

DESCRIPTION

Title of Invention: RESIDUAL-STRESS MEASUREMENT DEVICE
AND RESIDUAL-STRESS MEASUREMENT METHOD

5 **Technical Field**

[0001] The present disclosure relates to a residual stress measuring apparatus and a residual stress measuring method.

Background Art

10 [0002] An apparatus adapted to measure residual stress of a measuring object using X-rays is described in Patent Literature 1. The apparatus comprises an X-ray emitter adapted to emit X-rays to a measuring object, an imaging plate adapted to receive diffracted light from the measuring object, a rotating mechanism adapted to rotate the imaging plate, a laser device adapted to take a reading from the imaging plate,
15 and a controller adapted to control these components.

 [0003] The controller stores geometries of diffraction rings corresponding to residual stresses as references in advance. Then, the apparatus receives diffracted light from the measuring object using the imaging plate, acquires a diffraction ring by reading received light
20 intensity with the laser device while rotating the imaging plate with the rotating mechanism, and compares the geometry of the acquired diffraction ring with the geometries of reference diffraction rings. Then, the apparatus calculates the residual stress corresponding to the diffraction ring of the closest geometry as the residual stress of the
25 measuring object. When a measured diffraction ring is discontinuous, the apparatus calculates the residual stress by $\cos\alpha$ method based on the

geometry of the diffraction ring.

Citation List

Patent Literature

[0004] Patent Literature 1: Japanese Unexamined Patent Publication
5 No. 2013-113734

Summary of Invention

Technical Problem

[0005] However, with the apparatus described in Patent Literature 1,
there is a risk that the measurement of residual stress may take time.
10 For example, since it is necessary to acquire signals by rotating the
imaging plate, signal reading may take time. In the present technical
field, it is desired to reduce the measurement time of residual stress.

Solution to Problem

[0006] A residual stress measuring apparatus according to one aspect of
15 the present invention comprises: an X-ray generating source adapted to
radiate X-rays toward a measuring object; a first detecting element
adapted to detect intensity of diffracted X-rays of the measuring object
at a first detecting position; a second detecting element adapted to detect
intensity of the diffracted X-rays of the measuring object at a second
20 detecting position different from the first detecting position; a moving
mechanism adapted to move each of the first detecting element and the
second detecting element along a straight line extending in a direction
orthogonal to a direction of incidence of the X-rays; a movement
control unit adapted to control respective detecting positions of the first
25 detecting element and the second detecting element by driving the
moving mechanism; and a stress calculation unit adapted to calculate

residual stress of the measuring object based on intensity peaks of the diffracted X-rays detected, respectively, by the first detecting element and the second detecting element each moved by the moving mechanism.

5 [0007] The apparatus comprises the first detecting element adapted to detect the intensity of diffracted X-rays of a measuring object at a first detecting position and the second detecting element adapted to detect the intensity of the diffracted X-rays of the measuring object at a second detecting position different from the first detecting position, using the
10 moving mechanism and the movement control unit. With this configuration, diffracted X-rays can be obtained at two angles by a single X-ray irradiation. Furthermore, by moving, respectively, along straight lines extending in directions orthogonal to a direction of incidence of the X-rays, the first detecting element and the second
15 detecting element can acquire respective X-ray intensity distributions for each element (diffraction peaks). Also, because the residual stress of a measuring object can be calculated by acquiring at least two diffraction peaks, the need to acquire all data on a diffraction ring by rotating the imaging plate is eliminated. Thus, compared to
20 conventional residual stress measuring apparatus, measurement time of residual stress can be reduced.

[0008] According to one embodiment, the movement control unit may synchronize movement of the first detecting element and movement of the second detecting element with each other. In this case, compared
25 to when the first detecting element and the second detecting element are controlled individually, the measurement time of residual stress can be

reduced.

[0009] A residual stress measuring method according to another aspect of the present invention is a residual stress measuring method for measuring residual stress of a measuring object using a residual stress measuring apparatus equipped with an X-ray generating source, a first detecting element adapted to detect intensity of diffracted X-rays of the measuring object at a first detecting position, a second detecting element adapted to detect intensity of the diffracted X-rays of the measuring object at a second detecting position different from the first detecting position, and a moving mechanism adapted to move each of the first detecting element and the second detecting element along a straight line extending in a direction orthogonal to a direction of incidence of the X-rays, the residual stress measuring method comprising: an X-ray irradiation step of radiating X-rays toward the measuring object; a movement control step of moving the first detecting element and the second detecting element by driving the moving mechanism; and a stress calculation step of calculating residual stress of the measuring object based on intensity peaks of the diffracted X-rays of the measuring object detected, respectively, by the first detecting element and the second detecting element during execution of the movement control step.

[0010] According to one embodiment, movement of the first detecting element and movement of the second detecting element may be synchronized with each other in the movement control step.

[0011] The residual stress measuring method described above provides advantageous effects similar to those of the residual stress measuring

apparatus described above.

Advantageous Effects of Invention

[0012] According to aspects and embodiments of the present invention, the measurement time of residual stress can be reduced.

5 Brief Description of Drawings

[0013] [Figure 1] Figure 1 is a schematic diagram describing a configuration of a residual stress measuring apparatus according to the present embodiment.

10 [Figure 2] Figure 2 is a diagram describing a schematic configuration of the residual stress measuring apparatus according to the present embodiment.

[Figure 3] Figure 3 is a schematic diagram describing a detecting position of the residual stress measuring apparatus according to the present embodiment.

15 [Figure 4] Figure 4 is a schematic diagram describing a diffraction ring.

[Figure 5] Figure 5 is a flowchart showing a residual stress measuring method according to the present embodiment.

Description of Embodiments

20 [0014] The present embodiment will be described below with reference to the drawings. Note that in the following description, same or equivalent elements are denoted by the same reference signs and redundant description thereof will be omitted.

25 [0015] A residual stress measuring apparatus 1 according to the present embodiment is an apparatus adapted to measure residual stress of a measuring object using X-rays. The residual stress measuring apparatus 1 can be adopted, for example, on a factory line to check

quality of manufactured products, but this is not restrictive. The measuring object, for example, is non-orientated (isotropic crystalline structure), and can be formed of a polycrystalline metallic material.

[0016] Figure 1 is a schematic diagram describing a configuration of the residual stress measuring apparatus 1 according to the present embodiment. As shown in Figure 1, the residual stress measuring apparatus 1 is equipped with an apparatus body 100 including an X-ray generating source 10 as well as with a control apparatus 200.

[0017] The apparatus body 100 is a box-shaped casing which houses, for example, the X-ray generating source 10 therein. The X-ray generating source 10 is a device which comprises an X-ray tube and generates X-rays of a predetermined wavelength. The X-ray generating source 10 is fixed, for example, to the apparatus body 100. Regarding X-rays, X-rays of an appropriate wavelength are used according to a measuring object S. A window (an example of a collimator: not shown) for X-ray irradiation is formed in a front face of the apparatus body 100. The X-rays generated by the X-ray generating source 10 are radiated toward the measuring object S through the window.

[0018] The apparatus body 100 comprises a first detecting element 11A and a second detecting element 11B. Here, the first detecting element 11A and second detecting element 11B are placed on a side face of the apparatus body 100 in which the window (not shown) for X-ray irradiation is formed. The first detecting element 11A and second detecting element 11B detect respective intensities of the diffracted X-rays of the measuring object S. The first detecting element 11A is a

zero-dimensional X-ray intensity measuring element.
"Zero-dimensional" means that the X-ray intensity is measured at a
placement location of the element. That is, the first detecting element
11A differs from a one-dimensional line sensor in which a plurality of
5 elements are placed along a straight line and a two-dimensional imaging
plate in which a plurality of elements are placed in a plane. The
second detecting element 11B is also a zero-dimensional X-ray intensity
measuring element. As the first detecting element 11A and second
detecting element 11B, scintillation counters are used, for example.

10 [0019] The apparatus body 100 comprises a moving mechanism 120
adapted to move each of the first detecting element 11A and second
detecting element 11B along a straight line extending in a direction
orthogonal to a direction of incidence of the X-rays. The straight line
extending in a direction orthogonal to a direction of incidence of the
15 X-rays means a straight line on a plane with a normal vector coinciding
with incident X-rays. In the example of Figure 1, the moving
mechanism 120 moves the first detecting element 11A and second
detecting element 11B along a straight line extending in an X direction.
As the moving mechanism 120, an electric actuator is used, for
20 example. In a more specific example, the moving mechanism 120
comprises, for example, an electric motor 121, a ball screw portion 122,
and nut portions 123A and 123B. The electric motor 121 is connected
to a screw shaft of the ball screw portion 122 so as to give a turning
force around an axial direction. The nut portions 123A and 123B are
25 attached to the ball screw portion 122 in such a way as to be movable in
the axial direction. The first detecting element 11A is attached to the

nut portion 123A while the second detecting element 11B is attached to the nut portion 123B. When the electric motor 121 operates, the screw shaft of the ball screw portion 122 rotates, and the nut portions 123A and 123B move in the same direction in synchronization. That is, the first detecting element 11A and second detecting element 11B move in the same direction along the same screw shaft in synchronization. The first detecting element 11A and second detecting element 11B can change a detecting position of X-ray intensity on straight line using the moving mechanism 120.

[0020] The first detecting element 11A detects the intensity of the diffracted X-rays of the measuring object S at a first detecting position. The second detecting element 11B detects the intensity of the diffracted X-rays of the measuring object S at a second detecting position different from the first detecting position. The first detecting position and second detecting position can be varied according to material of the measuring object S and focal length. According to the present embodiment, the first detecting element 11A and second detecting element 11B move the same preset distance in synchronization. The preset distance is a distance within a range in which a necessary diffraction intensity distribution can be obtained.

[0021] The moving mechanism 120 is connected to the control apparatus 200. The control apparatus 200 is made up of a general-purpose computer which comprises a CPU (Central Processing Unit), a ROM (Read Only Memory), a RAM (Random Access Memory), a HDD (Hard Disk Drive), and the like. The control apparatus 200 comprises, for example, a processing unit 201, an input

device 202, and an output device 203.

[0022] Figure 2 is a diagram describing a schematic configuration of the residual stress measuring apparatus according to the present embodiment. As shown in Figure 2, the processing unit 201 comprises an input/output unit 20, a movement control unit 21, a stress calculation unit 22, and a storage unit 23.

[0023] The input/output unit 20 includes communications equipment such as a network card and an input-output device such as a graphics card. For example, the input/output unit 20 is connected with the electric motor 121 in such a way as to be ready to communicate. The input/output unit 20 is connected, for example, with the input device 202 and output device 203 in such a way as to be ready to communicate. Furthermore, the input/output unit 20 is connected to the first detecting element 11A and second detecting element 11B. The movement control unit 21 and stress calculation unit 22 described below exchange information with each component via the input/output unit 20.

[0024] The movement control unit 21 controls the respective detecting positions of the first detecting element 11A and second detecting element 11B by driving the moving mechanism 120. For example, the movement control unit 21 preliminarily acquires a peak appearance angle determined based on material making up the measuring object S and controls the respective detecting positions of the first detecting element 11A and second detecting element 11B so as to include the peak appearance angle. The peak appearance position determined based on the material making up the measuring object S is stored, for example, in the storage unit 23.

[0025] Figure 3 is a schematic diagram describing a detecting position of the residual stress measuring apparatus 1 according to the present embodiment. Figure 3 shows a case in which incident X-rays X_{IN} are radiated toward the measuring object S and diffracted X-rays are outputted at a diffraction angle 2θ . In this case, a diffraction ring R is drawn by diffracted X-rays on a predetermined plane PL. Here, in the present embodiment, a case in which intensity peaks appear, respectively, at a detecting position corresponding to a 0-degree position on the diffraction ring of the diffracted X-rays and a detecting position corresponding to a 180-degree position on the diffraction ring of the diffracted X-rays and diffraction intensities are acquired in these portions (i.e., symmetrical points) is taken as an example. Figure 4 is a schematic diagram describing a diffraction ring. In Figure 4, parts corresponding to Figure 3 are denoted by the same reference signs. As shown in Figures 3 and 4, diffracted X-rays X_{R1} are detected at a first detecting position P1 corresponding to the 0-degree position on the diffraction ring and diffracted X-rays X_{R2} are detected at a second detecting position P2 corresponding to the 180-degree position on the diffraction ring R. In this case, the movement control unit 21 sets such that the first detecting element 11A will move in a range including the first detecting position P1 corresponding to the 0-degree position on the diffraction ring R. Likewise, the movement control unit 21 sets such that the second detecting element 11B will move in a range including the second detecting position P2 corresponding to the 180-degree position on the diffraction ring R. Consequently, diffracted X-rays at two angles are obtained by a single X-ray irradiation, and two X-ray

diffraction intensity distributions can be obtained.

[0026] The stress calculation unit 22 acquire diffraction peaks based on the X-ray diffraction intensity distributions (angle-intensity relationships) detected, respectively, at the first detecting position P1 and second detecting position P2. Here, two intensity peaks, an intensity peak corresponding to the 0-degree position on the diffraction ring R and an intensity peak corresponding to the 180-degree position on the diffraction ring R, can be obtained. The diffraction ring R_R of a broken line shown in Figure 4 is a diffraction ring in the absence of residual stress in the measuring object. Compared to the diffraction ring R_R in the absence of residual stress, a center location of the diffraction ring R in the presence of residual stress is displaced according to the residual stress. The stress calculation unit 22 calculates a residual stress value using this difference. For example, the stress calculation unit 22 calculates the residual stress value using a $\cos\alpha$ method. With the $\cos\alpha$ method, residual stress is obtained from a slope of a ε - $\cos\alpha$ chart which describes a relationship between $\cos\alpha$ (α : central angle of diffraction) and distortion ε expressed in terms of distortions at four locations (ε_α , $\varepsilon_{\pi+\alpha}$, $\varepsilon_{-\alpha}$, $\varepsilon_{\pi-\alpha}$) on a diffraction ring. The stress calculation unit 22 calculates the slope (slope of a primary function) of the ε - $\cos\alpha$ chart using two points $\alpha = 0^\circ, 180^\circ$. Then, the stress calculation unit 22 obtains the residual stress by multiplying the slope of the primary function by an X-ray stress measurement multiplier. The X-ray stress measurement multiplier is a constant determined by Young's modulus, Poisson's ratio, the complement of a Bragg angle, and an X-ray incidence angle and is stored beforehand, for

example, in the storage unit 23. The stress calculation unit 22 may store the calculated residual stress in the storage unit 23 or output it to the output device 203.

[0027] This concludes description of the configuration of the residual stress measuring apparatus 1. Next, a residual stress measuring method using the residual stress measuring apparatus 1 will be described. Figure 5 is a flowchart showing the residual stress measuring method according to the present embodiment.

[0028] First, an adjustment process prior to residual stress measurement is performed. Figure 5(A) is a flowchart showing the adjustment process prior to residual stress measurement. As shown in Figure 5(A), an angle adjustment process (S10) is carried out first. In this process, an angle of incident X-rays with respect to the measuring object S is adjusted. For example, as shown in Figure 2, by adjusting a tilt angle θ_1 by tilting the apparatus body 100, the angle of the incident X-rays is adjusted. Note that the process of tilting the apparatus body 100 may be performed by a separate device (control unit and actuator) or a measurer. The angle of incidence being measured is fixed at a predetermined angle (single angle) by the process of S10.

[0029] Next, a focus adjustment process (S12) is performed. In this process, focus of the incident X-rays with respect to the measuring object S is adjusted. For example, as height of the measuring object S is changed or position of the apparatus body 100 is changed, the focus of the incident X-rays is adjusted. Note that the process of changing the height or position may be performed by a separate device (control unit and actuator) or a measurer.

[0030] This ends the flowchart shown in Figure 5(A). When the flowchart shown in Figure 5(A) ends, conditions in which the residual stress of the measuring object S can be measured are established. Then, the residual stress is measured. Figure 5(B) is a flowchart showing a method for measuring residual stress.

[0031] As shown in Figure 5(B), an X-ray irradiation process (S20: X-ray irradiation step) is carried out first. In the X-ray irradiation process of S20, X-rays are radiated toward the measuring object S from the X-ray generating source 10. Next, during execution of the X-ray irradiation process of S20, a measurement process (S22: movement control step) is carried out. In the measurement process of S22, the first detecting element 11A and second detecting element 11B are moved by the moving mechanism 120 and movement control unit 21 and two X-ray diffraction intensity distributions are obtained based on detection results during the movement. When the measurement process of S22 finishes, the X-ray irradiation may be terminated. Next, a residual stress calculation process (S24: stress calculation step) is carried out. In the residual stress calculation process of S24, two intensity peaks are acquired by the stress calculation unit 22 based on the two X-ray diffraction intensity distributions obtained during the movement. Then, by the stress calculation unit 22, the slope of the $\epsilon\text{-cos}\alpha$ chart is calculated and multiplied by an X-ray stress measurement multiplier, and the residual stress is calculated. Finally, the residual stress calculated by the stress calculation unit 22 is stored in the storage unit 23 or outputted to the output device 203.

[0032] This concludes the flowchart shown in Figure 5(B). By

performing the control process shown in Figure 5(B), it is possible to calculate the residual stress using the data obtained by moving the first detecting element and second detecting element.

[0033] As described above, the residual stress measuring apparatus 1 according to the present embodiment comprises the first detecting element 11A adapted to detect the intensity of diffracted X-rays at the first detecting position P1 and the second detecting element adapted to detect the intensity of diffracted X-rays at the second detecting position P2 different from the first detecting position P1, by the moving mechanism 120 and movement control unit 21. With this configuration, diffracted X-rays can be obtained at two angles by a single X-ray irradiation (irradiation at one angle). Furthermore, by moving, respectively, along straight lines extending in directions orthogonal to a direction of incidence of the X-rays, the first detecting element 11A and the second detecting element 11B can acquire respective X-ray intensity distributions for each element (diffraction peaks). Also, because the residual stress of the measuring object S can be calculated by acquiring at least two diffraction peaks, the need to acquire all data on a diffraction ring by rotating the imaging plate is eliminated. Thus, compared to conventional residual stress measuring apparatus, the measurement time of residual stress can be reduced.

[0034] Also, with the residual stress measuring apparatus 1 according to the present embodiment, since there is no need to comprise a mechanism for rotating the imaging plate or a reading mechanism, the apparatus is simplified and reduced in weight in comparison with conventional residual stress measuring apparatus. Consequently, the

apparatus becomes easier to install or can be structured to be easier to incorporate into another machine than the conventional residual stress measuring apparatus. Furthermore, as the apparatus configuration is simplified, production cost of the apparatus can be reduced in comparison with conventional residual stress measuring apparatus.

[0035] Furthermore, as the movement control unit 21 synchronizes the movement of the first detecting element 11A and the movement of the second detecting element 11B with each other, the measurement time of residual stress can be reduced, compared to when the first detecting element 11A and second detecting element 11B are controlled individually.

[0036] An embodiment of the present invention has been described above, the present invention is not limited to the embodiment described above. The present invention can be embodied in various forms resulting from various changes or improvements made to the above-described embodiment based on the knowledge of those skilled in the art.

[0037] Whereas, for example, an example in which the residual stress measuring apparatus 1 is adopted on a factory line has been described in the above embodiment, the residual stress measuring apparatus 1 may be installed on an apparatus not placed on a line. Also, an example in which the residual stress measuring apparatus 1 comprises the first detecting element 11A and the second detecting element 11B has been described in the above embodiment, it is sufficient if the residual stress measuring apparatus 1 comprises at least two detecting elements. That is, the residual stress measuring apparatus 1 may comprise three or more

detecting elements.

[0038] Also, whereas an example in which the moving mechanism 120 moves both the first detecting element 11A and second detecting element 11B using a set of the electric motor 121 and ball screw portion 122 has been described in the above embodiment, the first detecting element 11A and second detecting element 11B may be provided with respective electric motors and ball screw portions. In this case, the control apparatus 200 can control the movements of the first detecting element 11A and second detecting element 11B by controlling the respective electric motors of the first detecting element 11A and second detecting element 11B. By controlling two ball screw shafts, the control apparatus 200 can cause the first detecting element 11A and second detecting element 11B either to synchronize in synchronization or to move differently.

[0039] Furthermore, the residual stress measuring apparatus 1 according to the above embodiment may be incorporated into a shot peening apparatus or the like. In this case, the input/output unit 20 described in the above embodiment is configured to receive a signal outputted from a sequencer on a control board of the shot peening apparatus, and the measurement of residual stress is performed when the movement control unit 21 and stress calculation unit 22 operate based on the signal.

Reference Signs List

[0040] 1 ... residual stress measuring apparatus, 2θ ... diffraction angle, 10 ... X-ray generating source, 11A ... first detecting element, 11B ... second detecting element, 21 ... movement control unit, 22 ... stress

calculation unit, 120 ... moving mechanism

CLAIMS

1. A residual stress measuring apparatus comprising:
 - an X-ray generating source adapted to radiate X-rays toward a measuring object;
 - 5 a first detecting element adapted to detect intensity of diffracted X-rays of the measuring object at a first detecting position;
 - a second detecting element adapted to detect intensity of the diffracted X-rays of the measuring object at a second detecting position different from the first detecting position;
 - 10 a moving mechanism adapted to move each of the first detecting element and the second detecting element along a straight line extending in a direction orthogonal to a direction of incidence of the X-rays;
 - a movement control unit adapted to control respective detecting positions of the first detecting element and the second detecting element by driving the moving mechanism; and
 - 15 a stress calculation unit adapted to calculate residual stress of the measuring object based on intensity peaks of the diffracted X-rays detected, respectively, by the first detecting element and the second detecting element each moved by the moving mechanism.
- 20 2. The residual stress measuring apparatus according to claim 1, wherein the movement control unit synchronizes movement of the first detecting element and movement of the second detecting element with each other.
- 25 3. A residual stress measuring method for measuring residual stress of a measuring object using a residual stress measuring apparatus equipped with an X-ray generating source, a first detecting element

adapted to detect intensity of diffracted X-rays of the measuring object at a first detecting position, a second detecting element adapted to detect intensity of the diffracted X-rays of the measuring object at a second detecting position different from the first detecting position, and a moving mechanism adapted to move each of the first detecting element and the second detecting element along a straight line extending in a direction orthogonal to a direction of incidence of the X-rays, the residual stress measuring method comprising:

an X-ray irradiation step of radiating X-rays toward the measuring object;

a movement control step of moving the first detecting element and the second detecting element by driving the moving mechanism; and

a stress calculation step of calculating residual stress of the measuring object based on intensity peaks of the diffracted X-rays of the measuring object detected, respectively, by the first detecting element and the second detecting element during execution of the movement control step.

4. The residual stress measuring method according to claim 3, wherein movement of the first detecting element and movement of the second detecting element are synchronized with each other in the movement control step.