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# ADAPTRONIC PRECISION POSITIONING TECHNOLOGY

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## ABSTRACT

The adaptronic precision positioning technology is applied to the fitting of rotation-symmetric components such as gearwheels in a hard turning process in order to compensate eccentricity. Distorted gearwheels, showing e.g. a significant quench distortion, cause a malposition in the chuck during clamping. This malposition leads to low quality workpieces or scrap in the hard turning process. To compensate the malposition of the workpieces, a new technology for precision positioning within the rotating chuck is being researched.

In the introduction, the motivation of the preceding research project "Allowance-oriented precision positioning" and the framework of the adaptronic precision positioning technology are summarized. Next part is the description of the system's components, beginning with the principles and the redesign of the mechatronic chuck. Completing the adaptronic precision positioning technology, the optical metrology, the data processing and automation aspects are shown in the following part. Afterwards, a short summary concludes this paper.

## 1 INTRODUCTION

One of the most important industry branches in Germany is the automotive industry. The quality of the produced goods is the basis for staying competitive in the globalized markets. Especially the end consumer demands a long lifecycle time and long service intervals in regard to automotives. This leads to the need of high performance and high quality automotive components. Due to this fact, the automotive industry as well as its suppliers face an increasing cost pressure.

In order to find new techniques in manufacturing, the Collaborative Research Centre 489 (CRC 489) called "Process chain for the production of precision-forged high-performance components" has been initiated at the Leibniz University Hannover [1]. As sample components for precision-forging gearwheels, pinion shafts and crankshafts have been chosen (see Figure 1). Conventional process chains include a high content of expensive metal cutting processes steps for the production of gearwheels and pinion shafts. Opposing to this, the initiated process chain offers a considerable reduction of manufacturing costs and cycle times due to innovative manufacturing steps. One example is the precision-forging with integrated heat treatment. This emerging technology uses the forging heat for the following heat treatment. So the two conventional manufacturing steps, forging and heat treatment, are combined to a single process step.

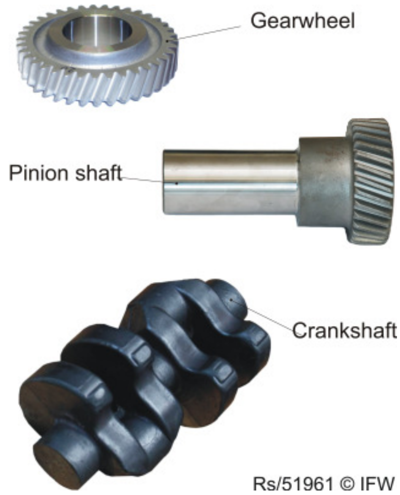


**Figure 1.** Precision-forged components of CRC 489

The different shaping process steps in the precision forging production can create random geometry variations on the surface of the manufactured components. These variations can

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lead to a low quality of the produced component as well as scrap. Using conventional production related tactile measurement procedures, the variations cannot be detected within the required short cycle times. In order to increase the performance of the following manufacturing processes, like grinding of the tooth flanks, a fast detection of distortion is needed.

### 1.1 Allowance-oriented precision positioning

The described deviations can cause a distortion of the manufactured components, for instance a non-uniform material allowance on the flanks of the gearwheel. So, a centric clamping of the manufactured gearwheel is impossible according to the existing distortion of the gearwheel, and the following grinding process may result in scrap and tool wear.

This behaviour was the motivation for the CRC 489`s subproject A5, in which a system for the identification of an eccentric clamp and variation of the material allowance on gearwheels flanks has been designed. The correction of the eccentricity can be accomplished by a mechatronic chuck [2, 3]. In this mechatronic chuck four piezoelectric actuators are integrated in two degrees of freedom, each orthogonal to the rotation axis, which can move the clamped workpiece about ±100 µm in both directions. Further mechatronic systems and their application for machine tools are shown in [4, 5].

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. The following steps in the manufacturing process are the hard turning of the central bore of the centric gearwheel and the grinding of the flanks.

Regarding to the centric hard turning of the central bore, the central bore can be used as a reference in the grinding process. In order to correct the deviations of manufactured pinion shafts, the mechatronic chuck and the measurement system were extended to four degrees of freedom. A system for the correction of crankshafts is still part of research activities [6, 7].

### 1.2. Transfer of technology

The main 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 environment.

The goal of the involved research institutes (Institute of Measurement and Automatic Control (imr) and Institute of Production Engineering and Machine Tools (IFW)) and the industrial partners of this transfer project is the research and development of a modular-designed precision positioning system, suitable for industrial applications. Background of the modular design is the favoured possibility to use this precision positioning system in several applications with only light changes in mechanics and software.

The pilot project for the adaptronic precision positioning technology is the conventional manufacturing process of camshaft gearwheels from one of the industrial partners. Some of the manufactured camshaft gearwheels (Figure 2) are lightly distorted because of the case hardening. The adaptronic precision positioning technology will be used for the correction of an eccentricity of a distorted gearwheel clamped in the mechatronic chuck.

**Figure 2.** Camshaft gearwheel

During manufacturing, the hard turning of the central bore as the reference for the grinding process is carried out (Figure 3). This process is similar to the hard turning process of the precision-forging.

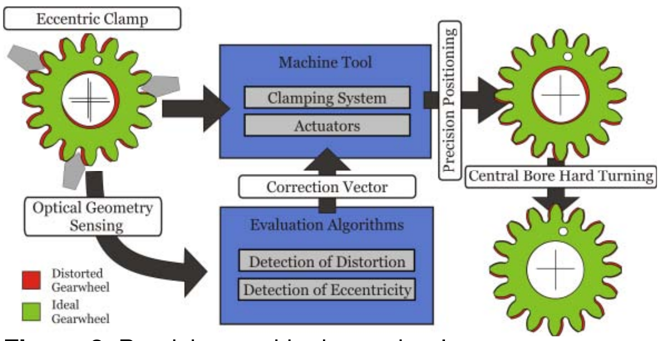


**Figure 3.** Precision positioning technology

### 1.3. Research program

The transfer project is divided into three different parts. The first part of the research activities focuses on the industrial requirements and the definition of the technical specifications. The definition is carried out in a close cooperation with the industrial partners. In addition to studies on the durability of the precision positioning system, after the creation of new concepts the assembly of the designed system as well as its test and finally the use of this system by one of the industrial partners is planned.

The general feasibility of a precision positioning system was verified in CRC 489´s A5 project. Most challenging for the metrology and data processing in this transfer project 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 into the automated process with a data connection to the quality management is a crucial challenge.

## 2 MECHATRONIC CHUCK

### 2.1. Technical requirements and design

A chuck with a positioning device is integrated into the machine tool. A highly compact unit has been designed, so that the work space in comparison to a standard chuck is not significantly restricted. The positioning process should be completed within a few seconds. Furthermore, components of machine tools integrated within the force flow must have a high stiffness in the direction of the force flow, so that form deviations and chatter due to static and dynamic displacement between the workpiece and the tool can be reduced or even avoided. Within the precision positioning device both, process forces and centrifugal forces due to the rotation, must be considered. With a required minimum average cutting speed of 150 m/min and a gear's inner diameter of 62 mm a minimum rotational frequency of 746 min-1 results. The maximum rotational frequency amounts to 3000 min-1. To avoid the shearing strain stress and bending stress of the actuators due the high centrifugal forces, a star-shaped configuration was chosen (Figure 4). Centrifugal forces act on the longitudinal direction, so in this case the piezoelectric actuators are highly resistant.

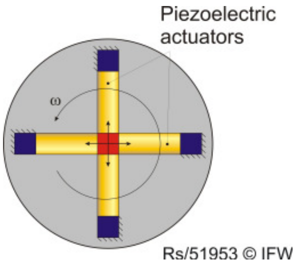


**Figure 4.** Star-shaped actuator configuration

The structure of the positioning device and its components are shown in Figure 5. A fixed basis ring connects the actuator unit with the flange of the rotary spindle. Two membranes fix a centrally arranged core. The piezo actuators are based on the one hand against a fixed basis ring, on the other hand against the core. The workpiece is clamped with a clamping device, which is fixed with the adjustable basis ring. This structure allows a positioning of the workpieces in two degrees of freedom.

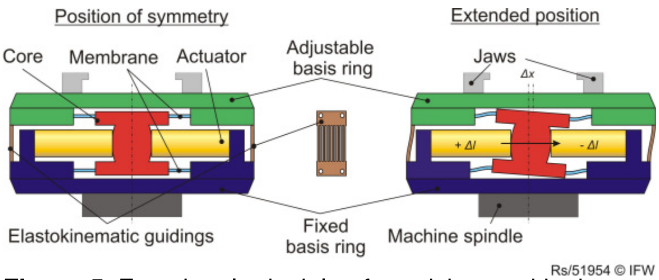


**Figure 5.** Functional principle of precision positioning

To ensure high-precision machining, the components must be stiff in the direction of the process forces, but elastic in the guiding direction. For small actuations elasto-kinematic structures are predestined compared to rolling contact guidings. They do not wear, have linear and hysteresis-free transmission behavior and are very compact [8]. The selected lattice structure has a lengthwise with 210 N/µm to a factor of 1000 greater stiffness than in the transverse direction in which the stiffness is 0.24 N/µm. The lattices permit the impermissible torsion of the chuck. To block this degree of freedom two membranes are used, which are bonded with the core. The torsion-stiff structure allows the transmission of the moment from the fixed to the adjustable basis ring. Furthermore, the torsion-stiff structure ensures that the piezoelectric actuators are not loaded by bending or shear stress.

The inner core has also the function to increase the positioning range of the actuators. The actuator's force is applied to the halfway up the core, so that the position rang of the adjustable basis ring can be doubled (see Figure 5). In the best case two actuators placed in opponent-arrangement can move the center about plus/minus half the maximum stroke of the actuators, in this case ±60 µm. With this conversion, the device can reach a maximum compensation with a theoretical range of ±120 µm. This rather theoretical value is not achievable because of the limited stiffness of the elasto-kinematic guidings and transmission elements in interaction with actuator and ring resilience. The measured position range of the in the machine tool integrated device is 100 µm and thus the degree of efficiency is 85 %.

## 2.2. Properties of the actuators

For actuation of the precision positioning device four piezo stack actuators were chosen. Especially piezo stack actuators are capable of high-precision positioning operations with high forces and relatively low weight under the restriction of a limited design space. Other advantages of piezo stack actuators are their very high stiffness in the direction of actuation compared to electromagnetic drives. The selected piezo stacks have a length of 100 mm, a diameter of 19 mm, a mass of 220 g and a capacity of 1.8 µF. Uncharged and at an excite voltage of 1000 V the maximum stroke is 120 µm.

## 2.3. Power transmission

The power supply is implemented using two inductive coil rings, where the magnetic field is kept on ferrite cores (Figure 6). A distance between two coils is 0.2 mm. The primary coil ring is fixed on the lathe and the secondary side on the rotating chuck. The advantage of this contactless arrangement is the wear-free use. The primary side is fed with a rectangular 15 V voltage, which is rectified to DC via fast switching diodes in the actuator unit. Via stabilizers on the board 3.3 V, 5 V and 12 V for various components are available.

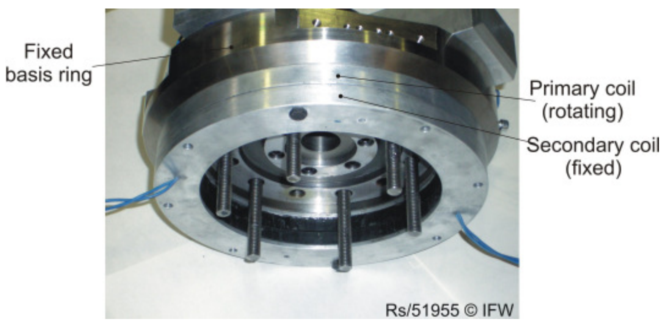


**Figure 6.** Contactless power supply

The unit is configured for a transfer of 30 W power output, where currently only 22 W in operation are required. The reserve can be used for peak loads or future enhancements/more components.

### 2.4. Electronic components

All electronic components are mounted on the board as shown in Figure 7. The evaluation of the strain gauges attached to the piezo stacks is done via A/D converters, which transmit the data over an I²C interface to the microcontroller. This chip performs both, the control functions as well as communication with the external controller to whom the data will be transmitted using a bi-directional wireless connection.

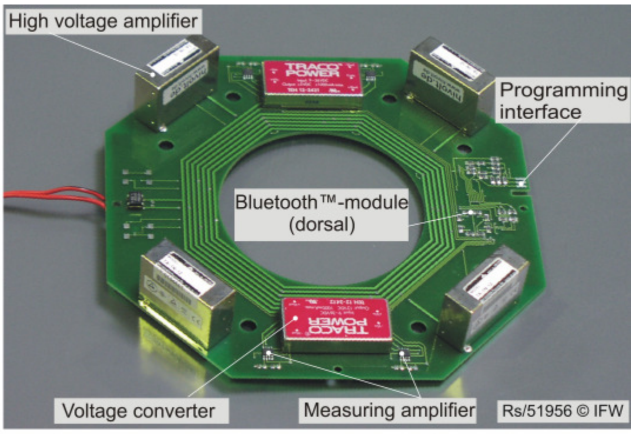


**Figure 7.** Electronic elements

The control commands are received via the I²C interface of the D/A converters, over whose voltage between zero and six volts as input signals of high voltage power supplies serve. These produce a proportional output voltage between zero and 1000 V to control the piezoelectric actuators. With an integrated programming interface, the transmission of the software to control the Bluetooth chips is programmed.

### 2.5. Bluetooth-data transmission

The communication between the control computer and the precision chuck is done bidirectional via Bluetooth at a frequency of 2.4 GHz. This technology allows to send a reference position to the rotating mechatronic chuck on the one hand and to receive the actual position for further analysis and control on the other hand. On the side of the control computer a Bluetooth stick using a USB connection is applied, which will be automatically detected and only the control of the serial port must be programmed. A user interface for the control of the mechatronic chuck has been created in C++.

The Bluetooth module with an integrated antenna (Figure 8) is placed upon the precision positioning unit. In addition to the main task to transmit data the computation of other operations is available. Thus, the D/A and A/D converter are queried and processed before data will be transmitted to the control computer.

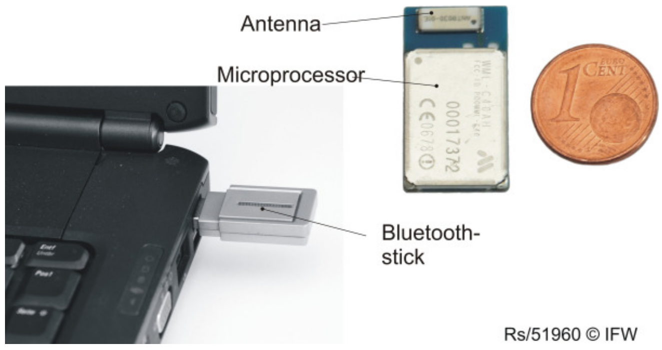


**Figure 8.** Bluetooth data transmission

### 2.6. Complete system setup

The mechatronic chuck, integrated into the lathe, is shown in Figure 9. On the left side the contactless power transmission is placed, in which the primary coil ring with the lathe is attached. The second coil ring rotates with the actuator unit. The fixed basis ring connects the precision positing device with the machine tool spindle. Furthermore, the fixed basis ring and the adjustable basis ring are fixed through elasto-kinematic guides. The clamping device in which gears can be clamped is located on top of the adjustable basis ring. The clamping device uses the diaphragm principle. It is based on elastic deformation of the diaphragm. Under the elastically designed diaphragm compressed air is directed, so that the jaws open by 90 µm. This jaw stroke is sufficient to clamp distorted gearwheels. The measured radial output stiffness on the adjustable basis ring amounts to 24 N/µm. As a reference value the stiffness of the turning tool can be used, which has been identified to 13 N/µm, hence it is significant below the achieved output stiffness.

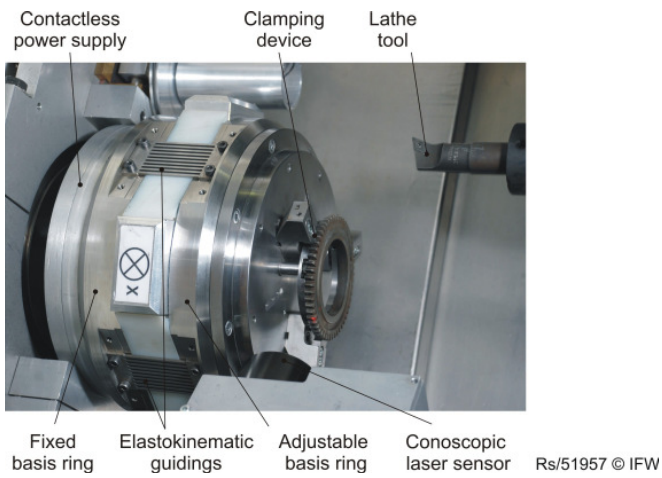


**Figure 9.** Adaptronic precision positioning system integrated in a lathe

### 2.7. Further development

The available prototype of the mechatronic chuck is being used for turning of camshaft gearwheels. The gearwheels are turned in charges of 100 pieces. Thereby, the behavior of the mechatronic chuck, the cutting process as well as the quality of the turned gearwheels are analyzed. Furthermore, the mechatronic chuck is being applied to test measurement software by measuring gearwheels with a conoscopic laser sensor under varying conditions.

The first step was the design of new jaws, which allow an optimal clamping of camshaft gearwheels. A configuration with three clamping jaws has been chosen to meet the boundary condition of a determined system. By camshaft gearwheel the pitch line is the reference for the middle hole, so that these must be coaxial. On account of this, the clamping on the pitch line has been realized with one of the industrial partners as shown in Figure 10.

The displayed clamping head is fixed on the base jaw and is adjustable in the radial direction. The clamping force of one jaw amounts to approx. 800 N. It is the static clamping force which acts in radial direction. Finite element calculation shows that higher radial forces lead to an unacceptable distortion of the thin-walled camshaft gearwheel when the gearwheel will be clamped on the tip. It results in an elastic distortion of the clamped gearwheel, which recedes after turning of the middle hole and the expansion of the gearwheel. This effect finally characterizes the circularity of the manufactured hole.

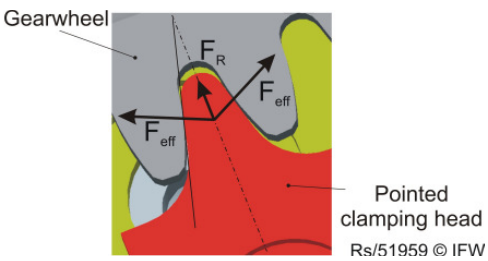


**Figure 10.** Gearwheels clamping

The advantage of the clamping with pointed heads is explained in the following. The clamping force acts in the direction normal to the contact face, which has an angle to the middle axis of 15 degrees. In this case the wedge effect can be used. Advantageous is both, an increase of the clamping force as well as a partial transmission of the clamping force from the radial into normal direction to reduce the radial distortion of the gearwheel. The effective clamping force can be calculated as shown in Figure 10 as follows:

$$F_{eff} = \frac{F_R}{\sin(15°)} \quad (1)$$

With the radial jaw force of 800 N an increasement of the effective clamping force acting on both gearwheel flanks of nearly factor four is achievable. After practical testing of clamping and turning of serial gearwheels this system has been proven to meet the requirements.

The next step is the definition of new requirements for the adaptronic precision positioning system in cooperation with industrial partners. The dimensions of the mechatronic chuck, the interface between the mechatronic chuck and the lathe, the compensation range and the drive mechanism of the clamping system have been modified. Figure 11 shows a CAD model of the modified mechatronic chuck.

The basic functional principle of the mechatronic chuck remains the same in comparison to the above-described available prototype. Due to more compact dimensions of the mechatronic chuck as well as a reduced compensation range, some parts in the force flow are redesigned. Furthermore, the sealing and the chipping rebuff measure are optimized. Again the clamping system a diaphragm principle is employed. The difference lies in its activation. Instead of compressed air a driving rod will be applied to actuate the clamping diaphragm.

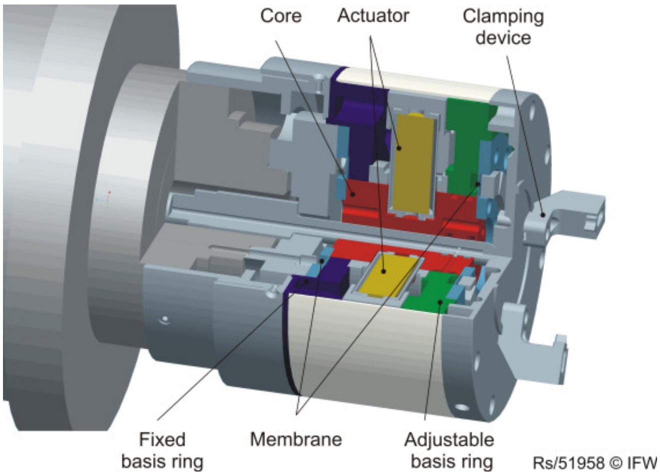


**Figure 11.** CAD-model of the modified mechatronic chuck

The following step will be the manufacturing of the newly-designed mechatronic chuck. This chuck must stand long-lasting testing procedures under different conditions with the goal of an application in mass-manufacturing at one of the industry partners.

## 3 METROLOGY AND DATA PROCESSING

The new metrology for the adaptronic precision positioning system is based on the data acquisition of the described preceding project A5. The three parts of the metrology are the geometry-capturing of the clamped workpiece, the detection of an eccentricity and finally the calculation of a correction vector and the storage and transfer of the measured data.

### 3.1 Optical measurement

For capturing the distance data, a fast non-contact optical measurement technology is used. The task of data acquisition is the take-up of a transverse plane of the gearwheel with an optical distance sensor. The used conoscopic lasersensor (Figure 12) 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 measurements this principal is a high advantage in opposite to triangulation systems, because both flanks can be captured in one measurement [9]. 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 [10].
The new version of the conoscopic laser sensor, ConoProbe Mark III, is used. This version of the optical sensor provides an increased measuring frequency (3000 Hz to 850 Hz) and a new data connection via Ethernet. According to this, the dimension of the needed powersupply box was considerably reduced [10].

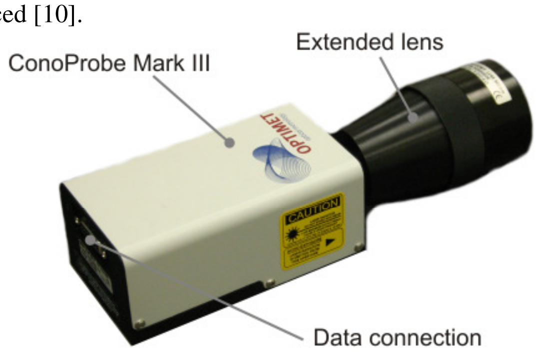


**Figure 12.** Conoscopic sensor ConoProbe Mark III

The accuracy of the sensor basically depends on the chosen lenses. 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 used test setup the absolute accuracy with the chosen lens “50 extended“ is about 6 µm with a reproducibility (1σ) of 1 µm. This lens provides a stand-off length of approximately 85 mm (Figure 13) and a measuring range of about 8 mm [10].

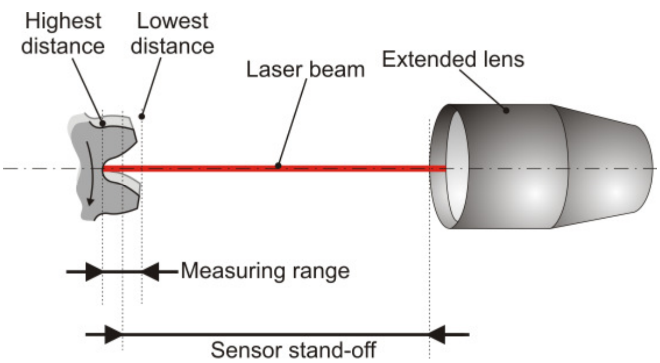


**Figure 13.** Draft of sensor specifications

The most-delimiting factor is the optical cooperativity of the workpiece surface. Highly reflecting surfaces like functional surfaces of shape cutting processes can not be measured with optical systems. Ideal surfaces for measurement are diffuse reflecting surfaces like forged, sandblasted or harded surfaces [11]. 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 the Signal to Noise Ratio (SNR) or the amount of light energy which was captured. Based on these 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.

### 3.2 System design

The metrology for the adaptronic precision positioning system is based on three different partitions. First part is the described optical measurement technology using the conoscopic lasersensor, second part is the reconstruction of the geometry using a rotary encoder and finally the third part is the data processing and the calculation of a correction vector.

To acquire the angle values during a turn of the clamped workpiece, common incremental rotary encoders with TTL signaloutput are used. In addition to that, sinusoid rotary encoders can be used with the interconnection of digital interpolation electronics.

The data processing of the incremental signal is provided by a counter/timer card, distributed by National Instruments. This PCI card allows a four-quadrant 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, called Z-channel, provides the opportunity for a reset of the counter and is also used for an absolute reference during one revolution [12]. 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.

The used National Instruments counter/timer offers many different functions like pulse generation, frequency detection and in this application most interesting 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 [12].

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

### 3.3 Synchronization

For reconstruction of the measured workpiecegeometry a synchronization of distance and angle data is needed. The best way for reconstruction of the geometry is an equidistant measurement of the clamped workpiece. Measurements of the optical sensor are taken at fixed angle intervals. By decoupling of constant rotating speeds, changes of the speed are irrelevant for the measurement. This procedure is only limited by the measurement frequency of the sensor respectively the rotational speed of the component is limited by the number of needed measuring points (and thus the resulting angle intervals).

The maximum number of points that can be captured per revolution of the component can be calculated as follows:

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

Thus, the number of points N is depending on the maximum rotational speed U in 1/min of the clamped workpiece and the maximum measurement frequency $f_{Meas}$ in Hz. At the maximum measurement frequency of the Mark III ConoProbe sensor (3000 Hz) and a speed of 120 revolutions per minute the maximum possible number of measurements is 1500 points per revolution.

The angle offset can be calculated by

$$\vartriangle\vartheta = \frac{360 \times 60}{f_{Meas} \times U} = \frac{360}{N} \quad (3)$$

For example, 1500 measurement points per revolution causing an angle interval of 0.24 degrees.

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

The optical sensor provides a square wave on its ROG (Read-Out-Gate) output with the duration 1/ $f_{Meas}$ as a response on the trigger signal. 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 counter value of the counter/timer card into the buffer. The schedule of the realized data synchronization is shown in Figure 14.

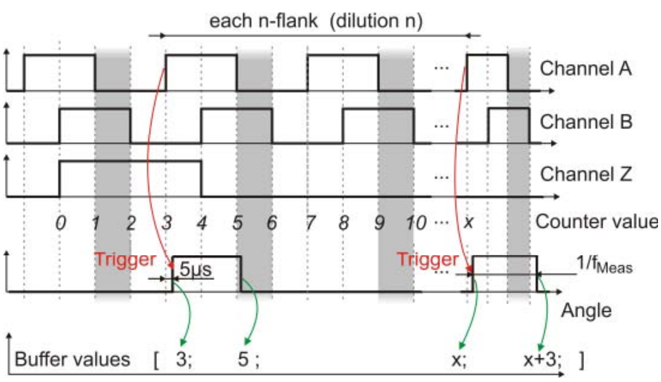


**Figure 14.** Realized Synchronization

From the transmitted 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 14. The delay time of the ConoProbe Mark III is specified with 5µs [10].
In addition to that, the angle between the two axes of the mechatronic chuck and the rotary encoder must be observed. The mechatronic chuck has a rotation symmetric holder on the spin axis of the machine tool. Thus, every time the chuck is mounted on the spin axis, there is the possibility of a different angular offset between the x-y axis of the chuck and the zero-angle of the rotary encoder.

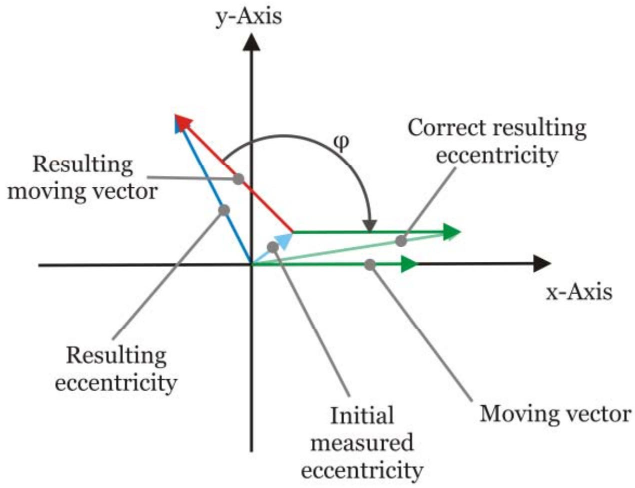


**Figure 15.** Angle synchronization

The procedure for calculating the offset angle between mechatronic chuck and the rotary encoder can be described as follows: the mechatronic chuck is fixed in the machine tool and a workpiece is clamped in the chuck's zero position. An initially measured eccentricity is stored and the mechatronic chuck is moved e.g. to the maximum positive x-value. The resulting eccentricity is the sum of the initial eccentricity and the moving vector (Figure 15). The correction angle φ for the angle synchronization is the angle between the calculated moving vector and the calculated corrected moving vector.

### 3.4 Principals of data processing

In the evaluation of the algorithms for the 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 the eccentricity can also be carried out with respect to other geometrical features of the measured workpiece, 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. The correction vector is transferred to the mechatronic chuck via wireless Bluetooth devices and the eccentricity is corrected by the piezo actuators.

### 3.5 Automation Aspects

The adaptronic precision positioning technology is designed for service in automated manufacturing processes. Due to the modular design of the components an easy adaption to most machine tools is possible. The automatic loading of workpieces can be achieved via pick-up operations in the mass production. The clamping of gearwheels must be simple and safe. Beneath the standardized mechanical connections, the data connection is important for an efficient adaption of the adaptronic precision positioning system into different manufacturing processes.

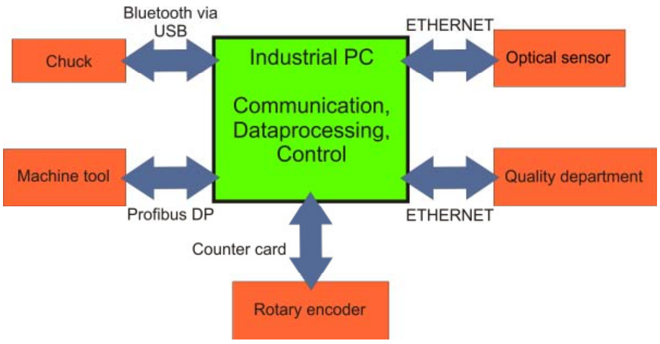


**Figure 16.** Connection-Diagram

The data connection can be divided in two different kinds of data transfer: the first kind are internal connections, i.e. connections between different system components, and the second one are connections between the system and peripheral components like the machine tool or the quality management. The most interesting connection with regard to automation aspects is the Profibus-Interface to the machine tool. This interface allows the interaction between the precision positioning system and the machine tool.

## 4 CONCLUDING REMARKS

Within the framework of the Collaborative Research Centre 489 a precision positioning system has been developed that allows exact alignment of flat parts such as gears on the axis of the lathe. Due to the highly precise turning of the middle hole as an initial reference a precise positioning along two degrees of freedom defining the eccentricity is available. Inside the precision rotary chuck, integrated piezoelectric actuators are controlled by highly compact electronics. The position range of ±100 µm is achievable. With an inductive, contactless power supply up to 30 W can be transmitted to the rotating device. The communication was implemented via the Bluetooth standard.

Essential for the data acquisition is the proposed optical sensor Conoprobe Mark III of Optimet Optical metrology Ltd. It offers a high measuring accuracy and frequency and thus best conditions for an efficient measurement of optical cooperative components. To synchronize the data, an angle equidistant synchronisation was developed, which enables a reliable measurement even at fluctuating speeds.

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, data recording, data synchronisation and data processing are in the focus of the development. Concerning the mechatronic chuck, the new optimized chuck (shown as a CAD-Model) will be manufactured and tested intensively. In data processing, efficient strategies for the detection of the eccentricity are term of the research activities, based on the geometric fitting into deposited reference geometries.


## 5 ACKNOWLEDGEMENTS

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