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].

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].

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]:

$$R_{th} = r_n + \sqrt{r_n^2 - \frac{b_r^2}{4}}$$

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

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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:

$$R_{thwk} = r_k - (r_k - r_n) \cos \frac{b_{wk}}{2r_k} - \sqrt{r_n^2 - \left[(r_k - r_n) \sin \frac{b_{wk}}{2r_k}\right]^2}$$

where: $b_{wk}$ - 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:

$$R_{thwy} = (r_n + r_k) \cos \frac{b_{wy}}{2r_k} - \sqrt{r_n^2 - \left[(r_n + r_k) \sin \frac{b_{wy}}{2r_k}\right]^2} - r_k$$

where: $b_{wy}$ - width of machining path for convex surface (arc value).
If the constant maximum profile height \((R_{th} = \text{const})\) is maintained by changing the width of the path \(b_r\), one can calculate the width of these paths for the \(b_{wrk}\) concave surface and for the convex surface of the path according to the relationship:

\[
b_{wrk} = 2r_k \cdot \cos \left[ \frac{2r_k^2 - 2r_k r_n - 2r_k R_{th wk} + R_{th wk}^2}{2(r_k - r_n)(r_k - R_{th wk})} \right]
\]

\[
b_{wvy} = 2r_k \cdot \cos \left[ \frac{2r_k^2 + 2r_k r_n + 2r_k R_{th vy} + R_{th vy}^2}{2(r_k + r_n)(r_k + R_{th vy})} \right]
\]

**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 \(R_{th} = 3 \, \mu m\). The width of the paths was \(b_r = 1.46 \pm 1.88\) mm for the concave surface (fig. 3) and \(1.20 \pm 1.44\) mm for the convex surface (fig.4).

![Fig. 3. Widths of the machining path as a function of the curvature radius – convex surface](image)

![Fig. 4. Widths of the machining path as a function of the curvature radius - concave surface](image)

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.

**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](image)

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 \( r_k = 200 \text{ mm} \), the cutting area of the cut layer \( A_{\text{max}} \) was 0.103 mm\(^2\) (fig. 6). This is about 30\% higher than the cut surface area of the concave surface with radius \( r_k = 2000 \text{ mm} \). 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 \( r_k = 200 \text{ mm} \) was about 20\% relative to the radius of curvature \( r_k = 2000 \text{ mm} \). 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 \( A_{\text{max}} \) as a function of the curvature radius of the work surface \( r_k \) for the concave surface at \( R_{\text{max}} = \text{const} \)](image)

![Fig. 7. Maximal surface area of the cut layer \( A_{\text{max}} \) as a function of the curvature radius of the work surface \( r_k \) for the convex surface at \( R_{\text{max}} = \text{const} \)](image)

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.

REFERENCES


