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Analysis of datum schemes for multi-faceted cutting inserts in cutting

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Abstract. Renovation of multi-faceted carbide inserts is one of the important problems of tool-making. One of the problems of tool renovation is its datum. Taking into account the volume of the tool, it is necessary to ensure not only its datum accuracy, but also the ability to automate the recovery process. Various mounting modes of multi-faceted carbide inserts are considered, and the method providing the maximum accuracy of datum and quick-release is proposed.
Keywords: datum schemes, grinding, cutting forces, cutting tool, multi-faceted carbide inserts.

1. Introduction
The operating life of a cutting tool depends on many factors, such as the properties of tool material, geometric and structural features of the cutting part, processing modes, types of strengthening coatings, etc. It is possible to increase the tool operating life due to multiple recovery of its cutting part by grinding and sharpening [1-11]. Thus, the total average period of tool-life is determined, which is expressed by the sum of the average tool-life periods from the beginning of its operation until its limit state, when further recovery and operation are not possible [12]. In the works [1, 11] equipment and processing schemes designed for sharpening the cutting part of brazed-tip tools and rotary cutting tools are considered. These schemes are implemented on universal cutter and tool grinding machines. In the automated manufacturing, tools with exchangeable cutting carbide inserts (CI) are used, which can also be recovered by diamond grinding and sharpening [2, 3, 4, 6, 7]. The tool-life period of such a tool is close to that of a new tool, in particular, it is obvious in roughing and peeling operations, while the cost of CI recovery is not more than 20-30% from the cost of new ones.

2. Problem statement
To recover the cutting unit of the MI, the authors [1] suggest using a copying method which is conducted in a special copying device or CNC tool and cutter grinding machine (Figure1).

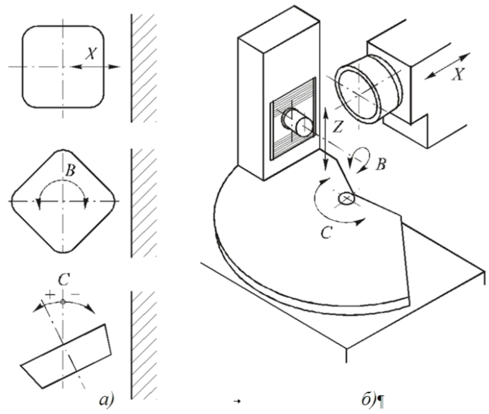
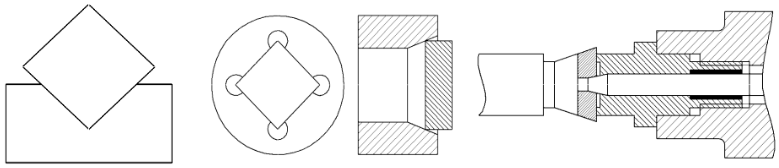


Figure 1. Shape forming movements in grinding back surfaces of inserts on CNC machines:
- the main shape forming movements; *b* - the same movements on the machine.

In works [1, 2, 9] the strategy of CI processing along a contour on CNC tool and cutter grinding machines is developed and various ways of datums are considered (Figure 2-3). Three main ways of MI datum are distinguished:

- in centering prism (figure 2a);
- in centering bush (figure 2b);
- on the hole (figure 2c).

The method of datum in the centering prism allows one to accurately mount the MI relative to its side surface, but in this case the positioning accuracy of the hole is not ensured, which is necessary for grinding along the contour. Such datum scheme is used for contour grinding of the MI cutting unit, however the problem of their holding in a turret arises, as well as the need for remounting each face when grinding and frequent contour adjustment of the working surface of the grinding wheel is required (because grinding is done by copying). MI datum in the centering bush is possible within the automated grinding process, which allows for rapid positioning of the product, but this method complicates the design of the device and is inferior in datum accuracy on the central hole. The hole datum proposed by the authors [1] allows one to quickly and accurately combine the axis of the workpiece with the axis of the device. In this method, due to the large number of structural elements in the clamping mechanism, grinding wheel supply to the grinding zone is difficult.



a) b) c)

Figure 2. MI datum method: a - on the centering prism; *b* - in the centering bush, c - on the hole.

To ensure a reliable and accurate clamping of MI in grinding and sharpening operations along the contour, it is essential to solve the following problems:

- To analyze MI mounting modes when grinding.
- To develop a datum scheme, this will provide a quick and accurate MI positioning, required clamping force, and grinding wheel supply in a region of grinding.

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3. Theory
Various MI mounting modes for grinding along the contour are considered (Figure 3). Figure 3 shows: 1 is the exchangeable mandrel for insert datum mounted in the indexing unit of the CNC tool and cutter grinding machine; 2 is MI; 3 is the clamp; 4 is the screw; 5 is the expanding collet; 6 is the screw with a cone head.

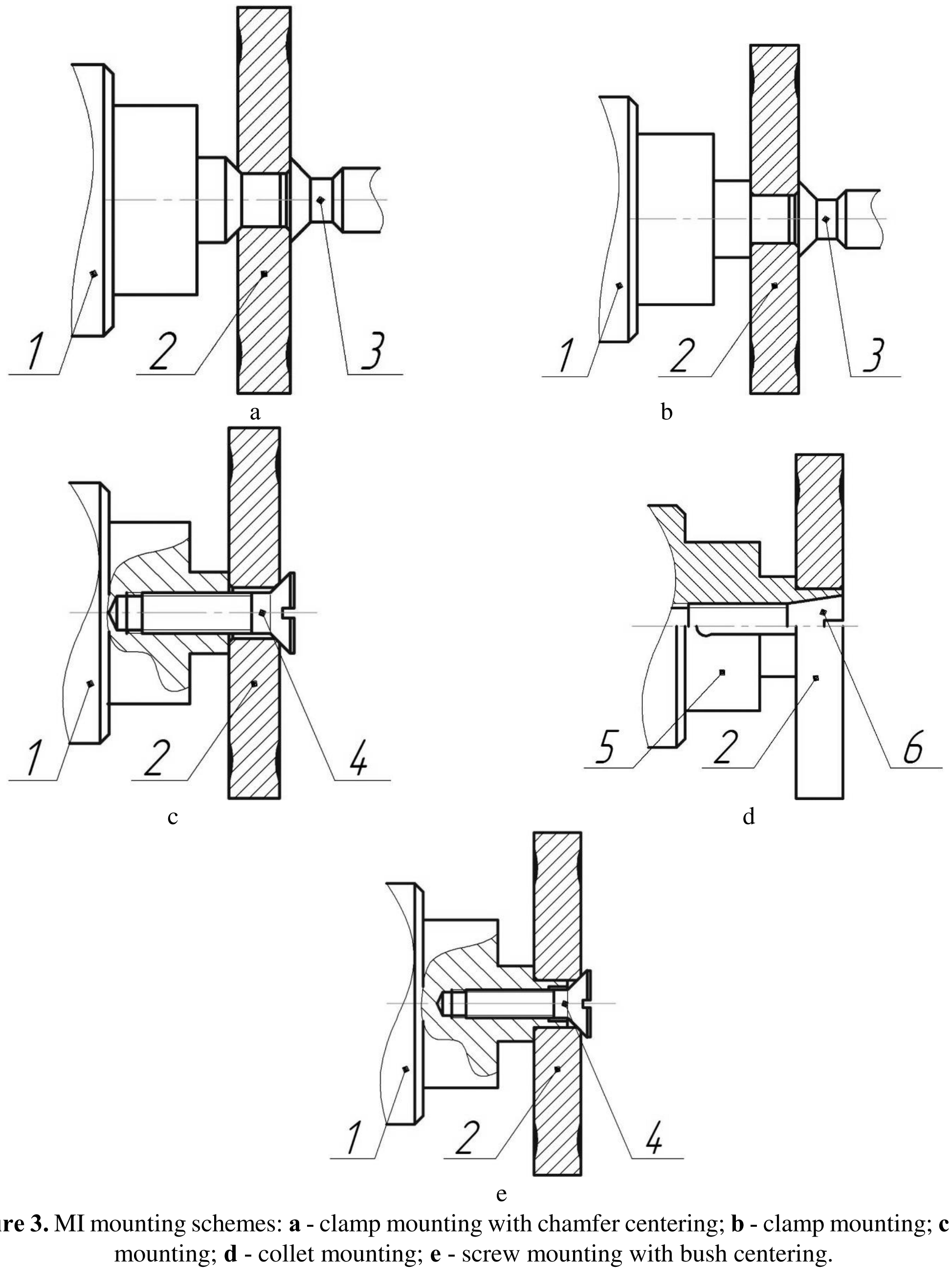

Figure 3. MI mounting schemes: **a** - clamp mounting with chamfer centering; **b** - clamp mounting; **c** - screw mounting; **d** - collet mounting; **e** - screw mounting with bush centering.

The calculation of the required clamping forces, excluding the turning of the insert in grinding, is determined as follows [13].
The scheme of applied forces and moments for the mounting option according to figure 3a is shown in figure 4.

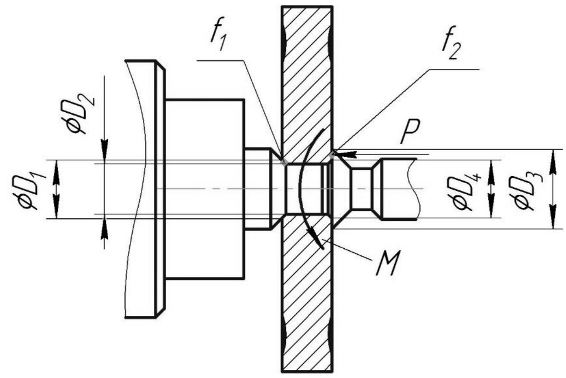

Figure 4. The scheme of applied forces and moments for the mounting option with a clamp centered on the chamfer.

Figure 4 shows the diameters of the contacting surfaces of the insert D_n, the friction coefficients f_1, f_2, the clamping force P and the moment M arising from the grinding. From the equilibrium equation, we make an equality to find the required clamping force P (1):

$$k \cdot M = P \cdot f_1 \cdot \frac{D_1 + D_2}{4} + P \cdot f_2 \cdot \frac{D_3 + D_4}{4} \quad (1)$$

where k is factor of safety, which is calculated by the formula (2):

$$k = \prod_{i=0}^{5} k_i \quad (2)$$

This factor is calculated for specific processing conditions. In our case, the following is taken: k_0=1.5 is the guaranteed safety factor for all cases; k_1=1 is the factor, which accounts for the state of the workpiece surface (finish surface in our case); k_2=1.5 is the factor, which accounts for the increase in cutting forces from the progressive tool blunting; k_3=1,2 is the factor which takes account of the increase in cutting forces with intermittent cutting; k_4=1 is the factor, taking into account the constancy of the clamping force, developed by the drive device (Figures 3a and b for the hydraulic drive); k_5=11 is the factor, taken into account in the presence of torques seeking to revolve the workpiece. Substituting the data into formula (2), we find the total factor k (3):

$$k = \prod_{i=0}^{5} k_i = 1.5 \cdot 1 \cdot 1.5 \cdot 1.2 \cdot 1.0 \cdot 1.0 = 2.7 \quad (3)$$

The moment M occurred during grinding is the product of the tangential component of the cutting force by the shoulder, which is the distance from the ground surface to the cutting insert rotation axis. For example, we use an insert of a "boat" type, the insert is shown in figure 5.

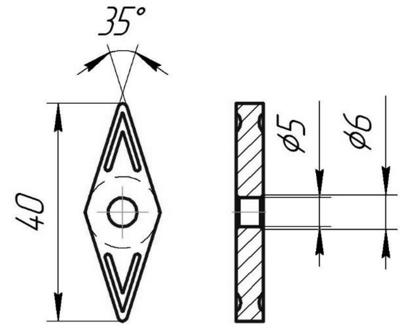

Figure 5. Metal-cutting insert of a "boat" type.

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The maximum torque will occur in passing from side grinding to the top of the insert. Let the force in this scheme be P_Z = 50 N, which approximately corresponds to the conditions of grinding with high circumferential speed and feed [14]. In this case, the moment is found by the formula (4):

$$M = l \cdot P_z = \frac{40 \cdot 10^{-3}}{2} \cdot 50 = 1 \text{ N·m} \tag{4}$$

Friction coefficients for the polished surfaces are $f_1 = f_2 = 0.2$, and diameters are according to the size of the insert and the size of the clamping device: D_1 = 6 mm, D_2 = 5 mm, D_3 = 8 mm, D_4 = 6 mm. Then expressing from formula (1) the clamping force P we obtain (5):

$$P = \frac{k \cdot M}{f_1 \cdot \frac{D_1 + D_2}{4} + f_2 \cdot \frac{D_3 + D_4}{4}} = 2160 \text{ N} \tag{5}$$

The scheme of applied forces and moments for the mounting option according to figure 3b is shown in the figure 6.

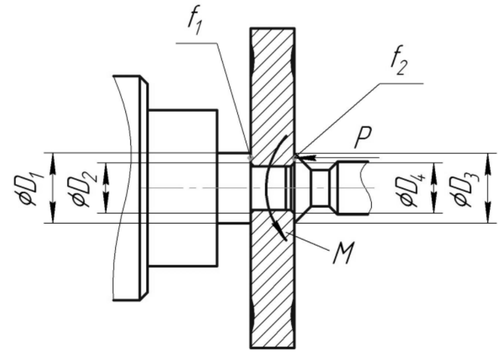

Figure 6. Scheme of applied forces and moments for the clamp mounting option.

Here $D_1=D_3=8$, $D_2=D_4=6$. Using the above technique we find:

$$P = \frac{k \cdot M}{f_1 \cdot \frac{D_1 + D_2}{4} + f_2 \cdot \frac{D_3 + D_4}{4}} = 1928 \text{ N} \tag{6}$$

The scheme of applied forces and moments for the mounting option according to figure 3c is shown in the figure 7.

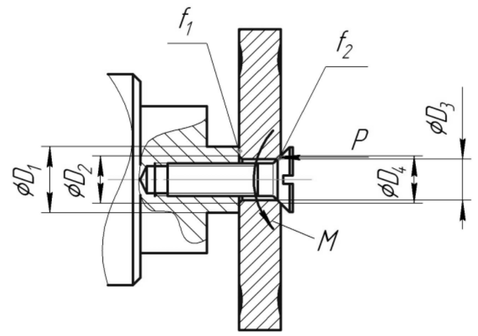

Figure 7. Scheme of applied forces and moments for the screw mounting option.

In this case $D_1 = 8$ mm, $D_2 = 6$ mm, $D_3 = 6$ mm, $D_4 = 5$ mm, $k_4 = 1{,}3$ mm, k_4 is the outer diameter of the screw thread M3.

$$P = \frac{k \cdot M}{f_1 \cdot \frac{D_1 + D_2}{4} + f_2 \cdot \frac{D_3 + D_4}{4}} = 2808 \text{ N} \tag{7}$$

Then we determine the screw torque for creating the calculated force by the simplified formula (8):

$$M = 0.15 \cdot P \cdot M_{screw} = 1.2636 \quad \text{N m} \tag{8}$$

Scheme of applied forces and moments for the mounting option according to figure 3d is shown in the figure 8.

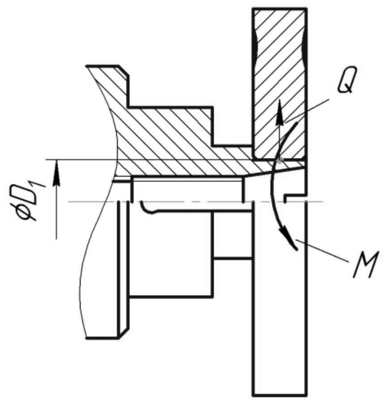

Figure 8. Scheme of applied forces and moments for the collet mounting option.

Here $D_1 = 5$ mm. Force Q is the force of release, sufficient to clamp the insert. It is derived from the formula:

$$Q = \frac{k \cdot M}{f_1 \cdot \frac{D_1}{D_2}} = 7020 \text{ N} \tag{9}$$

The scheme of applied forces and moments for the mounting option according to figure 3e is shown in the figure 9.

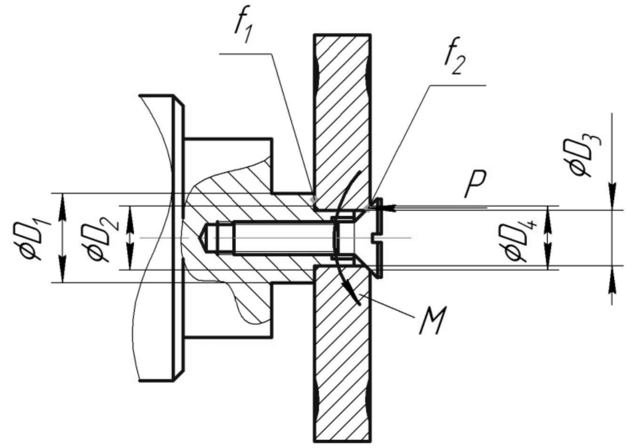

Figure 9. Scheme of applied forces and moments for the screw mounting option with chamfer centering.

The required clamping force *P* and the required screw torque force in this scheme will be the same as in the scheme in figure 7.

Analysis of the MI mounting modes when grinding showed, that in terms of grinding process automation, grinding schemes presented in figures 4 and 6 are preferable, however hole datum accuracy is not provided. First of all, this is due to a large error of hole making in MI, which can reach 0.1 mm in one batch of MI and up to 0.25 mm in different batches from different manufacturers. The schemes presented in figures 7 and 9 also do not provide the datum accuracy and exclude the possibility of grinding process automation. The scheme of collet and screw clamping provides error compensation of the hole manufacturing in MI, but excludes the possibility of automation. To eliminate this drawback, it is necessary to replace screw clamping with a countersink stop (Fig. 10).

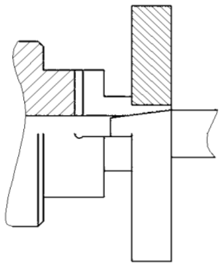

Figure 10. Scheme of MI clamping in the collet with the countersink stop.

4. Experiment results

MI grinding and sharpening on the schemes presented in figure 3 are performed on CNC tool and cutter grinding machine B3-700F4 and modernized grinding machine МШ-289-ВЕНД. In the rough grinding operation diamond wheel 12A2 160/125 B2-01 100% is used, grinding modes are: V_{wh}=30 m/s, S_{long}=2 m/min, S_{cross}=0,05mm/m.f. In grinding the characteristics of the diamond wheel is 1A1 80/63 B2-01 100%, grinding modes are: V_{wh}=35 m/s, S_{long}=4 m/min, S_{cross}=0,02mm/m.f. The material is MI vk10. In rough grinding according to schemes (Figures 3 a, b, c, d) there was an uneven removal of the allowance at the initial moment of grinding, associated with the error of MI datum (Figure 11). The unpolished segment was eliminated by removing the allowance of 0.1... 0.2 mm.

Figure 11. Uneven removal of the allowance at the back edge of MI.

The use of the scheme shown in figure 3d and the scheme of MI collet clamping with a countersink stop allowed for high accuracy processing (Figure 12).

Figure 12. Even removal of the allowance at the back edge of MI.

When grinding according to schemes (Figures 3c and 3e), in the case of increasing the value of the feed and the removed allowance, there was a turn of MI and the subsequent "cutting" of its contour (Figure 13).

Figure 13. MI contour damage.

5. Results and discussion

On the basis of the data obtained, it can be concluded that in MI grinding on the contour, the greatest accuracy and positioning speed can be achieved with a the clamp schemes in a collet with a countersink stop implemented on the upgraded grinding machine MS-289-VEND. The scheme shown in figure 3d can be used on CNC tool grinding machinery when grinding small batches of parts.

6. Conclusion

Most engineering enterprises introduce production technology and equipment for renovation of metal-cutting tools and this is mainly rotary cutting tools. A promising direction of costs reduction in tool-making is the renovation of multi-faceted carbide inserts. The use of the proposed datum scheme will reduce the auxiliary time for grinding and sharpening the cutting unit of MI by at least 50%.

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