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(54) DISTANCE MEASURING DEVICE, FRICTION STIR WELDING APPARATUS, AND FRICTION STIR WELDING METHOD

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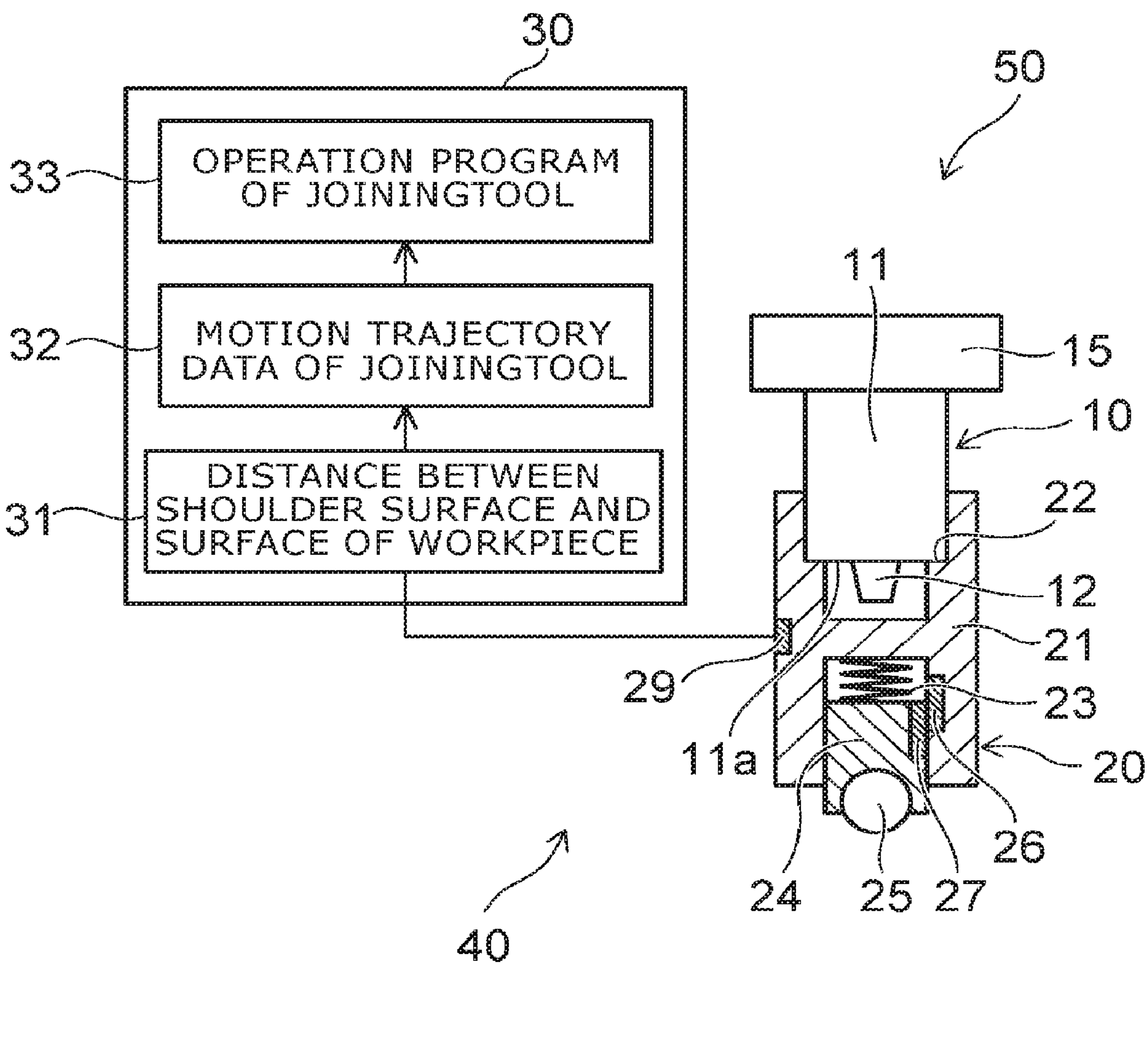
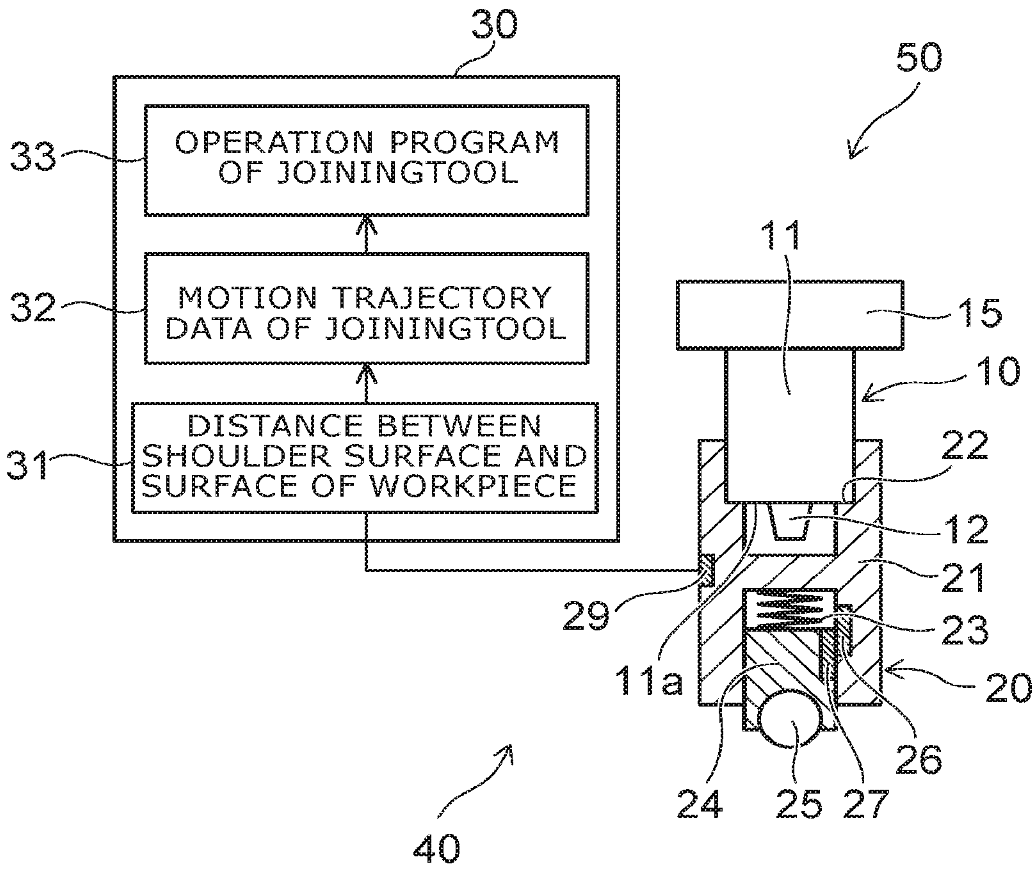
(57) **ABSTRACT**

The abutment portion touches with a shoulder surface of a joiningtool for friction stir welding. The tip portion is freely movable in a first direction connecting a surface of the workpiece and the shoulder surface in a state of contacting the surface of the workpiece. The detector is configured to detect a position of the tip portion in the first direction. The output unit is configured to output a data of the position of the tip portion in the first direction detected by the detector. The controller is configured to calculate a position of the tip portion to the abutment portion from the data of the position output from the output unit, and to calculate a distance between the shoulder surface of the joiningtool and the surface of the workpiece.

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50
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OPERATION PROGRAM OF JOININGTOOL
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MOTION TRAJECTORY DATA OF JOININGTOOL
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DISTANCE BETWEEN SHOULDER SURFACE AND SURFACE OF WORKPIECE
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11a
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FIG. 1

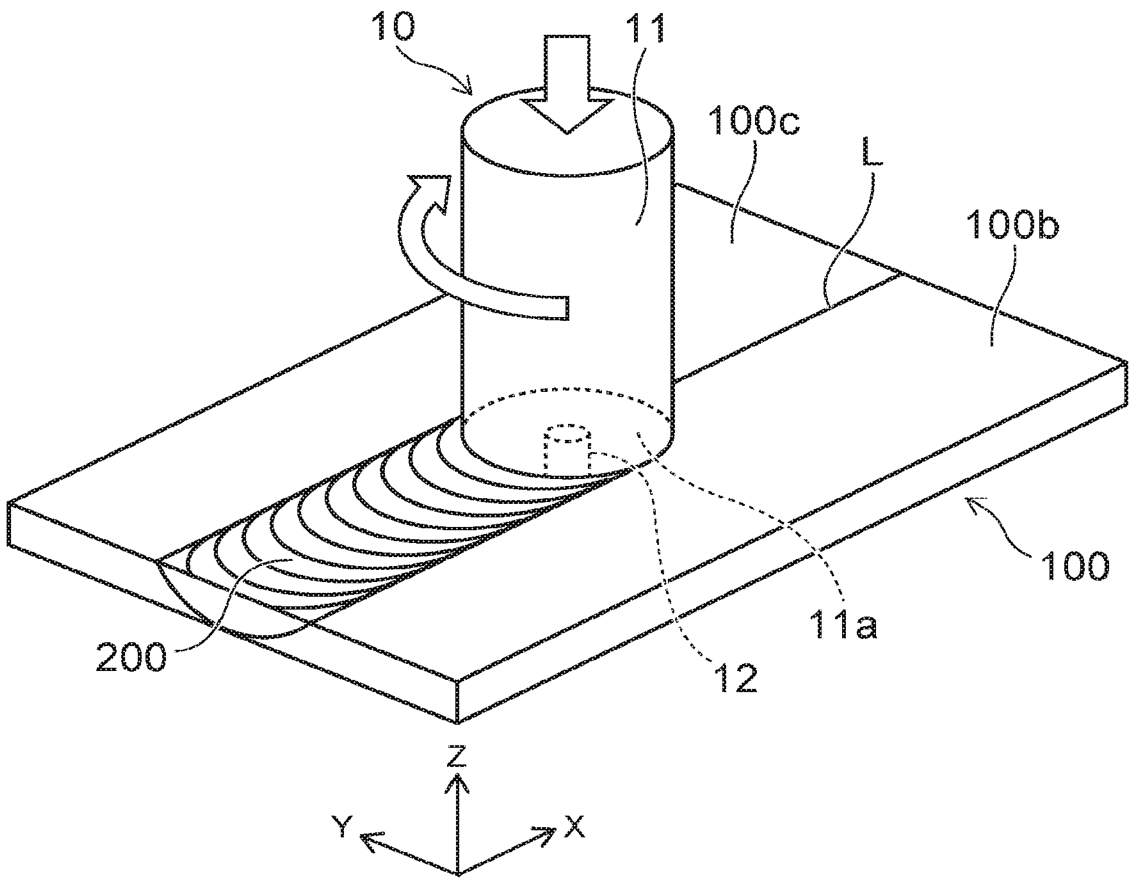

FIG. 2

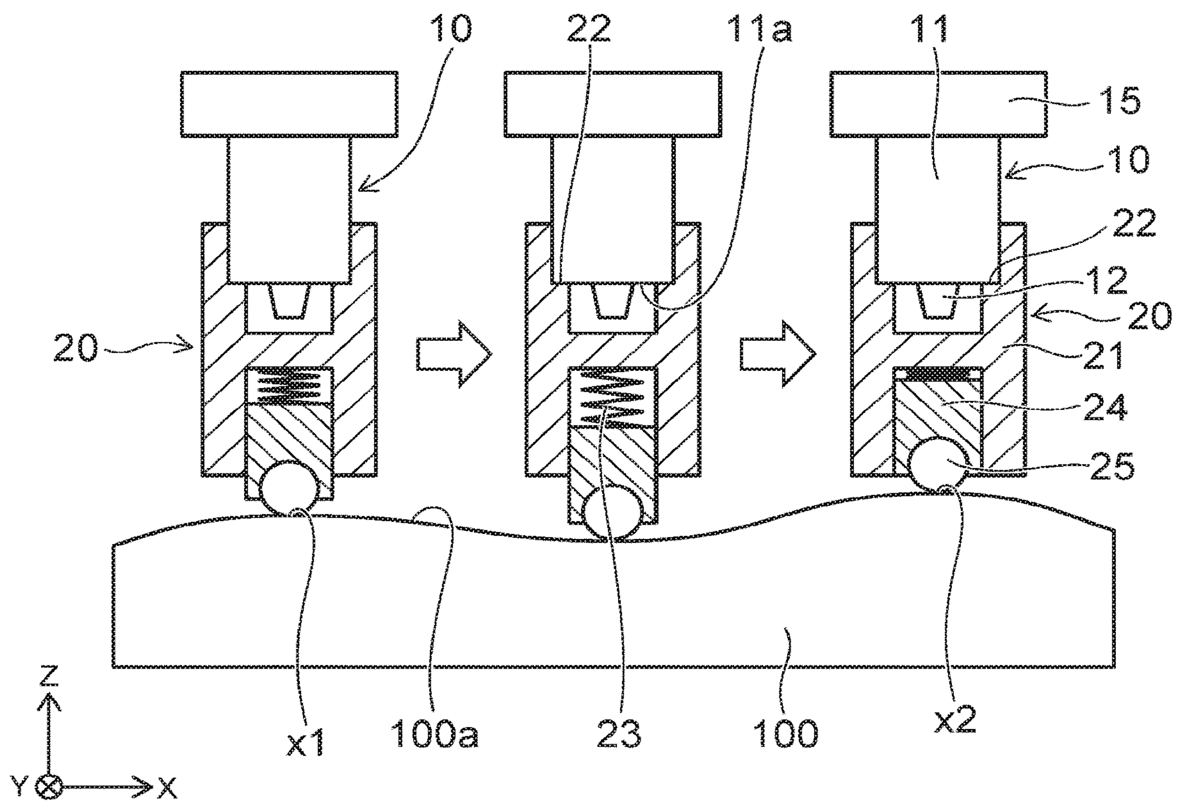
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FIG. 3

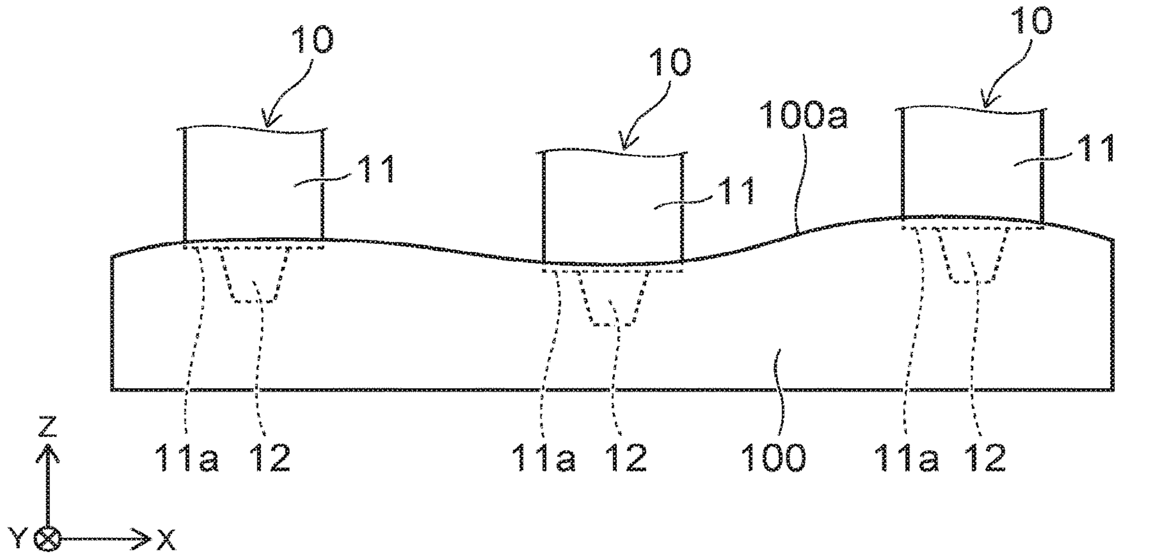
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FIG. 4

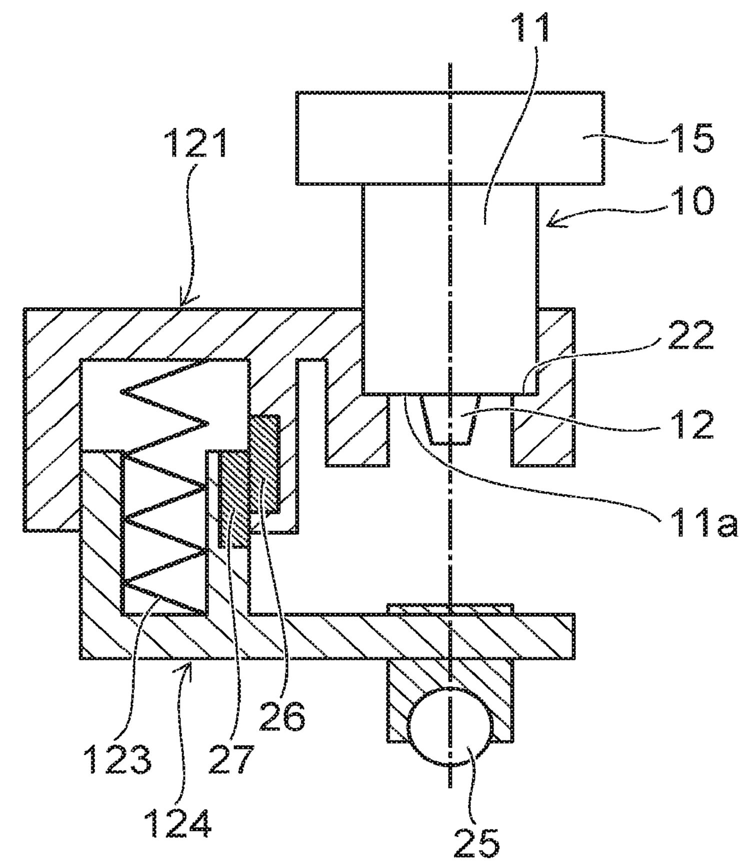

FIG. 5

DISTANCE MEASURING DEVICE, FRICTION STIR WELDING APPARATUS, AND FRICTION STIR WELDING METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2019-016735, filed on Feb. 1, 2019, and Japanese Patent Application No. 2019-227287, filed on Dec. 17, 2019; the entire contents of all of which are incorporated herein by reference.

FIELD

[0002] Embodiments described herein relate generally to a distance measuring device, a friction stir welding apparatus, and a friction stir welding method.

BACKGROUND

[0003] In friction stir welding (FSW), it is important to control the insertion depth of the shoulder surface of the joiningtool into the workpiece. In particular, long workpieces have a large variation in surface height, and the workpiece surface shape of the joint line is measured before FSW and the tool height during joining is changed. For this reason, it may take a long time from setting to joining.

[0004] As methods for controlling the amount of pushing of the shoulder surface of the joiningtool into the workpiece with surface height variation, a method of measuring the workpiece height using laser light, a method of controlling the height of the joiningtool so that the load falls within a prescribed range by detecting torque fluctuation in the motor that rotates the joiningtool, and a method of controlling the height of the worktable so that the load applied to the joiningtool is constant by supporting the worktable by a cylinder are known.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. **1** is a schematic view of a friction stir welding apparatus according to an embodiment of the invention;

[0006] FIG. **2** is a schematic view showing a friction stir welding method according to the embodiment of the invention;

[0007] FIG. **3** is a schematic view showing a measuring method of a distance between the shoulder surface of the joiningtool and the work surface using a measuring tool according to the embodiment of the invention;

[0008] FIG. **4** is a schematic view showing the friction stir welding method according to the embodiment of the invention; and

[0009] FIG. **5** is a schematic view of another example of the measuring tool according to the embodiment of the invention.

DETAILED DESCRIPTION

[0010] When using the method of measuring the workpiece height using laser beam to control the amount of pushing of the shoulder surface of the joiningtool into the workpiece with surface height variation, there is a problem that it is necessary to use a laser beam measuring device, and the apparatus and adjustment become complicated or the cost becomes high. In the method of controlling the height of the joiningtool so that the load falls within a prescribed range by detecting torque fluctuation in the motor that rotates the joiningtool, and the method of controlling the height of the worktable so that the load applied to the joiningtool is constant by supporting the worktable by a cylinder, there is a problem that detection of the torque fluctuation becomes difficult in the case of using the joiningtool having a small diameter.

[0011] The embodiment of the invention provides a distance measuring device, a friction stir welding apparatus and a friction stir welding method which are possible to make high quality joining also for the workpiece with large variation in surface height.

[0012] According to one embodiment, a distance measuring device includes a measuring tool and a controller. The measuring tool includes an abutment portion, a tip portion, a detector, and an output unit. The abutment portion touches with a shoulder surface of a joiningtool for friction stir welding. The tip portion is freely movable in a first direction connecting a surface of the workpiece and the shoulder surface in a state of contacting the surface of the workpiece. The detector is configured to detect a position of the tip portion in the first direction. The output unit is configured to output a data of the position of the tip portion in the first direction detected by the detector. The controller is configured to calculate a position of the tip portion to the abutment portion from the data of the position output from the output unit, and to calculate a distance between the shoulder surface of the joiningtool and the surface of the workpiece.

[0013] Various embodiments are described below with reference to the accompanying drawings. In the drawings, the same components are marked with the same reference numbers, and detailed description will be omitted as appropriate.

[0014] The drawings are schematic, and the relationships between the thickness and width of portions, the proportions of sizes among portions, etc., are not necessarily the same as the actual values. The dimensions and proportions may be illustrated differently among drawings, even for identical portions.

[0015] FIG. **1** is a schematic view of a friction stir welding apparatus **50** according to the embodiment of the invention.

[0016] The friction stir welding apparatus **50** includes a joiningtool **10** and a distance measuring device **40**. The distance measuring device **40** includes a distance measuring tool **20** and a controller **30**.

[0017] The joiningtool **10** includes, for example, a cylindrical shank **11** and a probe pin **12**. A shoulder surface **11***a* is formed on one end in an axial direction of the shank **11**. The probe pin **12** protruding from the shank **11** in the axial direction is provided at the center of the shoulder surface **11***a*. At least one of the probe pin **12** or the shoulder surface **11***a* is made of a material harder than the workpiece to be joined.

[0018] The joiningtool **10** is held by a tool holder **15**. The tool holder **15** is connected to a rotation mechanism, and the joiningtool **10** is driven to rotate with the central axis of the shank **11** as a rotation axis, for example.

[0019] The distance measuring tool **20** includes a main body **21**, a movable portion **24**, a tip portion **25**, detectors **26** and **27**, and an output unit **29**. The main body **21** has an abutment portion **22** touching with the shoulder surface **11***a* of the joiningtool **10**. The main body **21** is fixed to the joiningtool **10** in a state where the abutment portion **22** is brought into contact with the shoulder surface **11***a* of the joiningtool **10**.

[0020] The movable portion **24** is connected to the main body **21** via the connecting portion **23**. Due to the expansion and contraction of the connecting portion **23**, the movable portion **24** is freely movable with respect to the main body **21** fixed to the joiningtool **10**, for example, in the axial direction of the shank **11**. The connecting portion **23** is, for example, a spring or an electric actuator.

[0021] The main body **21** includes the detector **26**. The movable portion **24** includes the detector **27**. The detectors **26** and **27** detect Z-position of the movable portion **24** to the main body **21**. The Z-position is a position of the tip portion **25** of the movable portion **24** in a first direction connecting the surface of the workpiece and the shoulder surface **11***a* of the joiningtool **10**. The detectors **26** and **27** are, for example, non-contact position sensor. The measuring tool **20** includes the output unit **29** outputting the Z-position data detected by the detectors **26** and **27** to the controller **30**.

[0022] A tip portion **25** is provided at a tip of the movable portion **24**. The tip portion **25** is freely movable together with the movable portion **24** in the first direction connecting the surface of the workpiece and the shoulder surface **11***a* in a state of being in contact with the surface of the workpiece. The tip portion **25** is a rotating body, more specifically, a sphere.

[0023] The controller **30** is electrically connected to the distance measuring tool **20**. The controller **30** includes a distance calculation unit **31**. The distance calculation unit **31** calculates the position of the tip portion **25** to the abutment portion **22** based on the Z-position data of the tip portion **25** output from the output unit **29** of the measuring tool **20**, and calculates the distance between the shoulder surface **11***a* of the joiningtool **10** and the surface of the workpiece. The controller **30** instructs the output unit **29** of the measuring tool **20** to output the Z-position data for any moving distance of the joiningtool **10**. The controller **30** includes a calculation unit **32**. The calculation unit **32** associates X-coordinate (coordinate in a second direction crossing the first direction) and Y-coordinate (coordinate in a third direction crossing the first direction) on the measuring tool **20** and the distance between the shoulder surface **11***a* and the surface of the workpiece output from the distance calculation unit **31**. And the calculation unit **32** calculates the motion trajectory of the joiningtool **10** for the shoulder surface **11***a* of the joiningtool **10** to be pushed into the workpiece at a preset depth in the range from the joining start point to the joining end point. The controller **30** includes an operation program creating unit **33**. The operation program creating unit **33** creates an operation program of the friction stir welding apparatus to realize the motion trajectory.

[0024] Next, a friction stir welding method using the friction stir welding apparatus **50** will be described.

[0025] As shown in FIG. **2**, the side surfaces of two workpieces **100***b*, **100***c* (for example, which may be simply referred to as "**100**" hereinafter) that are the objects to be joined are butted with each other, and the workpieces **100***b*, **100***c* are supported on the stage. In FIG. **2**, two directions parallel to the surface of the workpiece **100** and perpendicular to each other are defined as an X direction and a Y direction. A direction (thickness direction of the workpiece **100**) orthogonal to the X direction and the Y direction is defined as a Z direction. The first direction connecting the surface of the workpiece **100** and the shoulder surface **11***a* of the joiningtool **10** corresponds to the Z-direction. In this embodiment, Z direction (the thickness direction perpendicular to the X-Y plane or the surface of the workpiece **100**) may also be referred to as a "vertical direction", and a direction perpendicular to the Z direction, i.e. a direction parallel to the X-Y plane or the surface of the workpiece **100**, may also be referred to as a "horizontal direction", even if the workpiece **100** is not horizontally provided with respect to the gravity direction.

[0026] The joiningtool **10** is inserted into the surface of the butted portion of the two workpieces **100***b* and **100***c* while rotating at a high speed. The probe pin **12** is completely inserted into the workpiece **100**, and the shoulder surface **11***a* is pushed into the surface of the workpiece **100** by a prescribed amount. Then, the rotating joiningtool **10** is moved along the butted portion (joining line L) of the workpiece **100**, and frictional heat between the joiningtool **10** and the workpiece **100** generated at this time and stirring of the material are used. Two works **100***b* and **100***c* are joined. The butted surface disappears at a joining portion **200** between the two workpieces **100***b* and **100***c*.

[0027] The joiningtool **10** may be moved relatively to the workpiece **100** along the joining line L, the joiningtool **10** may be moved to the stationary workpiece **100**, or the workpiece **100** may be moved to the stationary joiningtool **10**. Alternatively, the joiningtool **10** and the workpiece **100** may be moved in opposite directions.

[0028] Here, especially in the case of a long workpiece having a long region to be joined, in which the surface is likely to be wavy or to have a variation in height, it is important to control the amount of pushing of the shoulder surface **11***a* of the joiningtool **10** into the workpiece. If the amount of pushing of the shoulder surface **11***a* onto the workpiece surface is insufficient, a joining failure due to insufficient frictional heat is caused, and if the shoulder surface **11***a* is excessively pushed into the workpiece surface, excessive burrs are likely to occur at the joining portion.

[0029] Therefore, according to the embodiment, the distance between the workpiece surface and the shoulder surface **11***a* at the site to be joined is measured before joining using the distance measuring device **40** described above.

[0030] As shown in FIG. **3**, the measuring tool **20** is installed on the joiningtool **10**. The abutment portion **22** formed on the main body **21** of the measuring tool **20** is touched with the shoulder surface **11***a* of the joiningtool **10**.

[0031] After installing the measuring tool **20** on the joiningtool **10**, the tip portion **25** of the measuring tool **20** is brought into contact with the joining start point x**1** of the surface **100***a* of the workpiece **100**. Then, with the tip portion **25** brought into contact with the surface **100***a* of the workpiece **100** and the setting value on the measuring tool of the height of the welding tool **10** (position in the Z direction) being constant, the joiningtool **10** on which the measuring tool **20** is installed is substantially horizontally moved from the joining start point x**1** to the joining end point x**2** of the workpiece **100** along the site to be joined (joining line) of the workpiece **100**. The joiningtool **10** and the distance measuring device **40** are not rotated.

[0032] As the joiningtool **10** moves, the tip portion **25** that is a sphere moves while rolling on the surface **100***a* of the workpiece **100**. Following the variation of the distance between the surface **100***a* of the workpiece **100** and the shoulder surface **11***a* of the joiningtool **10**, the connecting portion **23** expands and contracts, and the movable portion **24** moves in the first direction connecting the surface **100***a* of the workpiece **100** and the shoulder surface **11***a*. For example, the movable portion **24** moves up and down.

[0033] During the movement of the joiningtool **10** from the joining start point x**1** to the joining end point x**2**, the controller **30** shown in FIG. **1** detects the position of the tip portion **25** to the abutment portion **22**. The position may be detected continuously from the joining start point x**1** to the joining end point x**2**. Or, the position may be detected for any moving distance of the joiningtool **10**. When the position is detected for any moving distance of the joiningtool **10**, the x-coordinate and the y-coordinate of the position of the joiningtool **10** are determined by the controller **30**. When the joiningtool **10** moves to the measurement position, the controller **30** detects the position of the tip portion **25** to the abutment portion **22** and acquires the position as data. From this detection result, the distance between the shoulder surface **11***a* and the surface **100***a* of the workpiece **100** is calculated in association with the position (x-coordinate, y-coordinate) of the site to be joined between the joining start point x**1** and the joining end point x**2**.

[0034] Further, the controller **30** creates motion trajectory data of the joiningtool **10** from the distance between the shoulder surface **11***a* and the surface **100***a* of the workpiece **100**. For example, the motion trajectory data associates the position (x-coordinate, y-coordinate) of the site to be joined between the joining start point x**1** and the joining end point x**2** and the height (z-coordinate) of the joiningtool **10**.

[0035] The controller **30** creates an operation program for the joiningtool **10** based on the operation trajectory data. And the measuring tool **20** is removed from the joiningtool **10**, and the friction stir welding of the workpiece **100** is performed with the joiningtool **10** according to the operation program described above.

[0036] That is, as shown in FIG. **4**, while the probe pin **12** of the joiningtool **10** is inserted into the site to be joined of the workpiece **100** and the shoulder surface **11***a* is pushed into the surface of the site to be joined, the joiningtool **10** is moved from the joining start point x**1** to the joining end point x**2** while rotating.

[0037] Based on the motion trajectory data, the position of the joiningtool **10** in the direction (Z direction) orthogonal to the moving direction along the site to be joined is controlled, and the amount of pushing of the shoulder surface **11***a* into the site to be joined is controlled within a prescribed range.

[0038] For example, when the outer diameter of the shoulder surface **11***a* is 10 mm and the length of the probe pin **12** is 3 mm, the amount of pushing of the shoulder surface **11***a* into the site to be joined is controlled within a range of 0.2 mm plus or minus 0.05 mm. More precise control of the amount of pushing is required for a thin workpiece to be joined. For example, when the thickness of the workpiece is 0.5 mm, the outer diameter of the shoulder surface **11***a* is 3 mm, and the length of the probe pin **12** is 0.4 mm, the amount of pushing of the shoulder surface **11***a* into the site to be joined is controlled within a range of 0.05 mm plus or minus 0.01 mm.

[0039] According to the embodiment, it is possible to appropriately control the amount of pushing of the shoulder surface **11***a* into the site to be joined even for the workpiece **100** having a variation in surface height, and high-quality joining can be performed.

[0040] For example, without using an expensive laser light measurement device such as a method of measuring the workpiece height using laser light, according to the embodiment, the distance between the shoulder surface **11***a* and the surface **100***a* of the workpiece **100** can be measured in a short time with a simple and low-cost contact-type measuring tool.

[0041] Examples of a method for controlling the amount of pushing of the shoulder surface of the joiningtool into a workpiece having a variation in surface height include the following methods. One method is a method of detecting the torque fluctuation of a motor that rotates the joiningtool and controlling the height of the joiningtool so that the load falls within a prescribed range. Another method is a method in which the work table is supported by a cylinder and the height of the work table is controlled so that the load applied to the joiningtool is constant. When these methods control the amount by which the shoulder surface of the joiningtool is pushed into the workpiece having variations in surface height, the small-diameter joiningtool makes it difficult to detect load fluctuations. In contrast, according to the embodiment, high-quality friction stir welding can be performed even when a small-diameter joiningtool is used.

[0042] The site to be joined (butted portion between the two workpieces) is not limited to a linear shape, and the joining surface may be a curved surface. Therefore, the movement trajectory of the joiningtool **10** that moves along the site to be joined is not limited to a straight line, and may be a curved line.

[0043] Further, the tip portion **25** that moves on the surface **100***a* while being in contact with the surface **100***a* of the workpiece **100** is not limited to a sphere but may be a rotating body such as a roller. Furthermore, the tip portion **25** may be configured not to rotate. In this case, the surface **100***a* of the workpiece **100** may be bent by friction between the tip portion **25** and the surface **100***a* of the workpiece **100**.

[0044] FIG. **1** shows an example in which the measuring tool **20** is arranged coaxially with the joiningtool **10**. As shown in FIG. **5**, the tip portion **25** touching the workpiece may be arranged coaxially with the joiningtool **10**, and the movable portion **124** connected to the tip portion **25** may be offset from the joiningtool **10**. In this embodiment shown in FIG. **5**, the same friction stir welding as in the above-described embodiment can be performed. The movable portion **124** is connected to the main body **121** fixed to the joiningtool **10** via the connecting portion **123**, and is freely movable with in the axial direction of the shank **11**. The connecting portion **123** is, for example, a spring or an electric actuator.

[0045] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the invention.

What is claimed is:

1. A distance measuring device, comprising:

a measuring tool including an abutment portion, a tip portion, a detector, and an output unit, the abutment portion touching with a shoulder surface of a joiningtool for friction stir welding, the tip portion being freely movable in a first direction connecting a surface of the workpiece and the shoulder surface in a state of contacting the surface of the workpiece, the detector configured to detect a position of the tip portion in the first direction, the output unit configured to output a data of the position of the tip portion in the first direction detected by the detector; and

a controller configured to calculate a position of the tip portion to the abutment portion from the data of the position output from the output unit, and to calculate a distance between the shoulder surface of the joiningtool and the surface of the workpiece.

2. The device according to claim **1**, wherein the tip portion is a rotating body.

3. The device according to claim **2**, wherein the tip portion is a ball.

4. The device according to claim **1**, wherein

the controller includes

a calculating unit configured to calculate a motion trajectory of the joiningtool from the data of the position output from the output unit, and coordinatas in a second direction and a third direction on the measuring tool, the second direction and the third direction crossing the first direction, and

an operation program creating unit configured to create an operation program of the joiningtool based on the motion trajectory.

5. A friction stir welding apparatus, comprising:

a joiningtool for friction stir welding; and

a distance measuring device,

the distance measuring device including

a distance measuring tool including an abutment portion, an tip portion, a detector, and an output unit, the abutment portion touching with a shoulder surface of the joiningtool, the tip portion being freely movable in a first direction connecting a surface of the workpiece and the shoulder surface in a state of contacting the surface of the workpiece, the detector configured to detect a position of the tip portion in the first direction, the output unit configured to output a data of the position of the tip portion in the first direction detected by the detector, and

a controller configured to calculate a position of the tip portion to the abutment portion from the data of the position output from the output unit, and to calculate a distance between the shoulder surface of the joiningtool and the surface of the workpiece.

6. The apparatus according to claim **5**, wherein the tip portion is a rotating body.

7. The apparatus according to claim **6**, wherein the tip portion is a ball.

8. The device according to claim **5**, wherein

the controller includes

a calculating unit configured to calculate a motion trajectory of the joiningtool from the data of the position output from the output unit, and coordinatas in a second direction and a third direction on the measuring tool, the second direction and the third direction crossing the first direction, and

an operation program creating unit configured to create an operation program of the joiningtool based on the motion trajectory.

9. A friction stir welding method, comprising:

installing a measuring tool on a joiningtool including a shoulder surface and a probe pin, the measuring tool including a tip portion being freely movable in a first direction connecting a surface of a workpiece and the shoulder surface in a state of contacting an abutment portion of the measuring tool with the shoulder surface of the joiningtool;

contacting the tip portion with a joining start point of the surface of the workpiece;

moving the joiningtool, parallel to the surface of the workpiece, from the joining start point to a joining end point of the workpiece along a site to be joined of the workpiece in a state of contacting the tip portion with the surface of the workpiece, the joiningtool being installed with the measuring tool;

during movement of the joiningtool from the joining start point to the joining end point, detecting a position of the tip portion to the abutment portion, and calculating a distance between the shoulder surface and the surface of the workpiece at the site to be joined of the workpiece;

creating motion trajectory data of the joiningtool from the distance between the shoulder surface and the surface of the workpiece, the shoulder surface of the joiningtool being pushed into the workpiece at a preset depth in a range from the joining start point to the joining end point according to the motion trajectory data;

creating an operation program of a friction stir welding apparatus based on the motion trajectory data; and

removing the measuring tool from the joiningtool, and

moving the joiningtool from the joining start point to the joining end point while rotating the joiningtool based on the operation program.

10. The method according to claim **9**, wherein

based on the motion trajectory data, a position of the joiningtool in a direction orthogonal to the movement direction along the site to be joined is controlled, and an amount of pushing of the shoulder surface into the site to be joined is controlled within a prescribed range.

* * * * *