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Micro-milling tool wear monitoring through a novel method for burrs evaluation

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Abstract
Due to the high performances it assures, micro-milling is increasingly used in the production of miniaturized components in many different fields, such as automotive, aerospace and biomedical. This technology is characterized by high material removal rate, high flexibility and the possibility to machine different metal alloys in complex 3D shape. However, micro-milling may produce three-dimensional burrs, which represent one of the major issues of this manufacturing process. When micro machining, burrs size are of the same magnitude of the cutting tool diameter, therefore their effects have to be taken into consideration for the overall effectiveness of the process. Thus, burrs may represent a huge problem; moreover, because of their correlation with tool wear, their quantification could be useful as an indicator for process control. This work is focused on the application to a slotting micro-milling operation of a newly developed method for fast, non-destructive and in-line evaluation of multiple geometrical parameters related to the slot quality. The methodology includes the quantification of the lateral distribution of burrs based on an unconventional use of void pixels resulting from limitations of optical microscopy, as well as quantification of the actual depth of cut and surface texture parameters. These multiple indicators allow monitoring the tool wear effects on machined surface quality to ensure a controlled output of the machining process.

Micro-milling, burrs, optical microscopy.

1. Introduction

Nowadays, micro-milling (μM) is increasingly used in the production of miniaturized components in many different fields, such as automotive, aerospace, biomedical. However, one of the major issues concerning the μM process is the generation of three-dimensional burrs. In fact, the burrs developing during micro-machining operations have dimensions comparable to those of the cutting tool diameter; therefore, their presence can affect the capability to obtain the part desired tolerances and the related product functionality [1, 2], besides being harmful for the operators.

Compared to conventional machining, the deburring process after micro-milling is more critical, since traditional deburring methods are often unfeasible as they can result in unacceptable damage of the micro-machined parts [2]. In order to reduce and control burrs formation, several studies reported in literature were focused on the optimization of the micro-milling process parameters [3]. The aforementioned studies dealing with the sensitivity of the process parameters to the burrs formation may help in reducing them; however, since in most micro-milling cases their formation is unavoidable and their removal unfeasible, in-line measuring techniques might be useful for their immediate identification to provide fast feedback on the process status. Optical measurement techniques are a very useful tool, thanks to their capability to provide real-time information based on in-process measuring setups. Among others, quantitative optical microscopy (e.g. confocal) enable the acquisition of surface topography and the extraction of both profile and areal surface texture parameters, as well as dimensions and form of relevant geometrical features [4].

However, burrs quantification is not a straightforward measuring task due to both their geometrical complexity and stochastic nature of burrs formation. In this work, a novel method for burrs characterisation in μM is described, with focus on its application to the slotting operation.

2. Burrs characterisation methodology

The newly developed method is based on the idea to extract more information from the measured data using application-specific understanding and modelling of the manufacturing process. The specific aim was to enable a more complete geometrical characterization of a machined slot and related burrs by extending the measuring capabilities of a standard confocal microscope.

A commercial 3D optical profiler (Sensofar™ Plu Neox, 20x confocal objective) was used to acquire the surface topography in the region of interest of the machined part. As shown in Figure 1, the use of an optical profiler enables a more complete characterization of the machined slot: data acquired on the bottom of the slot can be used for the quantification of surface texture parameters, and profiles on sections orthogonal to the machining direction can be useful for the characterisation of the slot geometry and related process parameters (e.g. actual depth of cut, tool geometry). Additionally, using a newly developed procedure to extract process-specific information, the acquired data can be processed for burrs quantification as described in the following.

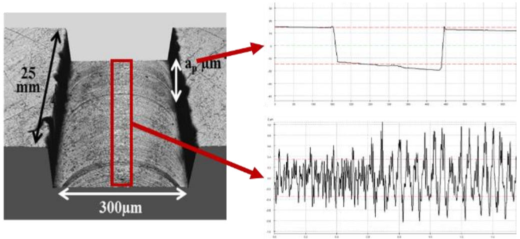

Figure 1. Schematic representation of a machined slot (left); slot geometry and bottom surface (right).

Since burrs have complex geometry, the acquisition of their surfaces results in measuring conditions characterized by high surface slope. As a result, these points cannot be measured through the optical systems (because of numerical aperture limitations [5]) and are therefore classified as void pixels, i.e. pixels of the topography map without height information. After observing that this effect is strongly related to the presence of burrs, a process-specific procedure for the quantification of burrs was developed..

The novel procedure combines image processing techniques and surface topography evaluation algorithms, enabling the extraction of the burrs longitudinal profile and projected area. A preliminary thresholding step is applied on the height map, in order to exclude all the points above the two lateral planes (a least-square plane is fitted and the dispersion of the points is used for the definition of a threshold level). Subsequently, the height map is transformed in a binary image and the area of the burrs is evaluated using image processing algorithms. A mean burr width can be computed, dividing the area by the longitudinal length. The procedure is shortly summarised in Figure 2. The procedure was implemented as Matlab™ code.

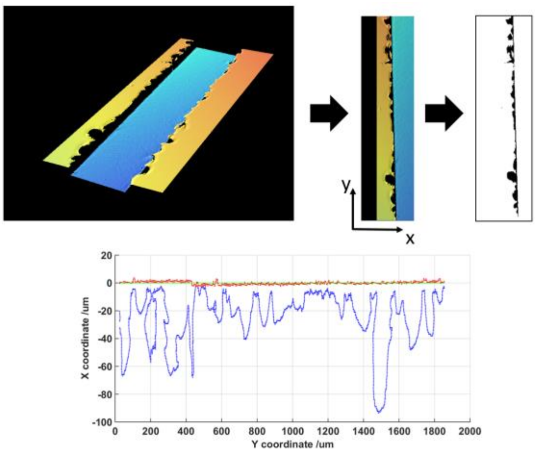

Figure 2. Schematic representation of the burrs longitudinal profile extraction procedure.

3. Micro-milling tool wear monitoring

The micro-milling experiments were carried out on a high-precision 5-axis micro-milling centre (Kugler™, Micromaster 5X) under fixed cutting parameters (i.e. nominal depth of cut 30 µm, feed rate 1430 mm/min, spindle speed 159000 rpm). Two fluted flat-end-square, uncoated, tungsten carbide tools were used.

A series of slots were machined to preliminarily check the sensitivity of the newly developed method for the control of tool wear. An image of the machined slots is reported in Figure 3; the slots are numbered from 1 (left) to 8 (right). The tool was new starting on slot 1 and broke at the end of slot number 8.

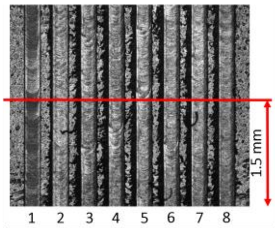

Figure 3. Identification of the machined slots and region of interest.

After machining, the eight slots were measured using the optical profiler on the region of interest for the current investigation, illustrated by the line visible in Figure 3. Roughness analysis was performed according to ISO standards [6] using the SPIP® software. Slot geometry and actual depth of cut were evaluated on 5 different sections extracted from the areal map and using least square fitting of lines on partial profiles not influenced by the burrs. Burrs geometry was quantified using the new procedure.

Figure 4 reports the results of burrs mean width quantification example using the slots numbering shown in Figure 3. The evaluation was carried out on the left side of the slot, in order to consider the exit burrs.

In this specific example, the mean burrs width increases rapidly from the first to the third slot, in accordance with the qualitative evaluation of Figure 3. The newly developed procedure is therefore sensitive to the actual burrs produced and could be used to detect their development in real time as indicator for the tool state change, in order to maintain a constant quality in terms of burrs generation. In slots 3-8 no significant difference is observed in terms of mean burrs width, while in slot 8 (last before tool breakage) the roughness increase of 30% with respect to the average Ra (Arithmetic mean height) value of 150 nm of slots 1-7 and the actual depth of cut decreased of 4% with respect to the initial value of 32.6 µm.

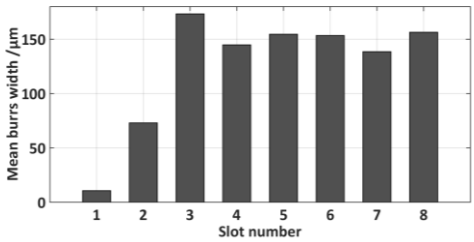

Figure 4.Example of burrs mean width quantification

4. Conclusions

The application to a slotting micro-milling operation of a newly developed procedure for the evaluation of multiple geometrical parameters related to the slot quality was presented. The methodology includes the quantification of the lateral distribution of burrs based on an unconventional use of void pixels resulting from limitations of optical microscopy, as well as quantification of the actual depth of cut and surface texture parameters. These multiple indicators allow monitoring the tool wear effects on machined surface quality to provide fast feedback and ensure a controlled output of the machining process.

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