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Selection of the tooth depth of the ball end mill based on the analysis of the working conditions of the tool

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Abstract. The working conditions of end radius cutters are analyzed. The length of the chips during processing and the required depth of the tooth are found.

When designing tools with a chip groove the question of its geometric parameters is always acute. So for high-speed steel cutters, the following requirements are imposed on the chip grooves: sufficient chip coverage to avoid jamming; the presence of a sufficient radius of the bottom of the chip groove to eliminate cracks during thermal hardening; the groove must be helical for good chip removal and milling uniformity; the height and shape of the tooth must provide sufficient resistance [1].

For end cylindrical cutters, the shape of the groove is sufficiently studied and conditionally constant in different end sections along the length of its cutting part [2]. For the radius section of the end radius cutters, the choice of tooth depth and shape of the chip groove is still an urgent task. Nowadays, the radius section is obtained by sharpening the end cylindrical cutters using the most simple for universal equipment trajectory of the grinding wheel.

Let us analyze the purpose of tooth depth for various tools that perform finishing work. For the small number of teeth of the end cylindrical milling cutters the recommended depth of the tooth is 0.3 from the district step. The work of broaching which removes a small layer of chips can be regarded as finishing work too. For this work the tooth depth is selected according to the following conditions $h < 0.2 \cdot D$ [3]. For the radius section, such values are not applicable due to too large tooth depth values, which will lead to a strong weakening of the design of the cutting part on the spherical section.

Let us consider the geometric conditions of the end radius cutters. End radius cutter is designed for cleaning and finishing of curved surfaces. Preliminary semi-finishing is usually performed equidistant to the final profile of the surface layer by layer or line by line with the formation of scallops. The presence of scallops has little effect on the thickness of the cut layer [4],[5],[6],[7], so we will consider the perfectly equidistant surface as a preliminary one.

The end mill processes surfaces of variable curvature for the largest amount of time, but in order to estimate the approximate length of the chip we shall consider surfaces with constant curvature (Fig. 1). It shows a scheme of layer-by-layer treatment of concave, straight and convex surfaces. In this case, the cut layer is limited from the top by the previous passage of the cutter.



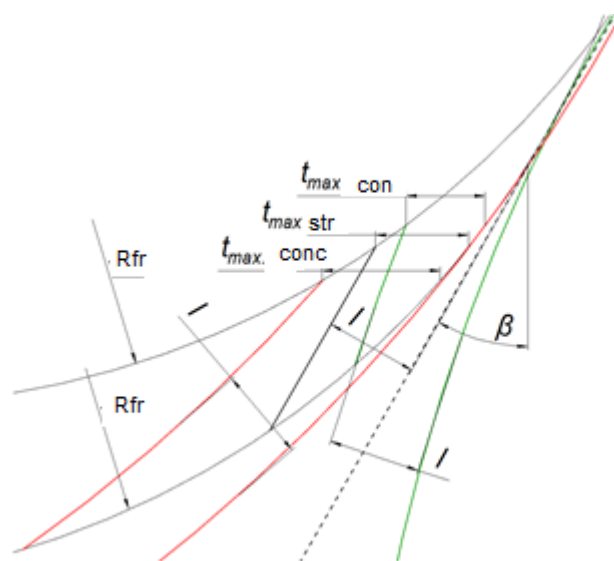


Figure 1. The scheme of treatment of surfaces with constant curvature

It can be seen from the figure that at the same value of equidistant l the maximum cutting depth of t_{max} is achieved when processing a concave surface. Thus, the smaller the radius of curvature of the concave surface, the greater the value of the maximum depth of cut for the considered point of the cutting edge. The minimum radius of curvature of the concave curve is limited by the radius of the tool.

Let us consider theoretically most unfavorable in terms of depth of cut for all points of the cutting edge case (Fig. 2).

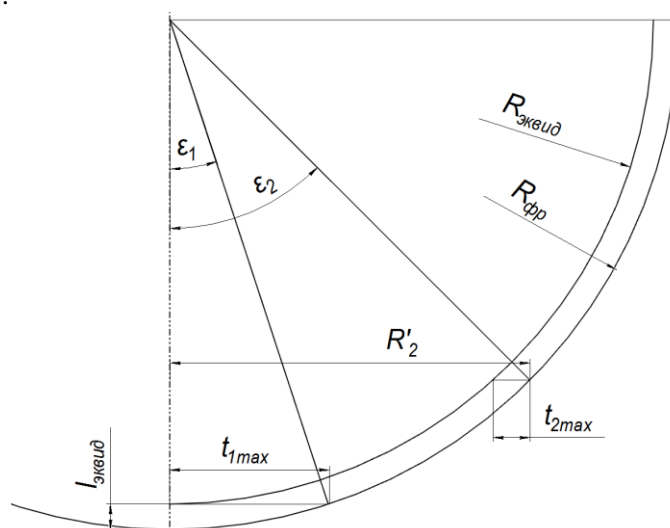


Figure 2. Processing scheme with a maximum depth of cut

In this case, it is a hypothetical surface treatment whose radius of curvature is equal to the radius of the tool, and the treated surface is equidistant by the value of the finishing work allowance. In this case, t_{max} will be for the case when the cutter operates in a solid material with a full diameter of t_{1max} and a more characteristic case when the depth of cut is variable over t_{1max} sections, which will be used as an assessment of the chip placement in the chip groove.

$$t_{1max} = R'_1 = \sqrt{R_{fp}^2 - (R_{fp} - l_{\text{экуд}})^2} = \sqrt{2R_{fp} \cdot l_{\text{экуд}} - l_{\text{экуд}}^2}$$

$$t_{i\max} = R_i - \sqrt{R_i^2 - 2 \cdot R_{\phi p} \cdot l_{\text{эквуд}} + l_{\text{эквуд}}^2}$$

In this case the chip length of the AB arc can be found from figure 3 without taking into account the shrinkage and the trochoidal component of the tooth trajectory. At the same time for two adjacent teeth, it is conditionally possible to consider the rectilinear motion of the equidistant plane.

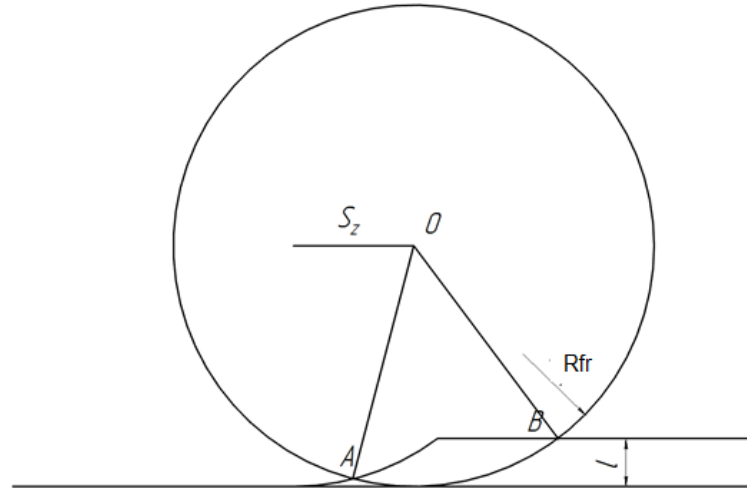


Figure 3. Diagram of the processing with two adjacent teeth

$$AB = \left(\arcsin\left(\frac{S_z}{2R_{i\phi p}}\right) + \arccos\left(\frac{R_{i\phi p} - l}{R_{i\phi p}}\right) \right) \cdot R_{i\phi p}$$

Assuming the condition that the chip descent is close to the normal to the cutting edge [8], the tooth depth will depend on the length of the front surface in the normal section. Taking into account that the depth of the tooth of cylindrical cutters is assigned as 0.45-0.5 of the circumferential pitch[9], it can be concluded that a sufficient depth of the chip groove, and hence the depth of the tooth will be 0.5 of the AB arc.

Thus, the expected height for each diameter along the spherical section in the normal section will be as follows:

$$h_z = \left(\arcsin\left(\frac{S_z}{2R_{i\phi p}}\right) + \arccos\left(\frac{R_{i\phi p} - t_{i\max}}{R_{i\phi p}}\right) \right) \cdot \frac{R_{i\phi p}}{2}$$

However, even with such a depth setting in reality due to the features of the kinematic scheme of sharpening the tool, the depth of the teeth on small diameters will increase (Fig. 4).

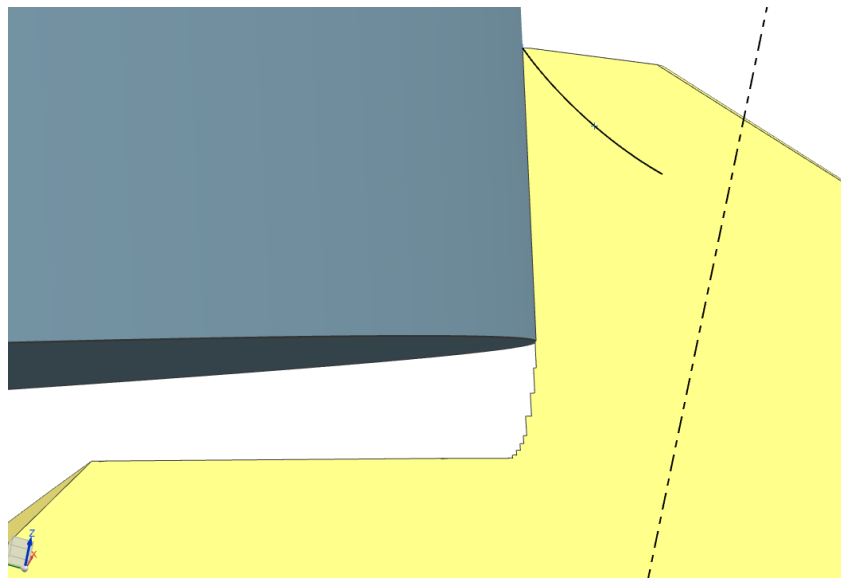


Figure 4. The scheme of formation of the tooth cutter on the i -th diameter in the normal section

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