Innovative Fast Tool Servo System using Mass Compensation and Damping System

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Abstract

New applications in illumination optics using LEDs require a lens or a mould design that combines free-form geometries with microstructures [1]. An efficient way of producing these so called hybrid optics is the machining by the use of a hybrid Fast Tool Servo system (FTS). Such hybrid FTS is the combination of a highly dynamic, piezo driven FTS with a dynamic axis or Slow Tool. Due to this arrangement it is necessary that any disturbances on the underlying axis caused by inertia forces of the highly dynamic tool movement have to be avoided. Further a high bandwidth of the FTS is needed for efficient microstructuring processes. Therefore this paper describes an innovative, piezo driven FTS with mass compensation and damping to improve the dynamic behavior.

1 Properties of FTS

The piezo driven FTS is designed to machine microstructures at high frequencies and short strokes. It needs a compact design to be mounted inside the slide of the dynamic axis. The main components of the FTS are the tool guiding system based on flexural bearings, the piezo actuator and the capacitive sensor for the position measurement. Small tool inserts are used as holder for diamond cutting edge to reduce the moving mass. The FTS has a maximal stroke of 35 µm and offers a closed loop bandwidth of 1500 Hz. The overall dimensions of the FTS are 110 x 126 x 230 mm³ (w x h x l). A bore of 60 mm is needed for the mounting inside the slide of the dynamic axis.

2 Tool guiding system with mass compensation

The core of the FTS is the tool guiding unit which is directly connected with the driving piezo actuator. The guiding system consists of a combination of flexural bearings. The stiffness in moving direction has to be adjusted carefully to ensure a high eigenfrequency but a sufficient stroke as well. The first eigenfrequency of the flexural guiding system combined with the piezo stack has to be about 4000 Hz to be able to machine secure up to frequencies of 2000 Hz. Different designs of flexural bearings, leaf springs or notch design, have been discussed as Figure 1 shows. Both designs of flexures can be adjusted to a certain stiffness to meet the eigenfrequency requirements. Although light weight design, large inertial forces are generated due to the high frequency movement. A force of 80 N is produced by a mass of 100 g moving with 2000 Hz at an amplitude of 5 µm. These inertial forces have to be compensated by the underlying axis in the hybrid FTS arrangement. But such disturbing forces have to be avoided for high precision machining. Hence a mass compensation system is required. Usually such systems are based on two identical slides moving in opposite direction [2]. But this is increasing costs, effort, and the overall size, since all components are needed twice. Hence, aim of this development has been to integrate the mass compensation into the flexure guide. The flexure guide has one central slide carrying the cutting tool and incorporates two counter slides at the top and the bottom (see Figure 1). Levers bypass and redirect the tool movement in such a way that the counter slides move exactly in the opposite direction and compensate for the inertial forces.

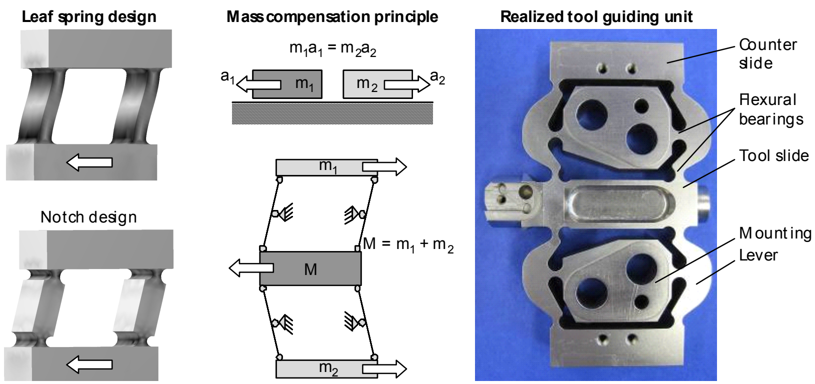

Figure 1: Concept and design of tool guiding unit with mass compensation

The mass of the counter slides can be adapted and balanced to match the real moving mass. During the balancing procedure the FTS is mounted in the dynamic axis and its response to the fast motion of the FTS is monitored. Depending on the mass ratio between central and counter slides the response of the underlying slide is in positive or negative direction (see Figure 2). The measurements prove that by applying the optimized mass, the reaction forces onto the underlying axis are eliminated.

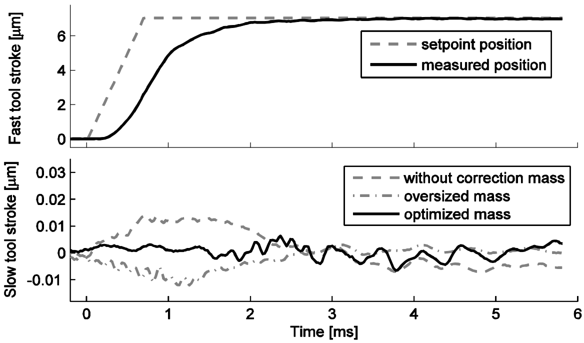

Figure 2: Measurement of compensation functionality

3 Integration of damping system

The dynamic properties of current FTS are strongly limited by missing damping systems. The mechanical system consisting of the tool guiding unit and the piezo stack shows a significant rise at the first eigenfrequency. This is strongly limiting the performance of the feedback control. Therefore different damping principles have been examined. Visco-elastic dampers loose their damping properties at high frequencies. Dampers based on the eddy current effect do not offer sufficient damping at high frequencies and short strokes. Hence a damping system based on squeeze film has been realized, see Figure 3. Therefore a piston attached to the counter slide is moving in radial direction inside a bore filled with oil. In total four dampers are used which reduce the rise at the eigenfrequency significantly.

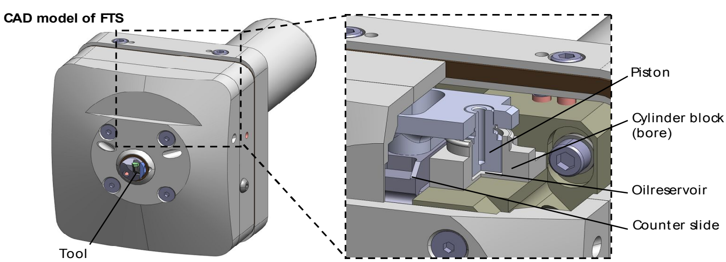

Figure 3: Damping system based on squeeze film principle for piezo driven FTS

4 Improved dynamic properties of FTS

Finally, the parameters of the position feedback control using a PI controller with feed forward filter were adapted to the optimized FTS. Compared to the system without damping, the closed loop bandwidth defined by a decrease in phase of 90° could be increased by 50% from 1000 Hz to 1500 Hz. Further improvements of the dynamic properties have been possible by the optimization of the control algorithms using additional filters for higher eigenfrequencies. Effects of the enhancements of the control loops are faster machining cycles for structured work pieces maintaining the machining accuracy.

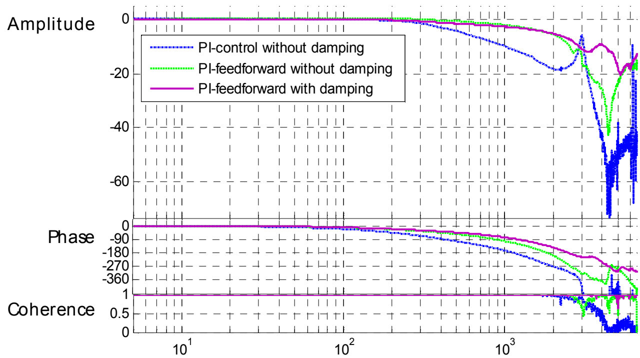

Figure 4: Optimized dynamic properties of FTS due to damping system

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