The analysis of barrel mill's cut-layer cross section

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The article presents the analysis of barrel mill's cut-layer cross section. A methodology of performing a machining simulation as well as its results during machining of concave and convex surfaces is presented.
KEYWORDS: five-axis milling, barrel mill

Complex surfaces are usually machined with ball mills. However, due to the relatively small width of the machining path, the work of these mills is not efficient. The small widths of the machining paths b_r are the consequence of the small radius of the cutting edge r_n. That is why new geometry of cutters is being sought, which will allow for much wider machining paths. These tools include mills with barrel shape of the cutting edge (fig. 1) [2-4].

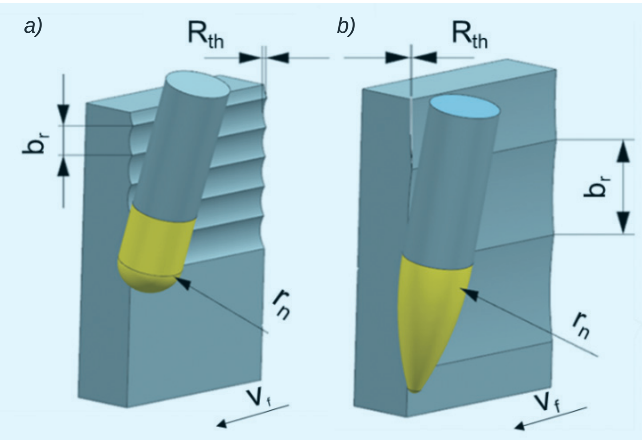

Fig. 1. Machining with: *a*) a ball mill *b*) a barrel mill [2, 3]

The use of these mills is associated with a completely different overlap of machining paths, which significantly affects the surface efficiency and maximum theoretical height of the R_{th} profile, which is determined by the formula [2-4]:

$$R_{\mathrm{th}} = r_{\mathrm{n}} + \sqrt{r_{\mathrm{n}}^2 - \frac{b_{\mathrm{r}}^2}{4}}$$

where: r_n – radius of the cutting edge, b_r - width of the path

As the machining path gets wider, the cross-sectional area of the cutting layer increases. This affects the distribution and value of the cutting force, which in turn results in the elastic deformation of the machine tool - tool - workpiece system and translates into errors in the dimensions and shape of the workpiece. Hence, it is important to analyze the area of cut-layer cross section [1, 9].

In addition to the radius r_n, the radius of curvature of the machined surface r_k – both concave and convex surfaces – has a significant effect on the maximum profile height (fig. 2) [5, 7].

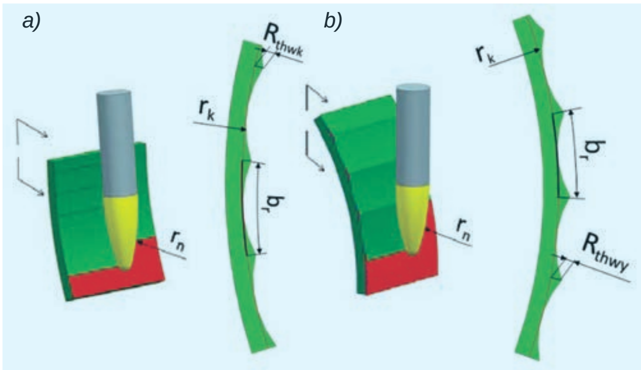

Fig. 2. Machining the surface with a barrel cutter: a) concave, b) convex

When machining a concave surface along with reducing the radius of curvature of the surface of the workpiece, the maximum height of the R_{thwk} profile decreases, according to the relation:

$$R_{\mathrm{thwk}} = r_{\mathrm{k}} - (r_{\mathrm{k}} - r_{\mathrm{n}}) \cos\frac{b_{\mathrm{rwk}}}{2r_{\mathrm{k}}} - \sqrt{r_{\mathrm{n}}^2 - \left[(r_{\mathrm{k}} - r_{\mathrm{n}}) \sin\frac{b_{\mathrm{rwk}}}{2r_{\mathrm{k}}}\right]^2}$$

where: b_{rwk} - width of machining path for concave surface (arc value).

On the other hand, in case of convex surfaces with the reduction of the radius of curvature, the maximum height of the R_{thwy} profile is increased according to the relation:

$$R_{\mathrm{thwy}} = (r_{\mathrm{n}} + r_{\mathrm{k}}) \cos\frac{b_{\mathrm{rwy}}}{2r_{\mathrm{k}}} - \sqrt{r_{\mathrm{n}}^2 - \left[(r_{\mathrm{k}} + r_{\mathrm{n}}) \sin\frac{b_{\mathrm{rwy}}}{2r_{\mathrm{k}}}\right]^2} - r_{\mathrm{k}}$$

where: b_{rwy} - width of machining path for convex surface (arc value).

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If the constant maximum profile height (R_{th} = const) is maintained by changing the width of the path b_r, one can calculate the width of these paths for the b_{rwk} concave surface and for the convex surface of the path according to the relationship:

$$b_{\mathrm{rwk}} = 2r_{\mathrm{k}} \cdot \mathrm{acos}\left[\frac{2r_{\mathrm{k}}^2 - 2r_{\mathrm{k}} \cdot r_{\mathrm{n}} - 2 \cdot r_{\mathrm{k}} \cdot R_{\mathrm{thwk}} + R_{\mathrm{thwk}}^2}{2(r_{\mathrm{k}} - r_{\mathrm{n}}) \cdot (r_{\mathrm{k}} - R_{\mathrm{thwk}})}\right]$$

$$b_{\mathrm{rwy}} = 2r_{\mathrm{k}} \cdot \mathrm{acos}\left[\frac{2r_{\mathrm{k}}^2 + 2r_{\mathrm{k}} \cdot r_{\mathrm{n}} + 2r_{\mathrm{k}} \cdot R_{\mathrm{thwy}} + R_{\mathrm{thwy}}^2}{2(r_{\mathrm{k}} + r_{\mathrm{n}}) \cdot (r_{\mathrm{k}} + R_{\mathrm{thwy}})}\right]$$

Simulation tests

Based on these relationships, the widths of the machining paths for the curvature radius from 200 to 2000 mm were determined. Calculations were performed for a fixed parameter R_{th} = 3 μm. The width of the paths was b_r = 1.46÷1.88 mm for the concave surface (fig. 3) and 1.20÷1.44 mm for the convex surface (fig.4).

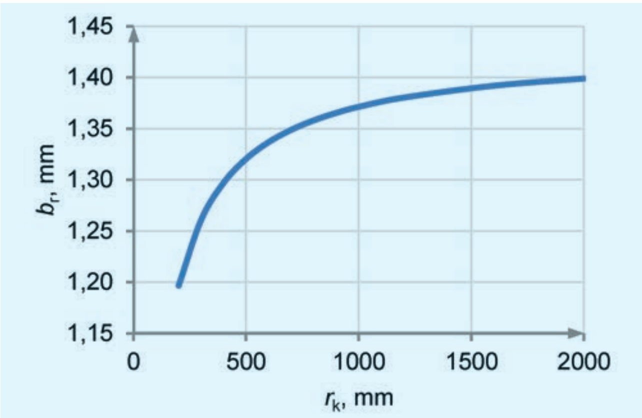

Fig. 3. Widths of the machining path as a function of the curvature radius – convex surface

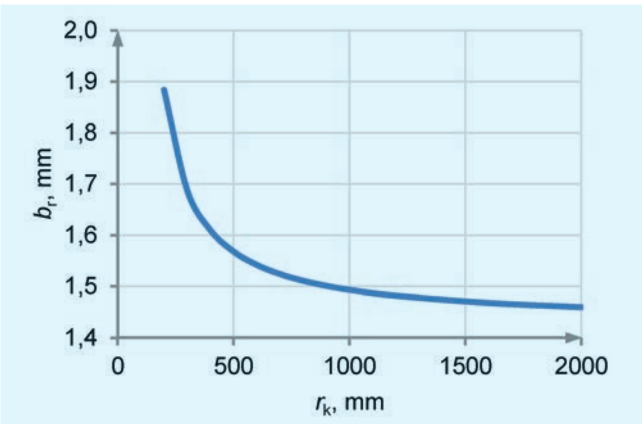

Fig. 4. Widths of the machining path as a function of the curvature radius - concave surface

The width of the path b_r in relation to the radius r_k for both types of surface is variable. There is much greater variation in the width of the b_r path in small range of radii of machined surface radii below r_k = 500 mm.

Simulation studies of the cut layer were performed during the machining of the concave surface and convex with a barrel mill. Constant geometric and technological parameters were assumed (Table). The analysis was performed for the widths of the paths obtained as a result of the calculations. The aim of the analysis was to determine the maximum cross-sectional area of the cut layer depending on the radius of curvature of the work surface, assuming constant maximum height of the R_{th} profile.

TABLICA. Parametry geometryczne i technologiczne przyjęte do analizy

Maksymalna wysokość profilu R_{th}, μm	3
Promień zarysu krawędzi skrawającej r_n, mm	85
Średnica narzędzia d, mm	10
Posuw na ostrze f_z, mm	0,1
Zakres szerokości ścieżek b_r, mm	1,2÷1,9
Zakres promieni krzywizny powierzchni obrabianej r_k, mm	200÷2000

Methodology of research

The analysis was based on Boolean operations. In order to simplify the simulation, no cutting edge inclination was assumed [6, 8].

Two types of surface models were created - separate for concave and convex surfaces. The radius of curvature r_k and the width of the path b_r were parameterized. Subsequently, a barrel mill with a diameter of d = 10 mm and a radius of the cutting edge r_n = 85 mm, was modeled. The analysis is shown in fig. 5.

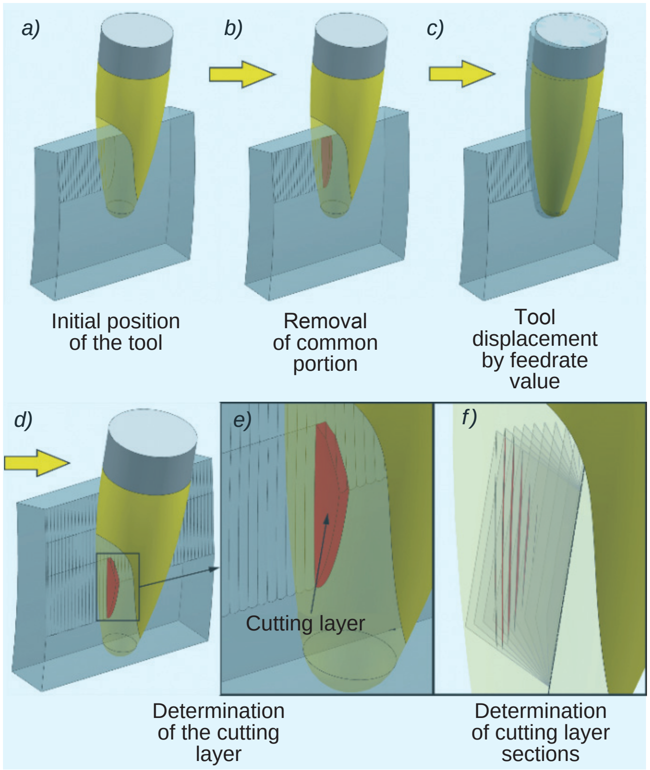

Fig. 5. Method of determining the area of a cut layer

In the first step, the position of the tool relative to the workpiece was determined (fig. 5a). The model of the tool body was subtracted from the machined surface (fig. 5b). The next step was to reposition the tool model from the previous position by the feedrate value (fig. 5c).

These actions were repeated until the desired number of paths were executed (fig. 5d). Next, the intersection of the machined surface model and the tool body was determined and the model of the cutting layer was obtained (fig. 5e). At the final stage, the cross-sections of the layer were determined and the surface areas were obtained (fig. 5f) [10].

Analysis of results

In the case of concave surface machining with a radius of curvature r_k = 200 mm, the cutting area of the cut layer A_{max} was 0.103 mm^2 (fig. 6). This is about 30% higher than the cut surface area of the concave surface with radius r_k = 2000 mm. The variability of the cross-sectional area of the cut layer was much higher in the radius of curvature r_k less than 500 mm. In addition, with the reduction of the radius of curvature of the workpiece surface, the tool contact was increased. There is a change in the shape of the cut layer, especially at the smallest radii of curvature of the work surface (fig. 8).

On the other hand, in the case of the machining of convex surfaces, with the reduction of the radius of curvature of the work surface, the cross-sectional area of the cut layer decreased. The difference in surface machined with a radius of curvature r_k = 200 mm was about 20% relative to the radius of curvature r_k = 2000 mm. As in the case of concave surfaces, the variability of the cross-sectional area was much higher for curvature radius r_k less than 500 mm.

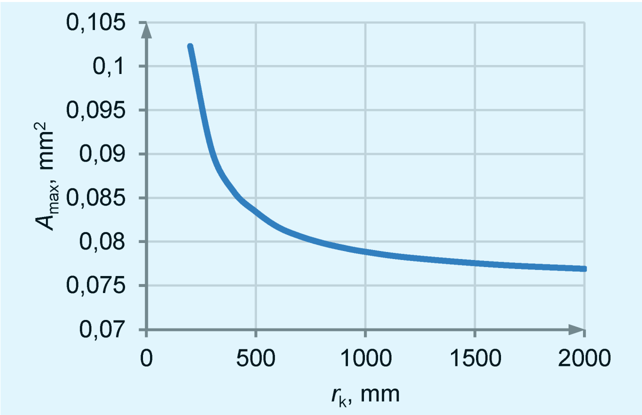

Fig. 6. Maximal surface area of the cut layer A_{max} as a function of the curvature radius of the work surface r_k for the concave surface at R_{thwk} = const

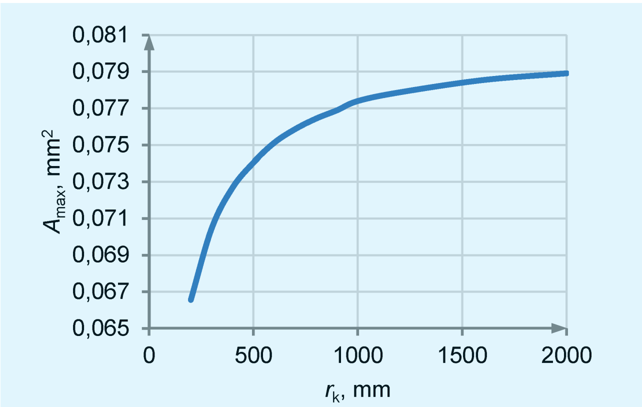

Fig. 7. Maximal surface area of the cut layer A_{max} as a function of the curvature radius of the work surface r_k for the convex surface at R_{thwy} = const

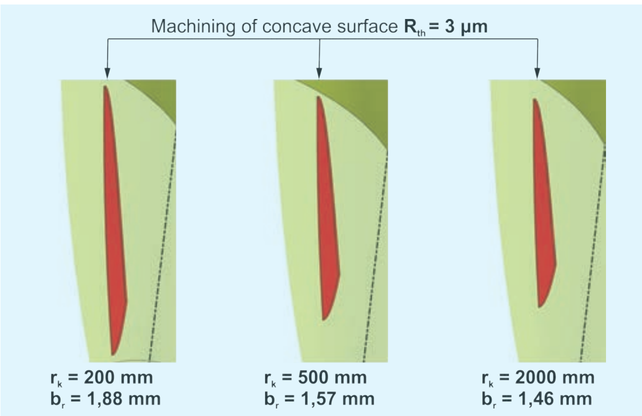

Fig. 8. Models of the cut layer of a concave surface

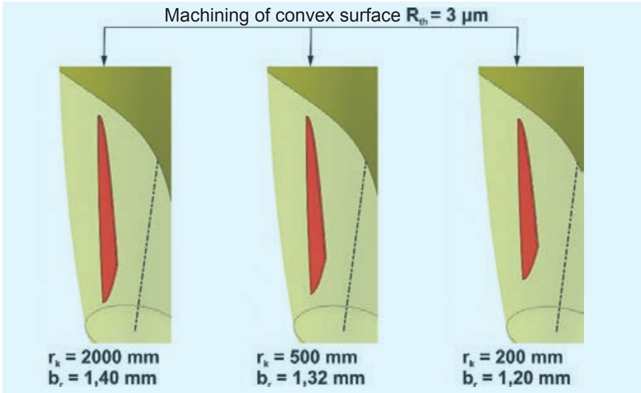

Fig. 9. Models of the cut layer of a convex surface

Conclusions

In surface machining with a barrel cutter, the radius of curvature of the machined surface is an important parameter. In order to obtain a constant surface quality, it is necessary to change the width of the machining paths, which translates into changes in the cross-sectional area of the cut layer. Since the differences are significant and exceed 20%, they should be taken into account when designing the machining process.

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