

Method and device for measuring the damage of a hollow airplane component or hollow gas turbine component

The invention relates to a device for measuring the damage of a hollow airplane component or hollow gas turbine component having the features of the preamble of claim 1 and to a method for measuring the damage of a hollow airplane component or hollow gas turbine component having the features of the preamble of claim 7.

Airplane components are exposed to high strain in operation. As well as components made of composite materials, such as structural components, or metal components, such as landing gear components, this may lead to damaging crack formation in particular in the components of the airplane engine. Similar damage situations also occur in other gas turbines, for example stationary gas turbines. In gas turbines, combustion chamber components are particularly severely affected by the crack formation. For reasons of weight, hollow components are used in this context where possible, where the strength of the components allows.

Cracks are local material separations within a structure or within a component. The occurrence of a crack is generally a local event in the microstructure of the surface, which is generally caused by lattice defects in the microstructure or by cyclical operating loads. Cracks generally propagate perpendicular to the acting normal stress. This propagation is referred to as being controlled by normal stress.

In the case of gas turbine parts, cracks occur as a result of high thermal and mechanical strain. On the one hand, the crack formation is caused by the prevailing high temperatures, and on the other hand, the oscillations from the high-pressure compressor and the high-pressure turbine promote crack growth and crack formation. In addition, short-term thermal material strains during the start-up of the gas turbine and possibly during the take-off phase of the airplane promote crack formation.

Solid particles that are sucked into the gas turbine, such as sand and dust, contribute greatly to erosion on gas turbine components. Further, the long-term thermal strains during the operating phase of the gas turbine contribute to the geometric shape of the gas turbine

components undergoing change. In this context, it is often problematic to establish the deviation in shape exactly with respect to the original contour after erosion or deformation.

In the maintenance of airplane and/or gas turbine components, the main problem is detecting the cracks and geometric changes (for example due to erosion) that have occurred in operation and repairing the components by way of suitable measures. As a result of the individually varying crack or damage development, this often turns out to be difficult.

Known methods for measuring damage comprise a range of non-destructive testing methods. Currently used methods comprise for example the color penetration method, ultrasonic testing, eddy current testing, X-ray testing and magnetic particle testing.

If the damage is measured manually using the appropriate sensors, the quality of the damage measurement is highly dependent on the experience and diligence of the tester. Further, the results have to be recorded, and this involves considerable effort, in particular in the case of paper documentation. Damage measurement thus requires a high level of training and very high qualification of the tester.

To simplify measuring the outer geometry and inner geometry, it is further known from US 7,921,575 B2 to arrange a sensor, for measuring the external contour, and an ultrasonic sensor, for measuring possible internal defects of a turbine blade, on a measurement head. The ascertained measurement data are passed to a processing device for processing and storing the measurement values. Further, a display device is provided, which is connected to the processing device and on which the ascertained measurement values are displayed.

It is further known in principle from WO 2012/159721 A1 to use a sensor device having white-light interferometry for crack testing which makes particularly high resolution of the geometry of the cracks possible.

Against this background, the object of the invention is to provide a device and a method that make further-improved damage measurement possible.

To achieve the object, a device having the features of claim 1 and a method having the features of claim 7 are proposed. Further preferred embodiments may be derived from the independent claims, the drawings, and the corresponding description.

To achieve the object of the invention, claim 1 proposes a device for measuring the damage of a hollow airplane component or hollow gas turbine component having a coordinate measurement arm, on which a first sensor device comprising an external contour sensor for detecting the external contour of the component and a second sensor device comprising an ultrasonic sensor for detecting the contour of the cavity in the component are provided, the basic idea of the invention being that a third sensor device comprising a white-light interferometer and/or a laser triangulation sensor is provided on the coordinate measurement arm.

The proposed device thus comprises a coordinate measurement arm comprising three different sensor types. First, an external contour sensor for example in the form of a touch probe or a contactless contour scanner is provided, by means of which the external contour of the component is detected. In this context, the position of the component with respect to a reference coordinate system defined by the coordinate measurement arm can be detected. In this context, the detection of the position and shape of the leading edge is of particular importance. Further, larger defects in the outer surface can already be localized by the external contour sensor. A second sensor device comprising an ultrasonic sensor, by means of which the internal contour of the cavity of the component is detected, is further provided on the coordinate measurement arm. The internal contour of the cavity of the component is the contour that is not subject to wear regardless of the duration of operation and thus always corresponds to the contour after production, in other words the contour when new. The internal contour can thus be used as a reference contour for evaluating the wear of the external contour. Further, according to the invention a third sensor device comprising a white-light interferometer is provided, which makes possible very precise measurement of the wear locations down to the range of ± 10 nanometers. Alternatively, a laser triangulation sensor may also be used, which likewise makes possible very precise measurement of the wear locations to a precision of $\pm 1 \mu\text{m}$ in the depth direction and ± 7 to $8 \mu\text{m}$ in width. As a result of the third sensor device, the defect localized using the first sensor device can be measured to a very high precision. The coordinate measurement arm can thus be understood as a type of sensor system comprising a plurality of sensor devices and by

means of which, as well as localizing the defects, the position of the defects with respect to the cavity or reference contour can also be detected. Further, the geometry of the defects can be measured to a very high precision. In this context, as a result of the knowledge of the reference contour and the measured external contour, the thickness progression of the component wall in the peripheral direction, and in particular the thickness in the region of the defects, can be measured to a very high precision.

Preferably, all sensor devices have a defined position on the coordinate measurement arm. In this way, at the time of the measurement, a precisely detectable orientation and position of the sensor devices, in particular of the second and third sensor devices, can be ascertained. This makes possible more precise allocation of measurement values of the second and/or third sensor device to a position and orientation on the external contour, and this has a positive effect on the precision of the damage measurement.

Further, in an advantageous embodiment, the second and/or third sensor devices have a defined position with respect to the external contour sensor of the first sensor device, making it possible to achieve higher precision in the damage measurement.

Further, a processing device for processing the ascertained measurement values and an assistance system comprising a display device for displaying the processed measurement values may be provided. In the processing device, the ascertained measurement values can be processed immediately and displayed on the display device of the assistance system to assist the handler.

In this context, the processing device and/or the assistance system may in particular have a storage unit for storing the ascertained and processed measurement values. In this way, record-keeping is not required, and the measurement values are stored digitally, and can thus subsequently be used again as required in a processing device for preparing the component and in particular for controlling corresponding coating machines and cutting machines for recontouring the component.

In this context, in a further preferred embodiment, component-related characteristic values and/or repair specifications can be stored in the storage unit, further making it possible for handling instructions, generated as a function of the ascertained measurement values and

while taking into account the component-related characteristic values and/or repair specifications, to be displayable on the display device. The component-related characteristic values and repair specifications can be used for additionally simplifying the measurement value recording, in that corresponding handling instructions are conveyed to the handler by way of the display device. It may thus for example be necessary, when special defects are detected, that further measurement of the same defects are required, for which special measurements are required that are only taken in this case.

For this purpose, the first and/or second and/or third sensor devices may be controllable by the processing device and/or the assistance system. In particular, the measurement of the component using the third sensor device comprising the white-light interferometer and/or the laser triangulation sensor may be controlled by using the measurement values ascertained by the first sensor device.

Further, a clamping device may be provided, in which the component can be fixed, and a fourth sensor device may be provided, which detects the position of the component with respect to the clamping device or with respect to a reference point or reference coordinate system. The clamping device fixes the component, and the fourth sensor device detects the underlying orientation of the component. In this context, the fourth sensor device is assigned to the clamping device, and is thus independent of the coordinate measurement arm. The measurement values of the fourth sensor device can subsequently be used for controlling the coordinate measurement arm during the displacement movement in the direction of the component into an initial position of the measurement value acquisition that is individualized for the component. Alternatively, the position or reference position of the component may be ascertained using the coordinate measurement arm, and a coordinate system may be placed in the ascertained reference position.

Further, a method for measuring the damage of a hollow airplane component or hollow gas turbine component is proposed, using a coordinate measurement arm, comprising a first sensor device comprising an external contour sensor and a second sensor device comprising an ultrasonic sensor, it being proposed in particular that a third sensor device comprising a white-light interferometer and/or a laser triangulation sensor is provided and the damage is measured using a combination of the measurement values of the first, second and third sensor devices. The damage is thus measured using a combination of the

measurement values of the three sensor devices, in particular the individual advantages of the respective sensor devices being used here to improve the measurement value recording overall as a result of the combination of the measurement values of the sensor device.

In this way, damage can be ascertained very precisely in relation to the reference contour using only one coordinate measurement arm, and this has a positive effect on the process speed and in particular on the precision. The positive effect on the precision can be achieved in that the second and third sensor devices have a precisely detectable orientation and position at the time of the measurement as a result of the coordinate measurement arm. In the first sensor device comprising the external contour sensor, this is provided as a result of the system. The result of a measurement of the second and/or third sensor device starting from a point on the surface of the external contour can thus be ascertained much more precisely.

The external contour can be detected precisely using the external contour sensor. In this context, to increase the precision in the allocation of measurement values of the second and/or third sensor devices to a position on the external contour, the fact can advantageously be exploited that the second and/or third sensor device have a defined, in other words known and constant, distance or vector in relation to the coordinate measurement arm from the external contour sensor of the first sensor device on the coordinate measurement arm. In advantageous embodiments, the position of the sensor devices with respect to one another in relation to the coordinate measurement arm is defined and is used to increase the precision.

In this context, the internal contour of the cavity is detected by the ultrasonic sensor as a reference contour, the external contour of the component is detected by the external contour sensor, and the damage is detected by comparing the detected external contour with the reference contour. The internal contour of the hollow component is not subject to wear, since the surface of the internal contour is not exposed to mechanical loads. The internal contour thus forms an ideal reference surface for measuring the wear of the external contour.

In this context, the intended relative progression of the external contour with respect to the reference contour is preferably stored in a storage unit, and the damage is ascertained by comparing the ascertained actual progression of the external contour with respect to the

reference contour with the intended relative progression of the external contour with respect to the reference contour. Thus, not only the relative position of the defect but also the depth or material removal of the defect can be ascertained on the basis of absolute values.

It is further proposed that an assistance system comprising a display device and a storage unit is provided and a predetermined testing sequence, in which the detected measurement values are compared with predetermined boundary values, is stored in the storage unit, the assistance system displaying handling instructions on the display device to assist the testing sequence as a function of the measurement values exceeding or undershooting the predetermined boundary values. The assistance system serves to guide the handler, in such a way that the measurement values can also be recorded by a less experienced person. Further, as a result, the probability of errors as a result of testing steps being forgotten can be reduced.

Further, to achieve the object of the invention, a method is proposed, which may also independently be inventive.

In the advantageous method for measuring the damage of a hollow airplane or gas turbine component using a coordinate measurement arm, comprising a first sensor device having an external contour sensor and a second sensor device having an ultrasonic sensor, in one step the internal contour of the cavity is detected by the ultrasonic sensor as a reference contour and in a further step the external contour of the component is detected by the external contour sensor, and the damage is detected by comparing the detected external contour with the reference contour.

In this way, damage can be ascertained very precisely in relation to the reference contour in two process steps, using only one coordinate measurement arm, which has a positive effect on the process speed and in particular on the precision. In this context, the fact is exploited that the internal contour forms an ideal reference surface for measuring the wear of the external contour, since it is not subject to wear. The order of the two steps before the comparison may be selected as desired. The positive effect on the precision can be achieved in that, by way of the coordinate measurement arm, the ultrasonic sensor has a precisely detectable orientation and position at the time of the measurement. By that, the result of a measurement of the ultrasonic sensor, in other words for example the depth of the

internal contour starting from a point on the surface of the external contour, can be assigned much more precisely.

In addition, the external contour is precisely detected using the external contour sensor. In this context, advantageously, to increase the precision in the assignment of measurement values of the ultrasonic sensor to a position on the external contour, the fact can be exploited that the ultrasonic sensor and the external contour sensor on the coordinate measurement arm have a defined, in other words known and constant, distance or vector in relation to the measurement arm.

In an advantageous embodiment, a third sensor device comprising a white-light interferometer and/or a laser triangulation sensor is provided, the damage being measured using a combination of the measurement values of the first, second and third sensor devices. The damage is thus measured using a combination of the measurement values of the three sensor devices, in particular the individual advantages of the respective sensor devices are used here by the combination of the measurement values of the sensor devices to improve the measurement value acquisition as a whole.

Hereinafter, the invention is explained by way of preferred embodiments, with reference to the accompanying drawings, in which:

Fig. 1 shows a head of a coordinate measurement arm of a device according to the invention; and

Fig. 2 shows a device according to the invention comprising a processing device and an assistance system.

Fig. 1 shows an enlarged measurement head 3 of a coordinate measurement arm 2, which is shown schematically in Fig. 2 as a module of a superordinate device.

As well as the coordinate measurement arm 2, the device shown in Fig. 2 additionally comprises a clamping device 5, a processing device 1, a storage unit 15 and a display device 4. Here, the storage unit 15 is arranged in the housing of the processing device 1. The processing device 1 is connected, in terms of signals, to the coordinate measurement

arm 2, the display device 4 and the storage unit 15. A large number of data are stored in the storage unit 15, such as the intended progression of the external contour of a component 6 to be measured, test specifications and/or boundary values from the manufacturer, and explicit handling instructions as to how particular testing steps are to be performed.

The coordinate measurement arm 2 further has a socket or a corresponding mounting by means of which the coordinate measurement arm 2 is arranged or held in a defined position with respect to the clamping device 5 and the component 6 held therein. The coordinate measurement arm 2 itself is known, and comprises a device (not shown) for ascertaining the position in space of the measurement head 3 shown in Fig. 1. In this context, the coordinate measurement arm 2 is calibrated in relation to the clamping device 5 in an initial position.

A first sensor device 11, comprising an external contour sensor 7 in the form of a touch probe, a second sensor device 12, comprising an ultrasonic sensor 8, and a third sensor device 13, comprising a white-light interferometer 9 and/or a laser triangulation sensor or laser line triangulation sensor, are provided on the measurement head 3.

The hollow component 6 is measured in accordance with the following steps. Initially, the component 6 is clamped in the clamping device 5 using suitable clamping tools 17. In this context, a fourth sensor device 14, which detects the underlying orientation of the component 6 in the clamping device 5, is provided in the clamping device 5, it alternatively being possible for the position or else the reference position of the component to be ascertained using the coordinate measurement arm 2 and for a coordinate system to be placed in the ascertained reference position. If the component 6 can be held only in a single orientation in the clamping tool 17 of the clamping device 5, it would also be conceivable to detect the orientation of the clamping tool 17 with respect to the clamping device 5 using the fourth sensor device 14 and thus also to detect the orientation of the component 6 directly. Subsequently, the operator calibrates the device comprising the clamped component 6. The operator subsequently references the component 6 in a second step by passing the external contour sensor 7 over particular edges and surfaces of the component 6, such as the trailing edge. The orientation of the component 6 is thus referenced in a first step.

Hereinafter, the component 6 is further referred to as a hollow blade of an airplane engine or of a gas turbine in a specific application. In this case, the measurement head 3 is brought to

the leading edge of the blade along with the external contour sensor 7 of the first sensor device 11. Subsequently, the handler passes the external contour sensor 7 over the leading edge of the blade, the contour and position of possible defects on the leading edge of the blade being detected. Further, in particular the position of the leading edge of the blade can be detected. The data detected by the first sensor device 11 are subsequently passed to the processing device 1, where they are processed appropriately for further use. The operator thus marks potential defects using the external contour sensor 7 so as to make the position known to the system. Subsequently, the operator switches to the second sensor device 12 comprising the ultrasonic sensor 8 and detects for example the transition region from solid material to the hollow region of the blade.

Moreover, the internal contour of the cavity 16 in the blade is measured by the ultrasonic sensor 8, and is subsequently used as a reference contour. In the processing device 1, an actual thickness progression of the wall thickness of the hollow blade is subsequently calculated from the measurement values ascertained by the first and second sensor devices 11 and 12, and is compared with an intended thickness progression stored in the storage unit 15. From the difference, the existing defects can be localized and also quantitatively calculated. After the measurement values of the first and second sensor devices 11 and 12 are taken and the ascertained measurement values are processed in the processing device 1, a complete damage profile is present. For further more precise measurement of the blade, the measurement head 3 comprising the third sensor device 13 is passed along the external contour of the blade again, it also being possible for the guidance of the movement of the measurement head 3 to be controlled as a function of the measurement values ascertained by the first and/or second sensor devices 11 and 12 or simplified by way of handling instructions of the assistance system to the operator. Alternatively, the measurement value can be taken by the third sensor device 13, but also immediately after the measurement value is taken by the first and second sensor devices 11 and 12, during a single movement sequence of the measurement head 3. In this context, the third sensor device 13 may preferably be arranged on the measurement head 3 in such a way that, during the movement of the coordinate measurement arm 2 and the acquisition of the measurement value, the third sensor device 13 always passes over the relevant point on the surface of the component 6 after the first and second sensor devices 11 and 12. In this case, it is possible to control the activation of the third sensor device 13 comprising the white-light interferometer 9 and/or the laser triangulation sensor and/or the laser line triangulation

sensor as a function of the ascertained measurement values of the first and/or second sensor device 11 or 12, in other words only ever to activate it when a defect has been detected using the measurement values of the first and/or second sensor devices 11 and 12. After the conclusion of the position ascertainment of all damaged regions of the component 6 using the tactile measurement head 3, which is specially configured for the geometry of the component 6, the laser line triangulation sensor is activated, and the ascertained positions of the damaged regions are passed over with the measurement head 3, scanned, and measured. In this context, the assistance system can suggest and visualize an order of the regions to be scanned. This can be implemented both using a screen and for example by way of targeted illumination or optical marking of the region to be scanned.

In this context, the processing device 1 is formed together with the storage unit 15 and the display device 4 to form an assistance system, which conveys handling instructions that facilitate carrying out the measurement to the handler on the display device. In this context, all process data required for the evaluation and calculation are stored in the central processing device 1. In this context, the handling instructions are generated while taking into account the individually ascertained measurement values, the data stored in the storage unit 15, such as the intended thickness progression stored there, or the intended external contour of the component 6 or manufacturer-specified instructions as to how the measurement is to be carried out. Further, the processing device 1 may serve as a central data management system and data processing system of the inspection process, as an interface for data exchange with connected IT systems, while the assistance system serves for user-friendly and reliable control of the overall system and for guiding the user through the work sequence. The assistance system thus digitally images the entire inspection process. Further, the device is controlled via the assistance system, and the assistance system provides possibilities for collaboration between the operator and additional networks, such as the development or quality division.

Measuring the defects or the external contour of the component 6 using the third sensor device 13 comprising the white-light interferometer 9 has the advantage of high-precision measurement of the defects in the range of ± 10 nanometers or, if a laser triangulation sensor is used, to a precision of $1\text{ }\mu\text{m}$ in the depth direction and 7 to $8\text{ }\mu\text{m}$ (point distance) in the width direction.

As a result of the proposed solution, the component 6 can be measured by a partially automated measurement process using an assistance system that assists the handler. Further, the measurement and the surface inspection can be objectively reproduced by way of the ascertained measurement values, in such a way that the surface inspection can be tracked and reproduced in the event of subsequently occurring damage. The measurement device on the measurement head 3 consists of the three sensor devices 11, 12 and 13, which can perceive all measurement functions of the component inspection. As a result of the central processing device 1, the necessary characteristic values, such as depth of the defect and diameter of the defect, are ascertained automatically or manually with the aid of the displayed measurement points and made available to the operator via the assistance system. Furthermore, the remaining wall thickness can be ascertained by the integrated ultrasonic sensor 8 and the position on the blade can be ascertained by the tactile external contour sensor 7. For all measurements, the spatial reference is achieved by way of the coupling of the processing device 1 to the coordinate measurement arm 2.

In the hollow blade, also referred to as a fan blade, the leading pocket edge is used as a reference for the evaluation of the damage experienced. The leading pocket edge characterizes the transition between the solid material and the thin-walled region of the blade on the flow entry side. The detection takes place by continuously measuring the wall thickness in the region of the edge by means of the ultrasonic probe 8 and the external contour sensor 7, the edge specifically being detected by way of the jump in wall thickness and a resulting characteristic change in measurement value in the region of the transition from the solid to the hollow region, and interpolation subsequently being carried out by way of a spline along the entire length of the leading edge of the blade.

To reduce the complexity of the measurement task and ensure a consistently high process quality for the operator, all of the steps of the operation are guided and assisted by the assistance system. The assistance system provides inspection decisions by displaying tolerance deviations to the operator and suggesting possible repair measures. Further, it visualizes any fault conditions for the operator and suggests corrective measures.

As a result of the intentionally partially automated configuration of the measurement device, by contrast with a fully automated device the process responsibility remains with the operator, meaning that the system complexity and the associated costs can be reduced and

also that the cognitive faculties of the operator can be made use of during the measurement sequence.

Thus, the entire device can also be made transportable, in such way that on-wing acquisition of measurement values in an airplane engine is also possible.

Claims:

1. Device for measuring the damage of a hollow airplane component or hollow gas turbine component (6) having
 - a coordinate measurement arm (2), on which
 - a first sensor device (11) comprising an external contour sensor (7) for detecting the external contour of the component (6) and/or for ascertaining the position of a damaged region, and
 - a second sensor device (12) comprising an ultrasonic sensor (8) for detecting the contour of a cavity (16) in the component (6) and/or for ascertaining a wall thickness of the damaged region and/or for ascertaining the wall thickness after a repair to the damaged region are provided,characterized in that
 - a third sensor device (13) comprising a white-light interferometer (9) and/or a laser triangulation sensor is provided on the coordinate measurement arm (2).
2. Device according to claim 1, characterized in that
 - a processing device (1) for processing the ascertained measurement values and an assistance system comprising a display device (4) for displaying the processed measurement values are provided.
3. Device according to claim 2, characterized in that
 - the processing device (1) and/or the assistance system have a storage unit (15) for storing the ascertained and processed measurement values.
4. Device according to claim 3, characterized in that
 - component-related characteristic values and/or repair specifications are stored in the storage unit (15), and
 - handling instructions, generated as a function of the ascertained measurement values and while taking into account the component-related characteristic values and/or repair specifications, are displayable on the display device (4).
5. Device according to either claim 2 or claim 3, characterized in that

- the first and/or second and/or third sensor devices (11, 12, 13) can be controlled by the processing device (1) and/or the assistance system.
6. Device according to any of the preceding claims, characterized in that
- a clamping device (5) is provided, in which the component (6) can be fixed, and
 - a fourth sensor device (14) is provided, which detects the position of the component (6) with respect to the clamping device (5) or with respect to a reference point or reference coordinate system.
7. Method for measuring the damage of a hollow airplane component or hollow gas turbine component (6), using
- a coordinate measurement arm (2), comprising
 - a first sensor device (11) comprising an external contour sensor (7) and
 - a second sensor device (12) comprising an ultrasonic sensor (8),
- characterized in that
- a third sensor device (13) comprising a white-light interferometer (9) and/or a laser triangulation sensor is provided, and
 - the damage is measured using a combination of the measurement values of the first, second and third sensor devices (11, 12 13).
8. Method according to claim 7, characterized in that
- the internal contour of a cavity (16) of the component is detected by the ultrasonic sensor (8) as a reference contour, and
 - the external contour of the component (6) is detected by the external contour sensor (7), and
 - the damage is detected by relating the detected external contour to the reference contour.
9. Method according to claim 8, characterized in that
- the intended relative progression of the external contour with respect to the reference contour is stored in a storage unit (15), and
 - the damage is ascertained by comparing the actual progression of the external contour with respect to the reference contour with the intended relative progression of the external contour with respect to the reference contour.

10. Method according to any of claims 7 to 9, characterized in that
 - an assistance system comprising a display device (4) and a storage unit (15) is provided, and
 - a predetermined testing sequence, in which the detected measurement values are compared with predetermined boundary values, is stored in the storage unit (15),
 - the assistance system displaying handling instructions on the display device (4) to assist the testing sequence as a function of the measurement values exceeding or undershooting the predetermined boundary values.
11. Method according to any of claims 7 to 10, characterized in that
 - the component position and the position of damage to the component (6) are detected using the first sensor device (11), and
 - the third sensor device (13) is controlled using the measurement values detected by the first sensor device (11).