Ultra Precision Process Monitoring

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Abstract

In modern applications the needs for highly advanced components with very precise contour accuracy and surface quality are rapidly increasing. To meet the demands for enhanced products, production machines and processes have to be improved with respect to not only the high aims for precision, but also issues of standardization and quality management. In this context process monitoring becomes a key technology to achieve a better understanding of ultra-precision machining and to enable process continuity, quality management and documentation. At Fraunhofer IPT a precision process monitoring system has been developed combining data acquisition, analysis, storage and visualization into one integrated system. The in-process sensor data is mapped onto a virtual tool path generated using the linear scale positions of the machine tool within the process monitoring system. Monitoring the sensor data in 3D with regard to time and location of its acquisition enables variable evaluation possibilities far beyond the state-of-the-art time plot or spectrum analysis methods.

1 Introduction – Process Monitoring using Acoustic Emission Sensors

In the manufacturing of precision components many influences affect the quality of the work piece. Tool wear or micro damages to the diamond tool, the cutting parameters, the dynamic machine behavior, material variations and environmental influences can lead to lower quality of the machined work piece or even to rejected parts. Process monitoring, being well established in standard machine tools, is an effective method to detect, analyze and overcome malfunctions resulting from the aforementioned influences. To detect process effects such as tool wear in an ultra-precision diamond machining process, which is characterized by low process forces and high demands for surface quality, very sensitive sensor probes have to be used. Acoustic emission (AE) sensor probes, integrated for instance into the tool holder, are very sensitive and provide high resolution and high frequency metrology data [1].

State-of-the-art process monitoring systems plot the acquired sensor data versus time or further process the data e.g. for spectral analysis. For data processing the sensor signal is first being transformed into a matrix description e.g. by short-time Fourier transform (STFT). Afterwards the matrix can be treated as an image containing discrete data information and can be analyzed using image processing strategies such as Law's analysis [2] or Haralik's textural image classification [3]. In a final step statistical analysis can be performed to find characteristic patterns for the individual process. These methods have the disadvantage of losing the information of local assignment to the work piece geometry and therefore lack of evaluation possibilities.

2 New Precision Process Monitoring Approach

To enhance the evaluation opportunities of process monitoring data in ultra-precision processes, further information – the tool path, measured with the linear scales of the machine tool axes – can be added to the process monitoring system. With this approach a sensor signal analysis not only time-based, but locally referred to the geometry of the work piece is possible. Using the 3D tool path, measured during machining, and superposing the AE sensor signal color-coded, which means plotting the sensor along a virtual tool path on the work piece, a 4D metrology plot results. Performing the data acquisition, data processing and data visualization in real-time while the part is being machined, a very flexible process monitoring tool has been developed at Fraunhofer IPT.

The system has been designed as a black box consisting of industrial standard components (IPC, metrology boards, connectors) and acquires all data signal synchronously at high sampling rates. After the acquisition various pre-processing features are implemented. The individual signals can be filtered using common digital filters. They further can be scaled and converted so that the electrical signals match the mechanical and physical conditions. Before the original analysis and visualization routines are applied, the initial sensor data can be saved into a HDF5 container file including metadata to describe the process monitoring environment [4]. Figure 1 illustrates the hardware and software structure of the novel process monitoring approach.

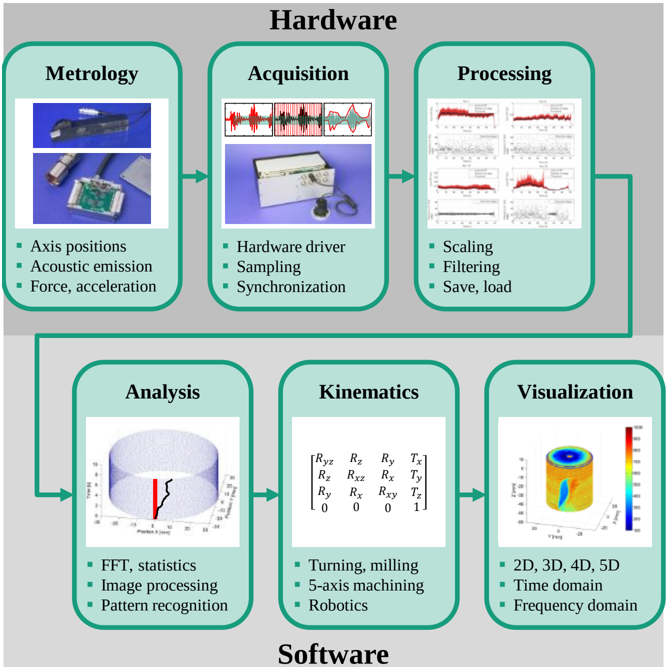

Figure 1: New process monitoring approach – hardware and software algorithms

3 Experimental Results

To validate the system various experimental tests have been performed. A bearing roll has been provided with a reference groove to analyze the sensitivity and capability of local assignment of the system. Figure 2 shows a picture and a 4D plot of the bearing roll after the finishing cut. The impact at the edges (reference groove and tool entering and exiting the work piece) can be clearly seen. Figure 3 displays the according 2D and 3D color-coded plots.

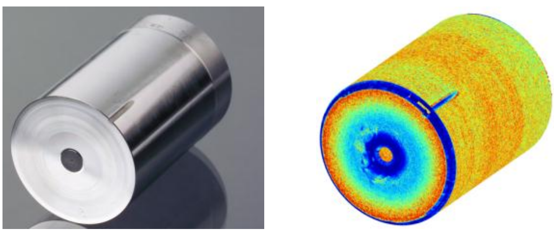

Figure 2: Experimental results of a bearing roll process analysis

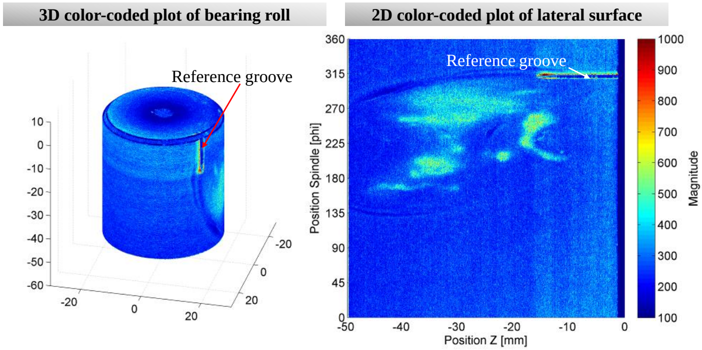

Figure 3: 2D and 3D color-coded plot of a bearing roll

4 Summary and Outlook

At Fraunhofer IPT a novel precision process monitoring system has been developed and tested that maps sensor data onto the tool path while a work piece is machined. With this method a local reference between part geometry and AE sensor signals is possible enabling evaluation strategies beyond state-of-the-art monitoring methods. Further research work will focus on porting and integrating the system to various machines and processes to prove its comparability.

References:

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