The analysis of cutter-workpiece engagement of conical ballmill during five-axis machining of ruled surfaces

Badania symulacyjne strefy styku w pięcioosiowej obróbce powierzchni prostokreślnych frezem stożkowym

JAN BUREK
KAROL ŻURAWSKI
PIOTR ŻUREK
MARCIN SAŁATA *

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The article presents the analysis of the influence of a conical mill's lead angle on cutter-workpiece engagement. A methodology of performing a machining simulation as well as its results during machining of ruled surfaces with varying angles of torsion is presented.
KEYWORDS: five-axis milling, conical ballmill, ruled surface

The commonly used rotor machining strategy is the rounding with the ballmill. The tool performs multiple passes with a small cutting width. This strategy makes it possible to create surfaces of any shape, however, it is not efficient. An alternative to this method is the flank milling with a conical ballmill (fig. 1) [2, 3, 8].

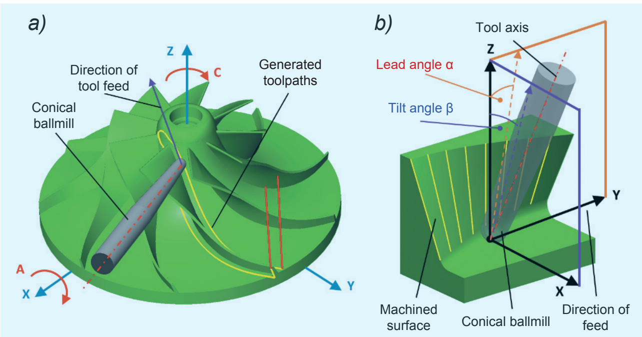

Fig. 1. Diagram: a) rotor flank milling, b) five-axis parameters of tool axis positioning [3]

During flank milling by conical ballmill, the machining takes place in one pass, in which the circumferential surface of the tool is cut across the entire line of contact. This allows the machining time to be reduced several times compared to the standard machining strategy [2, 3, 8].

This method can only be applied to the machining of the ruled surfaces (fig. 2). This limitation is due to the linear contact of the tool with the workpiece [2-5].

In addition, when machining non-expandable ruled surfaces, there is a risk of undercutting or leaving the machining allowance (fig. 3). In order to avoid this, it is necessary to change the lead angle α of tool continuously [2-5].

Analysis of the tool contact zone provides the basis for predicting the cutting force. On the other hand, the change in the value and the direction of the cutting force have a decisive influence on the elastic deformation of the MGTW (machine - grip - tool - workpiece) system, which result in errors in dimension and shape [1, 6, 7]. In addition, this method makes it possible to determine the maximum deviation of the shape of the machined surface with regard to the nominal surface [5, 6].

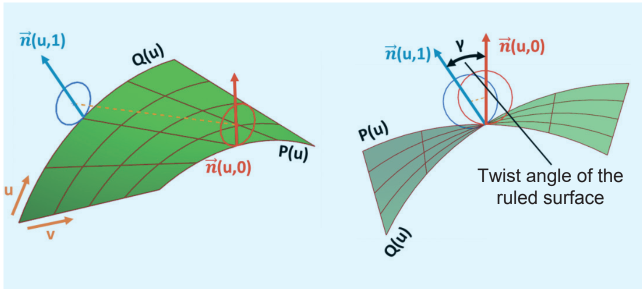

Fig. 2. Twist angle γ of the non-expandable ruled surface [3]

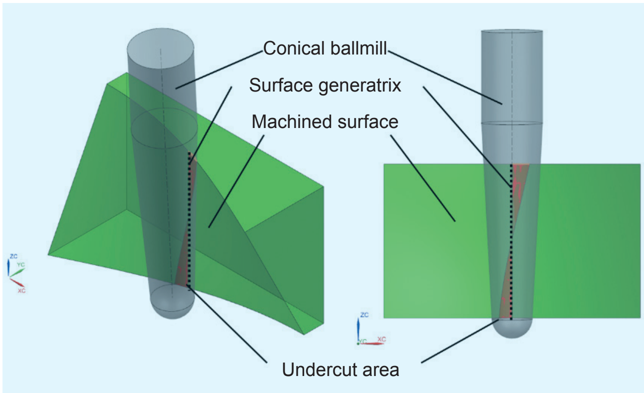

Fig. 3. Pattern of undercuts when machining a non-expandable ruled surface [3]

The purpose of this work was to determine the influence of the lead angle α and the twist angle of the ruled surface γ on the contact area A_S of the conical ballmill and the volume of the cut V in the process of five-axis flank milling.

Simulation tests

For simulation tests purposes, parameterized 3D models of a undeveloped ruled surface with fixed twist angle γ and a conical ballmill were created.

It was possible to modify the geometrical dimensions of the test surface, among others: length, width, height, angle of twist γ and the value of machined allowance.

However, in the conical ballmill model, it was possible to change the geometric dimensions, i.e. the cutter diameter, the working part length, the total length, the cone angle and the five axis tool position parameters, i.e. the lead angle α and the tilt angle β.

* Dr hab. inż. Jan Burek prof. PRz (jburek@prz.edu.pl), mgr inż. Karol Żurawski (zurawski@prz.edu.pl), mgr inż. Piotr Żurek (p_zurek@prz.edu.pl), mgr inż. Marcin Sałata (msalata@prz.edu.pl) – Katedra Technik Wytwarzania i Automatyzacji Politechniki Rzeszowskiej im. Ignacego Łukasiewicza

The geometric and technological parameters used in the analysis are presented in the Table.

TABLE. Geometric and technological parameters accepted for analysis

Tool diameter d	4 mm
Angle of cone	6°
Feed per tooth f_z	0,05 mm
Depth of cut a_p	0,2 mm
Cutting width a_e	20 mm
Lead angle α	0°÷3°
Tilt angle β	0°
Angle of surface twisting γ	0°÷30°

In the first phase, the initial position of the tool in regard to the workpiece was determined (fig. 4a). Subsequently, the operation of the tool body removal from the model of the work surface was conducted (fig. 4b). In the next phase, the milling model was moved from the previous position by the feedrate value. This procedure was performed in an iterative loop until the assumed path length was reached (fig. 4c) [9, 10].

At the next stage, the common part of the tool model and the workpiece was determined (fig. 5). As a result, the cut layer model was obtained. It was used to determine the volume of the material to be removed (fig. 6a) and the area of the A_S contact area (fig. 6b). In addition, based on the obtained model of the work surface, the value of the maximum deviation from the nominal model was determined (fig. 6c) [9, 10].

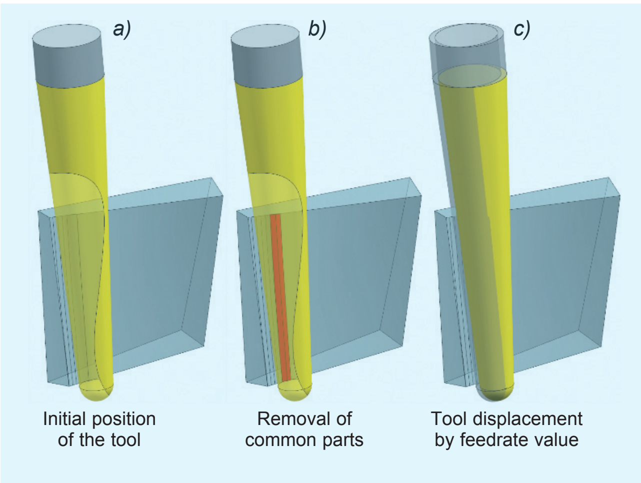

Fig. 4. Method of determining the model of the cutting layer – stage 1

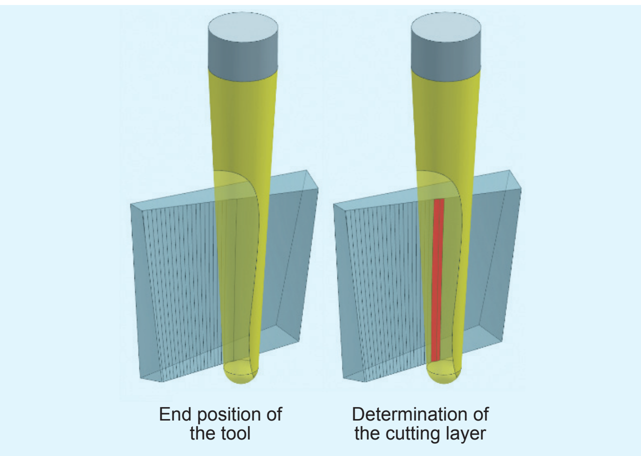

Fig. 5. Method of determining the model of the cutting layer – stage 2

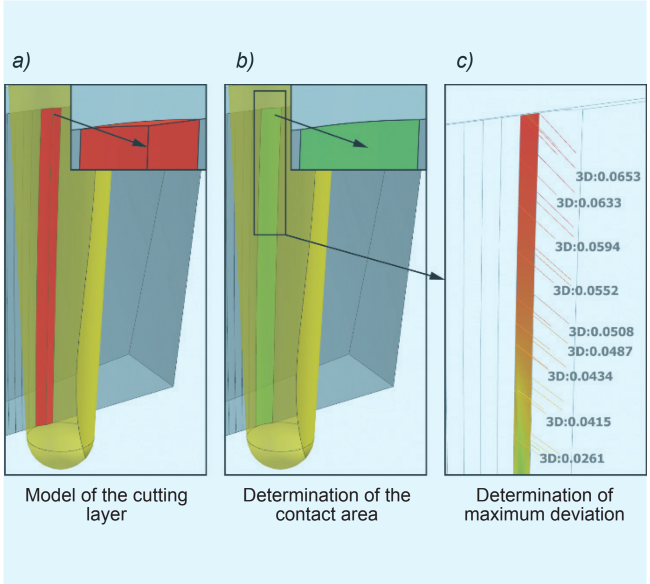

Fig. 6. Method of determining the contact area and maximum deviation from nominal model

Analysis of results

Figs. 7-9 show the graphs of the volume of the cutting layer V, the surface area of the contact area A_S, and the maximum deviation from the twist angle of the surface γ for the different angles α.

The analysis of fig. 7 shows that the twist angle γ of the machined surface and the lead angle α have a significant influence on the volume of the cut layer.

While it was machined with the lead angle equaled 0°, the volume of the cut layer was in the range of 0.20 to 0.36 mm^3. In this case, the volume of the cut layer V was increasing as the twist angle γ of the machined surface was rising. On the other hand, after the introduction of the angle α = 3°, the minimum volume of the cut V was obtained, which ranged from 0.14 to 0.19 mm^3. It should be noted that the maximum value was reached at zero angle of twisting of the machined surface γ while the minimal value was at γ = 20°.

Based on the analysis of fig. 8, it can be concluded that both the twist angle γ of ruled surface and the lead angle α affected the value of the area of the contact area A_S.

The highest values were obtained with lead angle α equaled 0° and they ranged from 20 to 26.7 mm^2. Similarly to the volume of cut layer V, the value of the contact area A_S was increasing while the twist angle γ of the machined surface was rising. For angle α = 3°, the contact area A_S decreased, ranging from 16.5 to 20 mm^2, with the minimum value being attained for the twist angle γ = 20°.

In addition, the change in the lead angle α influenced the shape of the tool contact area. This is noticeable at high values of the twist angle of ruled surface (fig. 10).

Based on fig. 9, it can be stated that depending on the twisting angle γ the ruled surface changed the value of the maximum deviation which was the result of undercutting

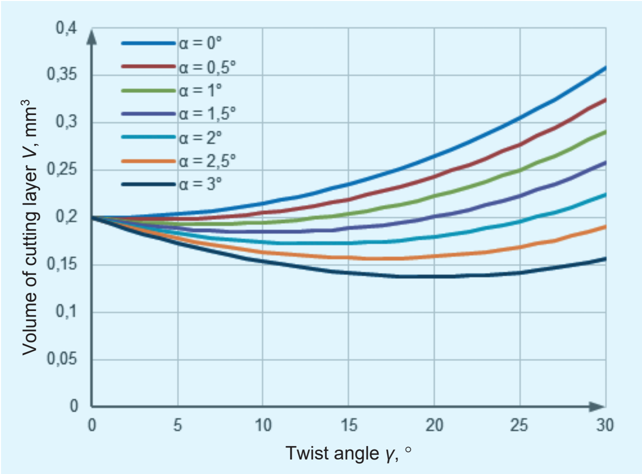

Fig. 7. Volume of cutting layer V as a function of twist angle γ for different lead angles α

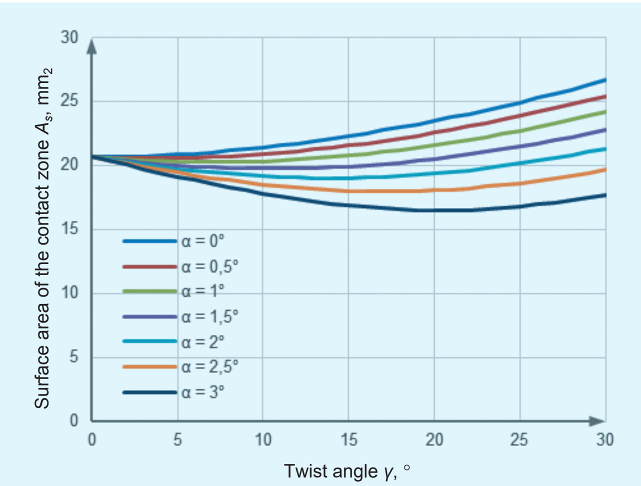

Fig. 8. The contact area A_S as a function of the twist angle γ for different lead angles α

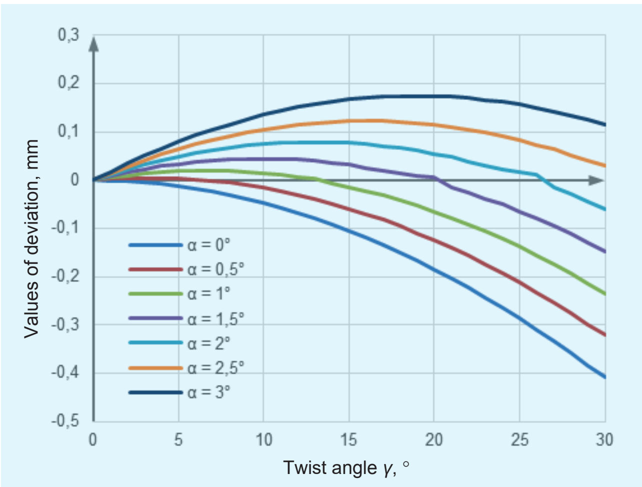

Fig. 9. Maximum deviation values from the nominal model as a function of the twist angle γ for different lead angles α

or leaving the allowance. It can be seen that the distribution of deviations was different depending on the lead angle. Particular attention should be paid to the fact that for each twist angle the minimum deviation was achieved at different lead angles.

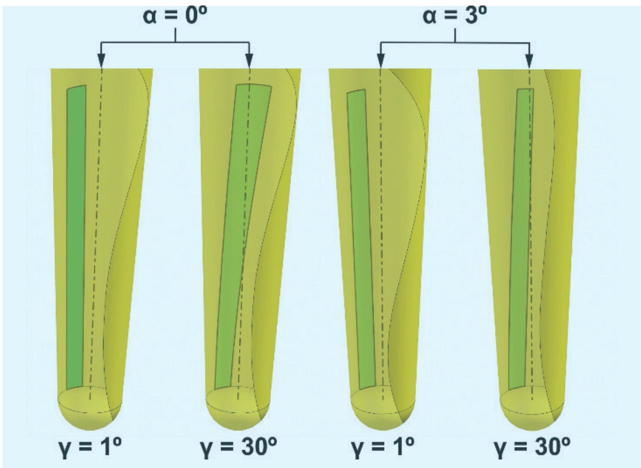

Fig. 10. Tool contact zones

Conclusions

Simulation studies suggest that the values of the milling lead angle α and the twist angle γ of the ruled surface have a great influence on both the volume of the cutting layer V and the area of the contact area A_S in the five-axis flank milling process.

The wide range of values of the tested parameters in the range of angles of twisting γ implies the variability of the cutting force components, which in turn is reflected in the accuracy of the workpiece surface.

In order to maintain a constant volume of the cutting layer V and the area of the contact zone A_S, it is necessary to change the lead angle α continuously during machining.

REFERENCES

1. Boz Y., Erdim H., Lazoglu I. “A comparison of solid model and three-orthogonal dexelfield methods for cutter-workpiece engagement calculations in three- and five-axis virtual milling”. *The International Journal of Advanced Manufacturing Technology*. (2013).
2. Burek J., Żurawski K., Żurek P. „Wpływ kąta prowadzenia frezu na dokładność wymiarowo-kształtową powierzchni prostokreślnych”. *Mechanik*. 87, 8–9 (2014): s. 729.
3. Burek J., Żurawski K., Żurek P. „Wpływ kąta pochylenia freza na dokładność kształtową powierzchni prostokreślnych”. *Mechanik*. 89, 10 (2016): s. 1472–1473.
4. Chu C.-H., Chen J.-T. „Tool path planning for five-axis flank milling with developable surface approximation”. *The International Journal of Advanced Manufacturing Technology*. 29 (2006): s. 707–713.
5. Ferry W. ”*Virtual Five-axis Flank Milling of Jet Engine Impellers*”. Vancouver: The University of British Columbia, 2008.
6. Lazogul I., Boz Y., Erdim H. “Five-axis milling mechanics for complex free form surfaces”. *CIRP Annals – Manufacturing Technology*. 60 (2011): pp. 117–120.
7. Li Z.-H., Wang X.-Z., Zhu L.-M. „Arc-surface intersection method to calculate cutter-workiepce engagements for generic cutter in five-axis milling”. *Computer-Aided Design*. 73 (2016): s. 1–10.
8. Waldt N. „*NC-Programmierung fur das funfachsige Flanken-frasen von Feriformflachen*”. Universitat Hannover, 2005.
9. Yang Y., Wan M., Zhang W., Ma Y. „Extraction of cutter-workpiece engagement for multi-axis milling”. *Materials Science Forum*. 770 (2014): s. 357–360.
10. Yang Y., Zhang W., Wan M., Ma Y. „A solid trimming method to extract cutter-workpiece engagement maps for multi-axis milling”. *The International Journal of Advanced Manufacturing Technology*. (2013).