Proceedings of the International Conference on Manufacturing Systems – ICMaS
Vol. 4, 2009, ISSN 1842-3183
University POLITEHNICA of Bucharest, Machine and Manufacturing Systems Department
Bucharest, Romania

CROSS SECTION STUDY OF THE UNCUT CHIP IN 5 AXES BALL NOSE END MILLING FOR THE SECOND QUADRANT OF THE TOOL INCLINATION

Marius COSMA, Dinu DARABĂ, Marius POP

Abstract: *The current paper looks into and assesses some aspects regarding the geometric simulation of the chip generating mechanism in 5 axes ball nose end milling. The cross section variation of the uncut chip produced by a ball nose cutter is very complicated. The influence of tool inclination, however, was not considered in the machining strategy, starting with the tool path program in CAM software which allows the management of various ways of tool path generation, but cannot decide which one is the best. The present study advances, with minimal approximation, a geometrical method to establish the volume of the uncut chip and area variation of the cross section, obtained in 3D-CAD (AutoCAD 2007) by four surfaces intersection. Both rotations in 5 axes are considered for the tool, in negative sense for A axis (A-) and positive for B axis (B+) for 0 to 30 degree range (second geometrical quadrant).*

Key words: *ball nose end mill, uncut chip, cutting edge, cross section area, milling.*

1. INTRODUCTION

A ball nose end mill, also known as spherical end mill or ball end mill has a semi-sphere at the tool end. Ball nose end mills are used extensively in the machining of complex surfaces of dies, molds for metal and for plastic injection molding in electronic industry, automotive work pieces, aircraft components (especially frame sections and gas turbine with spline like profile) and in the defense industry.

This modern milling is a universal machining method and during the past few years, along with machine tool developments, milling has evolved into a method that machines a wide range of configurations. Tooling developments have also contributed to the new possibilities along with the gains in productivity, reliability and quality. Complex surface machining by milling is characterized by high production rates, high dimensional and geometrical shape accuracy and roughness of surface and the development of cutting tools provides a competitive alternative to grinding and electrical discharge machining (EDM) [1].

More and more complex machining environment and complicated freeform surface challenge users to define more accurate and appropriate tool path and tool postures. By changing from 3-axes to 5-axes milling, cutting efficiency and machining quality could be enhanced a lot. The two more rotary axes (A around X and B around Y) make cutting flexible and efficient, but they also bring some troubles in controlling.

The ball nose end milling has a very complex machining mechanism, as the cutting edge is determined on a spherical surface. When a cutter with a non-flat end, such as a ball nose end mill, is used to cut a target surface with spindle speed *n***,** in bidirectional tool path going from one side to the other and back with feed *f*, an uncut strip, called cusp, is created between the two cutting passes with radial depth a_e (Fig. 1).

The big problem when using ball nose end mills is the center portion were the cutting speed is zero and chip evacuation is also critical due to the small space at the chisel edge. Avoid using the center portion of a ball nose end mill as much as possible by tilting the spindle (in 5-axes machine) or the workpiece in 3 or 3½-axis machine, can get good cutting conditions, but how much and in which sense is the best ?

Other problems are the impact of the cutting edge with uncut chip and cross sections area in different tilted tool positions (Fig. 2).

With adequate consideration of the chip cross section area and cutting forces, the result can lead to cutter failure and therefore lead to unnecessary waste of time, cost and poor surface quality, as is related in paper [3].

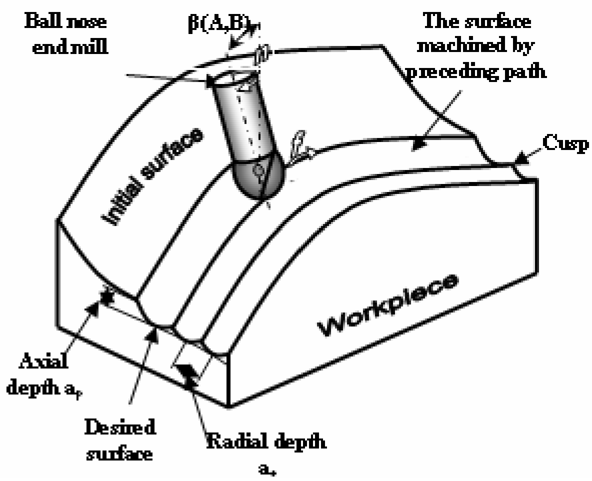

Fig. 1. Ball nose end milling process in 5 axes.

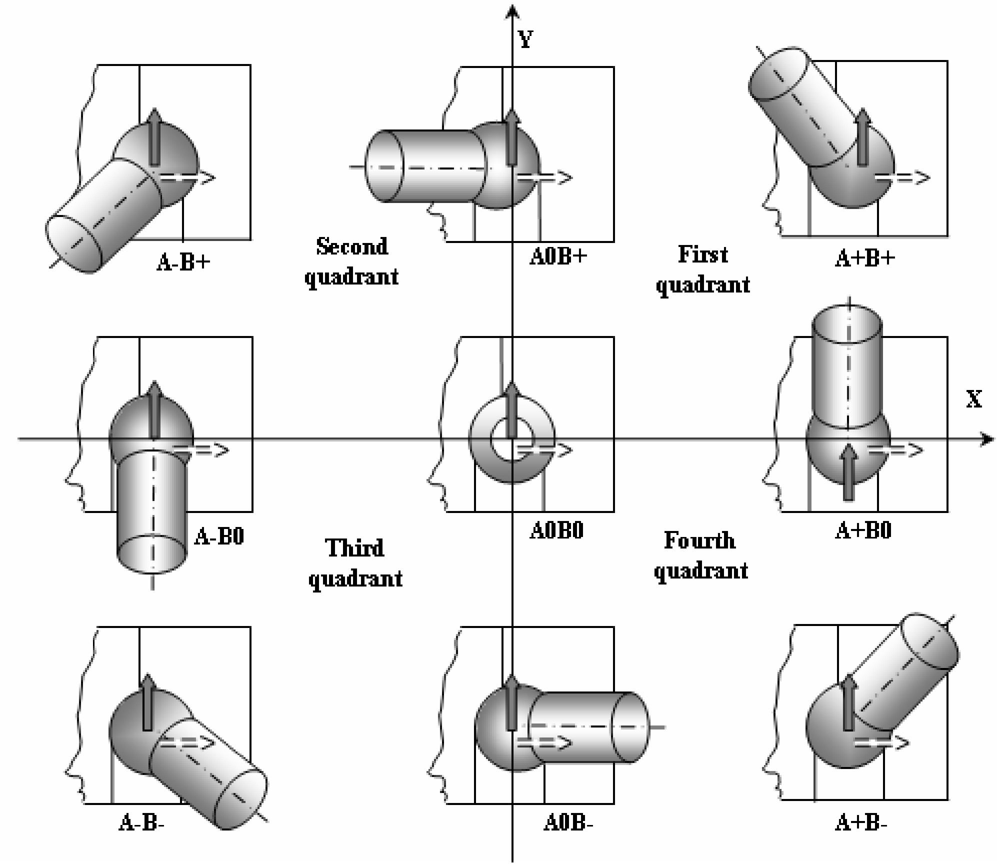

Fig. 2. Tilted tool position in 5 axes machining.

2. CROSS SECTION STUDY

2.1. Method of geometrical analysis

The geometrical method used in this study is available if boundary surfaces are generated, first by simplifying the motion of the cutting edge, only in the revolution of the tool, when the reference point of cutting edge moves along a closed circle trail (in reality it is a looped orthocycloidal track, called trachoid), secondly, the surface machined by the preceding path is constructed by the surface of sphere, and third, the initial surface can be considered to be flat for a very small area. As a result of these pre-conditions it is easy to determine the boundary surfaces as follows [2]:

1 - initial surface – *plane*;

2 - first revolution – *sphere*;

3 - second revolution – *sphere*;

4 - surface machined by preceding path – *circular cylinder*.

Giving real values to the parameters (R, a_p, a_e, f_z, (Table 1) and using 3D-CAD (AutoCAD 2007) geometric configuration for the above mentioned surfaces, we get the uncut chip (Fig. 3) which will be machined by one cutting edge of tool (Fig. 4).

Table 1

Parameters of milling process

Cutter radius	$R = 7$ mm
Axial depth	$a_p = 2$ mm
Radial depth	$a_e = 1$ mm
Tooth feed	$f_z = 0.1$ mm
Rake angle	$\gamma = 0^0$
Teeth number	$z = 2$

2.2. Tool orientation and the cross sections

A coordinate system used in this 3D-CAD (AutoCAD 2007) study is shown in Fig. 4 a). The origin of the system is the ball center and it moves along with the tool. Step direction is defined as axis X, feed direction as axis Y and tool axis is defined as axis Z. Both rotations are considered for tool inclination, A around axis X and B around axis Y. The cutting edge is considered a circular disk (rake angle $\gamma = 0^0$) and in tool rotation determines the cross sections in uncut chip Fig. 4. b).

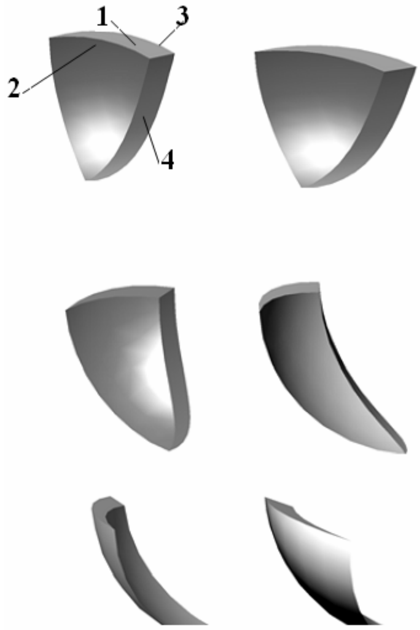

Fig.3. Different side views of uncut chip.

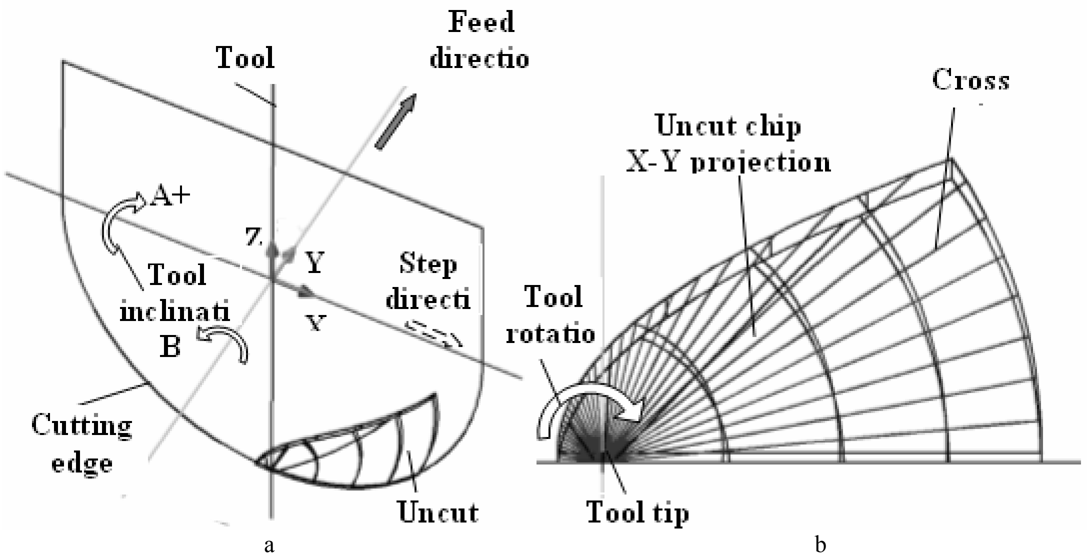

Fig. 4. CAD study of uncut chip cross sections (tilting tool A0B0).

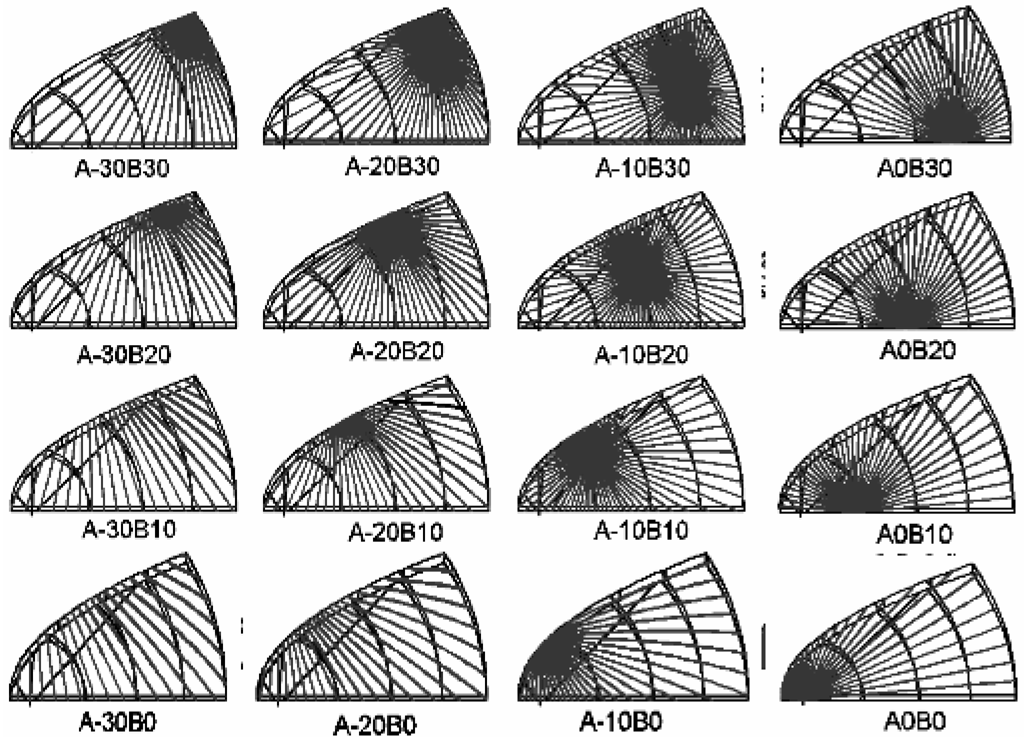

Fig. 5. Chips and cross sections in 3D-CAD projection for second quadrant.

All the situations for the second quadrant and tool tilt between 0 - 30 degree for *A* and 0 + 30 degree for *B* is presented in Fig. 5. It is clear that in this quadrant, in the most cases it is not possible to avoid tool tip contact with the chip and the workpiece surface (black area). Giving A-20B0 and A-30B0…10 values for *A* and *B* rotation axes it is possible to avoid tool tip contact with the machined surface and improves the cutting conditions.

The uncut chip (removal volume) is the same for all orientations but the transition of the cross sections in the uncut chip is very different [4, 5]. In the ball nose end milling, it cannot be referred to as “down cut” because the transition of the uncut chip thickness is not a simple one. The better situations for cutting edge entrance are A-30B0 and A-30B10, at higher thickness chip and minimum area. The cutting length and cross section area for each cutting edge changes with the tool orientations and so is necessary to optimize cutting conditions.

2.3. Cross sections area

Simulation of 3D-CAD tool rotation by shifting the cutting edge from 0 to 360 degrees, turning 5 to 5 degrees makes it possible/easy to infer the variation of cross sections area. The highest value of the cutting area and its rotation angle is different and it depends on the tilted tool positions (Fig. 6). The cutting area analysis shows that A-30B0 (Fig. 6. d) is the best situation for the second quadrant.

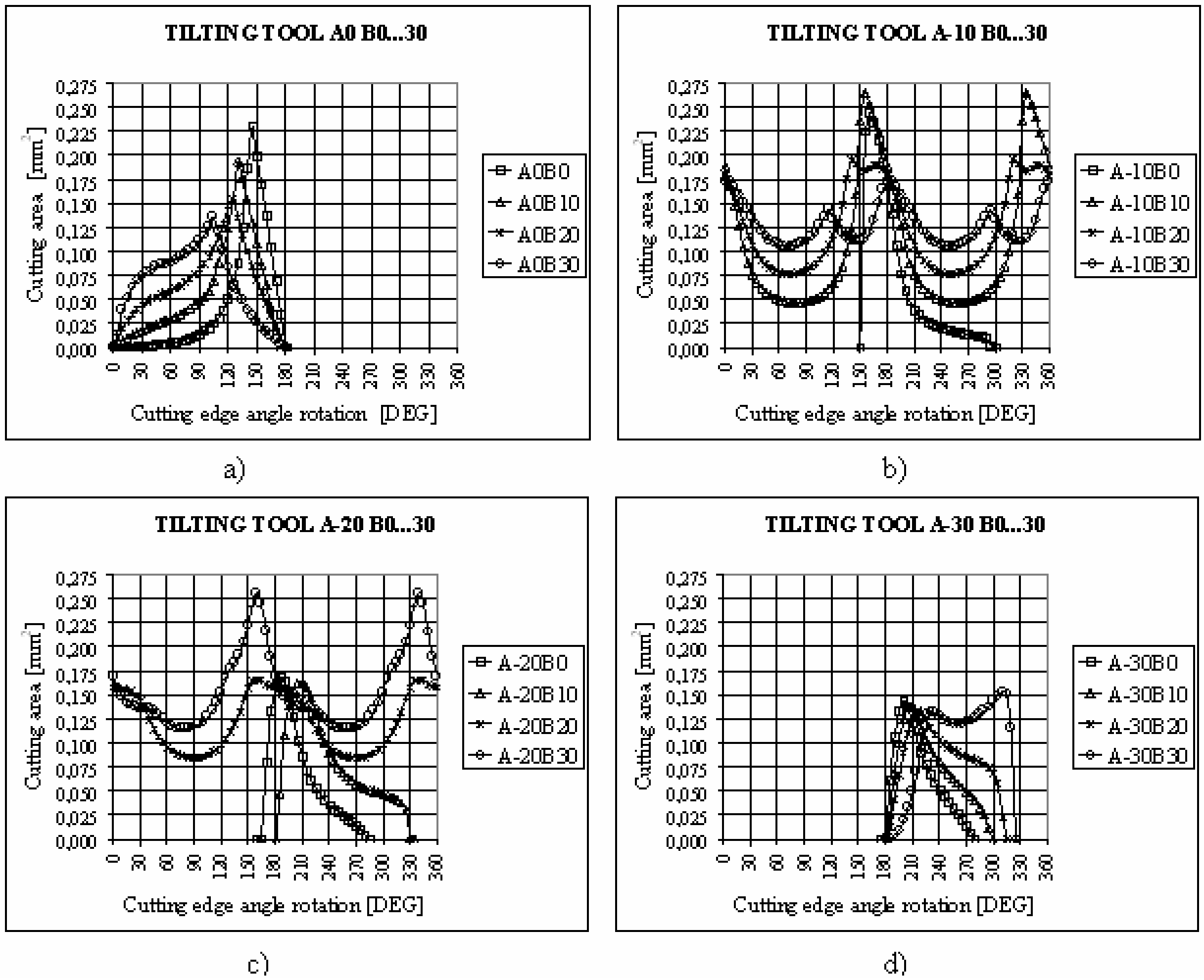

Fig. 6. Cutting area for different tilted tool position in second quadrant.

3. CONCLUSIONS

The cutting length and cutting area change at each inclination and it is very important to consider specific pressure on the cutting edge, cutting forces, tool wear, tool vibration and surface finishing.

In generally, in the second quadrant, cutting conditions are not so good and the best solution is tilted tool position A-30B0.

REFERENCES

[1] Cosma, M.,(2005). *Considerations concerning the milling of complex curved surfaces using ball nose end mills*, Inter-ING 2005, Universitatea Petru Maior, Tg. Mureş pag. 91–96, ISBN 973–7794–41–9.

[2] Cosma, M., (2006). *Geometric Method of Undeformed Chip Study in Ball Nose End Milling*, Scientific Buletin, Serie C, Vol. XX, North University of Baia Mare, pp. 49–54, ISSN 1224–3264.

[3] Iwabe, H., Natori, S., Masuda, M., Miyaguchi, T., (2004). *Analysis of Surface Generating Mechanism of Ball End Mill Based on Deflection by FEM*, JSME International Journal, Series C, Vol. 47, No. 1, pp. 8–13.

[4] Cosma, M., (2007). *Horizontal Path Strategy For 3D-CAD Analysis of Chip Area in 3-Axes Ball Nose End Milling*, 7th International Multidisciplinary Conference North University of Baia Mare, Scientific Buletin Serie C, Vol. XXI, ISSN–1224–3264, pp. 115–120.

[5] Pay, E., Cosma, M., (2007). *Vertical Path Strategy For 3D-CAD Analysis of Chip Area in 3-Axes Ball Nose End Milling*, 7th International Multidisciplinary Conference, North University of Baia Mare, Scientific Buletin Serie C, Vol. XXI, ISSN 1224–3264, pp. 585–590.

Authors:

PhD, Eng, Marius COSMA, Lecturer, North University of Baia Mare, Department of Industrial Systems and Technological Management,
E-mail: marius.cosma@ubm.ro

PhD, Eng, Ec, Dinu DARABĂ, Lecturer, North University of Baia Mare, Department of Industrial Systems and Technological Management,
E-mail: dinu.daraba@ubm.ro

Eng, Marius POP, S.C. RAMIRA S.A. Baia Mare, CAD/CAM/CNC Technology Department,
E-mail: mm05uot@yahoo.com