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Integration of a confocal microscope in a desktop machine tool for in situ process control

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Abstract

The miniaturization of components and the functionalization of component surfaces is a fast evolving area and poses many challenges in process development and design. A suitable process for producing the needed parts and components is micro milling. Micro milling offers high flexibility regarding machinable geometries and materials. One of the challenges of this process is the required high dynamic of the machine tool, which is essential to keep a high production efficiency and quality. Desktop sized machine tools with low moving masses can meet those requirements. The downside of these small machine tools is a lower stiffness of the guideways, shorter travel of the axes, limited load capacity and the small space available for complementary measuring equipment. Thus, to be able to integrate measurement equipment into a desktop sized machine tool, it has to be small and lightweight.

The research described in this paper demonstrates the compatibility of optical measuring equipment and desktop sized machine tools. Therefore, a confocal microscope was integrated in a desktop machine tool developed in previous works at the Institute for Manufacturing Technology and Production Systems. This microscope allows for the in situ analysis and evaluation of the manufactured micro components and functionalized surfaces. The challenges for the mechanical integration as well as the integration of the machine-sensor-interface is presented. To demonstrate the capabilities and advantages of this system, measurements of were conducted and compared to the results when a conventional mount of a confocal microscope is used.

Keywords: Micro machining, micro milling, desktop sized machine tool

1. Introduction

The research on miniaturized components and the functionalization of component surfaces by micro structures is gaining importance for the realization of future technologies [1]. New as well as improved production processes are needed to be able to manufacture those goods for future technologies. One of these manufacturing technologies is micro milling. Due to the combination of high geometrical flexibility and the ability to manufacture a high variety of different materials [2], it is a promising technology for the production of micro components and structures.

Micro milling is often conducted on desktop sized machine tools [3]. The reasons are the low power consumption, the reduced thermal influences and first of all, the high axes dynamic due to the low moving masses. The downside of these machine tools are the reduced load capacity (smaller electrical drives, smaller guideways), lower stiffness of the guideways and the limited space for additional measurement equipment. This measurement equipment is needed for research or for quality control. To avoid reclamping errors of the tools or the workpiece, only in situ measuring techniques are suitable.

In this research article, the integration of a confocal microscope for in situ process analysis of micro milling applications is presented.

2. Confocal microscope integration

The desktop machine tool for the integration of the confocal microscope was described in [4]. It has a dimension of

760x675x500 mm³. The workpiece is mounted on a X-Y-table with a travel of 110 mm each. The Z-axis carries the air bearing main spindle. It also has a travel of 110 mm and a maximum load capacity of 12 kg. The main spindle, the spindle mount and peripheral equipment have a combined weight of 7 kg. Hence, the maximum weight of the confocal microscope and it's mounting has to be less than 5 kg.

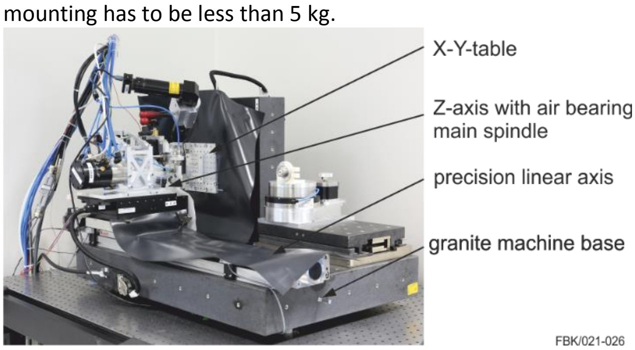

Figure 1. desktop sized micro milling machine tool

For the integration, a Nanofocus[1] confocal microscope was chosen. It weighs about 4 kg, has a length of about 430 mm and a comparably slim body of 66x100 mm². To reduce the dimension of the confocal microscope as well as the weight, an automatic objective change was neglected. The resolution of the Nanofocus in Z-direction is 2 nm. The resolution in X-Y-direction depends on the objective used (the camera has a resolution of 1200 x 1200 ppi). The microscope is not protected against the micro and nano sized chips of the micro milling process, thus it has to be removed during machining. To be able to automate the measuring process, the repositioning of the microscope is crucial. To achieve this, a 3R-chuck system[1] was implemented in the desktop machine tool. The mounting and demounting of the microscope is quick (< 1 minute) and the positioning accuracy is about 2 µm (manufacturer specifications). The microscope was positioned next to the main spindle, 5 mm in front of the micro end mill in Z-direction (see Fig.2). That is, the micro end mill does not need to be removed during measurements.

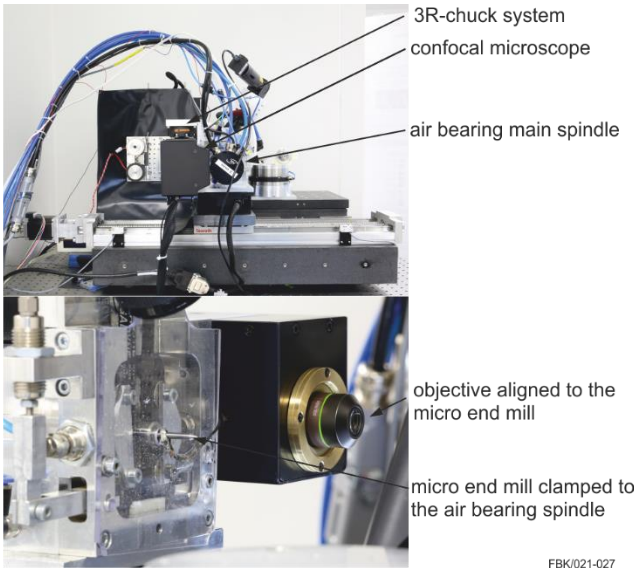

Figure 2. desktop sized micro milling machine tool

With this configuration, the microscope can be attached and detached from the machine without the need to remove the micro end mill or the workpiece. Thus, the process is not influenced.

For the automation of the process, the software of the confocal microscope can communicate with the machine control via TCP/IP-Ethernet. Hence it is possible to move to areas to be measured and to stitch measurements. It is even possible to suspend machining, analyse the process results and continue micro milling after the measurement.

3. Measurement results

Test measurements have been conducted to evaluate the functionality of the integrated confocal microscope. A roughness artefact with R_z = 3 µm has been measured with the same microscope mounted on the desktop machine tool as well as mounted to a separate stand without moving axes. Thus, influences on the measurement results by vibrations of the machine tool and oscillations of the axes resulting from limited stiffness or the feedback can be identified. All measurements were performed without stitching with a 20x magnification objective (evaluation area 0.86 x 0.86 µm²). In a first step, the area was aligned using a plane transformation, thus errors due to the mounting of the artefact can be neglected. In a second step blind spots were removed. For the extraction of the R_z and R_a values, the whole measurement area was considered and lines orthogonal to the structure orientation analyzed. The values were Gauss filtered with a cut off length of 0.25 mm.

The results of the measurements are shown in Fig. 3. The R_z and R_a values for the measurements conducted in the stand were R_z = 3.02 µm and R_a = 0.850 µm. With the confocal microscope as well as the roughness artefact mounted to the desktop sized machine tool, R_z = 3.03 µm and R_a = 0.851 µm resulted. The difference for R_z is 0.01 µm and for R_a 0.001 µm. This deviation due to the change of the microscope can be regarded as very mall and hence the implementation as feasible.

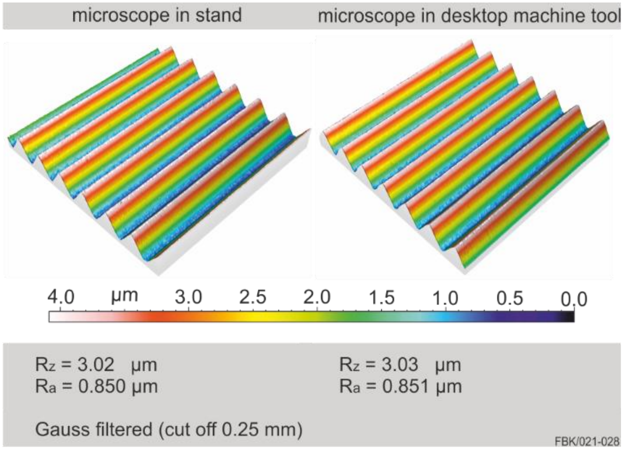

Figure 3. Measurement results of the confocal microscope

4. Conclusion

To be able to analyse and research the micro milling process, a confocal microscope was integrated in a desktop sized machine tool. Due to the limited load capacity, the short travel and the reduced stiffness of the small axes in these desktop machine tools, a light weight Nanofocus confocal microscope was chosen. The implementation was shown and measurements of a roughness artefact compared to those outside the machine. There were only slight differences in the lower nanometre range.

When micro milling with micro end mills (< 50 µm diameter) neither the workpiece nor the micro end mill can be removed from the machine tool. This limits the possibilities to analyse the process, e.g. in terms of the influence of tool wear. With the set up presented in this article, it is possible to research the process in depth, especially the tool wear. By reducing the tool wear, more precise parts and better surfaces are possible which enhances the possibilities of micro milling.

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[1]Naming of specific manufacturers is done solely for the sake completeness and does not necessarily imply an endorsement of the named companies nor that the products are necessarily the best for the purpose.