due to the contact stiffness of the "tap - spindle" connection, the calculated values were in good agreement with the required accuracy parameters.

Figure 7 shows the results of the modal calculation for the tap of a special design. The modal calculation for the tap of the standard design showed that even the standard design of the tap provides its high vibration resistance. The first eigenfrequency is about 1500 Hz, and for a special tap the first eigenfrequency is about 5000 Hz. Forms of oscillations of the first four modes are shown in figure 7. The obtained results of the modal calculation made it possible to eliminate the need for dynamic calculation, because at present the taps do not work with such cutting speeds. Although for the implementation of breakthrough technologies, high vibration resistance of taps should be taken into account.

4. Conclusions

1. The original design of a special tap for cutting precise threads is presented.
2. The Prototype made on the lathe showed the manufacturability of the design.
3. Studies conducted in the CAE system ANSYS have shown a significant increase in structural rigidity, and a significant increase in natural frequencies shows a new direction of research in the field of thread cutting with a special tap.
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Figure 6. Results of static calculation of a special tap
(a) total deformation
(b) directional deformation (X Axes)
(c) directional deformation (Y Axes)
(d) directional deformation (Z Axes)

Figure 7. The results of modal analysis
(a) the first mode
(b) the second mode
(c) the third mode
(d) the fourth mode
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