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VERTICAL PATH STRATEGY FOR 3D-CAD ANALYSIS OF CHIP AREA IN 3-AXES BALL NOSE END MILLING

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Abstract: *Vertical cutter path orientations strategy is investigated and evaluated in this 3D-CAD study, for the chip area, in upward and downward feed directions of ball nose end mill, for different workpiece inclination angle. A minimum workpiece inclination angle to avoid cutting at the tip of the cutter is defined such the angle between cutter axis and surface normal. The result of analysis between the chip area and the inclination angle has been shown in graphics, for one cutting edge rotation. The cutting force on the tool edge is in proportion with the chip area and using this study, can be predicted the inclination angle and direction of milling to improve the cutting performance.*

Key words: *Ball Nose End Milling, Chip Area, 3D-CAD, Vertical Upward, Vertical Downward.*

1. INTRODUCTION

In 3-axes ball nose end milling, other possibility to avoid cutting at tool tip that is moving in a linear motion and the cutting speed is zero [1], is to assure for workpiece surface a minimal inclination angle, in vertical direction of feed, between tool axis and surface normal and stepover to be in horizontal direction.

The cutter path orientation is crucial in achieving desired machined surface [7] and without considering the impact of cutting edge with undeformed chip in different path strategy with adequate consideration of the chip area variation, cutting forces, temperature and vibration analysis, the result can lead to cutter failure and therefore lead to unnecessary waste of time, cost and poor surface quality [4,8,9]. In this report the vertical path strategy, in climb-milling (feed and cutting speeds are in the same sense, tool-left in CNC program) is evaluated using 3D-CAD geometric method [3] and according to the feed direction the milling can be (Fig.1):

1 - vertical upward;

2 - vertical downward.

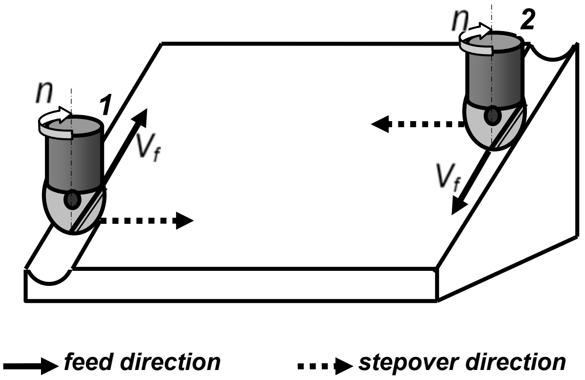


Fig. 1. *Vertical path strategy*

2. GENERALIZED GEOMETRIC REPRESENTATION

That in the horizontal path strategy, the local coordinate system of the ball nose end mill is defined as the rectangular coordinate system (Fig.2.) and the geometrical method used in this study is available if boundary chip surfaces are generated in the preconditions presented in [3] and the tools model is with plane rake face (helical cutting edge angle and rake angle are zero) [9].

Minimal inclination angle θ_x (X around rotation Fig. 2) to avoid cutting at tool tip, depends of the machining configuration and for upward is given by relations:

$$\theta_x > arcsin \left(\frac{f_z}{2R} \right), \qquad (1)$$

where θ_x is workpiece surface inclination, f_z is feed per tooth and R is radius of ball nose. For vertical downward the minimal inclination angle θ_x (2) depends of value $h = R - \sqrt{R^2 - a_e^2}$, which is tool axis intersection with preceding surface generated by stepover Fig. 3:

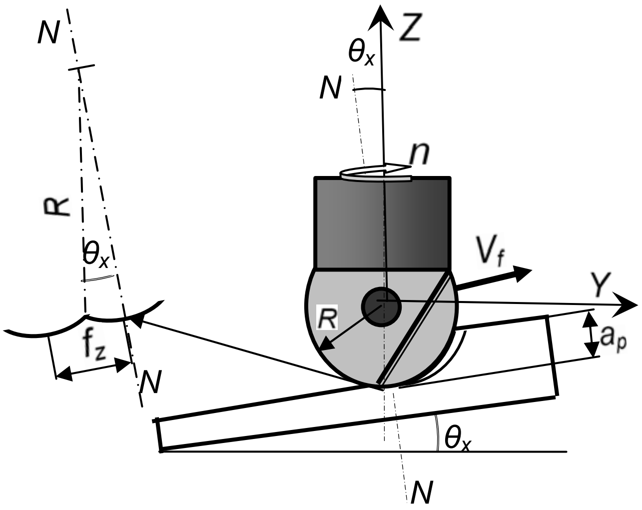


Fig. 2. *Vertical upward milling*

$$\theta_x > arccos \left(\frac{R-h}{R} \right) \quad \text{or} \quad \theta_x > arccos \left(\frac{\sqrt{R^2 - a_e^2}}{R} \right) \qquad (2)$$

where a_e is radial depth of cut and R is radius of ball nose. Vertical downward milling has a cutting process at low cutting speed that in upward, but in very good conditions for finished surface and edge cut entrance and chip area transition is important study for a good process.

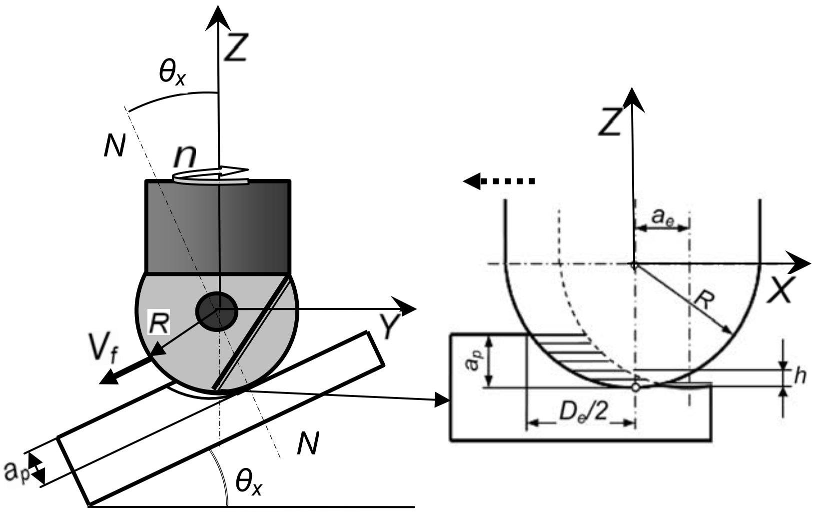


Fig. 3. *Vertical downward milling*

3. CHIP AND CUTTING EDGE SECTIONS IN 3D-CAD PROJECTION

Vertical path study is for the same machining parameters, radial depth of cut a_e=*0.8mm*, axial depth of cut a_p=*0.8mm*, tool radius R=*4mm*, feed per tooth f_z=*0.1mm/tooth* and for workpiece surface inclination θ_x = *(0, 15, 30, 45, 60, 75) DEG.*

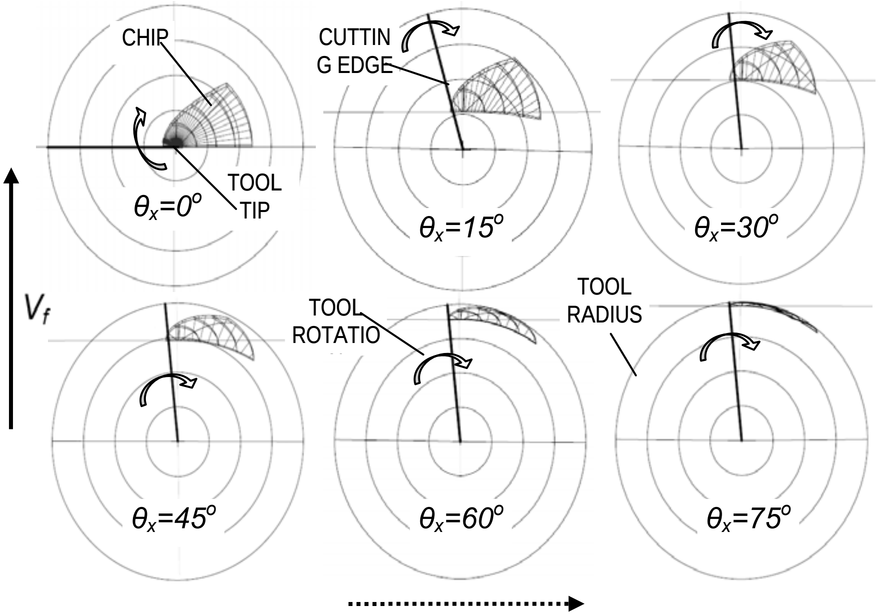


Fig. 4. *Vertical projections to the tool axis (vertical*

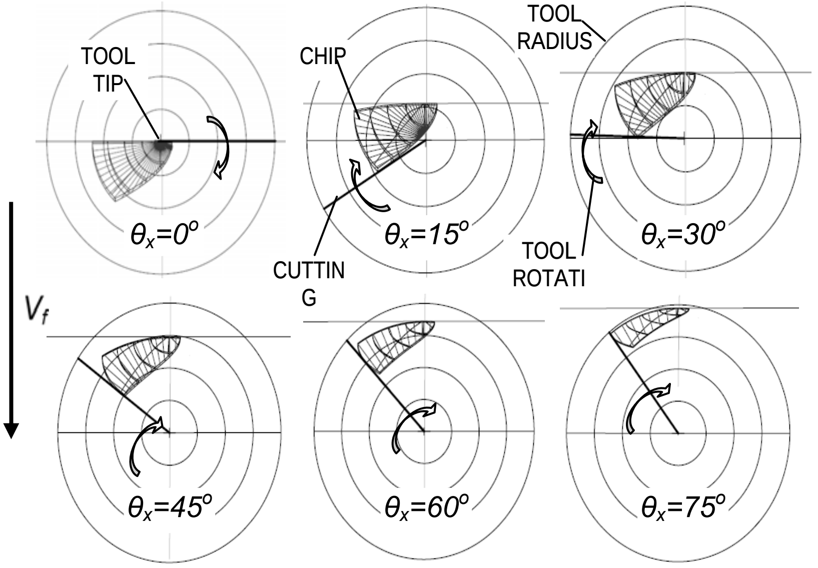


Fig. 5. *Vertical projections to the tool axis (vertical*

The boundaries of surfaces intersection are graphic evaluated by above 3D-CAD method and are represented in two type projection only for climb-milling (tool-left) because, the chip volume became symmetric for conventional milling (tool-right) to the feed direction (Y axis). In figure 4, the undeformed chip and tool are drown as the vertical projection to the tool axis, feed direction is upward, stepover direction is left to right and cutting edge revolve in clockwise.

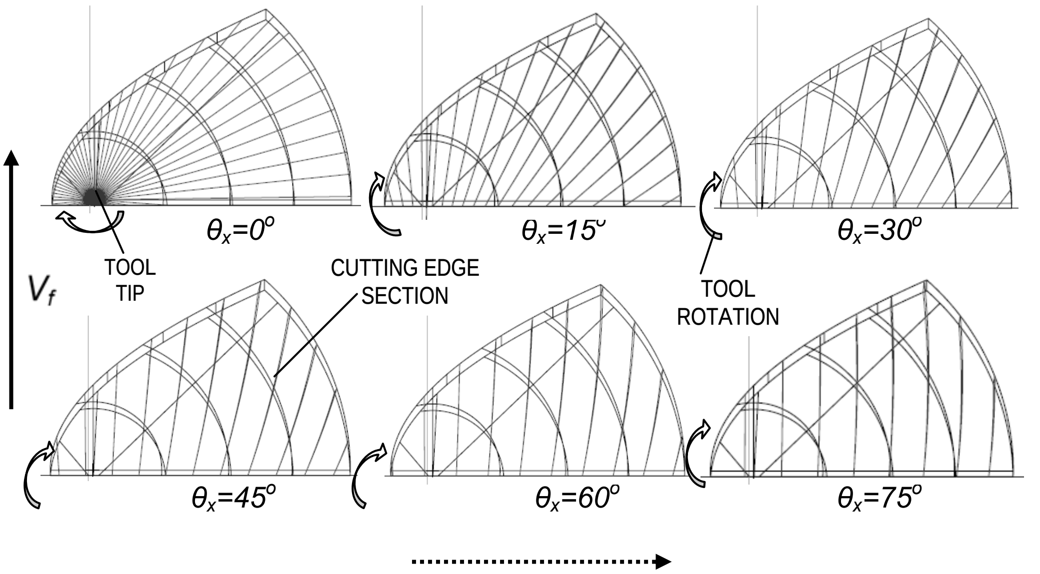


Fig. 6. *Chip projections to the N-N surface normal (vertical upward)*

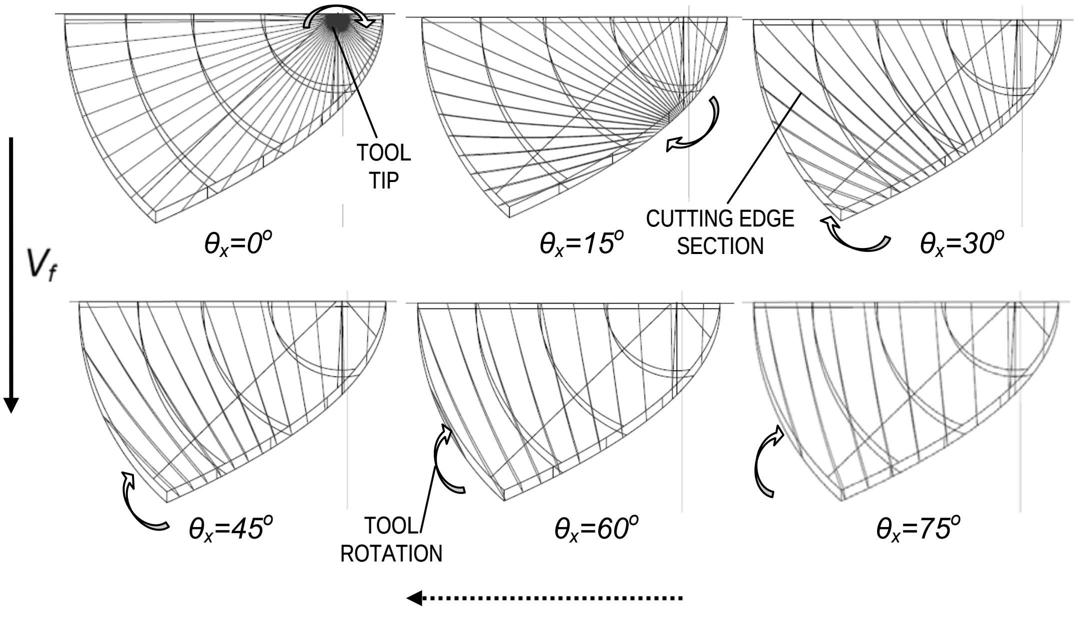


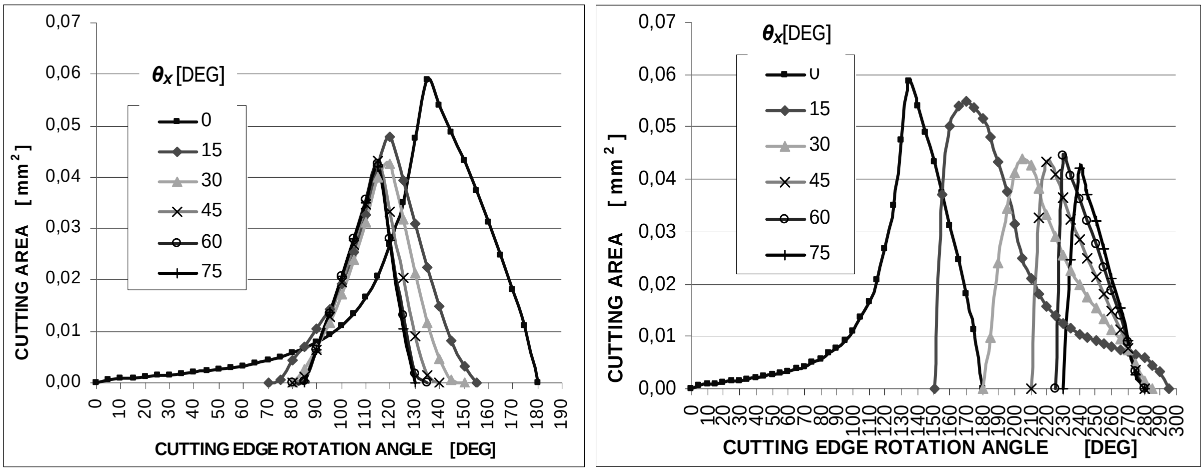
Fig. 7. *Chip projections to the N-N surface normal (vertical downward)*

The undeformed chip volume is similar to each other, but the relative position to the cutting edge and to the tool axis is very different for each workpiece surface inclination. In vertical upward for workpiece surface inclination $\theta_x=75^o$ (Fig. 4) cutting operation occurs cylindrical part of the tool and for avoid a big contact length with risk for vibration, radius of ball nose must be bigger that radius of the cylindrical tool part. The tool tip is in cutting only for $\theta_y=0^o$ (bolded area Fig. 4; Fig. 6) and the minimal angle for avoid tip cutting for above machining parameters in vertical upward is very low $\theta_{x,min}=0.716^o$ eq. (1), and for vertical downward $\theta_x=11.536^o$ (Fig. 3), eq. (3).

The transition of undeformed chip thickness is varied *thin-maximum-thin* for vertical up milling (Fig.6) and tool edge starts the cutting at thick chip thickness for vertical downward (except zero workpiece inclination) with the best condition near to the $\theta_x=30^o$, (Fig. 7). The cutting length changes at each workpiece surface inclination (see cutting edge sections Fig. 6 and Fig. 7) and is very important for consideration to improve the cutting performance.

4. CUTTING AREA TRANSITION AND CONSIDERATIONS

The cutting force is proportional with the maximum chip area [5,6] and undeformed chip area analysis for 3-axes ball nose end milling, considering workpiece surface inclination, is very important for high process efficiency. The cutting area is the intersected part by the undeformed chip volume and the rake surface [3] while one cutting edge turns around tool axis and its transition calculated using software built into the 3D-CAD is shown in Fig. 8. Each cutting conditions are the same (above-mentioned) except workpiece surface inclination and feed direction upward Fig.8 a) and downward Fig. 7 b). In the condition of $\theta_x=0^o$ with the increase of the rotational angle becomes greater slowly and after reaching the maximum value decreases quickly. However, the maximum value of the cutting area and its cutting edge rotation angle is different and depend on the workpiece surface inclination. The maximum value of cutting area decreases with increasing inclination angle and becomes almost constant and the same, in the condition of θ_x is more than 30^o in booth path strategy Fig. 8 a), b). Generally the cutting area is less in downward direction that in upward direction but the cutting edge is near to the tool center with low cutting speed that in upward, where is to the high effective diameter with best cutting conditions (Fig. 2). Increasing the inclination angle, the chip fast-moves far away from the tool tip in upward, entering rotation angle near 140^o for $\theta_y=15^o$ and the range of cutting contact edge angle decreases.



a) vertical upward *b) vertical downward*

Fig. 8. *Cutting area diagram*

5. CONCLUSIONS

The transition of undeformed chip thickness is varied thin to thin for vertical up milling and tool edge starts the cutting at thick chip thickness for vertical downward with the best condition near to the $\theta_x=30^{\circ}$.

The undeformed chip volume is similar to each other, but the relative position to the cutting edge and to the tool axis is very different for each workpiece surface inclination. The cutting length changes at each inclination and is very important for consideration about specific pressure on cutting edge, cutting forces, tool wear, tool vibration and surface finish.

The results clearly illustrate that cutting area is less in vertical path strategy but the cutting edge is near to the tool center with low cutting speed that in upward, where is to the high effective diameter with best cutting conditions.

6. REFERENCES

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