INFLUENCE OF TOOL ORIENTATION IN FIVE-AXES MACHINING PROCESS

Marius COSMA[1]

ABSTRACT: This study describes a geometrical analysis of the influence of tool orientations on the machining process, in five axes ball nose end milling. The ball nose end milling has very complex machining mechanism, because the cutting edge is determined on spherical surface and the result of milling is roughness of surface that is an uncut strip created between the two cylindrical cutting passes. The influence of tool orientation, 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. This geometrical study, confirmed by geometric model of ball nose end milling in three axes, and experimental researches made by author, establish a few recommendations for finishing milling, using a ball nose end mill, on five-axes milling centre.

KEY WORDS: tool, five-axes, ball nose end mill, undetached chip.

1 INTRODUCTION

Productivity and accuracy are important attributes in the competition for machine tools. Five-axes machining provides considerable potential for increasing productivity. In many cases it permits higher metal removal rates than three-axes machining. Production times can be shortened thanks to a reduction of time required for resetting, for example, or through multi-operation machining in one setup. In any case, with increasingly complex workpiece geometry, five-axes machining is becoming an indispensable part of the machining process.

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, provide a very competitive alternative to grinding and electrical discharge machining (EDM). Complex curved surfaces (sculptured surfaces) are encountered in many objects such as small batch components, automotive parts, aircraft components, turbine blades, injection moulds and dies, electrodes for electrical discharge machining, in the field of the medical technology etc.

Moreover, the two rotary axes in a five-axes machine tool can greatly influence attainable workpiece accuracy.

[1] Tech. Univ. of Cluj-Napoca, North Univ. Center of Baia Mare, Department of the Engineering and Technology Management, Dr. V. Babes 62A, 430083, Baia Mare, Romania.

E-mail: marius.cosma@cunbm.utcluj.ro;

Besides the rotary axes, in most cases the linear axes must also be moved in order to change the orientation of the cutter to the workpiece surface. This can cause visible flaws in the traverse range of up to five-axes within a small area of the workpiece surface. The positioning of a tool axis by rotary axes plays a decisive role here in the performance of the five-axis machine tool on surface quality (Diciuc, 2011).

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).

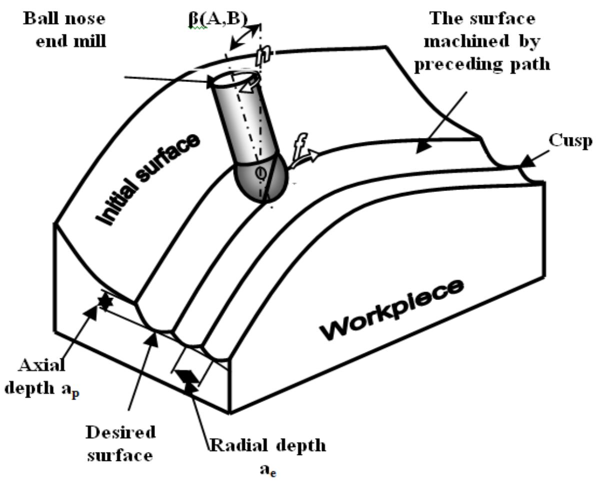


Figure 1. Tool path orientations

The most critical area when using ball nose end mills is the tool tip, were the cutting speed is zero and chip evacuation is also critical, due to the small space at the chisel edge. By now, five-axis machining has become indispensable in many areas of metal-cutting machining.

Clear economic advantages result from the capability to machine workpieces completely in one setup and time of a part can be dramatically reduced. At the same time, part accuracy can be significantly increased. Beyond this, the additional rotary axes allow better access to complex workpiece contour, for example cavities in dies or molds. Often, they permit shorter tools with less inclination to chattering so that even higher metal removal rates are achieved.

With five-axes simultaneous machining, the cutting speed at the tool tooth can be held within narrow limits even on complex contours. This brings significant benefits with regard to the attainable surface quality. What is more, the use of highly productive tools when milling freeform contours would not be possible at all without five-axes simultaneous machining. A computer-aided topology optimization is conducted that adapts the geometry of the component to the respective loads. The result: the material is brought specifically to where the mechanical load can be highest. In the other areas, material is specifically reduced.

Uncounted molds and dies are needed in automobile manufacturing for sheet metal and plastic processing. In the field of medical technology the devices are often characterized by very complex geometries that make 5-axis machining of single parts on milling machines attractive. A workpiece coordinate system fixed on the programming coordinate system as well. a machine coordinate system can be employed as. Avoid using the center portion of a ball nose end mill as much as possible by tilting the tool or workpieces, in five-axes machine, in a favorable orientations of undetached chip, will get good cutting conditions.

2 OVERVIEW ON FIVE-AXES MACHINNG FUNCTIONS

On a five-axes machine having two rotary axes that turn a tool or table, this function performs tool length compensation constantly, even in the middle of a block, and exerts control so that the tool center point moves along the specified path.

This function is intended to perform machining on such five-axes machines having rotary axes that turn a tool or table as well as three orthogonal axes (X, Y, and Z-axes) by accomplishing tool length compensation while changing the attitude of the tool. It enables the tool center point to move along the specified path even if the tool's direction changes with respect to the workpiece. A coordinate system used for programming the tool center point control is called the programming coordinate system.

A coordinate system fixed on the table can be used as the programming coordinate system, which makes CAM programming easy and this coordinate system is particularly called the table coordinate system.

There are three different types of five-axes machines which can put the tool relative to workpiece surface in different orientations (Fig. 2):
- 1 tool rotation type (rotate the tool only)
- 2 table rotation type (rotate the table only)
- 3 composite type (rotate both the tool and table).
conditions.

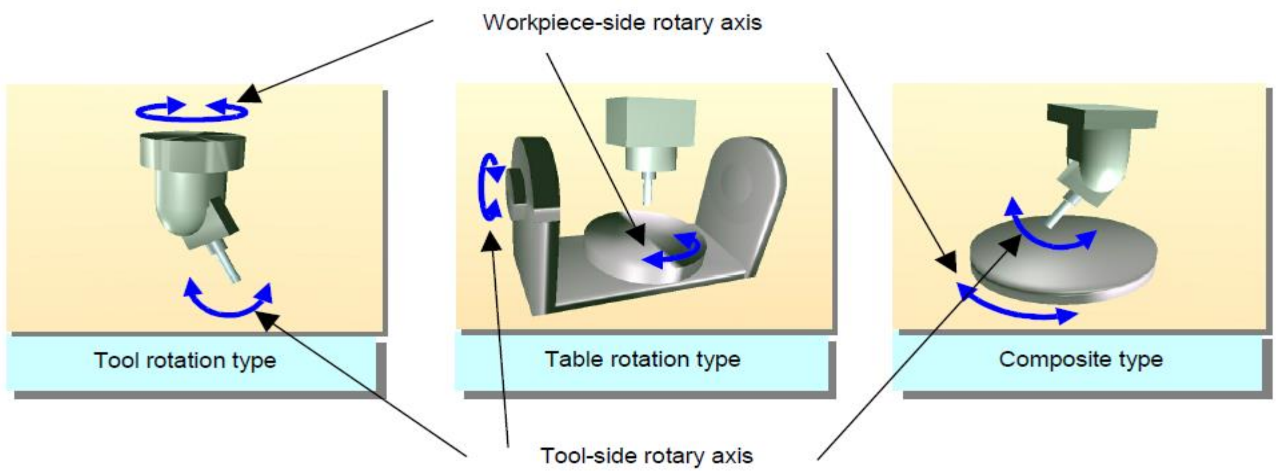


Figure 2. Different types of five-axes machines

3 TOOL ORIENTATION

Without considering the impact of the cutting edge with uncut chip in different tilted tool positions (Fig. 3) with adequate consideration of the chip cross section area variation and cutting forces, the result can lead to cutter failure and therefore lead to unnecessary waste of time, cost and poor surface quality (Cosma, 2010).

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 (Cosma, 2006):

- initial surface – plane;
- first revolution – sphere;
- second revolution – sphere;
- surface machined by preceding path circular cylinder. A coordinate system used in this 3D-CAD study is with origin of the system in 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. 5).

The tilted tool relative position on workpiece, is represented in figure 3, where the orientations from 1 to 4 represent a single axis rotation, orientations from 5 to 8 represent both axes rotations and position 0 is for no tilt tool, orientation which must be avoided in milling process.

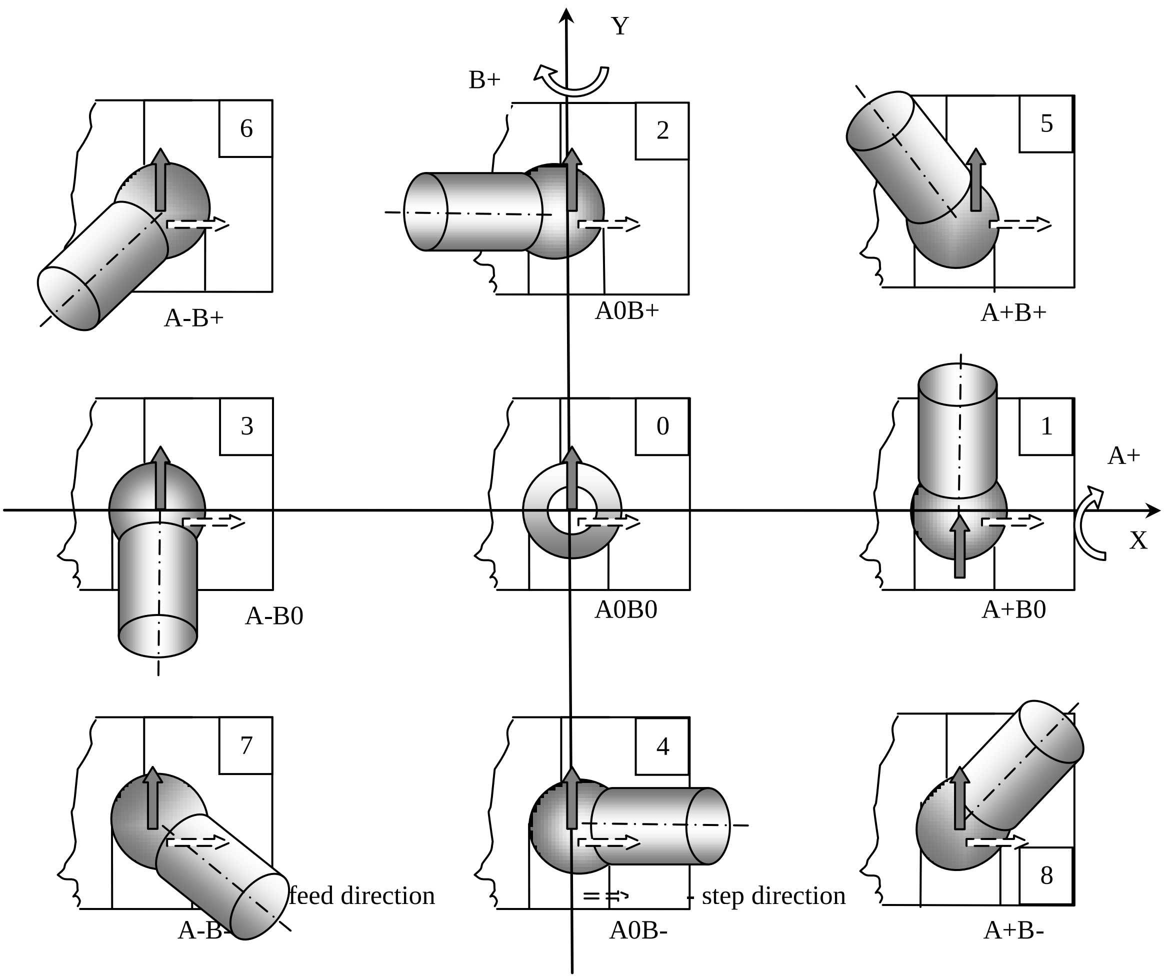


Figure 3. Tilted tool relative position in five-axes machining

4 GEOMETRICAL STUDY

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 and understand how cutting edge attach the chip. In figure 4, is represented an intermediate position of the tools at A20 and B-20 degrees. The uncut chip and tool radius are drowning as the vertical projection to the tool axis in figure 4. b, where the feed direction is along the Y-axis, stepover direction is along the X-axis and cutting edge revolve in clockwise. The uncut chip volume (Fig. 4. d) is similar to each other, but the relative position to the cutting edge and cross sections are very different for each tool axis inclination (Fig. 4. c). The cutting length and area of the cross sections, changes at each tool inclination (see cutting edge sections Fig. 5) and is very important for consideration about specific pressure on cutting edge, cutting forces, tool vibration and surface finish, (Pasca, 2013).

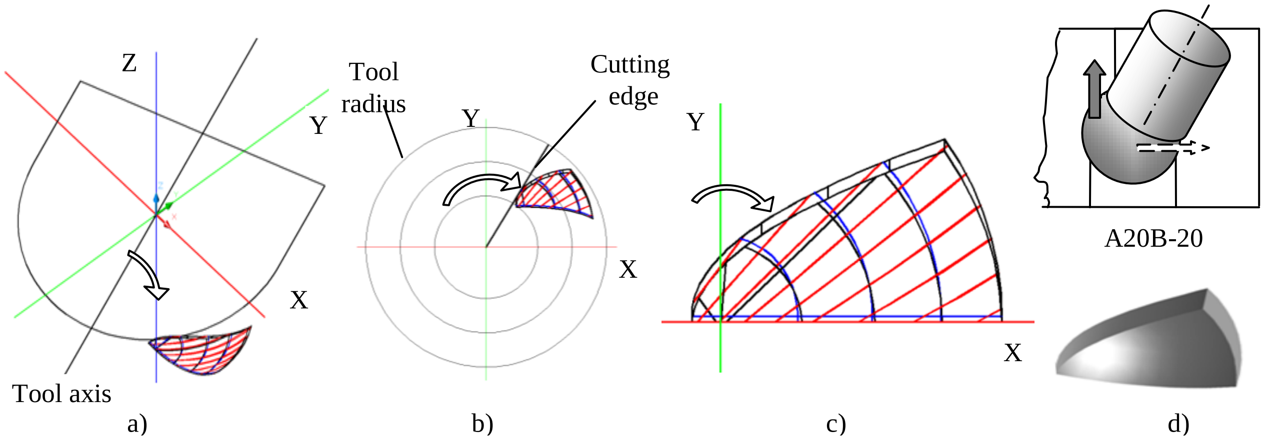


Figure 4. Example of CAD study for A20B-20 tilting tool position

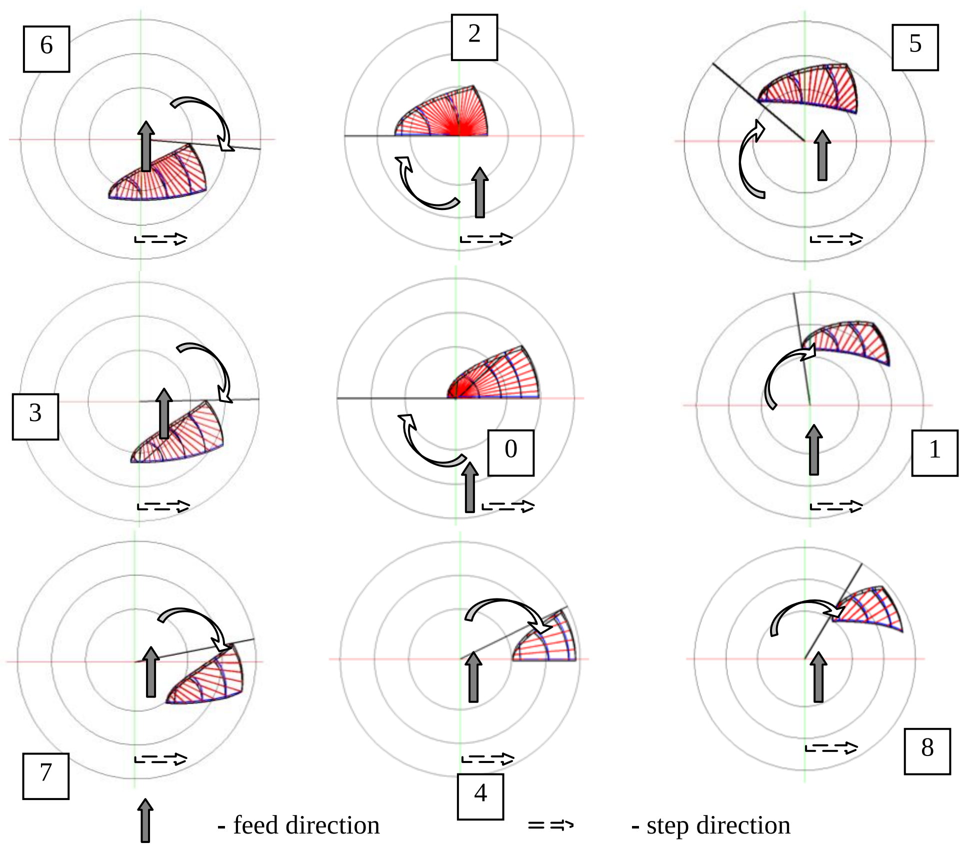


Figure 5. Tool radius projection and uncut chip positions in 5-axes machining

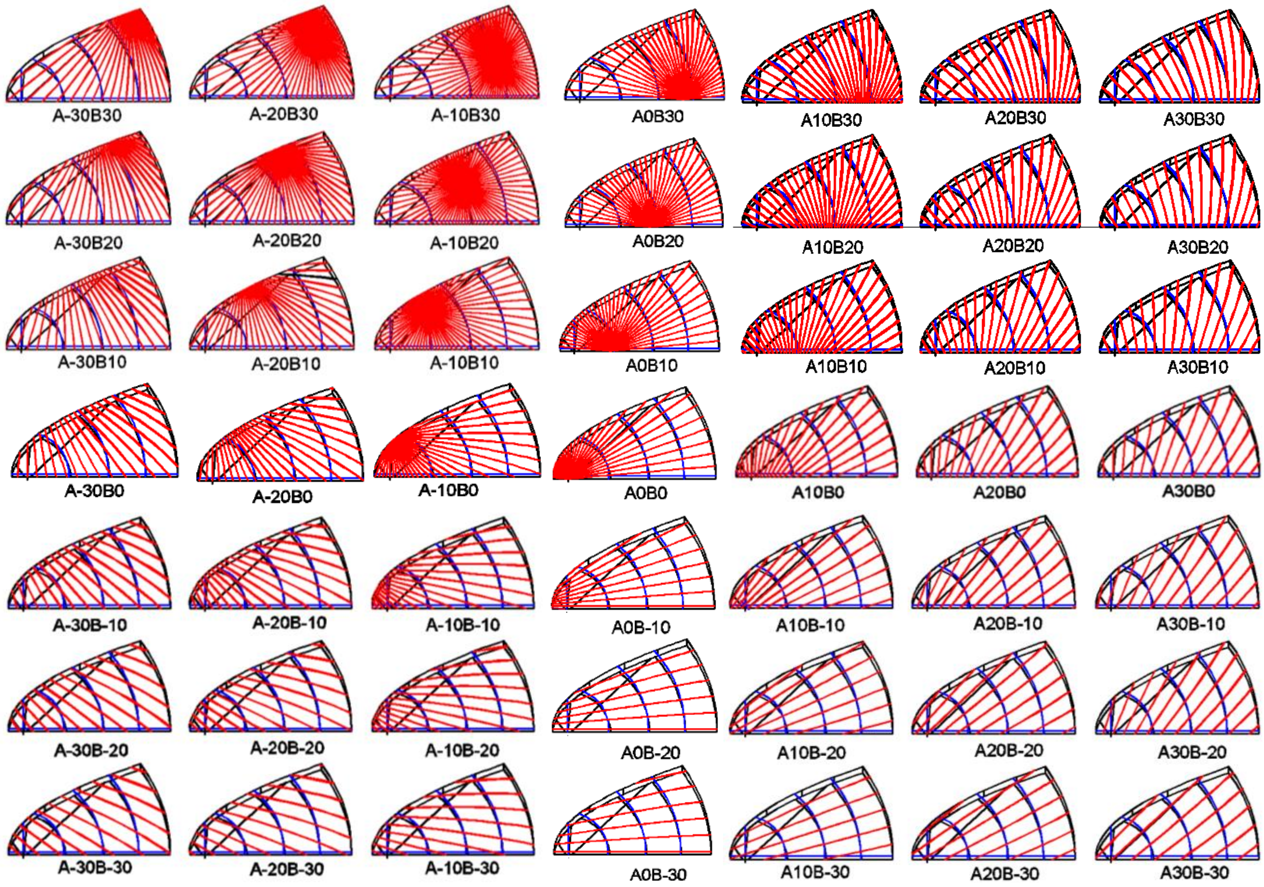


Figure 6. Chips and cross sections in 3D-CAD projection in 5-axes machining

5 RESEARCH RESULT

5.1 Cross Sections Orientations

Analyzing all the situations of the tool tilt between 0 to ±30 degrees for A and B axis (Fig. 6), it is clear that in the case of no tilting tool (A0B0) and a few other situations (A0B0 to A0B30, A-10B0 to A-10B30, A-20B10 to A-20B30 and A-30B20 to A-30B30) the tool tip is in contact with workpiece (shaded area) where cutting speed is zero resulting in cutting, small craters (Fig 7.) that are very hard to finish that, below the surface of the tool setting (Cosma, 2010).

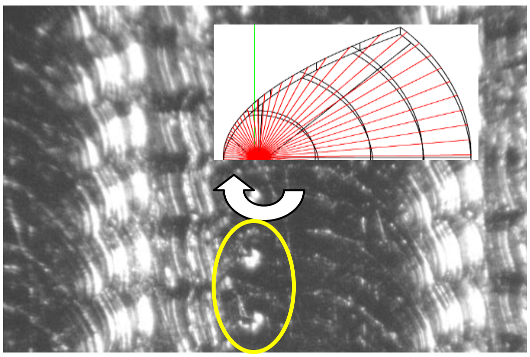
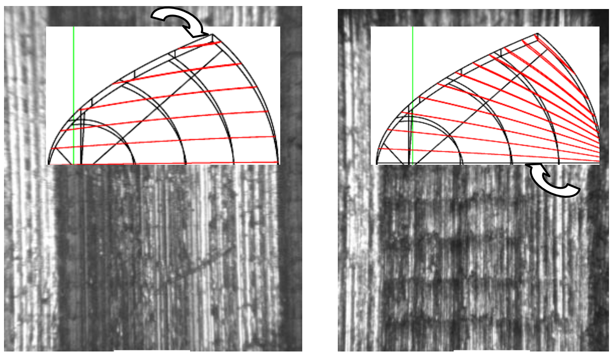


Figure 7. Surface appearance at A0B0

The other orientations of the tool show that is possible to avoid tool tip contact with the chip and the workpiece surface. The proper orientation will depend on entering cutting edge and cutting area.

The best entrance of cutting edge in uncut chip is in the high thickness (down milling) and short cutting length contact with uncut chip (Fig. 8. a). This situation was proved in the experimental researches by author on 3-axis ball nose mill cutting process (Cosma, 2010).



a) b)

Figure 8. Surface appearance at opposite entrances (fig. a) good and fig b) worse)

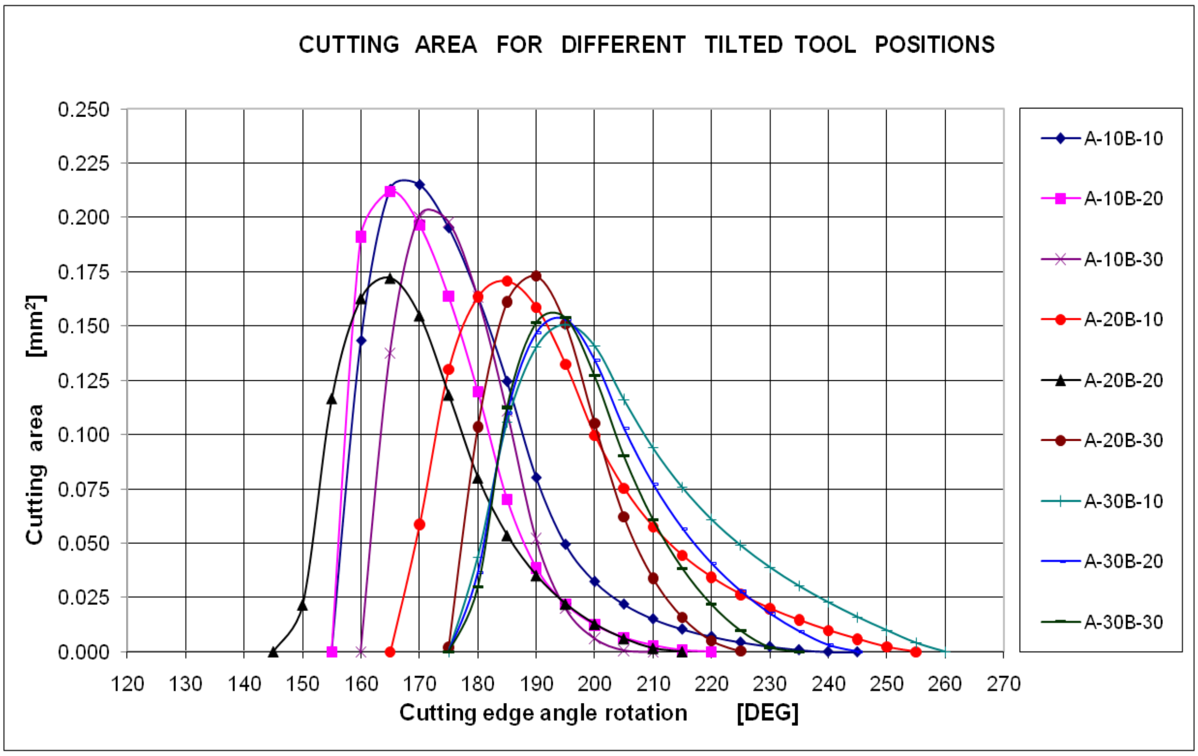


Figure 9. Cutting area for the best entrance of cutting edge

5.2 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.4). The cutting area analysis for the ball nose end milling, considering tool axis inclination, is very important for high process efficiency because the cutting force is proportional with the maximum chip area. In figure 9 is presented cutting area for the best orientations of the tool, (A-10B-10 to A-30B-30) considering entrance of cutting edge.

6 CONCLUDING REMARKS

The machining process using a ball nose end mill is very complex, because the cutting edge is on spherical surface, the tool tip moves on a linear track and the cutting speed is zero.

The volume of the uncut chip is similar for all orientations but the transition of the cross sections in the uncut chip is very different.

Tool orientation in the second quadrant does not lead to avoidance cutting with tool tip.

The best conditions (minimum value for cutting area) are obtained for tilting tool between A-30 and B-10 to -30 degrees (Fig. 9.).

Good entrance of cutting edge in uncut chip is for both A and B negative angle inclination, and the best cutting conditions are for A-30B-10 to A-30B-30 when both conditions are fulfilled when reaching minimum values for cutting area. These theoretical researches must be verified by experimental tests.

7 REFERENCES

► 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, 2006, ISSN 1224-3264, pp. 49-54.

► Cosma, M. (2010). *Aschierea cu freze cilindro-frontale cu cap (Cutting With Ball Nose End Mill)* Editura Universitații de Nord, Baia Mare, ISBN 978-606-536-070-9.

► Cosma, M. (2013). *Study of the Uncut Chip in 5 Axes Ball Nose End Milling for the Third Quadrant of the Tool Inclination*, Applied Mechanics and Materials Vol. 371, Trans Tech Publications, Switzerland (2013) 37-41.

►Diciuc, V., Lobontiu M., Nasui V. (2011). *The Model of Ball Nose End Milling Process by Using CAD Methods*. Academic Journal of Manufacturing engineering Vol. 9 ISSUE 2/2011, ISSN 1583-7904, pp. 42-47.

►Pașca, I. Lobonțiu, M., Cep, R., Bănică, M. (2013). *Experimental Design Methodology in Ball End Milling of C45 Material by Using Tool Tilt Angle - Analysis and Estimation of Surface Roughness Variation*, Applied Mechanics and Materials Vol. 371, Trans Tech Publications, Switzerland pp. 48-53.