Advanced Integrated Machine Control for Fast Tool Assisted Ultra Precision Machining

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Abstract

The mechanical integration of additional highly dynamic axes such as Fast Tools into ultra precision lathes can be regarded as state of the art to achieve the objectives of advanced optical components [1]. In contrast to that, neither advanced control strategies for ultra precision machines nor the control integration of additional Fast Tool systems have been sufficiently developed yet. Considering a complex machine setup as a mechatronic system, it becomes obvious that enhancements to further increase the achievable accuracy and at the same time decrease cycle times and error sensitivity can only be accomplished by advanced, integrated control systems. Additionally, the major drawback of a discontinuous safety concept has to be inhibited to enable efficient and safe machining. At the Fraunhofer IPT a novel, fully integrated control approach has been developed to overcome the drawbacks of state-of-the-art machine controls for ultra precision processes.

1 Introduction

Current control systems for Fast Tool equipped ultra precision machines are often realized as decentralized solutions consisting of various computational hardware components for setpoint generation, machine control, GUI, Slow Tool control and Fast Tool control. When implementing such a distributed control strategy, many disadvantages arise in terms of complex communication interfaces, discontinuous safety structures, synchronization of cycle times and the machining accuracy as a whole. The novel control approach has been developed as a fully integrated machine control including standard CNC and PLC functionality, advanced setpoint generation methods, an extended GUI as well as the integration of a Slow Tool axis and an FPGA-based controller for a piezo driven Fast Tool axis. As the new control system has been implemented as a fully integrated platform using digital communication via

EtherCAT, a continuous safety strategy could be realized, the error sensitivity and EMC susceptibility could be decreased and the overall process accuracy from setpoint generation over path interpolation to axes movements could be enhanced.

2 Fully integrated control approach

An integrated control for a Fast Tool equipped ultra precision lathe has been developed at the Fraunhofer IPT including all major features of standard machine tool controls and thereby enabling safe and efficient manufacturing processes for ultra precision parts. To overcome the aforementioned drawbacks of complex communication and synchronization structures and to ensure a continuous safety concept for the whole machine system, a novel control approach has been developed using a PC-based CNC with very high computing power as well as the EtherCAT fieldbus technology with up to 20 kHz. In this way, a very fast control system has been implemented based on industrial standards. Figure 1 illustrates a comparison of decentralized machine controls and the novel fully integrated control approach.

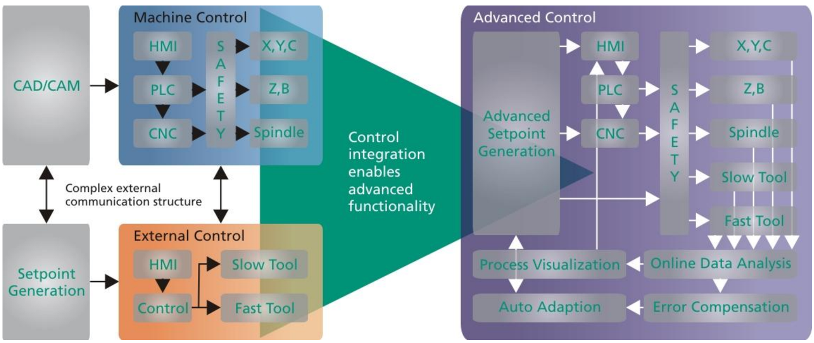

Figure 1: Comparison of state-of-the-art and novel control strategy

3 Integration of Slow Tool and Fast Tool servo control

The integration of the Fast Tool control is implemented with an additional real-time control system based on FPGA technology. The communication is realized via EtherCAT, which allows for communication rates up to 20 kHz (Figure 2). Using modern processor technology enables CNC path planer sample rates above 5 kHz. The setpoint generator uses the workpiece position X and the angle C to calculate the

Z'/Z'' tool path. X and C are transferred by the CNC control over EtherCAT. Depending on the surface function complexity setpoint clocks up to 20 kHz are possible. To reduce interpolation errors for the highly dynamic axes the calculation algorithms use C or Matlab functions to generate setpoint signals for the Slow Tool axis Z' and the piezo driven Fast Tool axis Z''. By using FPGA-based position controls the system latencies can be extremely reduced, which leads to higher axis dynamics and more axis stiffness [2].

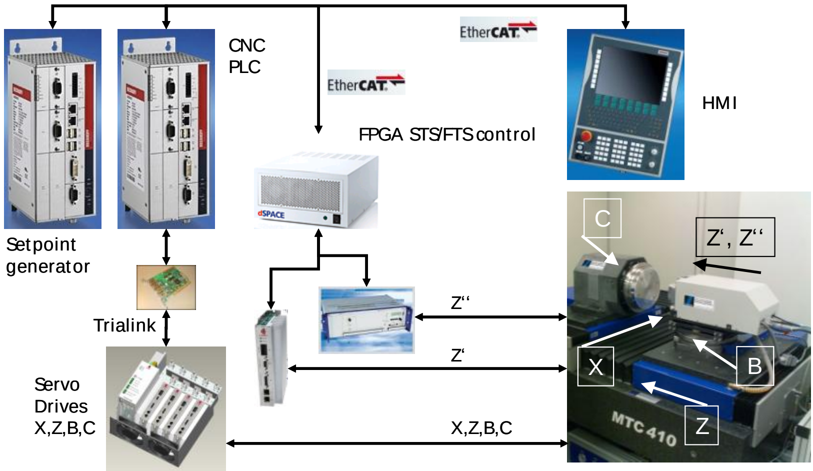

Figure 2: Control structure and signal flow of the fully integrated control approach

4 Advanced setpoint generation

Setpoint generators that are programmed without using full-blown CNC kernels can deliver setpoints with the maximum PLC frequencies offered by the control system. A simple approach to deliver fast setpoints is a streaming function that delivers pre-calculated position values to the Fast Tool axis. An example for a complex free form surface structure is given in Figure 3. The displayed mold insert consists of an array of free form lenses with the given contour and arrangement. For the lenses at the outer radius the highest setpoint frequency is required as the rotating spindle is driven at constant speed while the X-Axis moves along the radius. To achieve the necessary surface accuracy and roughness, the setpoint frequency is in the 10-20 kHz range. Thus, the novel setpoint generation strategy allows for more accurate and more dynamic diamond machining. As a result, much higher setpoint densities than in normal CNC machining can be realized, resulting in better form accuracy and lower surface roughness.

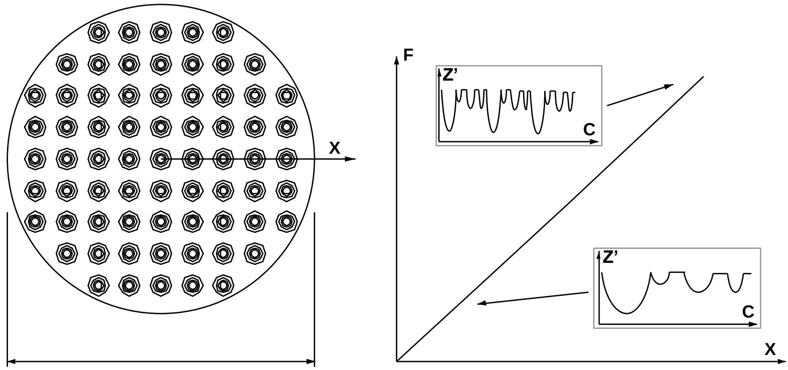

Figure 3: Example of a complex surface structure – free form lens array

5 Conclusions

The paper presented a novel control approach for ultra precision diamond machining. Current drawbacks of state-of-the-art machine controls resulting from distributed control devices for base machine, Fast Tool system and setpoint generation can be avoided by realizing a fully integrated control strategy. The control system developed at the Fraunhofer IPT integrates machine tool CNC, controller for additional highly dynamic axis and setpoint generators into one centralized precision control by implementing EtherCAT-Slaves for all devices. Thus, more precision and dynamics can be achieved, which leads to better accuracy of the machined workpiece.

References:

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[2] Kucera, L.: "Optimale Architektur zur Regelung hochdynamischer und resonanzbehafteter Antriebe", Proceedings of the SPS/IPC/Drives Nürnberg, 2006.