Indirect measurement and diagnostics of the tool wear for ceramics micro-milling optimisation

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Abstract. Based on their favourable mechanical features, applications of ceramics are continuously spreading in industrial environment. Such a good feature is their resistance against heat shock, so, currently they are applied e.g. as coating material for gas turbines. The paper proposes an indirect method for supervision of the cutting tool wear in the optimisation of a micro-milling process of ceramics. It replaces the expensive and time consuming measurement of the cutting tool wear in which the experiment have to be stopped, the tool has to be taken from the machine and it has to be measured e.g. by microscope. The replaced measurement has also the disadvantage that the tool has to be positioned (again) when putting it back to the machine bringing also inaccuracies to the machining. Experiments show that the proposed novel technique allows monitoring the tool wearing process characteristics without measuring the tool directly, even if the applied indirect measurement (on the workpiece) incorporates some inaccuracies. The introduced methodology supported the ceramics milling technology optimisation according to tool live and machining process time, simultaneously.

1. Introduction

There is an increasing trend using ceramics in the application areas where high hardness and thermal resistance are faced [1]. Among others, the energy industry takes advantage of this trend, e.g. gas turbines are applied for producing electric energy with the aim to reach the highest efficiency through coating the turbine blade surfaces with ceramics. Having already the ceramic coating on the surface the cooling drains have to be manufactured, consequently, the first step of the drains production is the removal of the ceramics from the related part of the workpiece surface. There are different technologies for that assignment, e.g. water sandblasting, laser drilling [2][3]. The weak points of these technologies are their complexity, they are expensive and their long machining time. Nowadays machining with regular geometry (turning, milling) has been one of the most reasonably priced technologies, however, because of fast tool wearing, the method could be economically poor if it is not optimized for that particular ceramic material and machining process. There are several theoretical and practical open issues in this area, such as whether the milling is the best technology for that purpose. Considering this challenge, a comprehensive experiment plan was created that aims to adapt this technology to the given industrial environment by technological parameter and tool life optimization. The direct measurement of the tool wear is not realistic in industrial environment during micro-milling, so, it is especially important having an indirect method to recognize early the wearing-out situation.

2. Factors influencing the tool wear of ceramics' micro-milling

There are plenty of technological parameters that influence the micro-milling of ceramics. One of the most important questions of the cutting process with regular geometry tool is how to perform the cutting in plastic deformation area instead of in brittle area [4]. Difference should to be considered between two types of cutting depth, axial cutting depth and radial cutting depth [5][6], another important aspect of the mechanism is the tilt angle of the tool [7]. Another interesting way for enhancing the lifetime of a cutting tool is the combined technology; Toru et al. combined the conventional cutting technology with laser technology [8]. J. Feng et al. performed machining with irregular cutting tool geometry while they made conclusions on the cutting tool's wear on the basis of cutting force and vibration, too [9].

3. Experiments

A set of experiments was designed to perform and analyse the micro-cutting process on a special type of ceramics material to be removed from coated metal surface. For evaluation, two aspects were emphasized at the same time, one is the lifetime of the cutting tool the other is the machining time of the cutting process. Figure 1 shows the applied machine during the experiments.

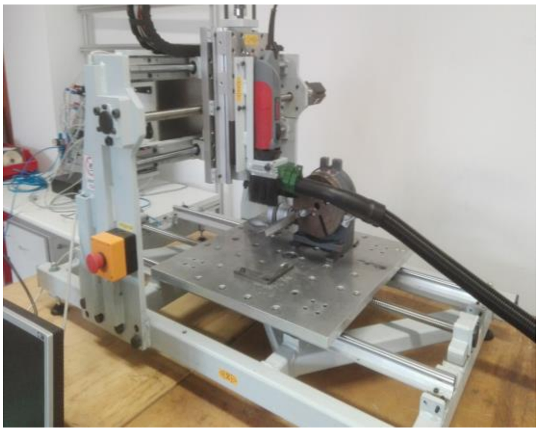

Figure 1. The applied CNC (micro-)milling machine was planned, built and it is operated in Zalaegerszeg, by the CncTeamZeg group of the Mechatronic Education and Research Institute on the Faculty of Engineering of the University of Pannonia. Originally, the machine was planned to serve with metal cutting and 3D printing operations but the preliminary calculations and the first tests on ceramic material removal proved its applicability to perform the related micro-milling of ceramics, too.

Four parameters proposed in majority of the scientific and industrial literature were subject of the Design of Experiments (DoE) according to the linear DoE planning methodology of Taguchi [10]. Beyond these parameters, at first, the tool path strategy was optimised that reflected significant influence of the arising cutting force and its appropriate selection results decrease in the milling tool wear, too [11].

4. Evaluation of the experiments

4.1. Indirect measurement and supervision

The cutting process removes a special part of the ceramics coating on the workpiece having a prescribed geometry. According to the CAD design and the NC code of the milling the theoretical geometry of the removed workpiece feature is prescribed. The wearing of the tool results inaccuracies in the produced workpiece geometry on the remaining ceramics, consequently, measuring the deviation between the theoretical and produced geometry of the resulted workpiece feature could be used for measuring the milling tool wear in the proposed, indirect way. Naturally, the final geometry is influenced by many other factors, too, like machine inaccuracies, vibration, positioning accuracy, or any other e.g. process related factors, so, it is not straightforward that the proposed measurement can be used for tool wear measurement.

In the experiments, a tool was applied until its break and the number of the produced workpiece features was summarized as one efficiency measure. Another performance indicator was the machining time per feature. After performing the experiments according to the DoE two machine settings were selected that represented surpassing process efficiency according to these indicators (Technology A and B). Two possible macro-geometrical set-ups of the tool-workpiece relative position were applied (Relation 1 and 2) in each experiment. Two geometrical parameters of the produced geometry were measured after the experiments (Geometry I and II.) and their trend is represented in figures 2-5.

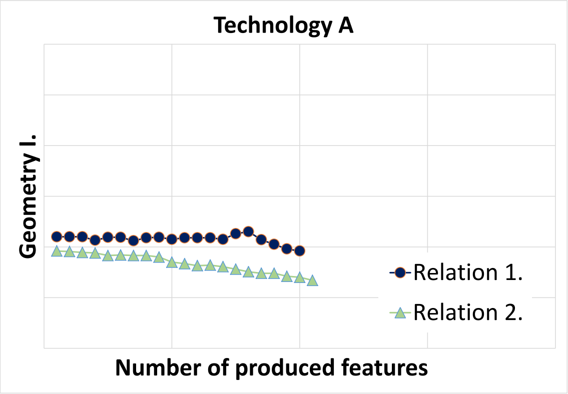

Figure 2. Number of produced features and the measured indirect tool wear trend (measured Geometry I. after cutting with Technology A)

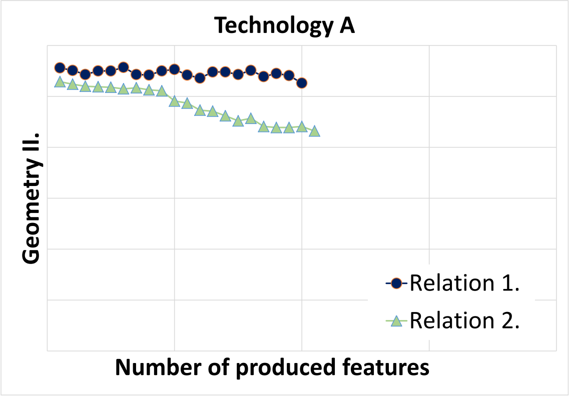

Figure 3. Number of produced features and the measured indirect tool wear trend (measured Geometry II. after cutting with Technology A)

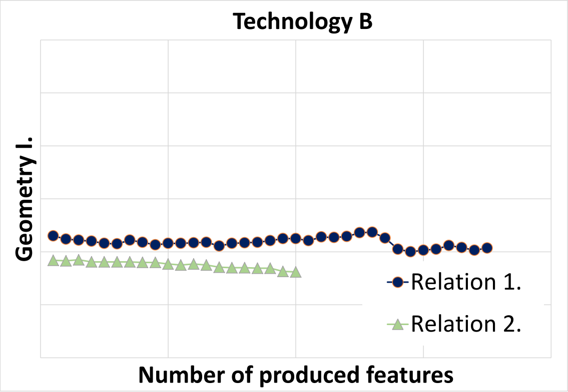

Figure 4. Number of produced features and the measured indirect tool wear trend (measured Geometry I. after cutting with Technology B)

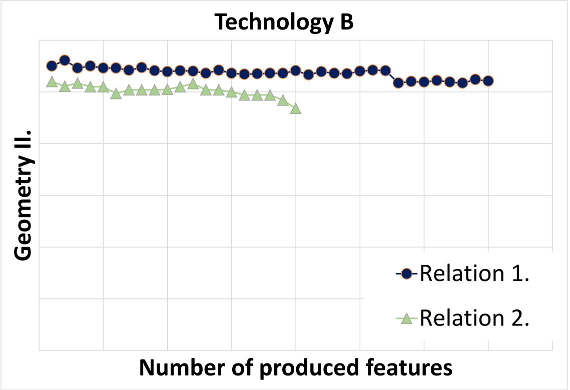

Figure 5. Number of produced features and the measured indirect tool wear trend (measured Geometry II. after cutting with Technology B)

Using the tool-workpiece relative position of Relation 1., much smaller tool wearing was identified and the Technology B results the best tool wear, that is also the resulted optimum value of the linear

DoE. *Although the measured geometrical values do not serve with exact, absolute values for the tool wear but the characteristics and trends of these measured workpiece geometries clearly represent the changes in the tool wear, consequently, the applicability of the proposed indirect measurement is proven.* Another interesting and positive aspect of the proposed measurement method is that the direct tool wear measurement was anyhow not possible during or after the machining because it was used until the break but the proposed solution overcomes this problem, too.

5. Conclusions

The paper introduced a novel indirect measurement technique of the tool wear for micro-drilling of ceramics. Experiments resulted that the proposed novel technique allows monitoring the tool wearing process characteristics without measuring the tool directly, even if the applied indirect measurement (on the workpiece) incorporates measurement inaccuracies. The introduced methodology supported the ceramics milling technology optimisation according to tool live and machining process time, simultaneously and resulted in a technological parameter range that can support the further search for optimal set-up values using the new nonlinear design of experiment methodology [12].

6. Acknowledgements

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7. References

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