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A CAD-Based Method for the Design of Profiled Prismatic Cutting Tools and Their Three-Dimensional Modelling

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Abstract
Starting from the three established methods for determining the cutting edge of the tool, this paper presents an alternative approach based on the use of CAD environments for generating both the cutting edge and the tool body. The proposed method enables the rapid development of complex geometries, since the cutting edge is derived directly from the profile of the workpiece to be machined. Consequently, the errors associated with traditional methods are eliminated, particularly those that may occur when processing curves with complex geometry.

Keywords
flat form tool, CAD modelling of form tools, machining processes

1. Introduction

Machining remains one of the most widely used methods for obtaining functional surfaces in the machine building industry, and turning holds an important position due to its versatility, precision, and adaptability to a wide range of materials and geometric configurations. In the current context, characterized by increasing demands for productivity, repeatability, and surface quality, the optimization of cutting tools used in turning processes has become a key objective in industrial machining. For this reason, form tools represent a particularly efficient technological solution for producing complex contours, special profiles, and parts manufactured in medium and large series.

The use of form tools enables the accurate reproduction of the final shape of the workpiece in a single pass, eliminating the need for compound tool movements or the successive use of multiple tools. This characteristic leads to a significant increase in productivity by reducing both machining time and the number of auxiliary operations. Moreover, due to the direct correspondence between the tool profile and the geometry of the workpiece, low dimensional deviations and high repeatability are achieved, essential aspects in the manufacturing of precision components.

Another major advantage is the superior quality of the resulting surfaces. The increased rigidity of the tool and the distribution of wear along the entire cutting edge contribute to reduced vibrations, lower surface roughness, and improved stability during machining.

Through their ability to generate complex shapes quickly and accurately, form tools prove to be indispensable in applications where efficiency, consistent quality, and cost reduction are priorities. The analysis of their performance and their integration into turning processes represent a necessary step toward optimizing technological workflows and increasing industrial competitiveness. The advantages of these cutting tools have also attracted the attention of tool manufacturers who produce form profiled inserts according to customer specifications [1].

2. Design of Form Tools

The design methods for form tools used in turning, as presented in the specialized literature, are: the analytical method, the geometric method, and the graphical method [2].

Using classical methods for designing such tools involves a set of technical activities, calculations, constructions, and verifications that require time, precision, and experience.

The analytical method involves the use of parametric equations describing the workpiece profile in its reference system and determining the intersection between the tool's rake surface and the workpiece surface, resulting in the equation of the cutting edge. Subsequently, this equation is expressed in the tool's reference system, which allows the formulation of analytical relations defining the constructive surfaces of the tool.

The graphical method is the most intuitive of the classical approaches; however, the accuracy of the results depends largely on the designer's experience and the quality of the graphical instruments used. This method presents significant limitations when dealing with complex profiles or when tight tolerances are required, as precision is strongly influenced by drawing accuracy.

In the following, the geometric method will be presented in detail, as it is analysed more extensively in order to validate the new CAD (Computer Aided Design) method used in this work for determining the prismatic profile of the tool.

The geometric method is based on constructing a precise geometric representation. Starting from this construction and applying various geometric relations, the profile of the prismatic form tool can be determined. The method, however, presents limitations when the profile is complex.

2.1. Method

To illustrate the geometric method, a simple workpiece shown in Figure 1 will be used. This is a rotational part in which the transition from the maximum to the minimum diameter is achieved through conical surfaces.

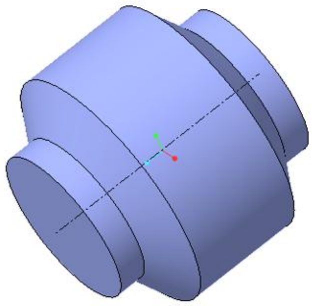

Fig. 1. Workpiece in three-dimensional view

The dimensions of the workpiece are indicated in Figure 2, and they can be identified in any axial section of the part.

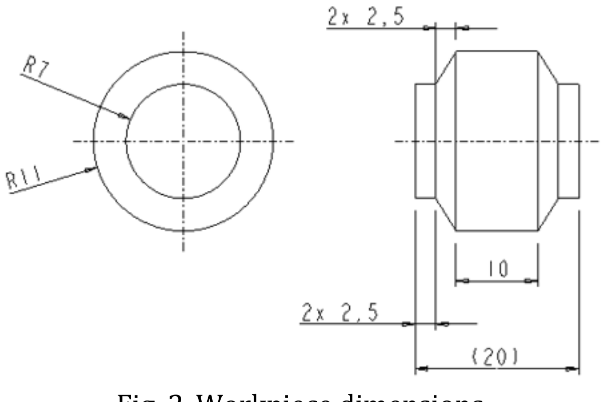

Fig. 2. Workpiece dimensions

The rake angle (γ) and clearance angle (α) of the tool, which depend on the tool and workpiece materials, are presented in [3] and typically range between α = 8° ... 15° and γ = 0° ... 25°.

Machining with form tools requires knowledge of the three characteristic planes through which the workpiece profile can be transferred onto the cutting tool.

Figure 3 illustrates these three characteristic planes:

- P plane: the axial plane containing the workpiece dimensions,
- R plane: the rake surface plane, where the cutting edge of the tool is located,
- T plane: the plane normal to the clearance surface, containing the dimensions of the tool's profile section.

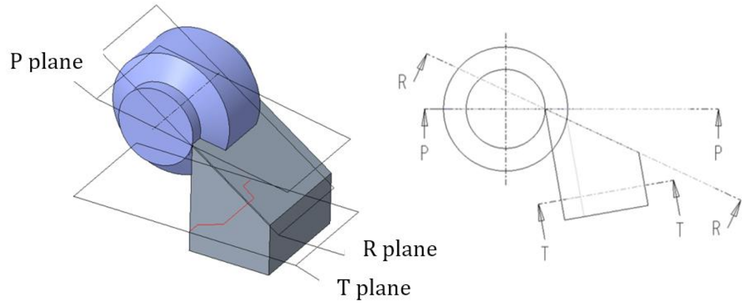

Fig. 3. Characteristic planes of a prismatic form tool

Figures 3 and 4 highlight that the axial dimensions, the cylindrical surfaces of 2.5 mm and 10 mm in length, and the conical surfaces of 2.5 mm in height are identical on both the workpiece and the cutting tool. However, the segments representing the difference between the maximum and minimum diameters of the workpiece, measured in the axial plane, in the rake face plane, and in the plane normal to the clearance face, have different values. Regarding segments BC and CE, these represent the hypotenuse and the leg of triangle BCE, respectively, and therefore have different lengths. For segments BD and BC, if γ=0°, then BD equals BC; as γ increases, the length of BC increases relative to BD.

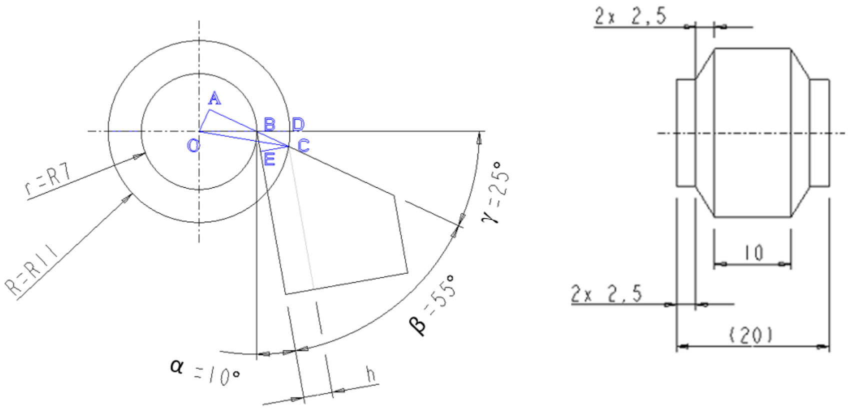

Fig. 4. Geometric scheme for determining the profile of the prismatic form tool

The geometric determination of the profile consists in establishing the profile depth h, shown in Figure 4, or a set of depths in the case of complex profiles, required to define the cutting edge located in the rake plane.

The following section derives the value of h as a function of *r*, *R*, and the clearance (α) and rake (γ) angles, where *r* and *R* are dimensions of the workpiece, and α and γ are selected according to the workpiece and tool materials. In this case, the chosen values are: *r* = 7, *R* = 11, α = 10° and γ = 25°.

From the literature, it is known that the sum of the rake, clearance, and wedge angles equals a right angle:

$$\alpha + \beta + \gamma = 90° \tag{1}$$

From this relation, the wedge angle is β = 55°.

To establish the relationship between segments BD, BC, and CE (*h*), we begin with right triangle ΔOAB. In this triangle:

$$\begin{aligned} AO &= sin\,\gamma * OB = sin\,\gamma * r \\ AB &= \cos\gamma * OB = \cos\gamma * r \end{aligned} \tag{2}$$

In right triangle ΔOAC, knowing OC = R and AO from (2), segment AC is:

$$AC^2 = \sqrt[2]{OC^2 - OA^2} = \sqrt[2]{R^2 - (\sin\gamma * r)^2} \tag{3}$$

Segment BC is then:

$$BC = AC - AB = \sqrt[2]{R^2 - (\sin\gamma \, * \, r)^2} - \cos\gamma * r \tag{4}$$

In right triangle ΔBEC, segment EC (h) is:

$$EC = BC * sin\,\beta = BC * \cos\,(\alpha + \gamma)\,;$$
$$h = \left(\sqrt[2]{R^2 - (\sin\gamma * \, r)^2} - \cos\gamma * r\right) * \cos\,(\alpha \, + \, \gamma) \tag{5}$$

Substituting the values of r, R, α, and γ into relations (2) … (5), we obtain (in mm):

$$\begin{gathered} AO = 2.95832 \\ AB = 6.34415 \\ AC = 10.59473 \\ BC = 4.25058 \\ EC = h = 3.48187 \end{gathered} \tag{6}$$

2.2. Designing a prismatic form tool using the CAD method

The profiled shape of the prismatic form tool is obtained through a sequence of steps using the Creo 9 Student Edition modelling environment [4] and its associated commands [5]. The first step consists in modelling the surface of the finished workpiece, which serves as the reference surface for generating the cutting edge.

In the second step, the body of the prismatic tool is modelled as a solid with the geometry of a right prism. The solid is constructed with one edge located at the intersection between the horizontal axial plane of the workpiece and its minimum diameter. This edge represents the cutting edge of the tool. Relative to this edge, the tool is rotated about a vertical plane, as shown in Figure 5, by the clearance angle α = 10°.

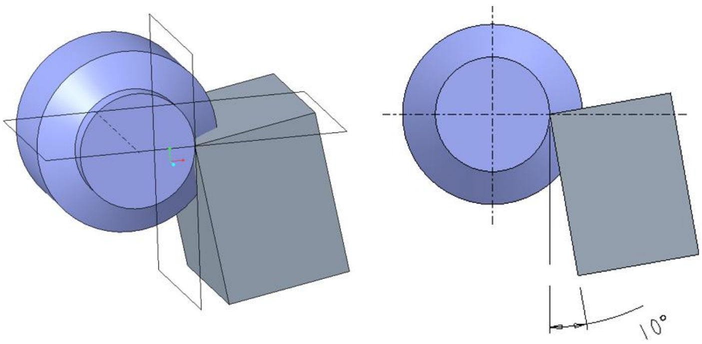

Fig. 5. Modelling the workpiece and the turning tool

The next step consists in modelling the rake surface and determining the cutting edge through the intersection between this surface and the workpiece, as illustrated in Figure 6.

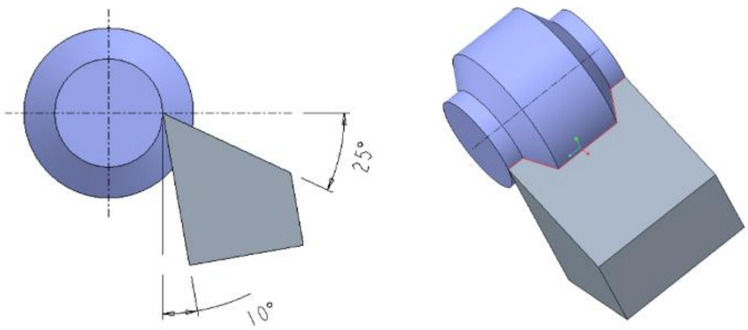

Fig. 6. Modelling the rake surface and obtaining the cutting edge

In the final step, the Sweep command is used to obtain the final shape of the prismatic form tool. This command generates a geometry by moving a section along a curve. In this case, the section is defined by the cutting edge, and the curve corresponds to an edge of the clearance surface. The resulting volume is removed from the tool body, producing the final geometry of the prismatic form tool (Figure 7).

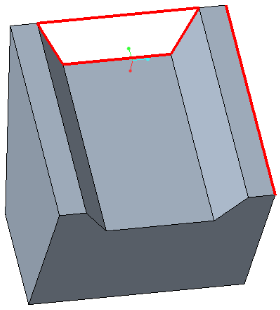

Fig. 7. Resulting Prismatic Form Tool

Figure 8 presents the dimensions of the tool obtained using the CAD method, rounded to three decimals. These values match those obtained from relations (6), confirming the accuracy of the method.

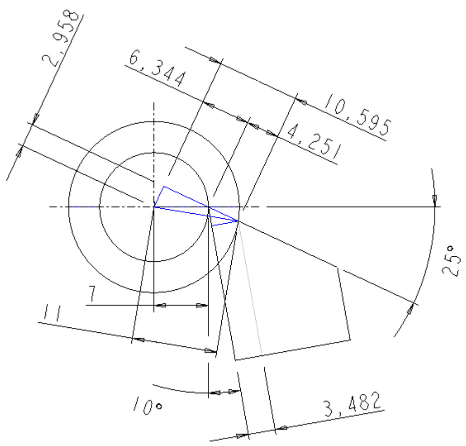

Fig. 8. Dimensions of the prismatic form tool

5. Conclusions

The comparative analysis shows that the values obtained using the geometric method and the CAD method are identical, confirming the validity of the CAD approach. The CAD method eliminates the need for mathematical calculations, significantly reducing the time required to obtain the tool profile.

The resulting three-dimensional model can be used directly in computer aided manufacturing (CAM), facilitating integration into a fully digital workflow.

The profile generated using the CAD method is error free, making this approach suitable even for workpieces with complex surfaces.

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