(57) Abstract: A method for determination of dimension and shape deviations of mechanical components (1) in process of forming and machining, especially the mechanical components (1) warmed-up to temperature over 450°C, consists in that the distances between selected reference point and measuring points selected on that part of the mechanical component (1) area near the reference point are measured, after which approximation of the surface fitted with the measured points is performed and then the dimension and shape deviations of the mechanical component (1) are determined by comparison of this surface with the surface of the mechanical component (1) model. An equipment for performing the method includes a laser distance meter (2), the sensor (3) of which is provided with a pre-filter (4) for filtering off parasitic emission of the mechanical component (1) radiation in the area nearing the wavelength of the laser used. The laser distance meter (2) is either arranged on a carriage (6) of a sensor (7) of the laser distance meter (2) carriage position and is provided with a sensor (8) of the laser distance meter (2) rotation in the plane perpendicular to the laser distance meter (2) carriage (6) movement direction. The laser distance meter (2) is either laser radar or laser triangulation detector or laser interferometer.
METHOD AND APPARATUS FOR MEASURING SHAPE DEVIATIONS OF MECHANICAL PARTS

Field of the invention

The invention relates to a method for detection of dimension and shape deviations of mechanical components in the process of forming and machining, especially mechanical components warmed-up to a temperature over 450°C, and to an equipment for performing the method.

Background to the invention

Producing especially more complicated mechanical components by forming and/or machining it is usually important to check, even before their use in a device they are intended for, whether they have been manufactured with such an accuracy in order that they may be really functional in the given device. This is usually performed by re-measuring of certain, especially critical, dimensions of the manufactured component. However such measurements are unpractical and difficult especially when the measured surfaces are more complicated, e.g. when they are not flat or cylindrical or spherical. In such cases it is often necessary to test the manufactured mechanical component only when it is installed in the device which it is designed for. And only from the fact that the device does not operate as it should do, the conclusion could be drawn that some of the mechanical components is faulty. When detecting dimensional and shape deviations of products in the process of high-temperature forming and machining, e.g. products with their surface temperature approaching 1000°C, it is not possible to measure the mechanical component directly but it is necessary to use contactless methods of measuring. It is possible to perform the measurement with equipment using a laser emission, which is transmitted from the laser source to a specific place of the product in question and subsequently the emission reflects off the product surface and is processed.

After the contactless detection of products dimensions so-called triangulation method of distance detection can be used, whereat the laser beams are deflected because of their scattering when reflected off the measured surface, and an angle of incidence is subsequently detected by a linear CCD element.

It is a drawback of the triangulation detector that its operating range in a practical test was from 100 mm to 300 mm between the detector and the surface. This relatively
short range is disadvantageous in case that it is necessary to protect the detector from the product heat by drawing it further at a distance longer than 500 mm. Another drawback was that undesirable reflections of the laser emission outside a field of view of the CCD detector occurred on the product uneven surface. Then the detector was not able to evaluate the correct distance and thus it showed measurement errors.

**Summary of the invention**

Above mentioned drawbacks of the state of the art are eliminated to a great extent by the method for determination of dimension and shape deviations of mechanical components when formed and machined, especially of mechanical components warmed up to a temperature exceeding 450°C, according to the invention, the subject matter of which consists in that the distance between a selected reference point and selected measuring points on the tested component is measured, after which an approximation of the component surface area fitted with the measured points is performed and then the dimensional and shape deviations of the mechanical components made by forming and machining are determined by comparison of this area with the component model area.

In an advantageous embodiment of the method, measuring of the distance between the selected reference point and the selected measuring points on the tested component is performed by a laser beam.

According to another advantageous embodiment of the method, the reflected laser beam coming from the selected measuring points on the tested component passes through a filter for filtering off the parasitic emission of the mechanical component radiation in the area nearing the wavelength of the laser used.

Above mentioned drawbacks of the state of the art are eliminated to a great extent also by an equipment for performing the above mentioned method, where the subject matter of the equipment consists in its containing the laser distance meter, the sensor of which is provided with pre-filter for filtering off the parasitic emission of the mechanical component radiation in the area nearing the wavelength of the laser used, and the laser distance meter is arranged on a carriage with a sensor of the laser distance meter carriage position and is provided with a sensor of the laser distance meter angular position in the plane perpendicular to the direction of the laser distance meter carriage movement.
According to an advantageous embodiment of the equipment, the laser distance meter is either laser radar or laser triangulation detector or laser interferometer.

**Brief description of the drawings**

The invention will be hereinafter described in details with reference to accompanying drawings, wherein

Fig. 1 is a schematic illustration of the first exemplary embodiment of the equipment for determination of dimension and shape deviations of mechanical components in the process of forming and machining according to the invention, and

Fig. 2 is a schematic illustration of the second exemplary embodiment of the equipment for determination of dimension and shape deviations of mechanical components in the process of forming and machining according to the invention.

**Detailed description of preferred embodiments**

In an exemplary embodiment of the method for determination of dimension and shape deviations of mechanical components in the process of forming and machining, especially the mechanical components 1 warmed up to temperature over 450°C, the distance between the selected reference point and the measuring points selected on that part of area of the tested mechanical component 1, which is facing the reference point, is measured, after which approximation of the area fitted with the measured points is performed and then the dimensional and shape deviations of the mechanical component 1 are determined by comparison of this area with the mechanical component 1 model area. By machining any manufacturing process is meant here, whereat a shape of the processed material is being changed by external force effect, such as forging, casting, drawing, pressing, cutting, rolling and the like.

In an exemplary procedure, during the measuring the reference point moves along a line that is parallel with the longitudinal axis of the tested mechanical component 1, whereas the measuring is performed in cylindrical coordinates and measured values of the distance between the reference point and the selected points on the tested mechanical component are subsequently converted to Cartesian coordinates, whereas the reference point is positioned on the axis of symmetry of the cylindrical system of coordinates or close to it.

In another exemplary procedure, the measuring proceeds in spherical coordinates and measured values of the distance between the reference point and
the selected points on the tested mechanical component 1 are subsequently converted to Cartesian coordinates, whereas the reference point is positioned in the origin of the spherical system of coordinates or close to it.

Measuring of the distance between the selected reference point and the selected measuring points on the tested mechanical component 1 is performed by a laser beam 11, which after being reflected from the tested mechanical component 1 passes through the filter 4 for filtering off the parasitic emission of the mechanical component 1 radiation in the area nearing the wavelength of the laser used. Determination of a shape deviation is often performed with the mechanical component 1, which has a shape of an axisymmetrical object, e.g. a cylindrical rod, whereas, after determination of the distance of the selected points on the object surface near the reference point and based on the knowledge of these distances, parameters of the surface of revolution, which fits best to the expected course of the mechanical component 1 shape, are calculated, and afterwards these parameters are compared with the parameters of the surface of revolution of the model, which determines an ideal shape of the object manufactured.

Another time, determination of a shape deviation is performed with the mechanical component 1 having a shape of a thin sheet, which goes out of a rolling furnace in a hot state. In such a case the shape of the sheet is determined very easily just by scanning perpendicular to the sheet surface, and it is not necessary to calculate surfaces of revolution.

With reference to Fig. 1, it illustrates schematically the first exemplary embodiment of the equipment for determination of dimension and shape deviations of the mechanical component 1 of a rod shape in the process of forming and machining, according to the invention. In this particular case measuring of straightness of the component axis is the object. This equipment includes a laser distance meter 2, the sensor 3 of which is provided with a pre-filter 4 for filtering off parasitic emission of the mechanical component 1 radiation in the area nearing the wavelength of the laser used. The mechanical component 1 is fixed in a manipulator 5. The laser distance meter 2 is arranged on a carriage 6 having a sensor 7 of the laser distance meter 2 carriage position. Furthermore, the laser distance meter 2 is provided with a sensor 8 of the laser distance meter 2 rotation in the plane perpendicular to the direction of the laser distance meter 2 carriage movement.
In operation of the equipment, the mechanical component 1 is fixed by the manipulator 5 with the component 1 axis approximately parallel to the carriage 6 axis and the laser distance meter 2 transmits the laser beam 11 in the direction towards the mechanical component 1. The laser beam 11 point of incidence on the mechanical component 1 is determined by the sensor 7 of the laser distance meter 2 carriage position and by the sensor 8 of the laser distance meter 2 rotation in the plane perpendicular to the direction of the laser distance meter 2 carriage movement. At that the sensor 7 of the laser distance meter 2 carriage position reading determines position of the laser beam 11 place of incidence on the mechanical component 1 in the direction of the mechanical component 1 longitudinal axis, while the sensor 8 of the laser distance meter 2 rotation in the plane perpendicular to the direction of the laser distance meter 2 carriage movement reading determines the distance of the place of incidence of the laser beam 11 on the mechanical component 1 from the sensor 8 of the laser distance meter 2 rotation. The measuring proceeds in cylindrical coordinates and measured values of the distance between the reference point and the selected points on the tested mechanical component 1 are converted subsequently to Cartesian coordinates. The reference point is positioned on the axis of symmetry of the cylindrical system of coordinates or in its proximity. Set of the coordinates of the measuring points on the mechanical component is obtained by this measuring/Provided that the shape of the mechanical component cross-section is constant, it is possible to fit a series of geometric figures, representing cross-sections of the mechanical component perpendicular to its axis, with these points by a calculation. Afterwards it is possible to determine from them a set of coordinates of the points that are located on the actual axis of the mechanical component and from them subsequently the deviations from the desired shape, typically a line.

Parasitic emission of radiation in a spectral range of wavelengths, where the laser wavelength of the laser radar, i.e. 650 nm, was used, appeared to be a big problem with such measuring. For those reasons an analysis of spectrum of the radiation from the hot surface of the tested product was performed and subsequently the optical filter 4 for filtering off the parasitic emission of the mechanical component 1 radiation in the area nearing the wavelength of the laser used was selected which eliminated that area of radiation. But at the same time the filter 4 had to ensure lest the wavelength 650 nm be suppressed by the filter. Ability to filter off the heat part of
the radiation that emanated from the hot surface of the tested product was another requirement on the filter.

A system designed this way optimises accuracy of the dimensions measurement and combines it with simplicity of the plane of interest measurement. It is the system in cylindrical coordinates and their conversion to 3D plane x, y, z is a mathematical problem only.

In exemplary embodiment of the equipment according to the invention, the resolution of positioning on axis x better than 1 μm was achieved. Maximum range of positioning on axis x depends on the length of the rail installed, in the exemplary embodiment this range was 380 mm. Tilt resolution was $1 \times 10^{-3}$°, maximum tilt range was ±25° from the plane xy. The measuring system provided data in cylindrical coordinates: displacement in direction of axis x, tilt angle $\phi$ and distance $r$ measured by the laser distance meter 2. Theoretical resolution of the distance measured by the laser distance meter 2 is 0.1 mm.

With reference to Fig. 2, it illustrates schematically the second exemplary embodiment of the equipment for determination of dimension and shape deviations of mechanical components 1 having a rod shape in the process of forming and machining according to the invention. This equipment includes the laser distance meter 2, the sensor 3 of which is provided with the pre-filter 4 for filtering off the parasitic emission of the mechanical component 1 radiation in the area nearing the wavelength of the laser used. The mechanical component 1 is fixed in the manipulator 5. The laser-distance meter 2 is arranged on a horizontal turntable 9. Furthermore, the laser distance meter 2 is provided with a sensor 10 of the laser distance meter 2 rotation in the plane defined by the laser beam 11 and the longitudinal axis of the mechanical component 1, and with the sensor 8 of the laser distance meter 2 rotation in the plane perpendicular to the direction of the longitudinal axis of the mechanical component 1.

In operation of the equipment, the mechanical component 1 is fixed by the manipulator 5 with its axis approximately so that the laser beam 11 may fall perpendicularly to the longitudinal axis of the mechanical component 1 approximately in the axis midpoint. The laser beam 11 point of incidence on the mechanical component 1 can be determined from data of the sensor 8 of the laser distance meter 2 rotation in the plane perpendicular to the longitudinal axis of the mechanical component 1 and from data on the horizontal turntable 9 rotation. Indication of the
sensor 8 of the laser distance meter 2 rotation in the plane perpendicular to the
direction of the laser distance meter 2 carriage movement determines the distance of
the incidence point of the laser beam 11 on the mechanical component 1 from the
sensor 8 of the laser distance meter 2 rotation. The measured data are converted to
spherical coordinates and the measured values of the distance between the
reference point and the selected points on the tested component are subsequently
converted to Cartesian coordinates. The reference point is positioned in the origin of
the spherical system of coordinates or in its proximity. Set of coordinates of the
measuring points on the mechanical component is obtained by the measuring.

Provided that the shape of the mechanical component cross-section is constant, it is
possible to fit with these points a series of geometric figures, representing cross-
sections of the mechanical component perpendicular to its axis by a calculation.
Afterwards it is possible to determine from them a set of coordinates of the points
that are located on the actual axis of the mechanical component and from them
subsequently the deviations from the desired shape, typically a line.

The complete measuring was computerized under use of a control software,
supporting electronics for the sensed data transfer into PC and electronics to control
the laser distance meter 2 position on axis x and its inclination at the desired angle
were realized.

Afterwards the system was arranged on a base plate, and wiring and high
thermal heat protecting elements were completed.
The system on principal of the laser distance meter 2 turned out to be very suitable,
because the meter was able to produce correct distance values even on uneven
parts of the tested surface. Also its operating range of 0.3 m to 30.0 m predetermined
this sensor to its using in desired experimental system.

**Industrial applicability**

Method and equipment according to the invention can be used in industry for
determination of dimension and shape deviations of mechanical components in the
process of forming and machining, especially mechanical components warmed-up to
temperature over 450°C.
Claims

1. A method for determination of dimension and shape deviations of mechanical components (1) in a process of forming and machining, especially of mechanical components (1) warmed-up to a temperature over 450°C characterized in that the distances between a selected reference point and measuring points selected on that part of the area of the tested mechanical component (1), which faces the reference point, is measured, after which an approximation of the surface fitted with the measured points is performed and then the dimension and shape deviations of the mechanical component (1) are determined by comparing said surface with the surface of the mechanical component (1) model.

2. A method according to claim 1, characterized in that during the course of measuring the reference point is moving along a line parallel with the longitudinal axis of the tested mechanical component (1), while the measuring is performed in cylindrical coordinates and the measured values of distances between the reference point and the selected points on the tested component are subsequently converted to Cartesian coordinates, the reference point being positioned on the cylindrical system of coordinates axis of symmetry or close to it.

3. A method according to claim 1, characterized in that the measuring is performed in spherical coordinates and the measured values of distances between the reference point and the selected points on the tested component are subsequently converted to Cartesian coordinates, the reference point being positioned in the origin of the spherical system of coordinates or close to it.

4. A method according to any of claims 1 to 3, characterized in that the measuring of distances between the reference point and the selected points on the tested mechanical component (1) is performed by a laser beam (11).

5. A method according to claim 4, characterized in that the reflected laser beam (11) coming from the selected measuring points on the tested mechanical component (1) passes through a filter for filtering off parasitic emission of the
mechanical component (1) radiation in the area nearing the wavelength of the laser used.

6. An equipment for performing the method according to claims 1 to 5, characterized in that it includes a laser distance meter (2), the sensor (3) of which is provided with a pre-filter (4) for filtering off the parasitic emission of the mechanical component (1) radiation in the area nearing the wavelength of the laser used, and the laser distance meter (2) is arranged on a carriage (6) with a sensor (7) of the laser distance meter (2) carriage position, and is provided with a sensor (8) of the laser distance meter (2) angular position in the plane perpendicular to the direction of the mechanical component (1) longitudinal axis.

7. An equipment for performing the method according to claims 1 to 5, characterized in that it includes a laser distance meter (2), a sensor (3) of which is provided with a pre-filter (4) for filtering off the parasitic emission of the mechanical component (1) radiation in the area nearing the wavelength of the laser used, and the laser distance meter (2) is arranged on a horizontal turntable (9) and is provided with a sensor (10) of the horizontal turntable (9) angular position in the plane defined by the laser beam (11) of the laser meter (2) and the mechanical component (1) longitudinal axis; and with a sensor (8) of the laser distance meter (2) angular position in the plane perpendicular to the mechanical component (1) longitudinal axis direction.

8. An equipment according to claims 6 or 7, characterized in that the laser distance meter (2) is a laser radar.

9. An equipment according to claims 6 or 7, characterized in that the laser distance meter (2) is a laser triangulation detector.

10. An equipment according to claims 6 or 7, characterized in that the laser distance meter (2) is a laser interferometer.
# INTERNATIONAL SEARCH REPORT

## A. CLASSIFICATION OF SUBJECT MATTER

### INV.
- B21B38/02
- B21B38/04
- G01B11/24

### ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

### Minimum documentation searched (classification system followed by classification symbols)
- B21B
- G01B

### Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[Further documents are listed in the continuation of Box C.]

[See patent family annex.]

*Special categories of cited documents:

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### Date of the actual completion of the international search

6 February 2013

### Date of mailing of the international search report

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### Name and mailing address of the ISA/

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### Authorized officer

Area, G iovanni

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