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

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Abstract: *This paper investigates and evaluates the chip area in horizontal path strategy (upward and downward) in ball nose end milling, for different workpiece inclination angle, using 3D-CAD software. 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: *3D-CAD, Chip Area, Ball Nose End Milling, Horizontal Upward, Horizontal Downward.*

1. INTRODUCTION

Ball nose end mill are generally used for finish milling of complex curved surface in aircraft industry or dies and moulds production [2, 8, 9]. Machining process by a ball nose end mill is very complex, because the cutting edge is determined on spherical surface and the tip of tool is moving in a linear motion and the cutting speed is zero [1]. This is the reason why workpiece surfaces cut with the tip of the ball have a dull appearance and when finish milling using a 3-axes CNC machine, the tool axis with respect to the workpiece surface is crucial in achieving optimum surface quality and maximum tool life. In 3-axes milling the possibility to avoid cutting at tool tip is to assure for workpiece surface a minimal inclination angle. In this report the horizontal 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 as stepover direction the milling can be (Fig.1.):

1 - horizontal upward;

2 - horizontal downward.

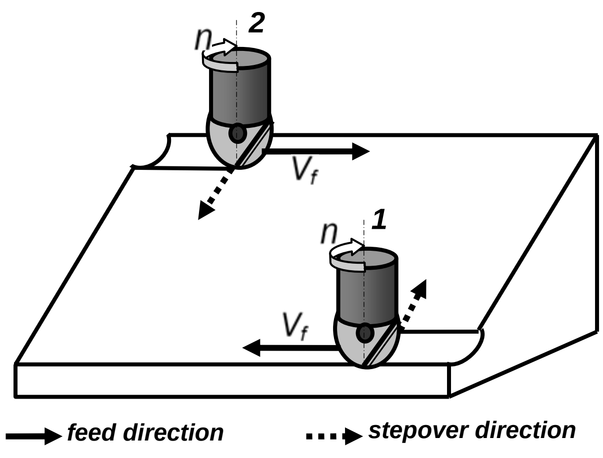


Fig. 1. *Horizontal path strategy*

The cutter path orientation is very important 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].

2. GENERALIZED GEOMETRIC REPRESENTATION

In this study, the local coordinate system of the ball nose end mill is defined as the rectangular coordinate system (ISO R-841-1968 recommendation and STAS 8902-1971 for CNC machines 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 (Y around rotation) between tool axis and surface normal N-N to avoid cutting at tool tip is given by relations:

- horizontal upward $$\theta_y > \arcsin\left(\frac{a_e}{2R}\right), \tag{1}$$

- horizontal downward $$\theta_y > \arccos\left(\frac{R-a_p}{R}\right), \tag{2}$$

where θ_y is workpiece surface inclination, a_e is radial depth of cut, R is radius of ball nose and a_p is axial depth of cut.

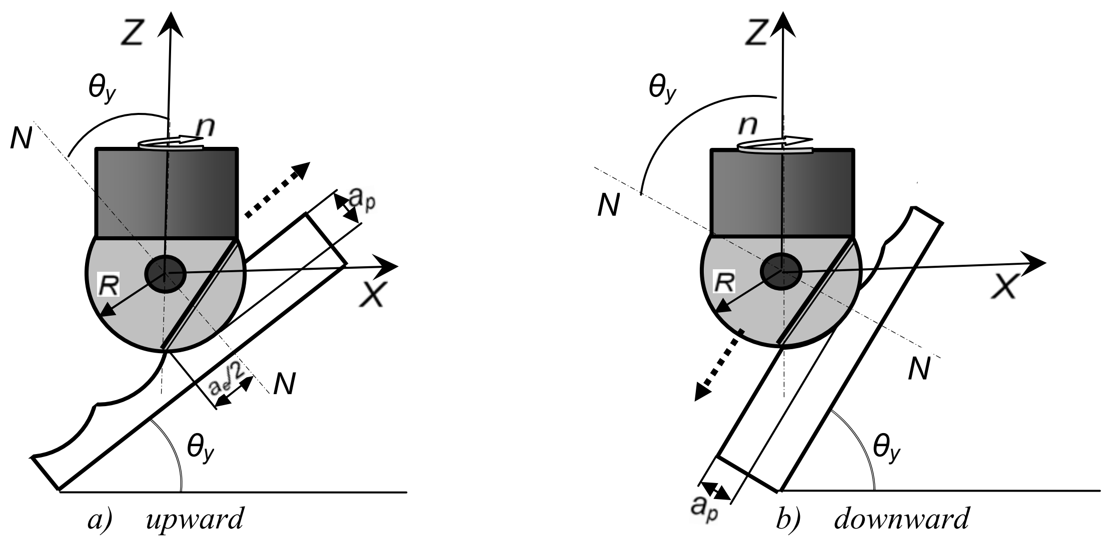


Fig. 2. *Horizontal upward and downward milling*

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

Machining parameters for this study are 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_y = *(0, 15, 30, 45, 60, 75) DEG*.

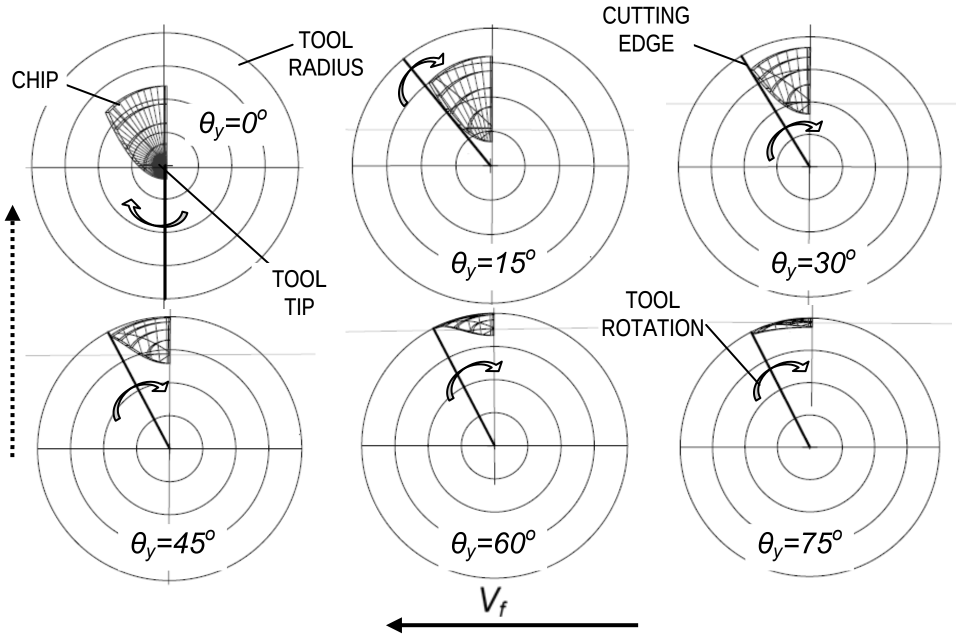


Fig. 3. *Vertical projections to the tool axis (horizontal upward)*

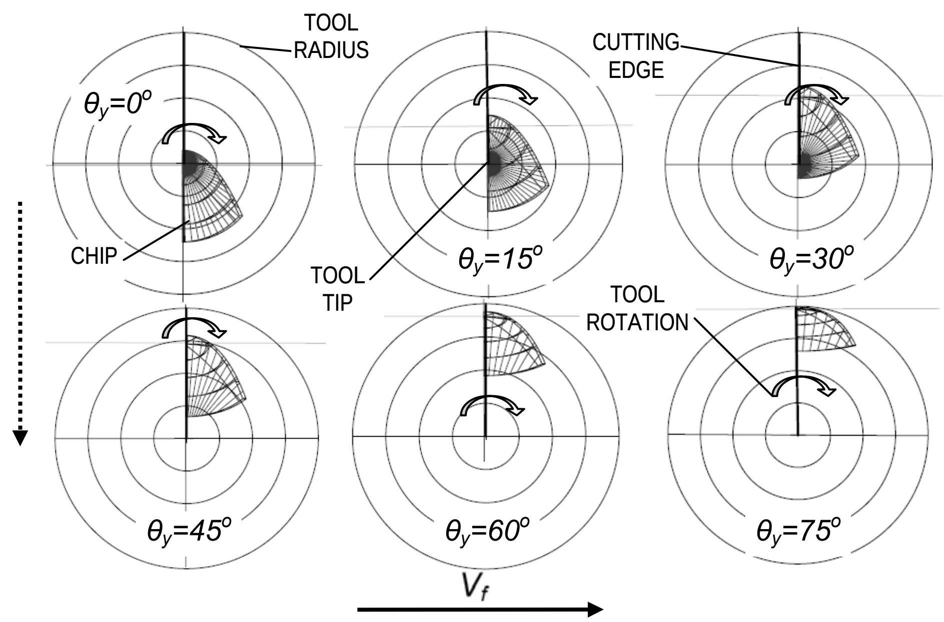


Fig. 4. *Vertical projections to the tool axis (horizontal downward)*

In figure 3, the undeformed chip and tool are drown as the vertical projection to the tool axis, feed direction is left to right, stepover direction is upward and cutting edge revolve in clockwise. 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 tool tip is in cutting only for $\theta_y=0^o$ (bolded area Fig. 3; Fig. 5) and the minimal angle for avoid tip cutting for above machining parameters in horizontal upward is $\theta_{y,\ min}=5.379^o$ eq. (1), and for horizontal downward only after $\theta_{y,\ min}=36,869^o$ eq. (2), (Fig. 4; Fig. 6).

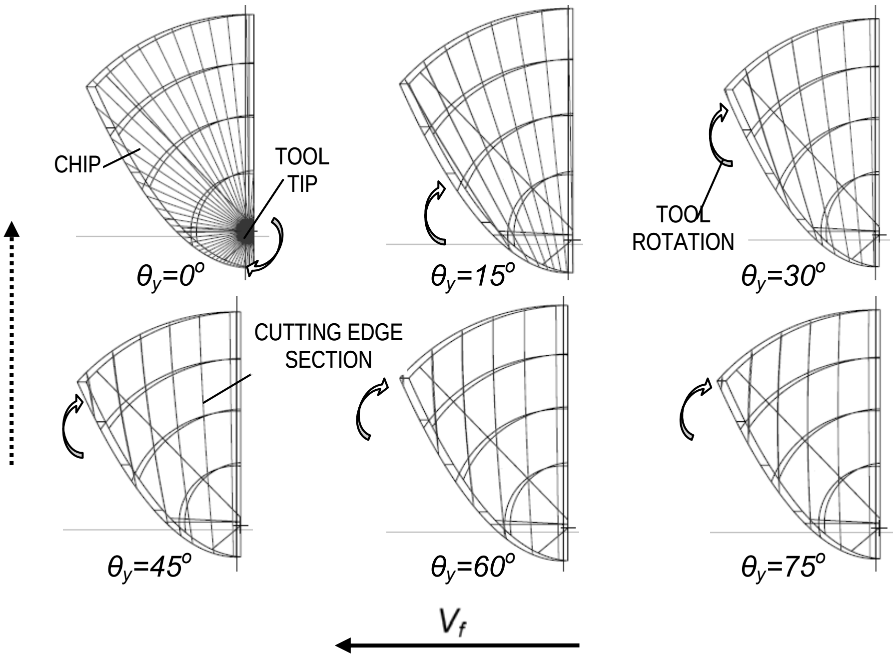


Fig. 5. *Chip projections to the N-N surface normal (horizontal upward)*

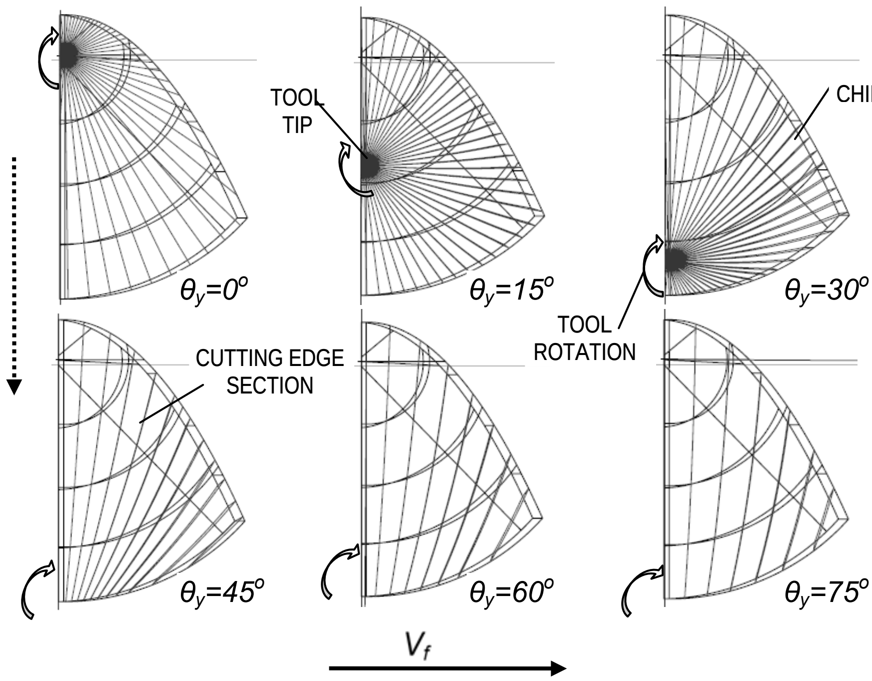


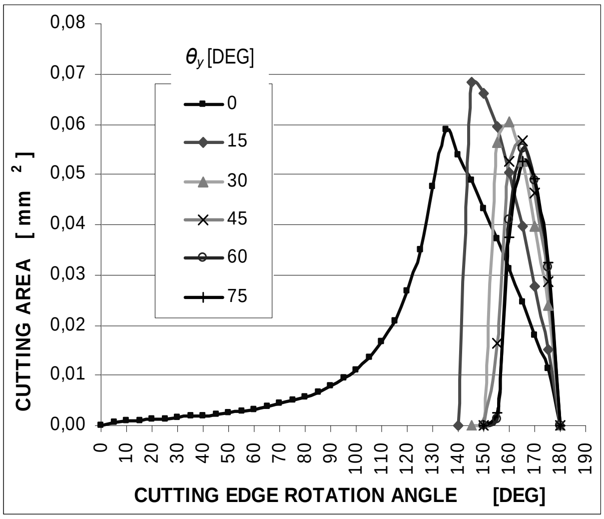
Fig. 6. *Chip projections to the N-N surface normal (horizontal downward)*

For horizontal upward, tool edge starts the cutting at thick chip thickness (Fig. 5) but for horizontal downward start at the minimal thickness (Fig. 6). The cutting length changes at each workpiece surface inclination (see cutting edge sections Fig. 5 and Fig. 6) and is very important for consideration about specific pressure on cutting edge, cutting forces, tool wear, tool vibration and surface finish.

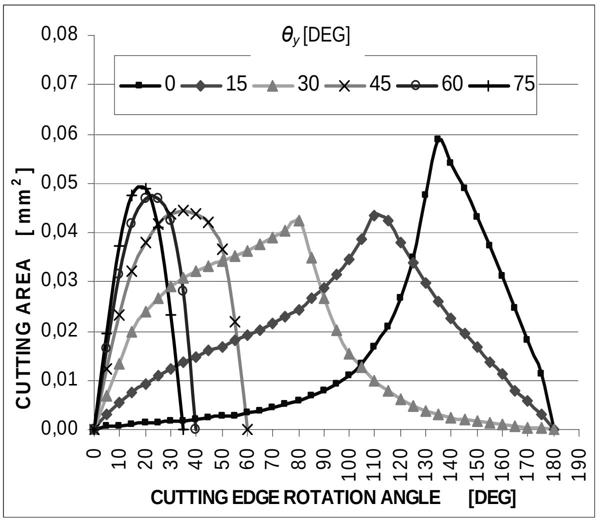
4. CUTTING AREA TRANSITION AND CONSIDERATIONS

The undeformed chip area analysis for 3-axes ball nose end milling, considering workpiece surface inclination, is very important for high process efficiency because the cutting force is proportional with the maximum chip area [5,6].

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. 7. Each cutting conditions are the same (above-mentioned) except workpiece surface inclination and stepover direction upward Fig.7,a) and downward Fig. 7,b).



a) horizontal upward



b) horizontal downward

Fig. 7. *Cutting area diagram*

However, the maximum value of the cutting area and its cutting edge rotation angle is different and depend on the workpiece surface inclination, becomes greater slowly in the condition of $\theta_y=0^\circ$ with the increase of the rotational angle and after reaching the maximum value decreases quickly. The maximum value of cutting area is reached for $\theta_y=15^\circ$ in horizontal upward Fig. 7,a) and minimum value for $\theta_y=30^\circ$ in horizontal downward Fig. 7,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. In horizontal downward entering and exit rotation angle are the same for workpiece surface inclination between $\theta_y=0^o$ to 30^o with 180^o range of cutting contact edge angle and decreases for $\theta_y=45^o$ to 75^o.

5. CONCLUSIONS

In horizontal upward tool edge starts the cutting at thick chip thickness but for horizontal downward start at the minimal thickness and the transition of undeformed chip thickness is varied to the workpiece inclinations.

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 finis.

The cutting area is less in downward direction that in upward direction, with minimum value for $\theta_y=30^o$ but the range of cutting contact edge angle is very large.

In downward the cutting area is less and the cutting process 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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