The actual geometry of the cutting tool involved in machining

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Abstract Understanding actual geometry of the cutting tool involved in machining is critical to the investigation of the mechanism of cutting process. According to control pattern of the flank and the insert shape, the cutting tools are classified into four different types in this paper including S- and non-S-shaped tools with cylindrical control and conical control. By establishing all the four kinds of tools’ 3-D models, the actual geometry of the cutting tool can be obtained. Research results suggest that the actual geometry involved in machining of the S-shaped inserts whether with cylindrical control or conical control is sphere; non-S-shaped with cylindrical control tools is ellipsoid while non-S-shaped with conical control is paraboloid.

Keywords Cylindrical control · Conical control · Tool shape · Actual geometry

List of symbols

- $A$ one point around tool nose
- $A_0$ projection of point $A$ in XOY plane
- $A_1$ projection of point $A$ in $X_1O_1Y_1$ plane
- $A_2$ projection of point $A$ in $X_2O_2Y_2$ plane
- $\beta$ the angle between $OA_0$ and $OX$
- $R$ the cutting tool nose radius
- $k$ coordinate of point $A$ in $Z$ direction in $O$-XYZ coordinate system
- $l$ the thickness of the cutting tool

- $C$ C-shaped tools that means that the angle of tool nose is 80°
- $D$ D-shaped tools that means that the angle of tool nose is 55°
- $K$ K-shaped tools that means that the angle of tool nose is 55°
- $V$ V-shaped tools that means that the angle of tool nose is 35°
- $W$ W-shaped tools that means that the angle of tool nose is 80°
- $T$ T-shaped tools that means that the angle of tool nose is 60°
- $S$ S-shaped tools that means that the angle of tool nose is 90°

- $x$ coordinate of point $A$ in $X$ direction in $O$-XYZ coordinate system
- $r_1$ the major cutting edge radius
- $y$ coordinate of point $A$ in $Y$ direction in $O$-XYZ coordinate system
- $z$ coordinate of point $A$ in $Z$ direction in $O$-XYZ coordinate system

- $x_1$ coordinate of point $A$ in $X_1$ direction in $O_1-X_1Y_1Z_1$ coordinate system
- $y_1$ coordinate of point $A$ in $Y_1$ direction in $O_1-X_1Y_1Z_1$ coordinate system
- $z_1$ coordinate of point $A$ in $Z_1$ direction in $O_1-X_1Y_1Z_1$ coordinate system

- $x_2$ coordinate of point $A$ in $X_2$ direction in $O_2-X_2Y_2Z_2$ coordinate system
- $y_2$ coordinate of point $A$ in $Y_2$ direction in $O_2-X_2Y_2Z_2$ coordinate system
- $z_2$ coordinate of point $A$ in $Z_2$ direction in $O_2-X_2Y_2Z_2$ coordinate system

- $v_1$ the angle between $Y_1O_1$ and $O_1A_1$
- $m$ the length of the major cutting edge

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$M_1$ transformation matrix from $O_1-X_1Y_1Z_1$ to $O$-XYZ
$V_2$ the angle between $O_2Z_2$ and $O_2A_2$
$n$ the length of the minor cutting edge
$r_2$ the minor cutting edge radius
$M_2$ transformation matrix from $O_2-X_2Y_2Z_2$ to $O$-XYZ
$Q$ from coordinate system $O$-XYZ to $O_1-X_1Y_1Z_1$, translations $Q$ units along $Y$ direction
$P$ from coordinate system $O$-XYZ to $O_2-X_2Y_2Z_2$, translations $P$ units along $X$ direction
t matrix parameter
$\varepsilon_r$ tool nose angle
$\theta$ rotate angle
$\omega$ half top angle of the control cone

1 Introduction

With increased emphasis on manufacturing, understanding the machining mechanism assumes great significance [1–5]. An important aspect of machining mechanism is the presence of the effect of the cutting tool geometry. The recent research in the effects of cutting tool geometry concentrates on studying the cutting edge [6, 7] and tool nose [8–11]. A number of researchers have analyzed the effect of the cutting tool geometry in machining either by cutting experiments [12, 13] or finite element method (FEM) simulations [14, 15]. Rech et al. [16] tested the behavior of coated PM-HSS milling inserts with different edge radius and concluded that the modifications of the cutting edge radius are the main criteria influencing the wear resistance. Chou and Evans [17] found that the distance from the cutting edge to the nominal machined surface changes is the main reason of the size effect of cutting force. Ceretti et al. [18] used DEFORM 2D software to simulate orthogonal cutting operation by changing the tool geometry and cutting speed. Li and Shih [19] used the Third Wave AdvantEdge machining simulation software to simulate the effects of cutting speed and cutting edge radius on cutting forces, chip thickness and tool temperature. These researches investigated the effect of the cutting tool geometry either from the tool edge or from the tool nose, but none of them had considered the two aspects comprehensively.

In actual cutting, especially in micromachining, the metal removal rate is very little. The major cutting edge and the minor cutting edge as well as the tool nose are all involved in microcutting processes, so it is important to study the actual geometry of the cutting tool involved in machining. This paper develops the model of the actual geometry of the cutting tool involved in machining using mathematic analysis method based on the insert shape and the control pattern of the flank including cylindrical control and conical control.

The relationship between the major cutting edge and the minor cutting edge is used to define the insert shape. The insert shape is represented as S according to ISO code when tool nose angle is 90°. The insert, otherwise, is designated as non-S-shaped. In this paper, four different 3-D models including S- and non-S-shaped tools with cylindrical control and conical control are established based on the flank face and the insert shape.

2 Three-dimension geometrical modeling

In traditional machining, only the primary cutting edge is mainly participated in cutting process. However, the whole nose of the cutting tool is participated in microcutting process due to the very little metal removal. Thus, the actual geometry involved in microcutting is determined by the major cutting edge, the minor cutting edge, and the third edge called backside cutting edge as shown in Fig. 1. It is necessary to develop the model of the actual geometry involved in machining to better understand the effects of tool geometry on cutting process.

According to the control model of the flank, the cutting tool can be classified into cylindrical control and conical control, as shown in Figs. 2 and 3.

When the cutting tool is with cylindrical control, the center of the tool nose is taken as the coordinate origin $O$, and the coordinate system $O$-XYZ can be established. Point $A$ at backside edge can be expressed in Eq. 1.

$$A(\beta, k) = \begin{cases} x = R \cos \beta \\ y = R \sin \beta \\ z = -k \end{cases}$$