THE INTERNATIONAL CONFERENCE OF THE CARPATHIAN EURO-REGION SPECIALISTS IN INDUSTRIAL SYSTEMS
6th edition

GEOMETRIC METHOD OF UNDEFORMED CHIP STUDY IN BALL NOSE END MILLING

Marius Cosma
Assist. Eng., North University Baia Mare, Dr. V. Babeş 62A street, Romania

Abstract: *The objective of this study is to give emphasis about some aspects in geometric analysis of chip generating mechanism in metal cutting by milling, using ball nose end mills. A ball nose end mill has a semi-sphere at the end tool and has very complex machining mechanism in chip generations. Ball nose cutters cut with the radius of the ball, from the tip of the tool to the tangency point at full diameter. The cross-section of the chip produced by a ball nose cutter resembles a section of a crescent moon. At shallower axial depth of cut the crescent is thinner, the chip thickness is less and the volume of material removed is also less. In this study the volume of undeformed chip and a few representatives cross-section are obtained in 3D-CAD, by four surfaces intersection. With the prevalent use of ball nose tools in the milling of dies and molds or complex surface parts from different area of industry, chip thinning can become an important productivity-enhancing tool.*
Key words: *ball nose end mill, cutting edge, chip geometry, milling, tool paths.*

1. INTRODUCTION

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 etc. 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 competitive alternative to grinding and electrical discharge machining (EDM) [1].

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 complex surfaces machining 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 profile) and defense industry. This modern milling is a very universal machining method and during the past few years, hand-in-hand machine tool developments, milling has evolved into a method that machines a very broad range of configurations. Tooling developments have also contributed to the new possibilities along with the gains in productivity, reliability and quality.

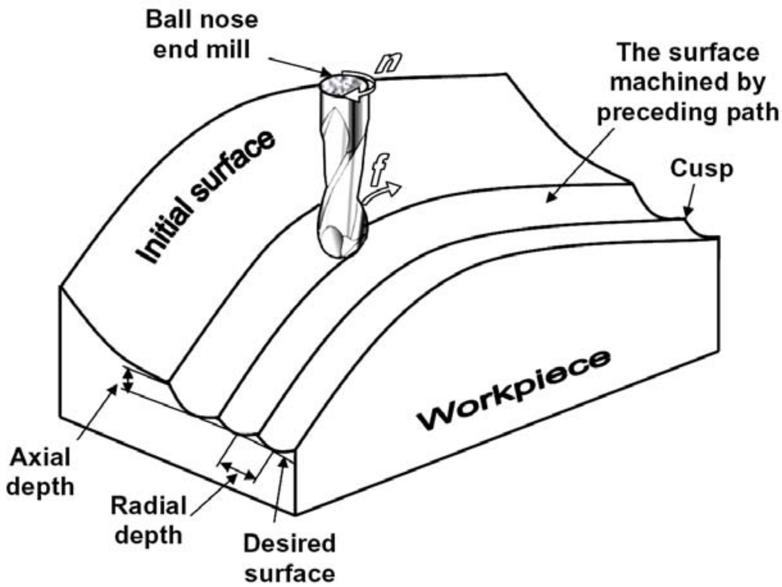

Fig.1. Ball nose end milling

The ball nose end milling has very complex machining mechanism, as the cutting edge is determined on spherical surface. When a cutter with a non-flat end, such as a ball nose end mill, is used to cut a desired 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 Fig.1.

When applying ball nose end mill, quite often the full diameter of the cutter is not engaged in the work. Only a short length of cutting edge is engaged in chip cutting at effective diameter that is the main factor used in the calculation of the required spindle speed and is defined as the actual diameter of the cutter at the axial depth of cut line as shown in Fig. 2. and can be calculated from:

$$D_e = 2 \cdot \sqrt{a_p (D - a_p)} \tag{1}$$

where: D_e – effective diameter, the diameter of tool at a given depth of cut;

a_p – axial cutting depth;

D – diameter of tool.

The step over distance which is radial cutting depth, in combination with tool nose radius determines the theoretical surface roughness in step-over direction Fig. 2. expressed as follow:

$$h_{th} = R - \frac{\sqrt{4R^2 - a_e^2}}{2} \tag{2}$$

where: h_{th} – theoretical surface roughness;

R – tool nose radius;

a_e – radial cutting depth.

A complete study about considerations concerning the milling of complex curved surfaces using ball nose end mills and his technological parameters are presented in [2].

2. GEOMETRICAL REPRESENTATION OF CUTTING PROCESS

In this study, the local coordinate system of the ball nose end mill is defined as the rectangular coordinate system with the origin of the coordinate set at the center of sphere of tool nose, X axes in the step-over direction, Y axes in feed direction and Z axes in tool axes direction, that is considered normal to the desired surface (see Fig.2.). Each of cutting edges (often used two) remove, in ψ rotational angle, a certain amount of metal, called here undeformed volume chip and it is included between initial surface, first pass, first revolution and second revolution. The distance from first revolution to second revolution is feed rate per tooth per revolution - f_z.

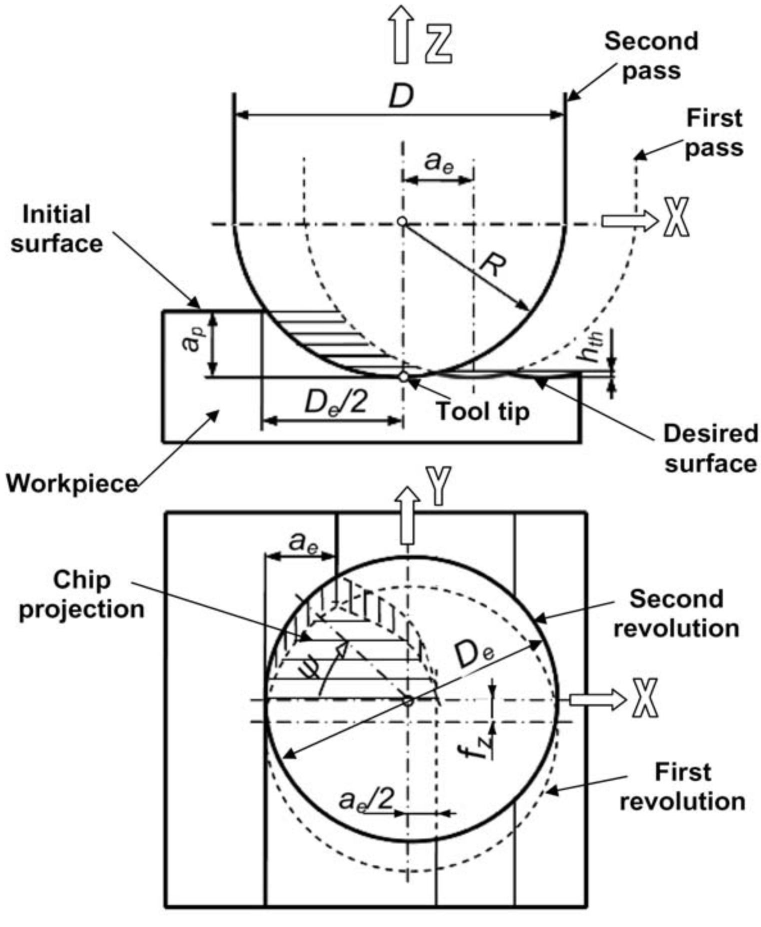

Fig.2. Geometrical representation of ball nose end milling

3. METHOD OF GEOMETRICAL ANALYSIS AND 3D-CAD MODEL

However the geometrical method used in this study is available if boundary surfaces are generated, in the first by simplify the motion of the cutting edge, only in the revolution of tool, when the considerate point of cutting edge moves along a closed circle trajectory (in reality is looped orthocycloidal trajectory, called trachoid [3]), secondary, the surface machined by preceding path (see Fig.1.) is constructed by swept surface of sphere and third, initial surface can be considered plane for a very small area. As a result of these preconditions it is easy to determine by calculus with analytic geometry [4] the equations of boundary surfaces as fellow (see Fig. 3.):

- initial surface – *plane* – pos. 1:

$$z = -(R - a_p) \tag{3}$$

- first revolution – *sphere* – pos. 2:

$$x^2 + (y - f_z)^2 + z^2 = R^2 \tag{4}$$

- second revolution – *sphere* - pos. 3:

$$x^2 + y^2 + z^2 = R^2 \tag{5}$$

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

$$(x-a_e)^2 + z^2 = R^2 \tag{6}$$

Giving real values for parameters (R, a_p, f_z, a_e) and using 3D-CAD geometric configuration for above mentioned equations, result undeformed chip (see pos.5, Fig.3.) which will be machined by one cutting edge of tool.

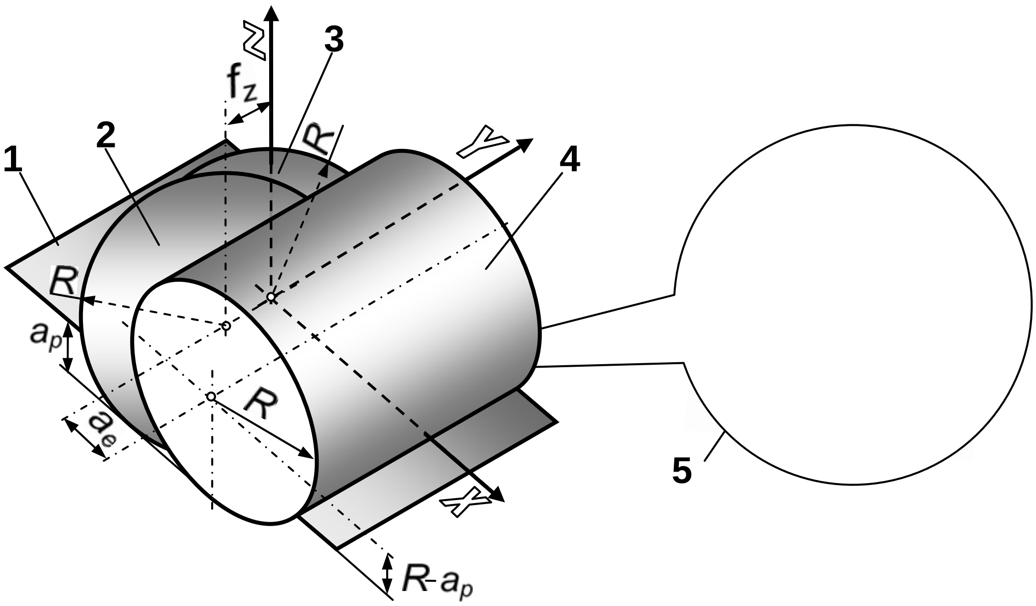

Fig.3. Definitions of boundary surfaces and undeformed chip

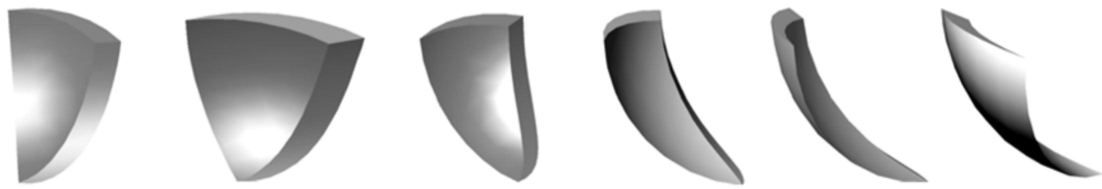

Fig.4. Different side views of undeformed chip

In figure 4 are presented a few different 3D-CAD side views of undeformed chip, determined only by the geometric configurations in the above preconditions established. These side views inform us that, it is a kind of area of the undeformed chip section at the cutting edge passing the chip volume. The influential sections in the cutting are defined by the tool fan cutting edge revolution angle (Fig. 5.) from the start point ψ_0 to the end contact point ψ_7 (here for up-milling) and in figure 6 are presented a few cutting area for representative cross-sections.

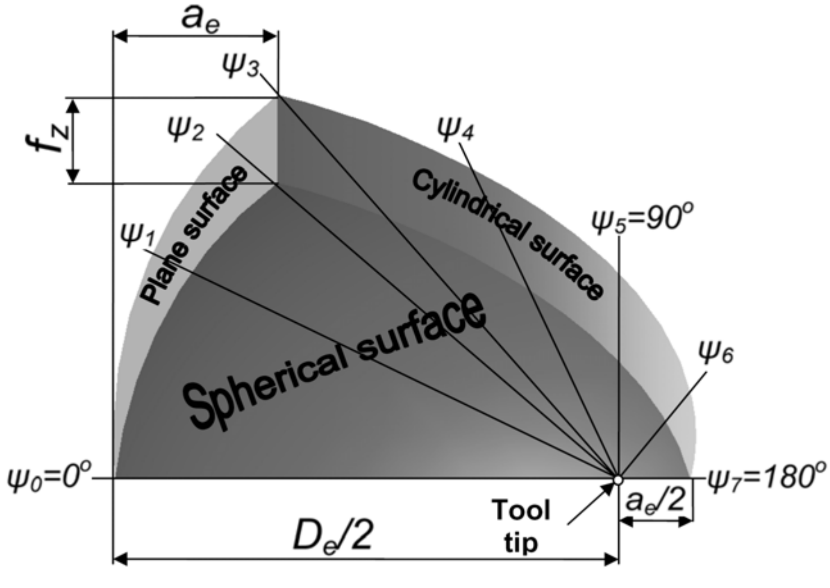

Fig.5. X-Y plane view of undeformed chip and cross-sections

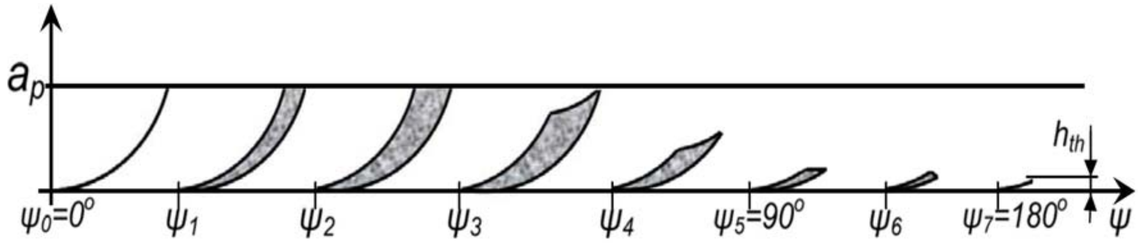

Fig.6. Cutting area for a few representative cross-sections

4. CONCLUSIONS

In ball nose end milling, the cutting process is very complex and very difficult to establish a mathematically algorithm for a complete process analysis. Using this geometrical method for 3D-CAD analysis and different values for tool nose radius R, axial cutting depth a_p and radial cutting depth a_e, can be predicted, with minimum error, the cutting process for different type of tools and technological parameters.

Is very clear up that the effective area of the fan of cutting edge is variable, and if the number of cross-sections at fan cutting edge revolution angle ψ is sufficient of high, can be calculated effective area for each angle ψ and predicted the cutting forces variation, for one cycle under certain machining conditions.

The limitations of the proposed method, by above preconditions, should be made clear in the future work where, is necessary to develop influence of feed, in up-milling and down-milling and workpiece inclination in 3-axes milling or tool orientation in 5-axes milling, for avoid the tool tip contact with machined surface.

5. REFERENCES

1. COSMA, M., *Sisteme tehnologice performante în prelucrarea prin frezare a suprafeţelor complexe.* Buletin ştiinţific-Management tehnologic, Universitatea de Nord din Baia Mare, 2005, ISSN 1584-7306, pag. 67-72.

2. COSMA, M., *Considerations concerning the milling of complex curved surfaces using ball nose end mills.* Inter-ING 2005, Universitatea Petru Maior Tg. Mureş, 2005. ISBN 973-7794-41-9, pag. 91-96.

3. DEACU, L., KEREKES, L., JULEAN, D., CĂREAN, M. *Bazele aşchierii şi generării suprafeţelor*. Universitatea Tehnică din Cluj-Napoca, 1992.

4. FRALEIGH, B. J., *Calculus with analytic geometry.* Addison-Wesley Publishing Company, Massachusetts, 1985.