In-Process Measurement and Positioning of Precision-forged Gear Shafts in 4 DOF

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Abstract

The application of high precision measurement devices in combination with mechatronic positioning chucks provides for enormous progression in production technology. In the collaborative research centre 489 which is funded by the German Research Foundation (DFG) the precision forging of highly charged components is researched. The workpiece under examination is a gear shaft. Due to the minimum stock of only 30 to 80 microns the workpiece has to be precisely aligned before hard machining of the function elements.

Therefore, two sensors in combination with a newly designed precision positioning chuck with integrated piezo actuators have been directly integrated into the machine tool. Due to the ability to measure steep angles, conoscopic sensors have been selected to ensure a save measurement of the toothing. After clamping the workpiece the profiles of the functional elements are measured in several sections. With the help of specially adapted best-fit algorithms a three-dimensional vector is calculated. This vector contains the necessary adjustment information to relocate the workpiece and put it into the optimal position for machining. Communication with the new chuck is based on wireless technology (Bluetooth). Chuck integrated piezoactuators position the workpiece in 4 DOF. Among those, 2 DOF are used for a compensation of the eccentricity and the remaining 2 DOF correct the inclination. Thus, a complete alignment of the workpiece to the axis of rotation is accomplished.

1 Introduction

Cost pressure and increasing demand on high quality products call for new approaches in production technology [1, 2, 3]. Therefore, the collaborative research centre 489 builds up new technologies of manufacturing [4]. This implements the precision-forging of highly charged components. After an innovative heat treatment [5] the net-near shaped workpieces need a precision positioning prior to further machining because functional elements have position and form deviations. By means of a material allowance oriented precision positioning these failures can be minimized. This can be realized by an adaptronic chuck in combination with an optical measurement system.

2 4 DOF precision positioning chuck for hard turning

The positioning of workpieces in 4 DOF in the machine tool is effected by a newly researched adaptronic chuck system in which piezo actuators are integrated. To enable positioning, the system structure has to be selectively weakened. In this context elasto-kinematic guidings are used for a precise and stiff behaviour. As shown in Figure 1, membranes and lattice elements are chosen.

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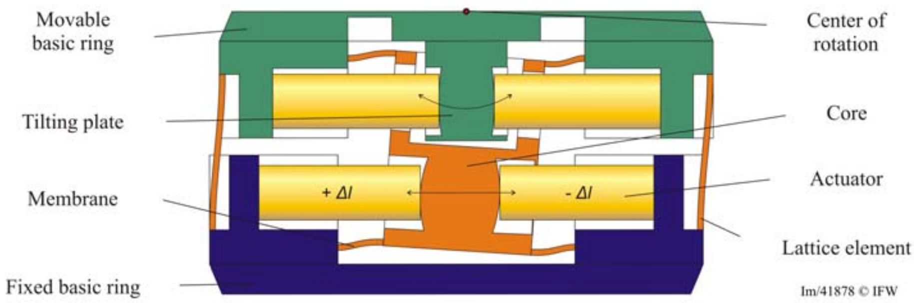

Figure 1: Operation method and realization of a 4 DOF precision positioning chuck

The system consists of two independent positioning systems for excenter and tilt compensation. For each degree of freedom two piezo actuators are being used. During the positioning process one of the actuators is elongated while the other one contracts. In the tilt compensation system this leads to a correction angle of ±0.07°. In x- and y-direction the actuator force causes a tilt of the central core which is connected to a fixed and a movable basic ring via two membranes. Flexible lattice elements at the outer side of the chuck allow a translatory movement with a positioning range of appr. ± 75 µm. A detailed explanation of the analytical model and the optimization process of the construction parameters is shown in [6].

For data and energy transmission wireless technologies have been chosen [7]. Via an emulated com-port the data is sent from a user interface to the chuck using Bluetooth. Decoding takes place inside the chuck with an integrated microchip. D/A-converters control small high voltage amplifiers (0-1000V) which are necessary for the piezo actuators. The actual position is determined via strain gauges in combination with a measuring bridge. 12 bit A/D-converters transmit the values to the microchip which sends the data out of the rotating system to the user interface.

2 Sensors and algorithms for precision positioning

In order to optimally adjust the component under production within the actual turning process and to precisely prepare for the subsequent grinding process of the toothing, the function elements (shaft and gearing) of the gear shaft have to be measured. Therefore, two conoscopic sensors take line-shaped measurements of the functional elements. These optical sensors are able to measure at angles up to ±85° from the normal direction of the surface of the measured object. Thus, these sensors are able to determine the steep angles at the tooth flanks of the gearing. Further technical specifications are described in [8]. The distance data of the conoscopic sensor are synchronized with the angle data of a rotary encoder. In combination with the knowledge of the sensor position in the longitudinal direction of the gear shaft 3D-data are generated.

The processing of the data includes filtering with different criteria like signal noise ratio and the extraction of important data ranges. Concerning the data of the gearing only the measured data points of the tooth flanks should be noticed, because these are the real functional elements of a gearing. So, the points of the tooth crests and the bottom of the tooth spaces are eliminated.

To optimize the position of the produced gear shaft for both subsequent machining processes, the processed data are fitted to a reference model, where the Euclidian distances between the measured data and the reference are minimized. Therefore, different optimization criteria with different objective functions can be used. These criteria, like the least square (LSC) or the Chebyshev (MZC) algorithm can be selected in a user interface [9]. The result of the fitting process is a calculated 3D-adjustment vector, which contains the necessary translations and rotations for the positioning process. This vector is transferred to the positioning chuck, so that the gear shaft is optimally adjusted for the machining.

3 Integration of the sensors and the positioning chuck in a machine tool

For in-process measurement and positioning the adaptronic chuck and the measurement system are integrated into a lathe. Figure 2 shows the integration of both components. The sensors can be positioned in the longitudinal direction of the gear shaft with a high precision linear axis to measure the toothing and the shaft on different positions.

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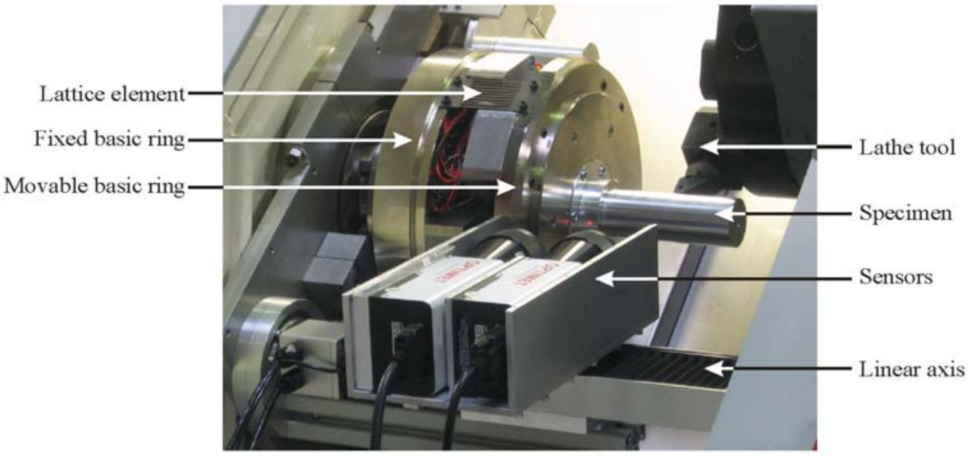

Figure 2: Integration of adaptronic chuck and measurement system

By these functional elements the optimal position of the workpiece is calculated. The result is an adjustment vector which is transferred to the adaptronic chuck. This allows the necessary corrections of the position. As a result, the shaft geometry can then be finished in a hard machining process. The surface is used as the reference for the subsequent grinding process of the gearing [10].

4 Conclusion

The paper shows a new possibility of aligning workpieces in 4 DOF before machining. Therefore, an optical measurement system detects the possible deviations to the optimal position of the workpiece. An adjustment vector is calculated by best-fit-algorithms and sent to an innovative adaptronic chuck with wireless energy- and data transmission. After the alignment in the optimal position the workpiece is finished in a hard machining process. This technology allows the reduction of the necessary stock to a minimum, which means less tool cost and less production time.

5 Acknowledgments

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