Metrology of Adaptronic Precision Positioning Technology

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Abstract
Part of the research activities at the Institute of Measurement and Automatic Control is the optical measurement of rotationally symmetric workpieces, especially gearwheels. This paper is about the metrology of gearwheels in machine tools, which is the topic in the research project T4 „Adaptronic Precision Positioning System in Chucks for Machine Tools" within the CRC 489 "Process Chain for Manufacturing of Precision Forged High-Performance Components". The content of this paper is divided into the basics of data acquisition and data processing as well as the background and the aims of this research project

Keywords:
Production measurement technology, optical metrology, gearwheels

1 INTRODUCTION

Within the Collaborative Research Center (CRC) 489 "Process Chain for manufacturing of precision forged high-performance components" the precision forging of automotive components is part of the research activities of different institutes at the Leibniz Universität Hannover.

At the Institute of Measurement and Automatic Control two basic research projects are located, first the subproject A5 „Allowance Based Fine Positioning" and second the subproject B5 „Complete Production-Related Geometry Inspection".

Based on the subproject A5 the transfer-project T4 „Adaptronic Precision Positioning System in chucks for Machine Tools" was initiated, with the aim of transferring the results of the basic research into the industrial environment. The two research institutes (Institute of Measurement and Automatic Control – IMR and Institute of Production Engineering and Machine Tools - IFW) do cooperate with four industrial partners, Fräger Antriebstechnik GmbH, Eras GmbH, Messtechnik Schroth GmbH and Schunk Spannsysteme GmbH & Co. Who are also involved in this transfer-project [1].

2 ALLOWANCE ORIENTED PRECISION POSITIONING TECHNOLOGY

2.1 General purposes and process sequence

Due the process characteristics of the precision forging of gearwheels there is a possibility of transferring a relative deviation in position between upper die and the lower die to the manufactured gearwheel. This deviation causes a distortion of the gearwheel and non uniform material allowance on the flanks of the gearwheel. So a centric clamp of the manufactured gearwheel is according to the existing distortion of the gearwheel impossible and the following grinding process may result in scrap and tool wear.

This behaviour was the motivation for the subproject A5, which designed a system for identification of an eccentric clamp and variation of the material allowance on gearwheel flanks. The correction of the eccentricity can be made by a mechatronic chuck [2].

In this mechatronic chuck four piezoelectric actuators are integrated in two degrees of freedom, each orthogonal to the center of rotation, which can move the clamped workpiece ±100 µm in both directions.

Thus, based on the calculation of a correction vector by processing the measured data and moving the gearwheel by the mechatronic chuck, the eccentricity of the distorted gearwheel can be compensated. Following steps in the manufacturing process are the hard turning of the central bore of the centric gearwheel and the grinding of the flanks.

Figure 1: Precision forged gearwheel, © IMR

The process of grinding the flanks utilizes the hard turned central bore as reference [3].

2.2 System design

The system of the allowance oriented precision positioning technology can be divided into three partitions. First partition consists of the optical data acquisition by a conoscopic laser sensor, partition two consists of the data processing and the calculation of the correction vector and finally partition three is the mechatronic chuck.

The task of data acquisition is the take-up of a transverse plane of the gearwheel with the optical distance sensor. A test setup of the data acquisition is shown in Figure 2. The test setup consists of the optical sensor, the manual x-y adjusting arrangement for simulation of eccentricity and a radial run-out testing system (Mahr MFU-7) equipped with an incremental rotary encoder.

The deployed conoscopic laser sensor is based on a co-linear principal: The lighting of the workpiece and the capturing of the reflected light are in one axis. Especially for gearwheel measurement this principal is a high advantage, because both flanks can be captured in one measurement taken. The maximum possible degree for detection is about ± 85 degrees orthogonal to the optical axis. Manufacturer of this optical sensor is Optimet Optical metrology Ltd. The stand-off and the possible resolution can easily be changed by using different accessory lenses [4].

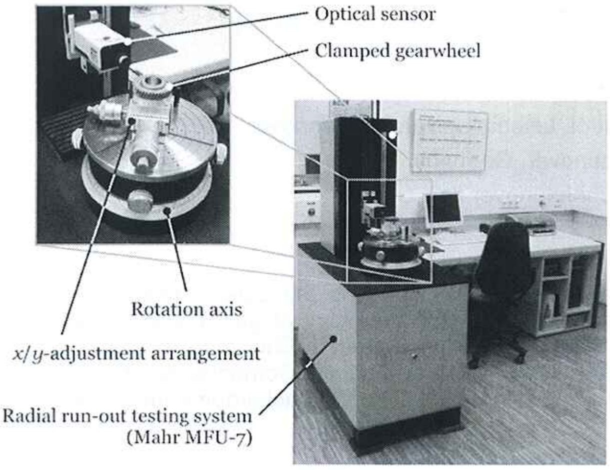

Figure 2: Test setup for optical data acquisition, [2]

The correction vector is calculated by extracting the captured flanks in the software application, calculating the individual allowance and fitting the data into reference geometry by different best-fit algorithms [2].

3 ADAPTRONIC PRECISION POSITIONING TECHNOLOGY

3.1 Basics and objectives

Common objective of the initiated transfer-project T4 „Adaptronic precision positioning system in chucks for machine tools" is the transfer of research results from the A5-project into the industrial application.

Pilot project for the adaptronic precision positioning technology is the conventional manufacturing process of camshaft gearwheels at one of the industrial partner, Fräger Antriebstechnik. Some of the manufactured camshaft gearwheels (Figure 3) are lightly distorted because of the case hardening. The adaptronic precision positioning technology should be used for the correction of an eccentricity of a distorted gearwheel, clamped in the mechatronic chuck.

In the manufacturing step, the hard turning of the central bore, the reference for the grinding process is made. This process is similar to the process of the precision forging.

Along with the leading research institutes at the LUH and the manufacturer of the gearwheels, Fräger Antriebstechnik, following partners are involved in this research project: ERAS, a small company with expertise in adaptronic systems, Schunk Spannsysteme GmbH & Co., a world leader in clamping technique and automation products, and Schroth, which is an important partner and the distributor of the optical metrology.

Figure 3: Gearwheel of Fräger Antriebstechnik, © IMR

Main goal of this transfer-project is the research and development of a modular designed precision positioning system, suitable for industrial applications, used for the precision positioning of camshaft gearwheels at Fräger Antriebstechnik. Background of the modular design is the favoured possibility to use this precision positioning system in other applications with only light changes in mechanics and software [5].

3.2 New system design

The new metrology for the adaptronic precision positioning system is based on the data acquisition of the described predecessor project A5. For capturing the distance data, a new version of the conoscopic lasersensor, ConoProbe Mark III, is used. The manufacturer is still Optimet Optical metrology Ltd.

This version of the optical sensor provides an improved measuring frequency (3000 Hz to 850 Hz) and a new PC connection via Ethernet. Also, the size of the needed powersupply-box was considerably reduced [6].

Figure 4: Conoscopic Sensor ConoProbe Mark III, © IMR

For the acquisition of the angle values during a turn of the clamped workpiece a common incremental rotary encoder are used. In addition to that, sinusoid rotary encoder can be used by the interconnection of digital interpolation electronics.

The data processing of the incremental signal is provided by a counter/timer card, produced by National Instruments.

This PCI-Card allows a four-quadrate encoding of the TTL-signals, which means both flanks, rising and falling, of each 90 degrees shifted signals (channel A and channel B) are counted.

Depending on the rotation direction, the counter value is incremented or decremented. A third channel, the so called Z-channel, provides the opportunity for a reset of the counter and is also used for an absolute reference during one revolution [7].

In the test setup, the counter/timer card is mounted into a conventional PC with Ethernet connection, which is used for the data connection to the optical sensor.

3.3 Data acquisition and -processing

The ConoProbe Mark III sensor offers two different opportunities for data acquisition. On the one hand, there is the possibility for time equidistant measurement ("Timemode"), on the other hand there is the Triggermode, which means after a rising edge on the triggerinput a measurement is taken. In both cases attention should be paid to the maximum possible measuring frequency of the sensor.

In addition to the measured distance values, additional data is put out with each measurement taken. These can be obtained to assess the distance value, examples are for instance Signal to Noise Ratio (SNR) or the amount of light energy which was captured. Based on this data, the illumination can be adjusted due to the given surface of the workpiece and in this way the quality of the distance data can be improved.

The possible accuracy of the sensor depends mainly on the chosen lens. Other factors are the optical cooperativity of the workpiece-surface, the parameter adjustment of the sensor and finally the angle of the laser beam to the workpiece-surface. In the described test setup the absolute accuracy with the chosen lens "50 extended" is about 6 µm with a reproducibility (1σ) of 1 µm [6].

The used National Instruments counter/timer offers many different functions like pulse generation, frequency detection and, most interesting to this application, the encoder functions. The card can be adjusted by software tools to the actual type of incremental encoder (Number of channels, phasing of the reference signal, etc). The internal 32 bit counter-ICs are providing high possible angle accuracy. The asynchronous data transfer-mode gives the opportunity to transfer counter values to the buffer while the counting is still running [7].

Both elements, the optical sensor and the counter/timer card, are programmed in C++ language, although other languages are possible.

4 RESULTS

4.1 Realized angle-distance synchronisation

For reconstruction of the measured workpiece geometry a synchronisation of distance and angle data is needed. Basically there are two different possibilities of synchronisation:

1. At the time equidistant synchronisation the measurements of the optical sensor are taken at fixed time intervals with the need of constant rotating speed of the workpiece. After deduction of systemic delay times, the angle of the individual measuring points can be reconstructed. This method has the great disadvantage that measurements at variable speeds are not possible, and smaller changes in the speed can effect the measurement useless. An important advantage of this synchronization is the simple structure.

2. At the angle equidistant synchronization measurements of the optical sensor are taken at fixed angle intervals. By decoupling of a constant rotating speed, changes of the speed are irrelevant for the measurement. This procedure is limited by the measurement frequency of the sensor, respectively the rotational speed of the component is limited by the number of measuring points to record (and thus the resulting angle intervals).

The comparison of both principles demonstrates the significant benefits of an angle equidistant synchronisation. The maximum number of points per revolution of the component can be calculated as follows:

$$N = \frac{U}{60} \times f_{Meas} \quad (1)$$

The number of points N is thus depending on the maximum rotational speed U in 1/min and the maximum measurement frequency f_{Meas} in Hz.

For the maximum measurement frequency of the Mark III ConoProbe sensor (3000 Hz) and a speed of 60 revolutions per minute the maximum possible number of measurements is 3000 points per revolution.

The angle offset $\Delta\vartheta$ can be calculated with

$$\Delta\vartheta = \frac{360 \times 60}{f_{Meas} \times U} = \frac{360}{N} \quad (2)$$

For example, 3000 measurement points per revolution cause an angle interval of 0.12 degrees.

The implementation of data synchronization is performed by the triggering of the optical sensor through a channel of the incremental encoder. To setup an angle offset, the sensor offers the possibility to omit individual flanks (Dilution).

The optical sensor provides as a response on the triggersignal a square wave on its ROG (Read-Out-Gate) Output with the duration $1/f_{Meas}$, its rising or falling edge marks the beginning and end of the measurement. The rising and falling edge of the sensor can be used to transfer the countervalue of the counter/timer card in to the buffer.

The schedule of the realized data synchronization is shown in Figure 5.

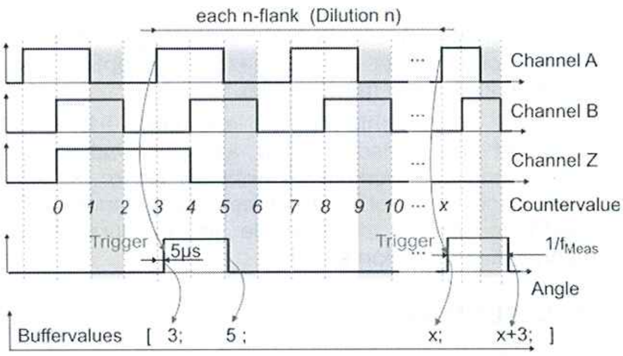

Figure 5: Realized Synchronisation, © IMR

From the transferred buffer values of the counter the current angle value can be determined by averaging the values of the beginning and end of the measurement. An increased rotational speed causes a small deviation due to the fixed measurement duration as shown in Figure 5.

The delay time of the ConoProbe Mark III is specified with 5 µs [6].

4.2 Principals of the estimating

In the evaluation of the algorithms for allowance oriented precision positioning was noted that the calculation of the individual allowance of the tooth flank and their incorporation into a deposited reference model takes enormous computing time.

An implementation within the adaptronic precision positioning system, which is linked to the gear manufacturing processes with its short cycle times, is not possible.

A simple and efficient detection of an eccentricity may also happen on other geometrical features, such as the extraction of the tip radius or extraction of the root radius.

In both cases, it is possible to fit the extracted data into a deposited reference circle (geometric fit). To calculate the existing eccentricity the center of the fitted circle must be determined. The vector of this center to the origin of the coordinate represents the correction vector.

4.3 Integration of the sensor

For the measurement of the clamped workpiece an integration of the optical sensor in the machine tool is required.

The workpiece is fixed to the clamping system of the mechatronic chuck and by the rotation of the spin axis of the machine tool the geometric data is captured in one revolution.

Depending on the manufacturing process, dry or wet processing, the effort of the enclosure is to be observed. In the existing dry processing a overpressure enclosures is not necessary.

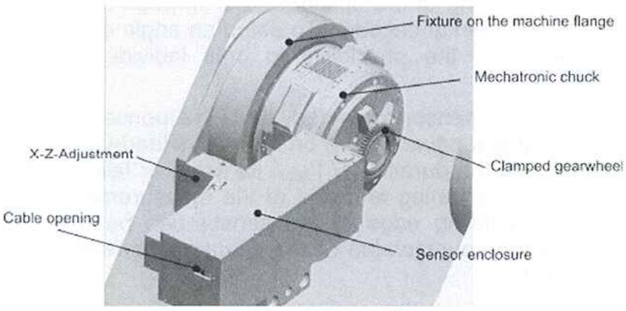

Figure 6: CAD-Design of the sensor-integration, © IMR

Key point of the construction shown in Figure 6 is the orientation of the encapsulated sensor, or its optical axis, on the spin axis of the machine tool.

Options for adjustments are on one hand the radial distance of the sensor to the axis of rotation (for measurements of workpieces with larger or smaller diameter) and on the other hand the axial distance to the mechatronic chuck, for example to measure larger components, e.g. pinion shafts.

5 PERSPECTIVES

5.1 Activities

In addition to studies on the durability of the precision positioning system, after the creation of new concepts, the assembling of the designed system as well as its test and finally the use of this system at Fräger Antriebstechnik is planned.

Most challenging for the metrology and data processing are the exploration of new intelligent evaluation algorithms for eccentricity detection, appropriate filtering techniques and tests for system stability. Furthermore, the integration of the precision positioning system in to the automated process with a data connection to the quality management is a crucial challenge.

6 CONCLUSIONS

Main goal of this transfer-project is the research and development of a modular designed precision positioning system, suitable for industrial applications. In the field of metrology, the partitions data recording, data synchronisation and data processing are in the focus of the development.

Core of the data acquisition is the proposed optical sensor Conoprobe Mark III of Optimet Company Ltd. It offers with a high measuring accuracy and frequency best conditions for an efficient measurement of optical cooperative components.

To synchronize the data, an angle equidistant synchronisation was developed, which enables even at fluctuating speeds a reliable measurement.

In the data processing, efficient strategies for the detection of eccentricity are part of the research activities, based on the geometric fitting into deposited reference geometries.

7 ACKNOWLEDGMENT

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