Manual measurements of cutting tools on a coordinate measuring machine

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Abstract. Coordinate measuring machines make it possible to measure the geometric parameters of precision parts, the measuring of which is not feasible with a universal hand tool. The purpose of the study was to develop a methodology for measuring the design and geometric parameters of a straight bull-nose turning tool. To test the effectiveness of the developed methodology for measuring the design and geometric parameters of the cutting tool, a full-scale experiment was conducted. During the experiment, the measurement of all the structural and geometric parameters of the cutting tool was carried out using hand-held measuring tools and the Wenzel XOrbit 55 coordinate measuring machine. A comparative analysis of the results of the measurements showed the following: all the geometric parameters of the cutting can only be measured using a coordinate measuring machine; geometric parameters measurements using a universal hand tool do not allow you to make unambiguous organizational decisions on the further operation of the cutting tool, since the measurement error is comparable to the current size tolerances, however, for such design parameters as length, height, and width of the cutting, due to the large tolerances, it is sufficient to use a universal hand measuring tool. The measurement practice using a coordinate measuring machine has shown that when performing critical measurements, the use of coordinate measuring machines, in manual mode, is not only accurate, but also more productive in comparison with a universal hand measuring tools.

1. Introduction

Coordinate measuring machines (CMM) of various types have recently been widely used in machine-building production [1-4]. The use of CMM allows you to: quickly measure geometric parameters of simple and complex precision parts whose measurement by traditional means or requires special expensive equipment, or measurement which it is impossible even theoretically; to minimize defects in products using the constant control of process precision machining parts, and make timely adjustments [5-10]. The control of part elements consists in determining the coordinates of individual points on the surface or contour and then comparing the measured actual values with the theoretical values specified in the drawing. The accuracy of the control depends on the number of measured points [11-15].

Despite the widespread use of a split-design tooling, the use of solid and composite construction tools is still relevant today. Basically, this is a small-sized, as well as a special combined tool for surfaced jobs of complex profiles. The control of the structural and geometric parameters of the tools is carried out with special templates, calipers and universal goniometers at engineering enterprises in the manufacture and subsequent regrinding.
Cutting tools are sharpened on the face, flank, or both surfaces, depending on their design and the nature of wear. Cutting tools are sharpened only on the flank with little wear on the face of them.

Currently, turning tools are available in a composite design with increased reliability. Their increased manufacturing accuracy and relative positioning of the toolholder surfaces allows for use on CNC machines. The use of new, including three-layer, solders and replacing the toolholder material with 35KhGSA or 30KhGSA steel (instead of steel grades St. 6, St. 7, 45, 50, U7, U8 and 40Kh) virtually eliminates crack formation during brazing, which reduces cutting tool consumption approximately 3-4 times.

2. Methods and results

2.1. Methodology of measuring the structural and geometric parameters of the cutting tool

The purpose of the study was the analysis and determination of rational control means the structural and geometric parameters of the cutting tools during manufacture and subsequent regrinding.

As the object under study, we selected a carbide-tipped straight bull-nose turning tool, left-hand of a composite structure.

The Wenzel XOrbit 55 coordinate measuring machine (CMM) allows both types of measurements to be performed in both manual and automatic modes. In this paper, the manual measurement mode is considered.

The CMM operation is based on coordinate measurements. In this case, the coordinates of various points on the surface of the cutting tool are measured alternately, and the errors of their normalized geometric parameters are determined by mathematical processing of the measurement results.

The cutting tool is installed and fixed on the CMM table. When the machine is operating in manual mode, the measuring head is moved using the joystick on the control panel. The joystick allows you to move the head along any of the three coordinate axes. The specialized Metrosoft Quartis software is responsible for processing, analyzing, visualizing and storing measurement results on CMM.

Measuring the linear and angular dimensions of the cutting tool on CMM is reduced to determining the nominal position of the actual surfaces of the tool in the coordinate system of the tool and then calculating the distances or angles between them. In this case, a point, a straight line and a plane are the main, standard geometric elements used in the software of coordinate measuring machines to represent real geometry.

The main procedure in all dimensions is to measure a point, since all other types of adjacent elements are built on the basis of measuring the coordinates of points that belong to the actual elements of the cutting tool. Accordingly, the more points will be used to determine the adjacent element, the more accurately the size will be calculated when processing the measurement results. However, the coordinates of only three points were used to construct the plane, in order to reduce the time for measurements and verify the sufficiency of measurement accuracy.

The nominal position of the real surfaces of the tool was determined as follows: with the joystick on the control panel, the probe of the measuring head was brought to the corresponding elements of the tool, and it was touched at arbitrary points related to this element and participating in determining the linear or angular size.

The flat lower face of the tool holder was used as the base surface of the cutting tool, which allowed for free access of the probe to all the measured surfaces, taking into account possible rotations of the measuring head.

After orientation of the measuring probe, the virtual construction of the elements used to determine all dimensions of the cutting tool is performed. To do this, it is enough to use the following set of geometric elements: eleven flat elements (PLN_1, ..., PLN_11, Figure 1), six straight lines (LIN_1, ..., LIN_6, Figure 1) and one point PT_1.
The order of measurement of flat faces does not matter much. However, in manual mode, these faces are more convenient to measure in pairs and immediately determine the necessary sizes for them.

Nominal dimensions, specifications, as well as upper and lower limit deviations are accepted according to the following standards: GOST 18878-73 «Carbide-tipped straight bull-nose turning tools. Design and dimensions»; GOST 5688-2015 «Carbide-tipped tools. Specifications»; GOST 25347-82 «Basic norms of interchangeability. Unified system of tolerances and fits Tolerance zones and recommendable fits».

To determine the width of the tool holder (size L1, figure 1), you need to measure and construct two flat elements PLN_1 AND PLN_2 in sequence (figure 2 (a)). On the computer monitor connected with the CMM, the following parameters are displayed: «Actual value», «Nominal value», as well as the limit deviations set for this size in the form of parameters «Upper tolerance» and «Lower tolerance». This allows you to check the actual size value for compliance with the specified tolerance. The program automatically recalculates the dimensional error in absolute (parameter «Deviation») and percentage (parameter «Data Analysis») ratios. A value of «Data Analysis» of less than 100% means that the actual size is within the tolerance field.

![Figure 1. Geometric elements and parameters of the cutting tool.](image1)

(a) ![Figure 2. Geometric elements for measuring the tool holder (a, b, c) and a screenshot of the program window with the results of calculating the height of the tool holder (d).](image2)
To determine the height of the tool holder (size L2, Figure 1), it is necessary to measure and build two flat elements PLN_3 and PLN_4 (Figure 2 (b)) in sequence. In this case, as the second flat element PLN_4, the CMM table is adopted, on which the cutting tool is based on the lower flat surface of the holder. The measurement results are shown in figure 2 (d).

To determine the cutting tool length (size L3, figure 1), it is necessary to measure and construct a flat element PLN_5 and a point PT_1 (figure 2 (c)).

To determine the cutting edge angles (dimensions A1, A2, A3, figure 1), it is necessary to measure and build a flat element PLN_6, built parallel to PLN_5, as well as measure and build two straight lines LIN_1 and LIN_2 (figure 3 (a)). Then you need to build projections of straight lines LIN_1 and LIN_2 on the plane PLN_4. As an illustration, the results of the main angle measurement in the plan in the form of a screenshot of the corresponding dialog box are shown in figure 3 (e).

The value of the corner angle can be obtained both by directly measuring the angular position of the projections of the straight lines LIN_1 and LIN_2 on the PLN_4 plane, and by calculating the measured angles A1 and A2:  $A_3 = 180° - (A_1 + A_2)$

To determine the orthogonal rake of the cutting tool (size A4, figure 1), it is necessary to measure and build a flat element PLN_7 and a straight line LIN_3, perpendicular to the line LIN_1 and lying in the plane PLN_7 (figure 3 (b)). The angle is measured between the PLN_3 plane and the LIN_3 straight line.

To determine the minor rake of the cutting tool (size A5, figure 1), it is necessary to measure and build a straight line LIN_4, perpendicular to the line LIN_2 and lying in the plane PLN_7 (figure 3 (c)). The angle is measured between the PLN_3 plane and the LIN_4 line.

To determine the orthogonal clearance of the cutting tool on the cutting blade (size A6, figure 1), it is necessary to measure and build a flat element PLN_8 and a straight line LIN_5, passing through the line LIN_1 and perpendicular to the plane PLN_4 (figure 3 (d)). The angle is measured between the PLN_8 plane and the LIN_5 line.

To determine the orthogonal clearance of the cutting tool on the holder (size A7, figure 1), it is necessary to measure and build a flat element PLN_9 (figure 4 (a)). The angle is measured between the PLN_9 plane and the LIN_5 line.

To determine the minor clearance of the cutting tool on the cutting blade (size A8, figure 1), it is necessary to measure and construct a flat element PLN_10 and a straight line LIN_6, passing through
the line LIN_2 and perpendicular to the plane PLN_4 (figure 4 (b)). The angle is measured between the PLN_10 plane and the LIN_6 line.

Figure 4. Geometrical elements for measuring angles of the cutting tool.

To determine the minor clearance of the cutting tool on the holder (size A9, figure 1), it is necessary to measure and construct the PLN_11 flat element sequentially (figure 4 (c)). The angle is measured between the PLN_11 plane and the LIN_6 line.

To determine the orthogonal wedge angle of the cutting tool (size A10, figure 1), the measurement is made between the PLN_7 and PLN_8 planes (figure 4 (d)). To determine the minor wedge angle of the cutting tool (size A11, figure 1), the measurement is performed between the PLN_7 and PLN_10 planes (figure 4 (e)).

To determine the cutting angle of the cutting tool (size A12, figure 1), the measurement is made between the plane PLN_7 and the straight line LIN_5 (figure 4 (f)). To determine the cutting edge inclination of the cutting tool (size A13, figure 1), the measurement is performed between the plane PLN_3 and the straight line LIN_1 (figure 4 (g)).

2.2. Experimental study

To test the effectiveness of the developed methodology for measuring the tool structural and geometric parameters, a full-scale experiment was conducted. During the experiment, all tool structural and geometric parameters were measured using hand-held measuring tools and CMM Wenzel XOrbit 55.

As manual measuring tools were used:
- vernier caliper type SHC-I-150-0.02 GOST 166-89 (the division value is 0.02 mm, and the margin of error ±0.02 mm);
- vernier protractor type 1 GOST 5378-88 (the base division value is 1°, the vernier reading magnitude is 2′, and the margin of error is ±2′);
- pendulum protractor type 3URI-M TU 2-034-666-82 (the division value is 1°, and the margin of error is ±1°).

Experimental data and calculation results are listed in table 1.

The time spent on measuring tool structural and geometric parameters using a universal measuring tool was 30 minutes, and using CMM in manual mode was 15 minutes.

A comparative analysis of the results of the measurements performed using a universal manual measuring tool and CMM showed:
- all tool geometry can only be measured using CMM;
- the measurement results of tool geometry using a universal hand tool do not allow you to make unambiguous organizational decisions for the further operation of the cutting tool, since the measurement error is comparable to the current size tolerances; however, for such design parameters
as length, height, width of the cutting tool (due to large tolerances), it is sufficient to use a universal hand tool.

**Table 1.** Experimental data and calculation results of cutting tool.

| Measuring method             | Cutting tool length L, mm | Cutting tool holder width B, mm | Cutting tool holder height H, mm | Cutting tool angles, degrees | The angle of inclination of the main cutting edge | Back corners on a holder |
|------------------------------|---------------------------|--------------------------------|---------------------------------|-------------------------------|-----------------------------------------------|-------------------------|
| Nominal dimensions of the cutting tool according to GOST 18878-73 and deviations according to GOST 5688-2015, GOST 25347-82 |
| Measuring tool               | 210,041                   | 15.76 – 15.82                  | 24.34 – 24.42                  | 5° ± 1°                      | 10° ± 1°                                     | 6° ± 1°                 |
| Coordinate measuring machine (manual mode) | 210                        | 15.76 – 15.82                  | 24.34 – 24.42                  | 5° ± 1°                      | 10° ± 1°                                     | 6° ± 1°                 |

3. Conclusions

Conclusion about the accuracy of the tool manufacturing in accordance with GOST 5688-61 «Carbide-tipped tools. Specifications» can only be obtained when using CMM, since the measurement with a manual measuring tool for multiple repeated measurements gives a dispersion of the actual size magnitudes comparable to the size tolerance zone set by the standard. The wedge and cutting angles, as well as the minor wedge angle on the blade can not be measured with a hand tool.

The developed methodology of measuring the structural and geometric parameters of the cutting tool can be extended to other types of machine tooling with minimal modifications, in view of the universality of the geometric parameters of the cutting wedge of the bull-nose turning tool.

The practice of measuring using CMM has shown that when performing critical measurements, which include measurements of geometric parameters of machine tooling, the use of CMM even in manual mode is not only accurate, but also more productive in comparison with the use of measuring tools. This creates the prospect of a wider implementation of control operations using CMM in the manufacturing process and regrinding of the machine tooling.

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