Evaluation of the potential of inline tool wear monitoring in micro milling

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Abstract

For a deeper process understanding and an improvement of process capability, it is crucial to monitor the tool wear of micro milling tools. Therefore, tool features within the cutting edge area have been analyzed which are most suitable for a robust characterization of milling tool wear. Optical non-contact measurement methods have been evaluated with respect to feature resolution and measurement time. The cutting edge quality was characterized by evaluating the cutting edge radius and edge chipping in the form of profile roughness parameters $R_{(p,v)k}$. In conclusion, the article provides an insight regarding the integration of measurement methods into machine tools in order to enable an in-process monitoring of tool wear.

1. Introduction

The ongoing trend of miniaturizing products and parts requires a continual development of existing technologies. The application of microsystems components and assemblies is indispensable in many industrial sectors. In mass manufacturing, primary shaping manufacturing processes like plastic injection molding or powder injection molding are of great importance. In order to cope with the demands for precision of molding tools, these tools need to be processed in hardened condition. State of the art process for this application is cutting with geometrically defined cutting edge. Processing hardened work pieces with micro milling tools leads to an increased tool wear which needs to be predicted by geometric features. For this purpose, the need of robust optical metrology systems capable of being integrated in-line grows steadily [1]. Micro milling enables a flexible manufacturing of arbitrary, complex geometries, mirror-like surface qualities and high cutting performances.

Tool diameters range down to 25 microns. Due to partially unknown and not yet characterized mechanisms in micro milling, tool wear cannot be predicted sufficiently throughout the whole milling process [2]. Due to the size effect, the cutting edge radii lie within the dimensions of the undeformed chip thickness, which leads to a negative rake angle. Thus, the workpiece material is no longer sheared, but ploughed off the surface. However, the sharper the edge, the higher the initial running-in wear of the tool. This leads to unknown tool condition and thus uncertainties in the process results which often require a post-machining of the manufactured parts.
There has been no standardization so far that specifies roughness measurements along short distances which is why this article focusses on evaluation methods for features along cutting edges with a length down to some hundredths of a millimeter.

2. Challenges in Micro Machining

Miniaturizing milling processes comes with various issues that can be neglected in conventional tooling methods. When the end mill cutter diameter is a few tens or hundreds microns, tool stability is reduced as well and the corresponding edge radius becomes as small as the chipping thickness. Low feed rates are required to avoid tool breakdown and minimal revolution ridges in case of finishing. At the same time, the minimum chip thickness needs to be adhered to. Interdependent factors affect the chance of cutting in ploughing mode which, on the other hand, has an influence on finish quality and process forces. One crucial factor is the geometry of the cutting edge. For instance, a blunt cutting edge (high edge radius) increases the minimum chip thickness, which increases ploughing. To predict the process behavior during milling, tool wear can quickly be evaluated under process-oriented conditions [1].

3. Measuring Devices for Micro Milling Tools

In-process wear evaluation of cutting tools requires measuring devices that can be used within the proximity of machine tools without removing the tool which produces steps on the surface. The measuring device needs to be compact to be moved inside the machine volume. Furthermore, the used sensor, which is used in rough environment, needs to feature a short measuring duration and must be able to measure both 2D and 3D profiles. Suitable measuring methods are focus variation, confocal microscopy, white light interferometry and structured light microprojection.

Measurements were conducted with the first three methods; the best results were achieved with an Alicona IF-SensorR25 focus variation system, which is also capable of being integrated into machine tools due to its compact size [3].

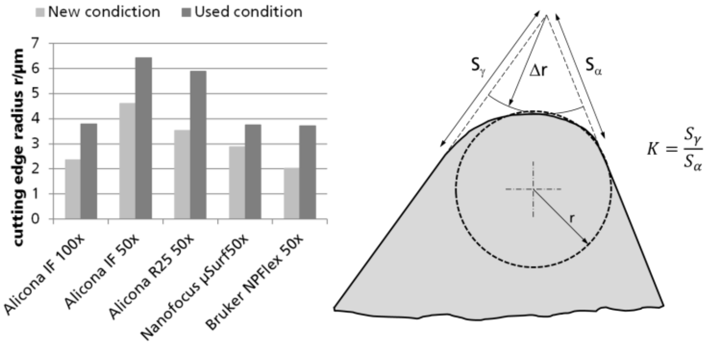

Figure 1: Measured cutting edge radii of a 2 mm end milling cutter (left); form feature of one cutting edge profile (right)

4. Cutting Edge Evaluation

4.1 Edge Radius

The mean radius of the cutting edge was determined by averaging all least square radii of five parallel profiles along the edge. Alternatives that can be used for radius fitting are the minimum circumscribed circle, maximum inscribed circle and minimum zone circle. Various evaluation methods for asymmetric edges are provided in [4]. Figure 1 shows the variation of the measured cutting edge radius by all three methods. Even with the same measuring system (i.e. Alicona Infinite Focus G4), the use of different lenses results in deviations of about 2.5 microns. This shows that one single radius value cannot be used to characterize a milling cutter, rather than the variation of the radius along the edge, which can depend on process modes. The right sketch shows different geometry properties which can be used to describe cross sections of asymmetric edges.

4.2 Edge Chipping

Process forces and running-in wear of the edge area are affected by the surface load. Therefore, a roughness evaluation along the cutting edge by means of the Abbott-Firestone-Curve seems appropriate. Due to the short measuring distance of a few hundred microns, profile filters cannot be applied using values recommended by standards like ISO 4288 [5]. Furthermore, cutting edges of micro milling tools are often curved which complicates both measurement and evaluation. Instead, a specialized analysis is required, omitting low pass filtering by the cutoff wavelength λ_c. However, the results of the conducted measurements do not show a significant influence of worn edges on the functional roughness values R_k R_{pk} and R_{vk} [6]. The lateral displacement of the measuring track by a few microns results in large variations up to 25 % of the mean values, which shoes that these values are hard to be reproduced, especially with various measuring systems.

5. Conclusion and Prospect

Results show that form and roughness of worn cutting edges can be characterized by a vast amount of evaluation methods. Both radius and roughness evaluation along the edge need special standards to deal with fitting uncertainties and short measuring distances, respectively. In order to determine a correlation between wear behavior and measurable edge features, large test series need to be conducted, also with respect to tool and workpiece material, cutting tool type and type of tool engagement. For short measuring distances along the cutting edge, new roughness quantities need to be derived to describe micro milling tool wear.

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