Machine integrated, direct measuring devices for the compensation of thermal deformation

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Abstract

This paper focuses on a robust method for the direct measurement of deformation of the structure of shape cutting machine tools. The idea is to capture the actual deviation of single measuring points within the machine structure by means of integrated direct measuring devices parallel to the machining process. Hereby the actual state of the thermo-elastic deformation of specific structure elements can be monitored and utilised for compensation. Two strategies for the compensation of structural deformation are proposed. The first strategy is based on active heat management of the structure. The second strategy is based on applying corrective motion of the feed axes in order to correct TCP dislocation.

1 Introduction

Cutting machine tool bed deformation, whether a consequence of mechanical or thermal load, leads to a dislocation of the tool centre point (TCP) and therewith to inaccuracies on the produced work piece [1], [2]. The potential loss of precision is especially significant for large or precision machine tools.

The solution approach is to measure deformations of machine components directly with multiple specially designed strain sensors [3], [4]. The sensor signals will be used in order to compensate structural deformation in the machine control system.

2 Integrated direct measurement and compensation concept

According to Figure 1, the robust measurement principle is based on reference rods, which are integrated in the machine structure. The reference rod is mounted in the machine bed with a fixed and loose bearing principle. Displacement sensors measure against a measurement surface at the loose bearing tip of the reference rod. The reference rods are made of carbon fiber reinforced plastic (CFRP) and are expected to have a constant length in the relevant temperature range. Thus, when the machine structure is elongating, due to thermal or other loads, the sensor is displaced relative to the tip of the reference rod. Therefore, the absolute elongation of the respective part can be measured.

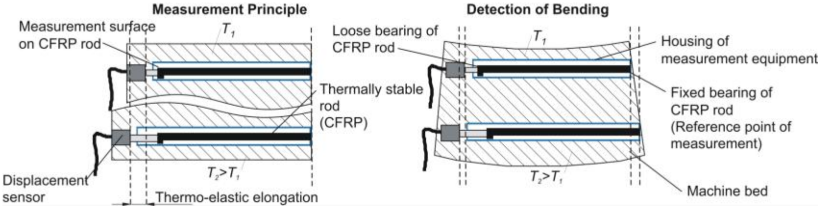

Figure 1: Measurement principle.

With integration of an array of measurement systems, the determination of complex deformation is possible. As shown in Figure 1, an array of two measurement systems allows the identification of elongation and bending in one plane.

In order to test the influence of the bearing design on the measurement results, different bearing types have been implemented.

2.1 Verification of measurement concepts

In order to verify the above described measurement concepts, a simple test bench has been realized. The test bench consists of a polymer concrete block comprising two measurement systems as well as heating elements and a cooling circuit. One measurement system is equipped with an eddy current sensor while the other utilises an LVDT sensor. The suitability of different measurement principles for the measurement task can therewith be evaluated. Additionally, thermocouples are integrated at multiple positions in order to be able to obtain a temperature profile of the structure (see Figure 2). For the verification of the internal sensor signals, external capacitive sensors are used for reference.

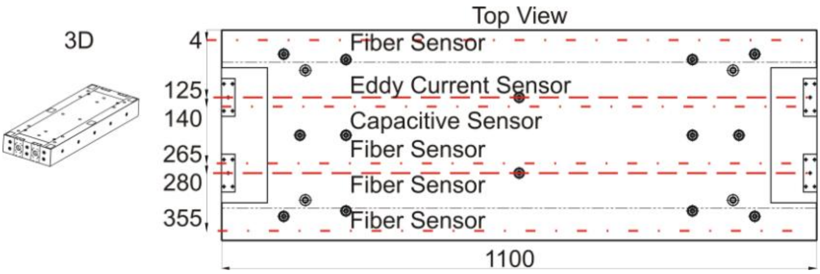

Figure 2: Design of machine bed test bench and sensor positions.

The heating elements can be operated independently, so that symmetrical and asymmetrical temperature profiles can be induced in the test bench.

Figure 3 shows measurements of the verification process. It is evident that the results of the integrated measurement system closely match the results of the external reference system for both, the LVDT and the eddy current sensor. Furthermore, in case of asymmetrical heating, the sensor signals at different positions at the front face allow the identification of bending.

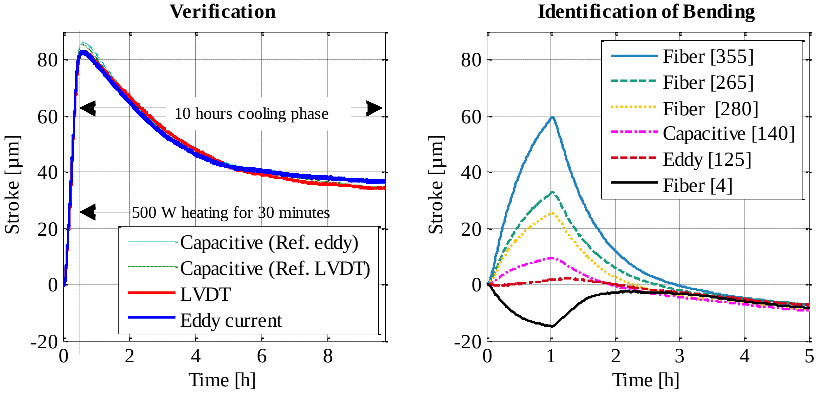

Figure 3: Signals of different sensors during strain cycle.

2.2 Active deformation compensation with integrated heating and cooling

Active deformation compensation is possible with a controlled heating and cooling system. The cooling system maintains a constant coolant temperature for passive cooling. Heating can be applied dynamically with a closed loop control system. The input values of the control system are temperature of the heating elements and the actual elongation of the machine bed.

3 Model based compensation concept

Measurements at Fraunhofer IPT showed, that the deformation compensation with an active heating and cooling concept is not effective because of delay times in the system and also not energy efficient. An optimised approach for deformation compensation is the utilisation of the strain sensor signals as input values for a mathematical model in order to identify the actual machine deformation. Herewith, the dislocation of the TCP can be determined. The resulting positioning errors can be compensated with corrective NC-axis motion.

In order to verify this compensation approach, the polymer concrete machine bed of a three axis machine will be equipped with multiple sensors. Additionally, the test bed contains heating elements in order to simulate different thermo-elastic loads. Hence, different temperature profiles can be induced in the machine bed.

The test machine, furthermore, contains three NC axes. With the control system integrated model and external measurement equipment the effectivity of the developed compensation strategy can be evaluated.

4 Conclusion

A machine integrated system for the measurement of strain has been developed. The functionality of the system has been demonstrated. The system is capable of measuring strain with adequate accuracy. The integration of multiple measurement systems in a machine test bench has shown the ability to identify complex deformation of integral machine parts.

The sensor signals have already been utilised to compensate thermal deformation with active heating and cooling of the structure. In the future, a model-based approach will be developed and verified in order to compensate complex thermo-elastic machine deformation via the control system.

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