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Yamaji et al.

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(54) **INSIDE-DIAMETER MEASURING UNIT, FLOATING JOINT MECHANISM UNIT, AND MEASURING UNIT**

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B25J 13/08 (2006.01)

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CPC ***G01B 5/12*** (2013.01); ***B25J 13/081*** (2013.01)

(58) **Field of Classification Search**
CPC G01B 5/12
USPC 33/542, 543
See application file for complete search history.

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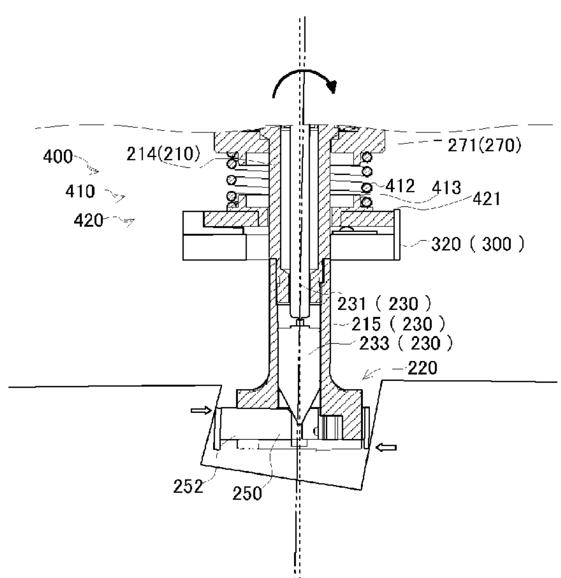
(57) **ABSTRACT**

There is provided an inside-diameter measuring unit capable of automating inside-diameter measurement and a control method for automatic inside-diameter measurement. An inside-diameter measuring part is supported by a support frame part via a floating joint part. The floating joint part includes a rotation-allowing mechanism part and a translation-allowing mechanism part. A measuring head part of the inside-diameter measuring part is inserted into a hole by a robot arm part. The inside-diameter measuring part adjusts its position and posture autonomously by the reaction force when a contact point pushes against the inner wall of the hole to align the axis of the inside-diameter measuring part with the axis of the hole. An electric inside-diameter measuring unit can automatically measure the inside diameter of a hole.

13 Claims, 33 Drawing Sheets



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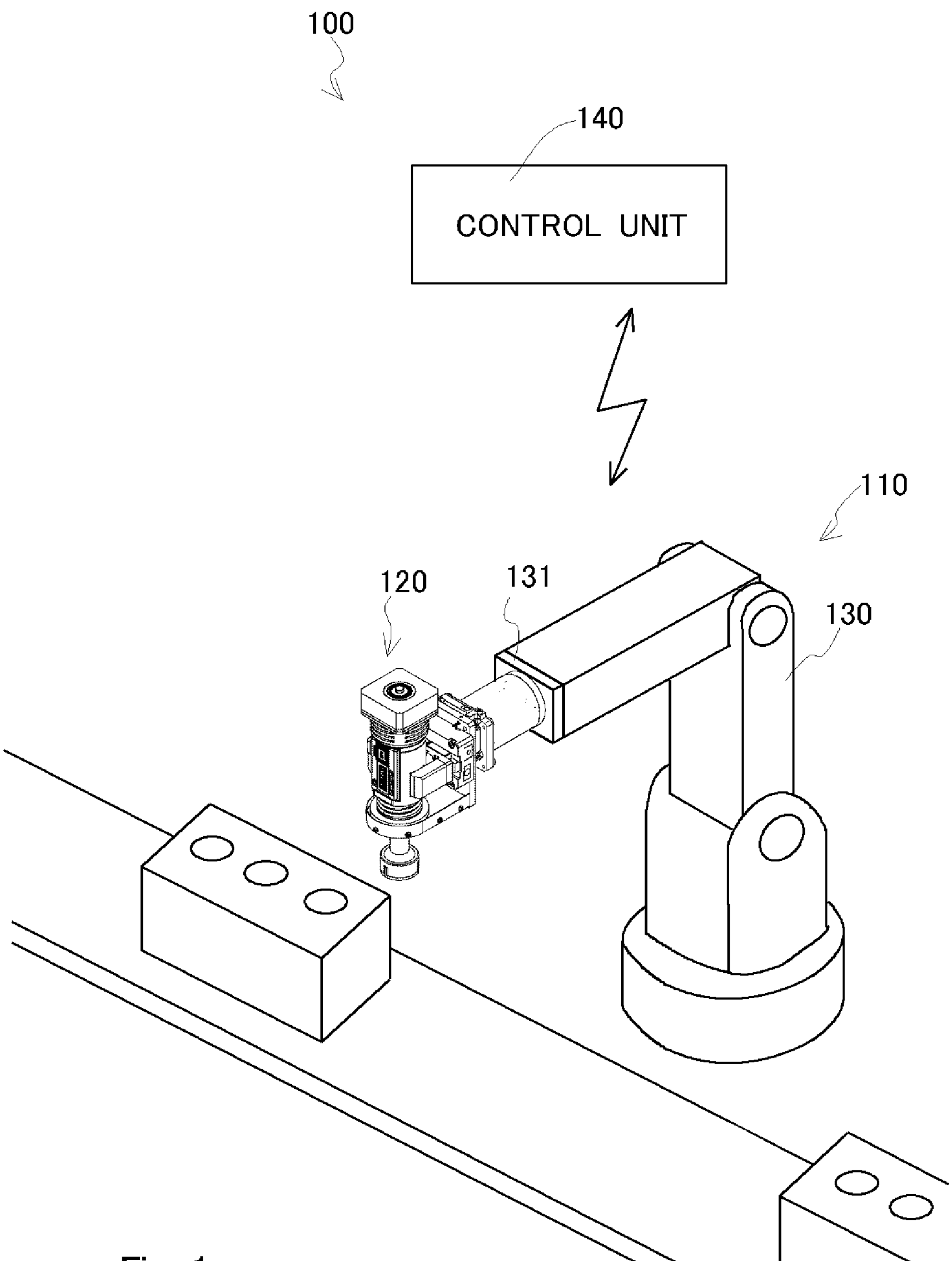

Fig. 1

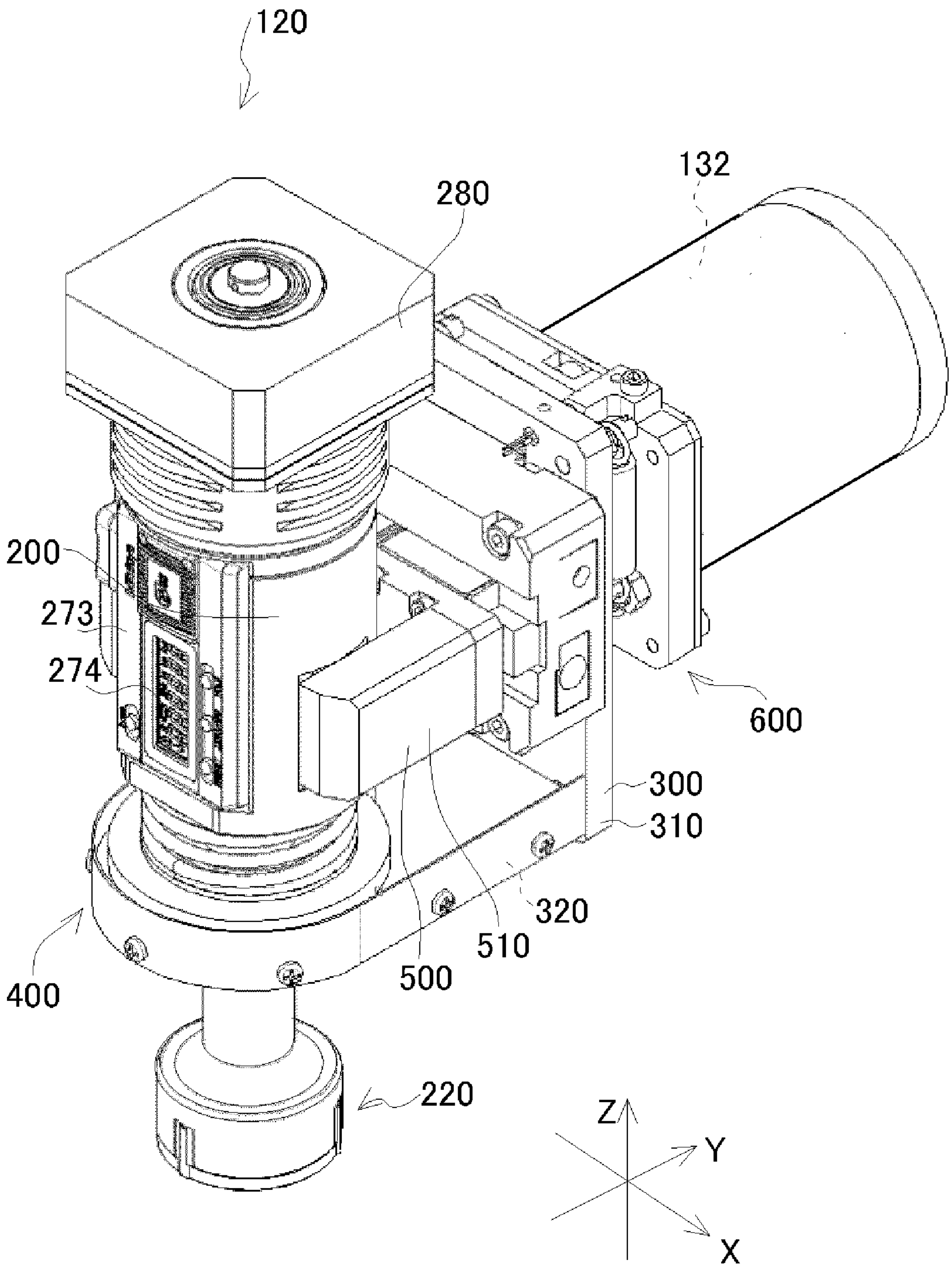

Fig. 2

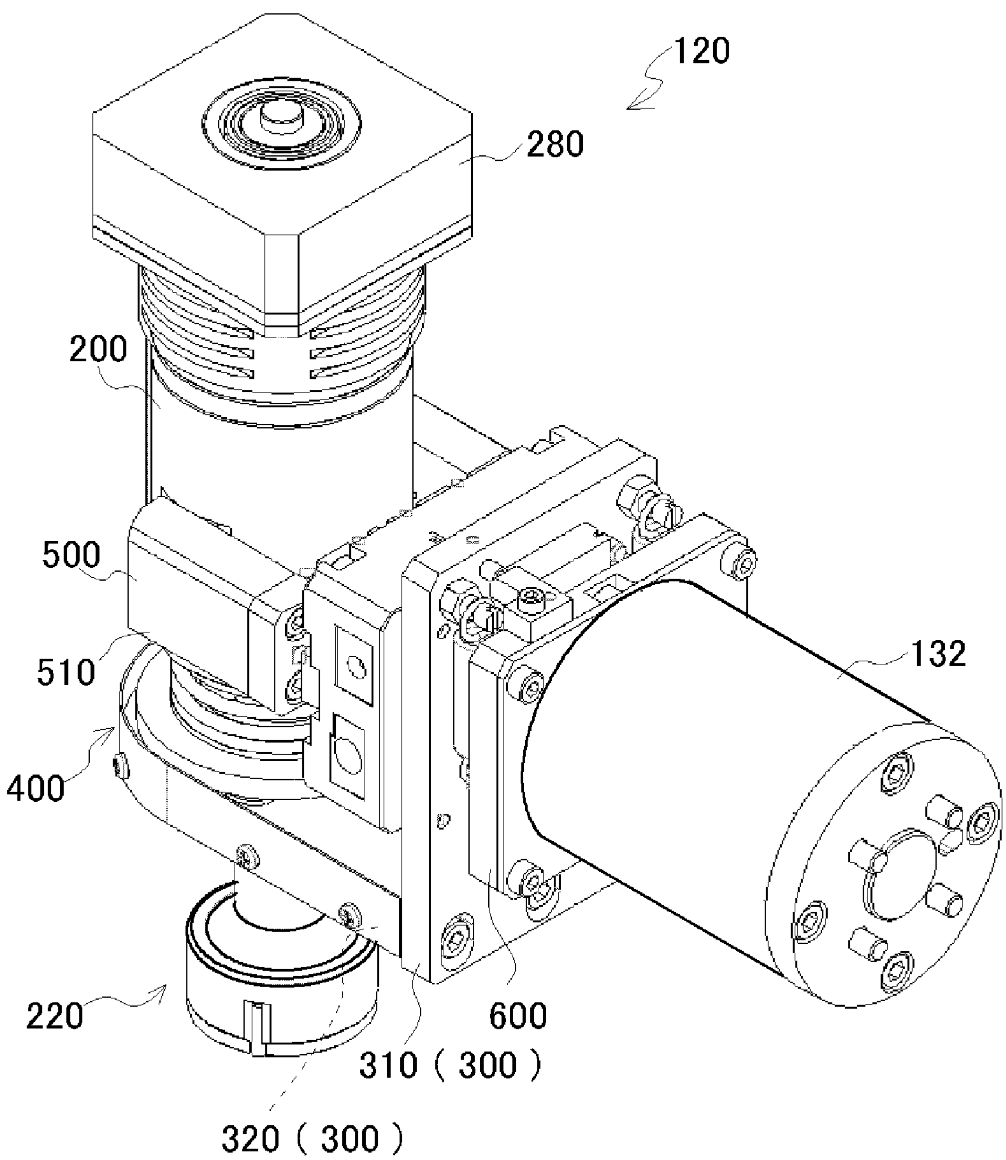

Fig. 3

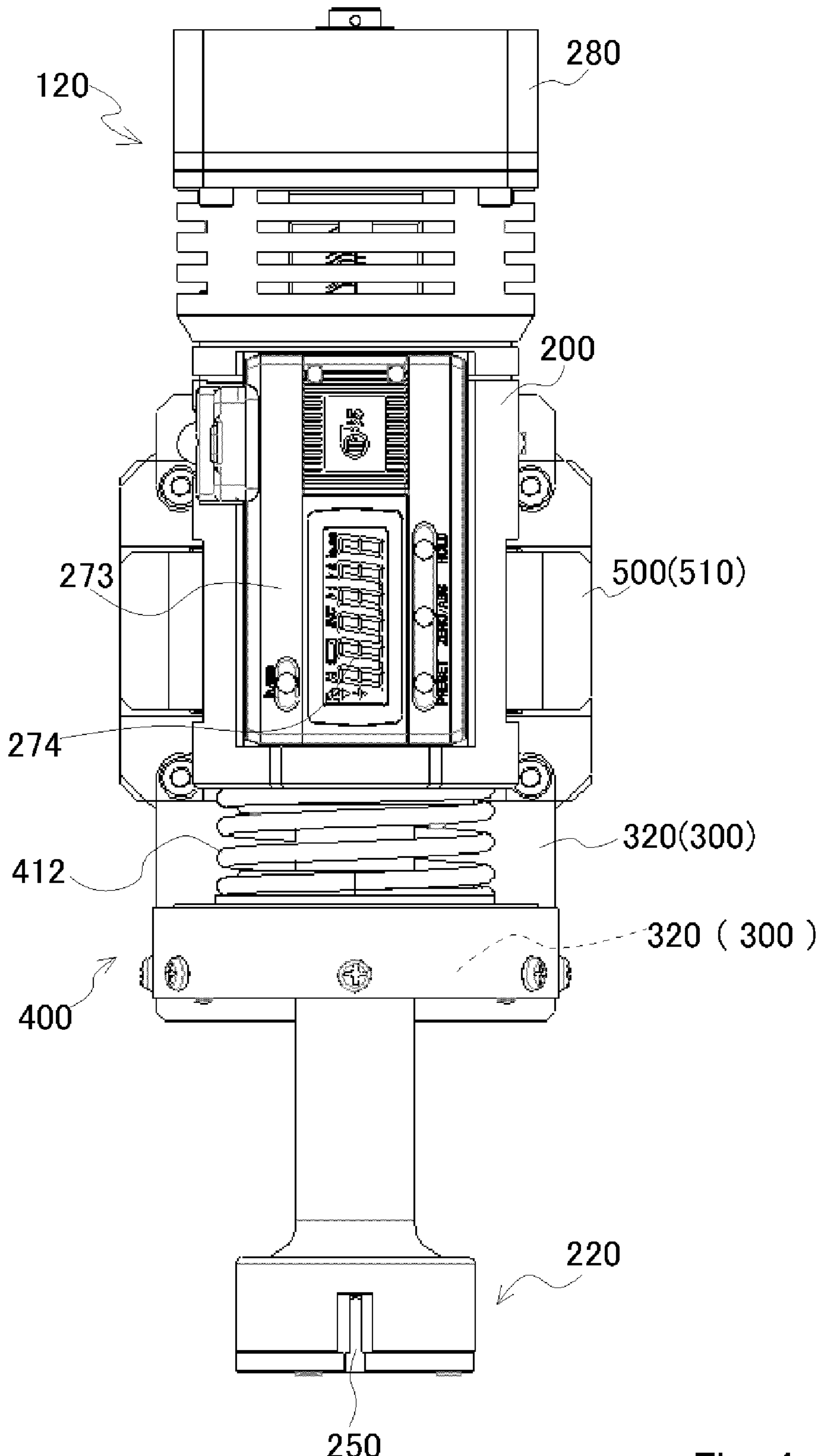

Fig. 4

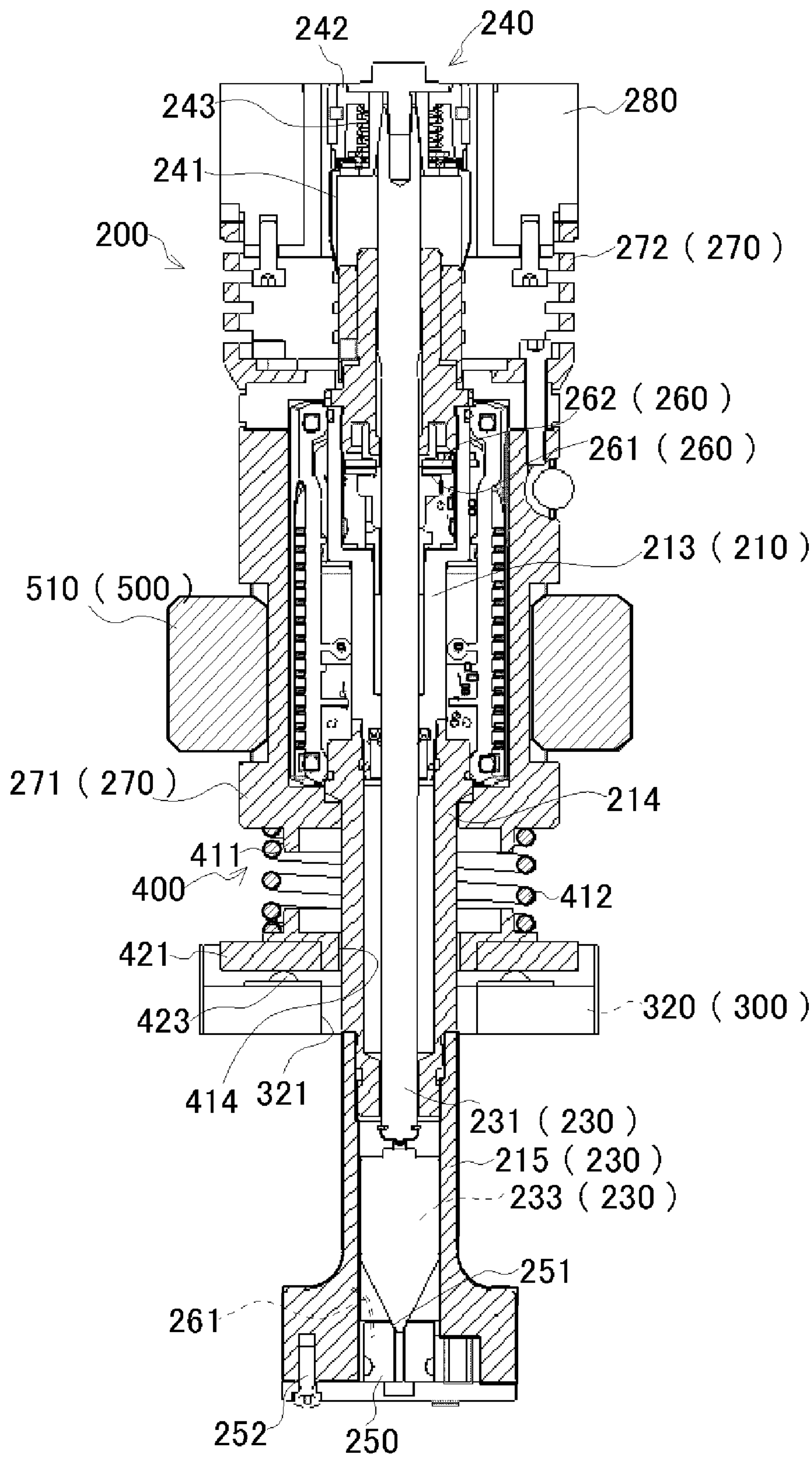
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Fig. 5

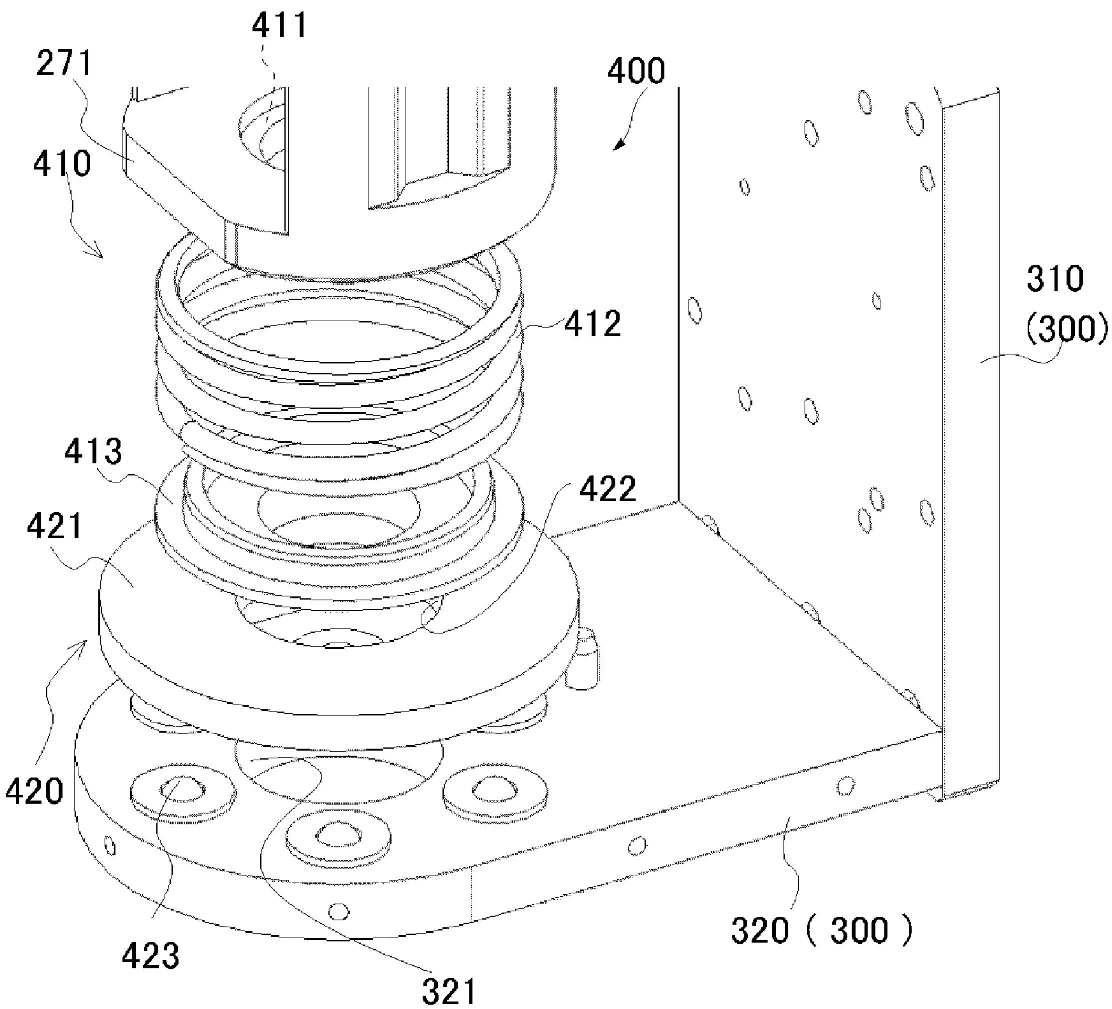

Fig. 6

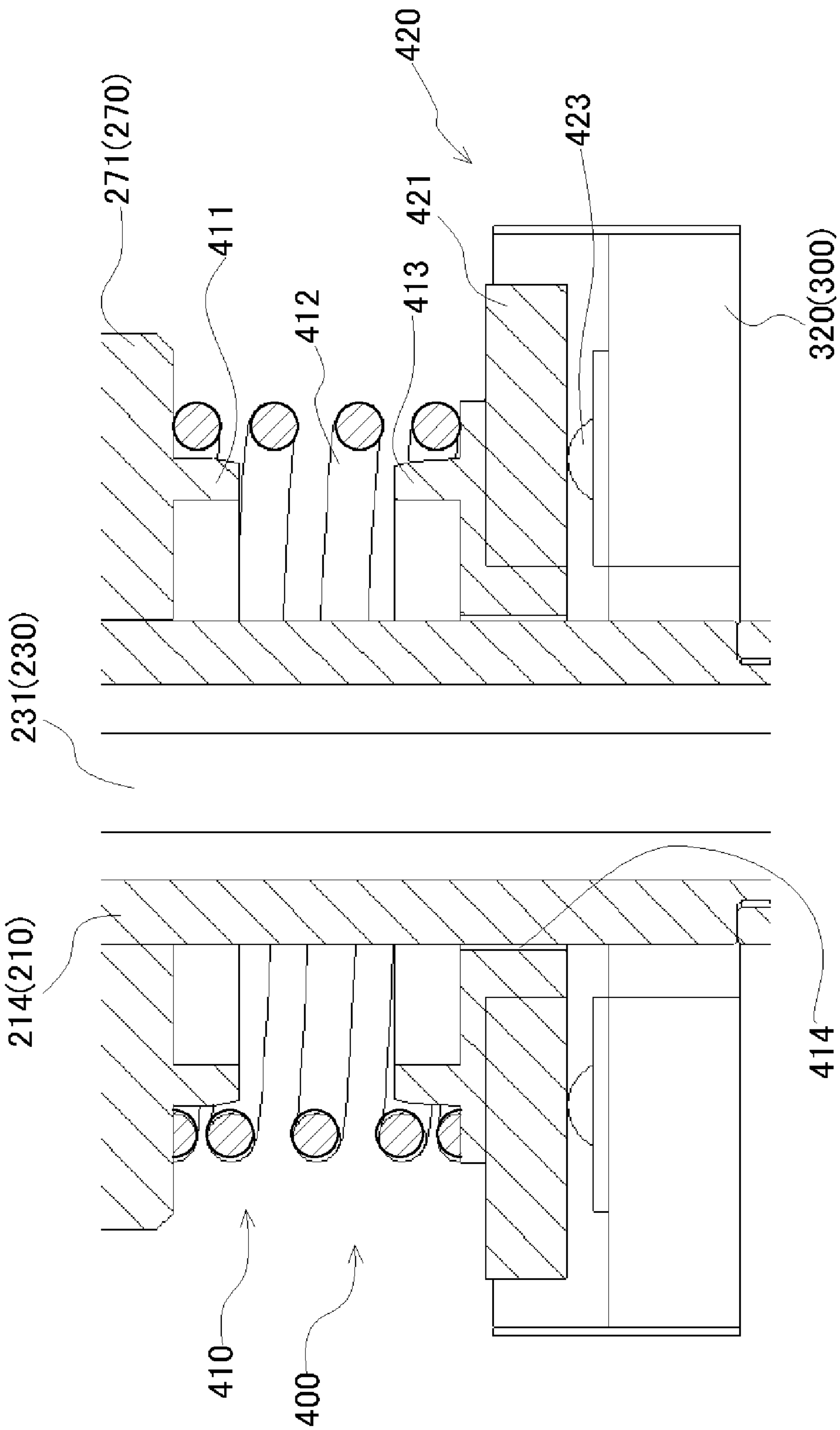
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Fig. 7

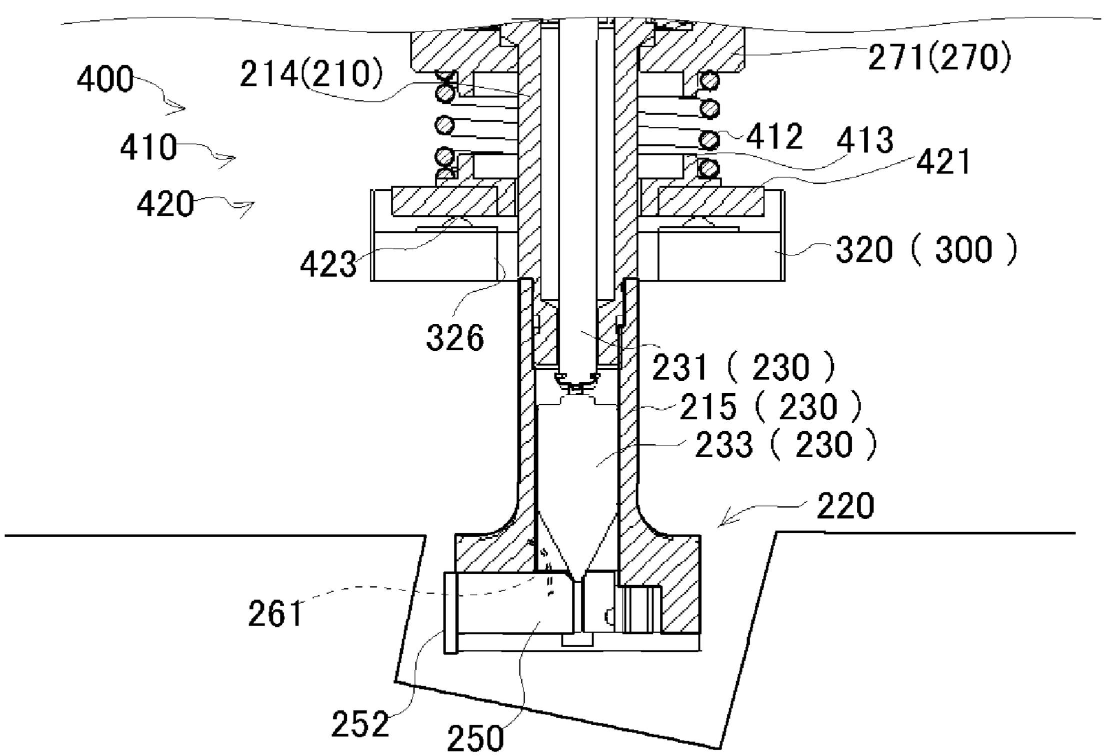
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Fig. 8

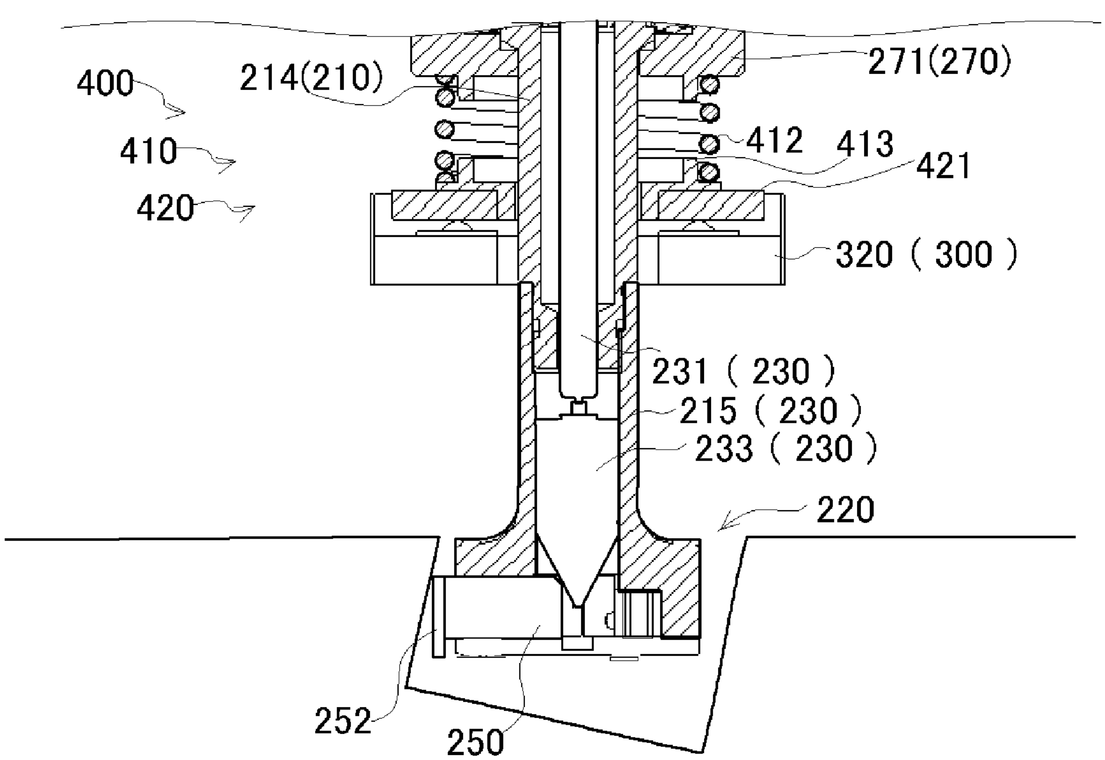
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Fig. 9

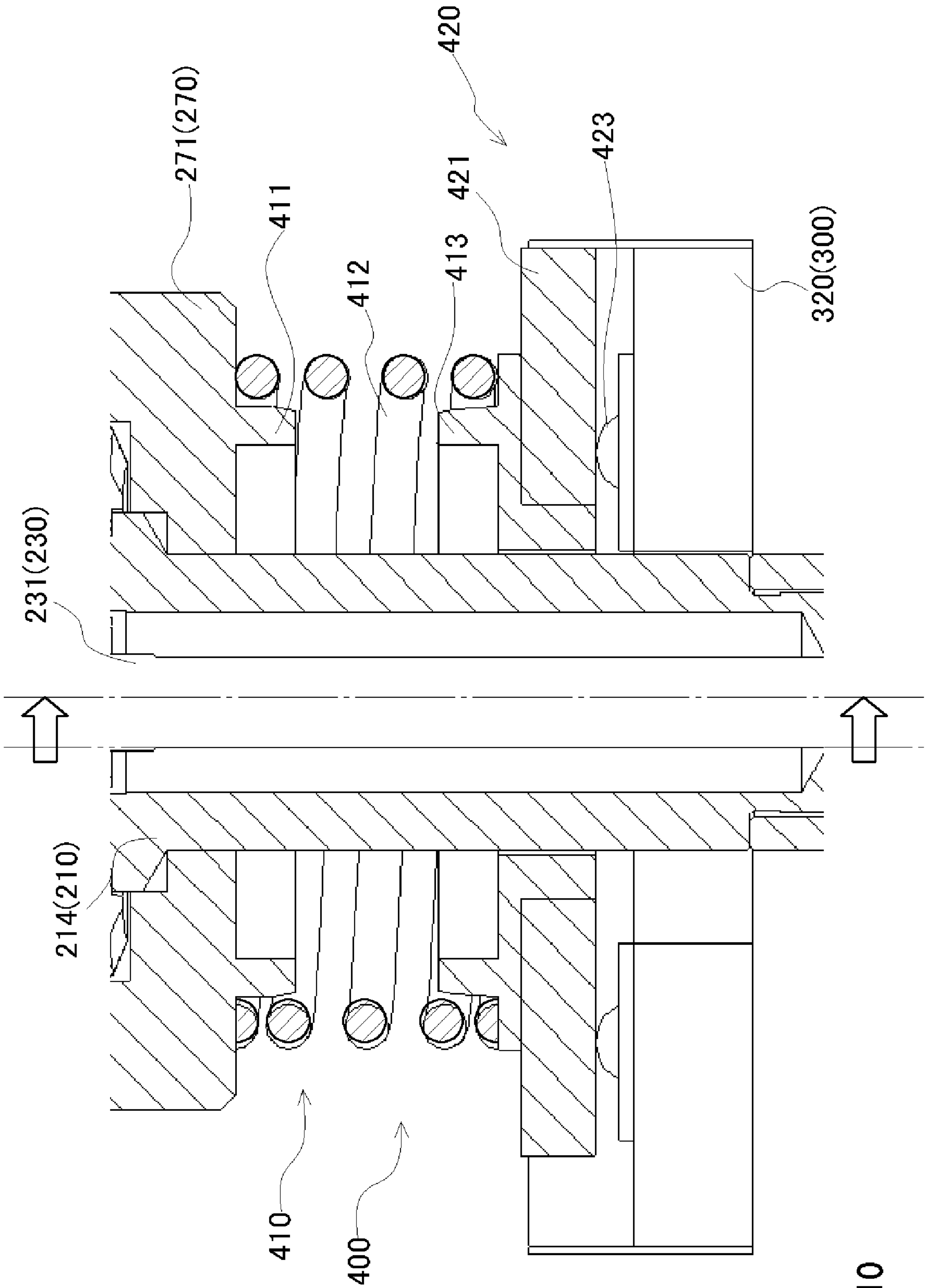

Fig. 10

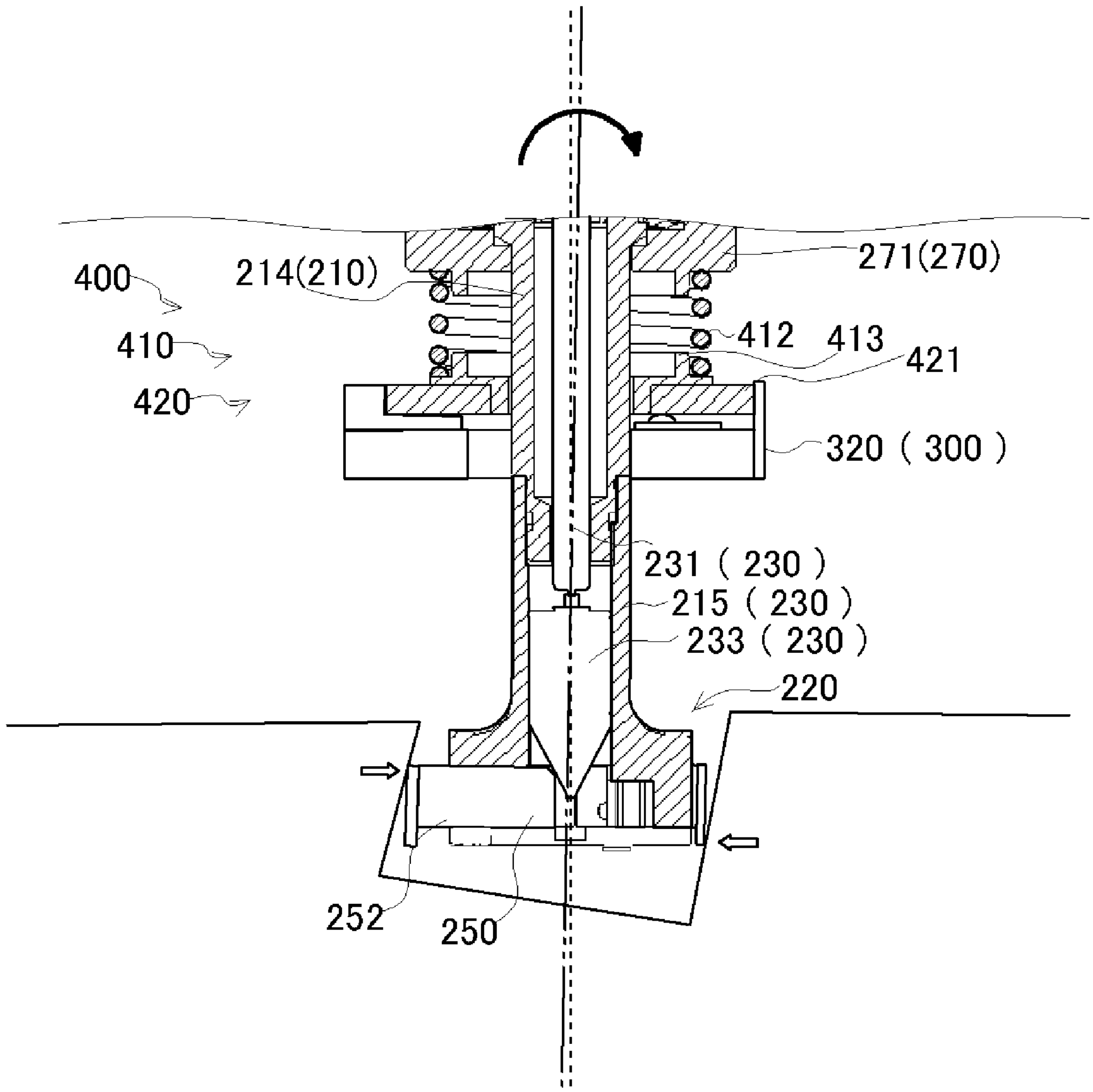
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Fig. 11

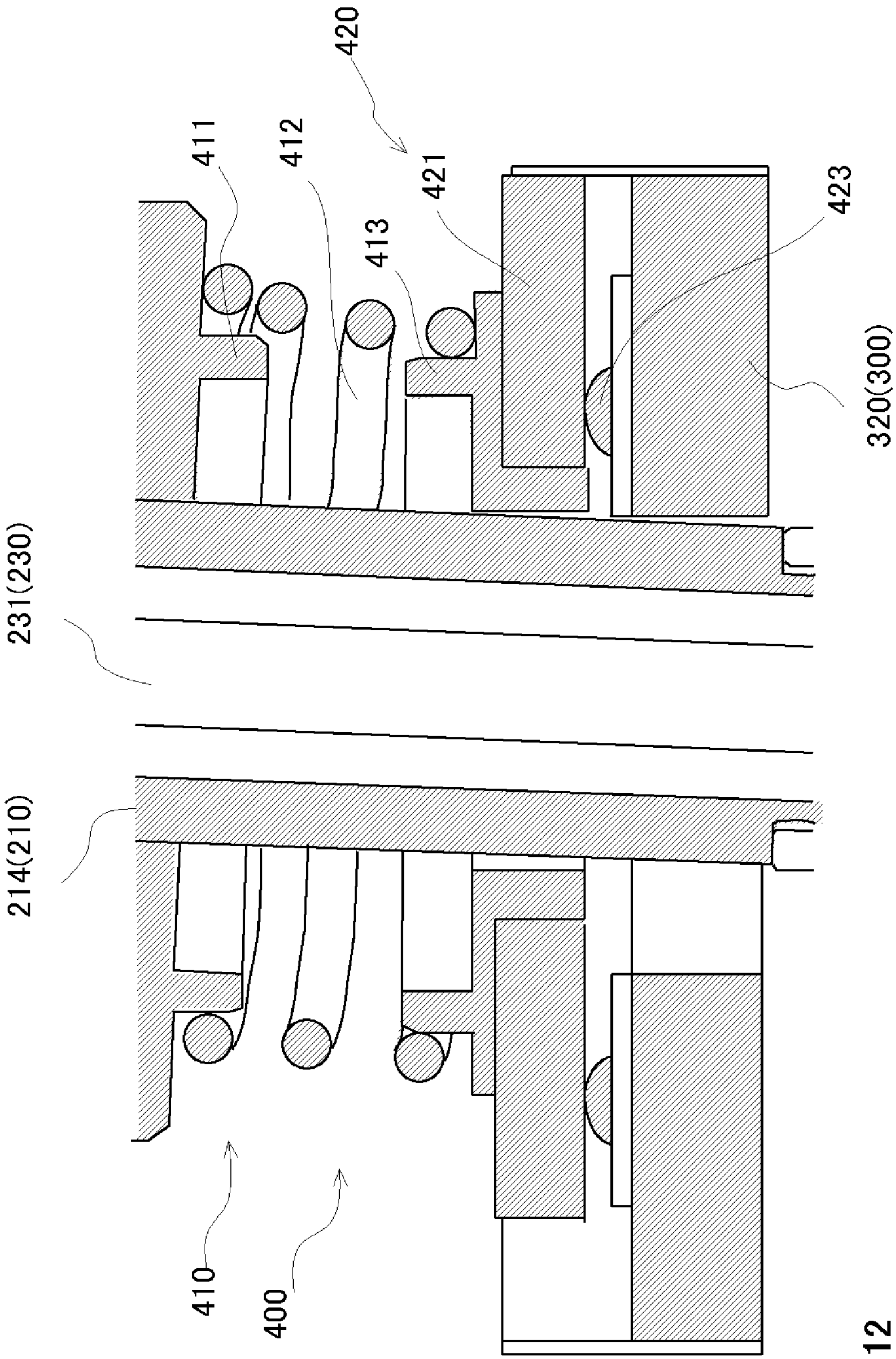


Fig. 12

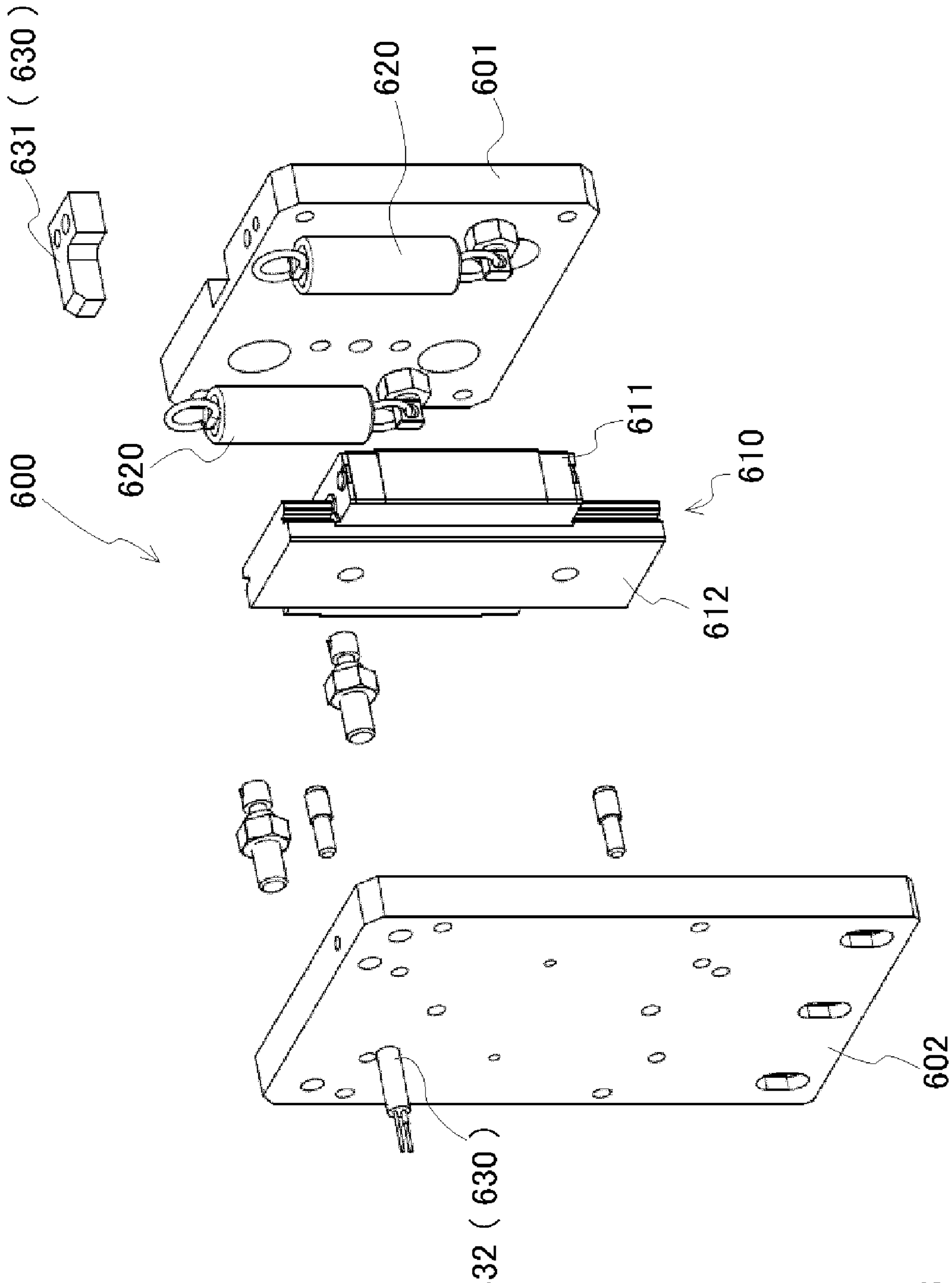


Fig. 13

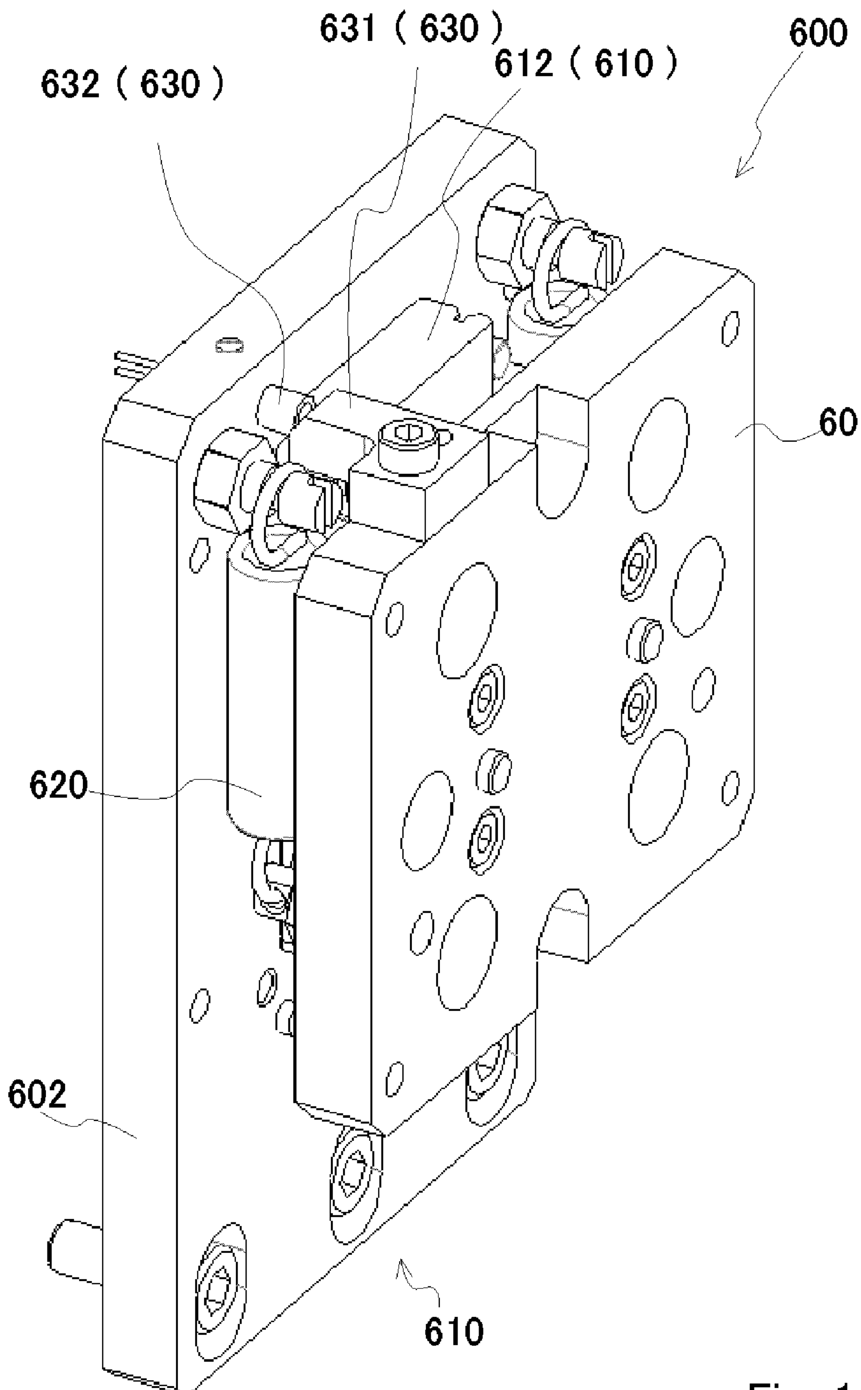
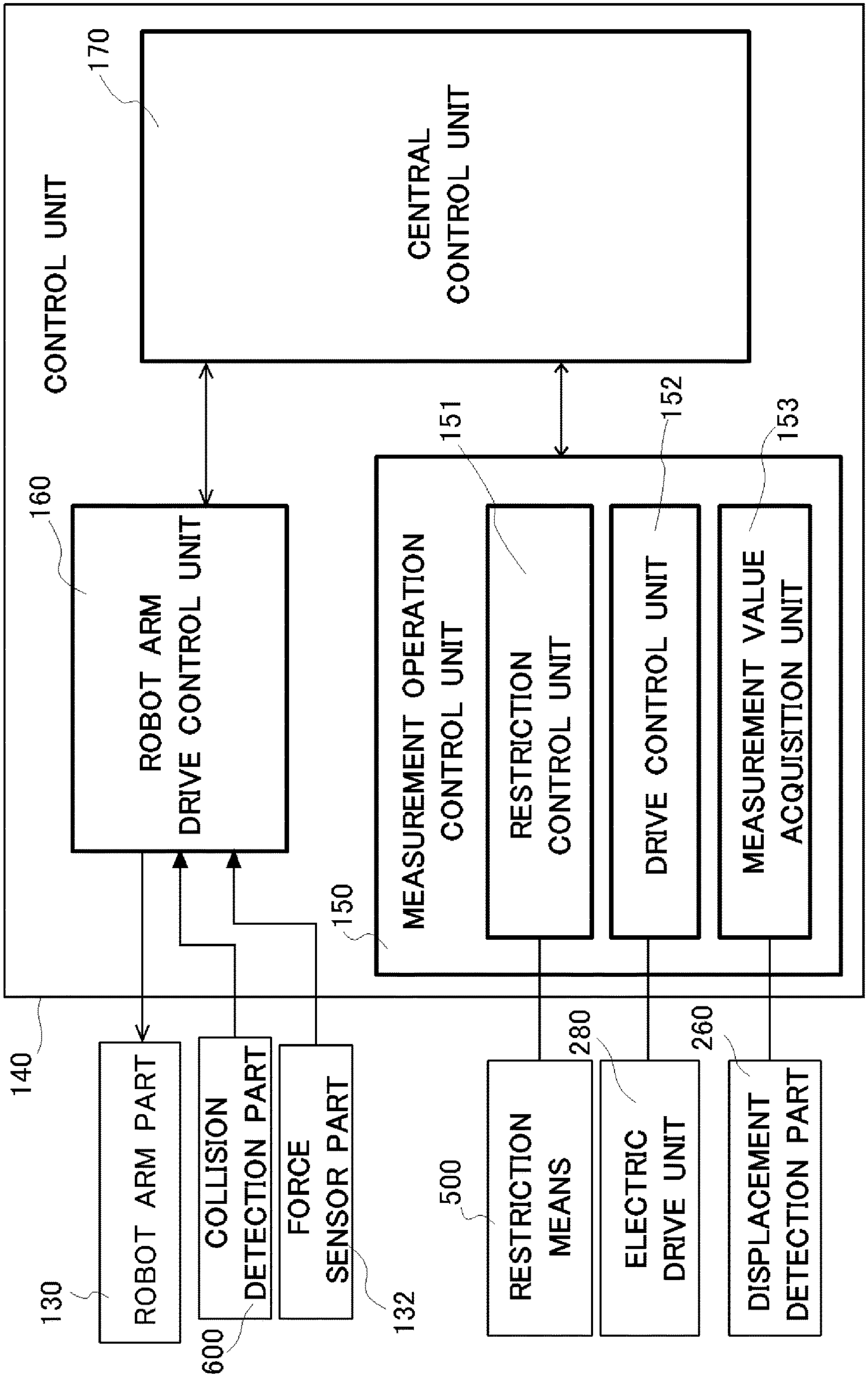


Fig. 14


CONTROL UNIT
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CENTRAL CONTROL UNIT
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ROBOT ARM DRIVE CONTROL UNIT
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MEASUREMENT OPERATION CONTROL UNIT
151
RESTRICTION CONTROL UNIT
152
DRIVE CONTROL UNIT
153
MEASUREMENT VALUE ACQUISITION UNIT
140
130
ROBOT ARM PART
600
COLLISION DETECTION PART
132
FORCE SENSOR PART
500
RESTRICTION MEANS
280
ELECTRIC DRIVE UNIT
260
DISPLACEMENT DETECTION PART

Fig. 15

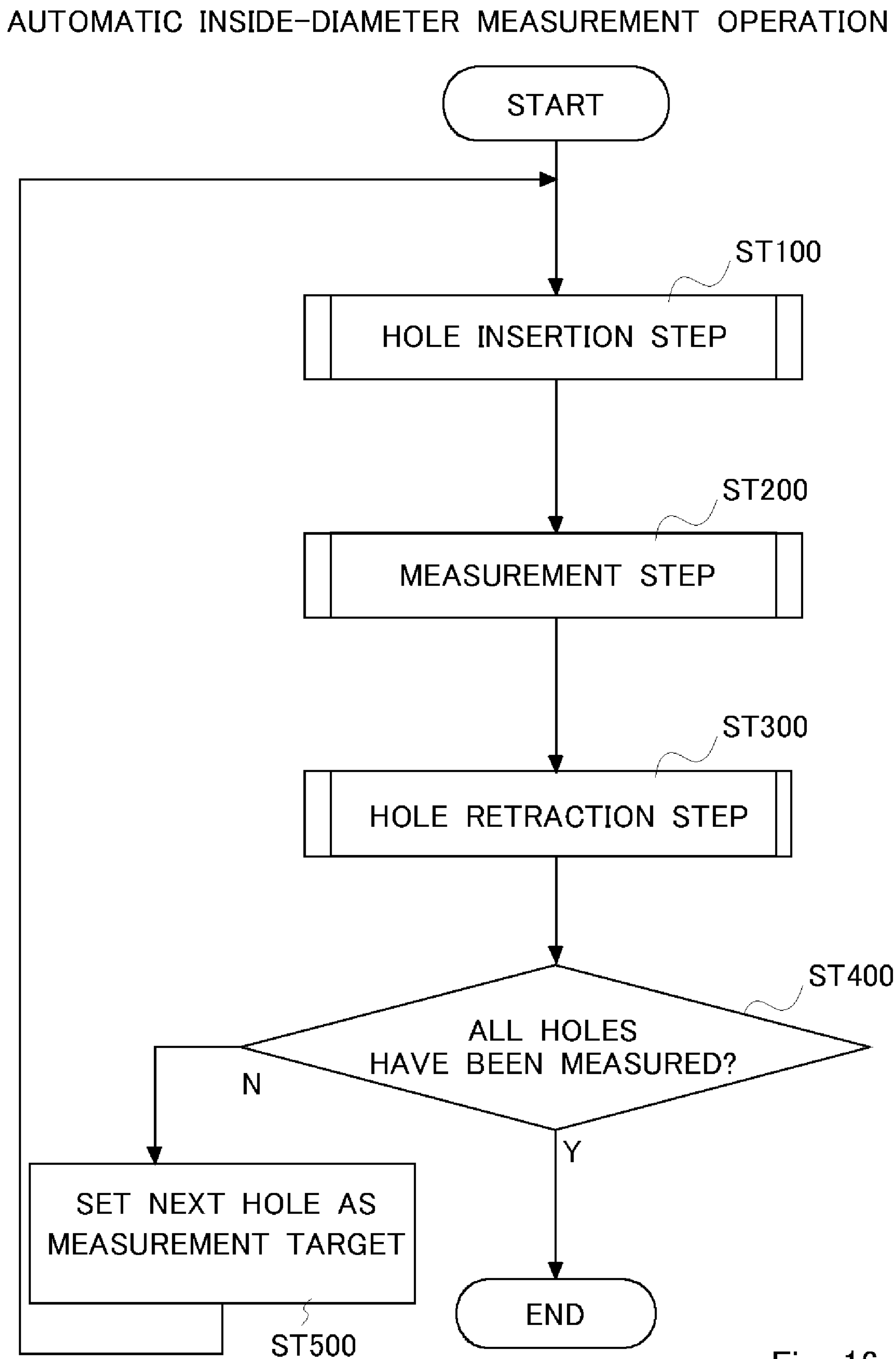
AUTOMATIC INSIDE-DIAMETER MEASUREMENT OPERATION
START
ST100
HOLE INSERTION STEP
ST200
MEASUREMENT STEP
ST300
HOLE RETRACTION STEP
ST400
ALL HOLES HAVE BEEN MEASURED?
N
Y
SET NEXT HOLE AS MEASUREMENT TARGET
ST500
END

Fig. 16

HOLE INSERTION STEP ST100

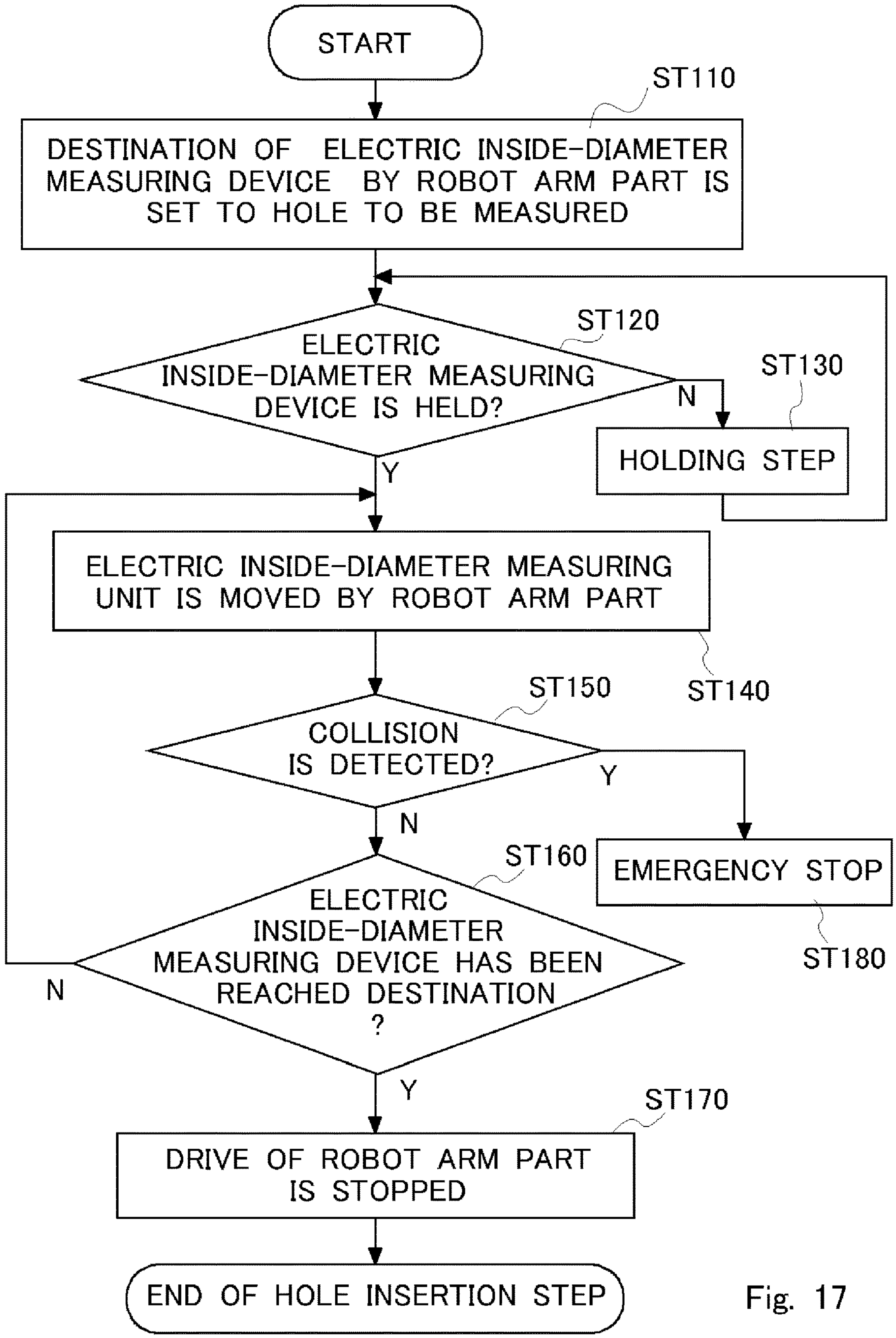

Fig. 17

MEASUREMENT STEP ST200

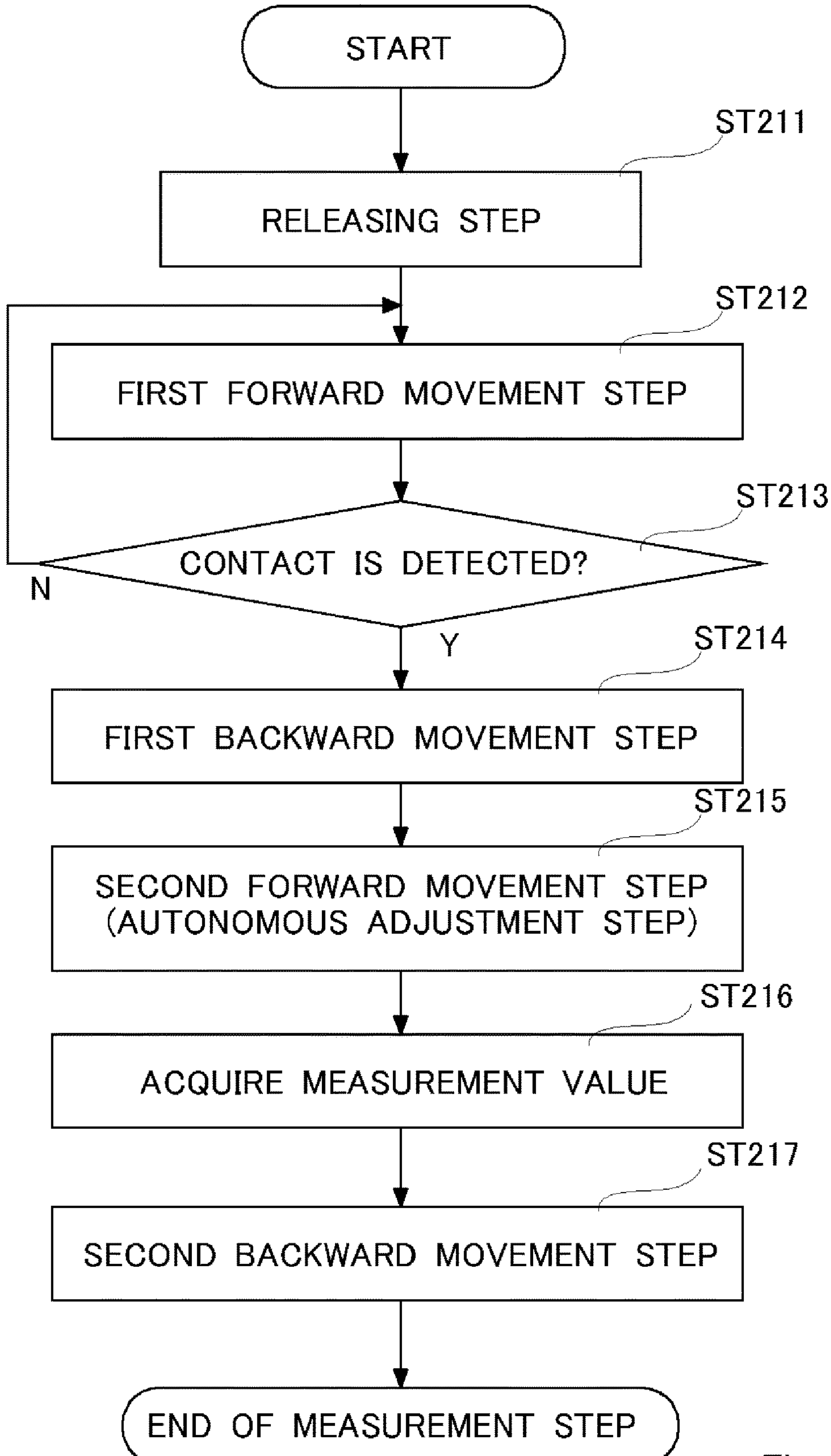

Fig. 18

HOLE RETRACTION STEP ST300

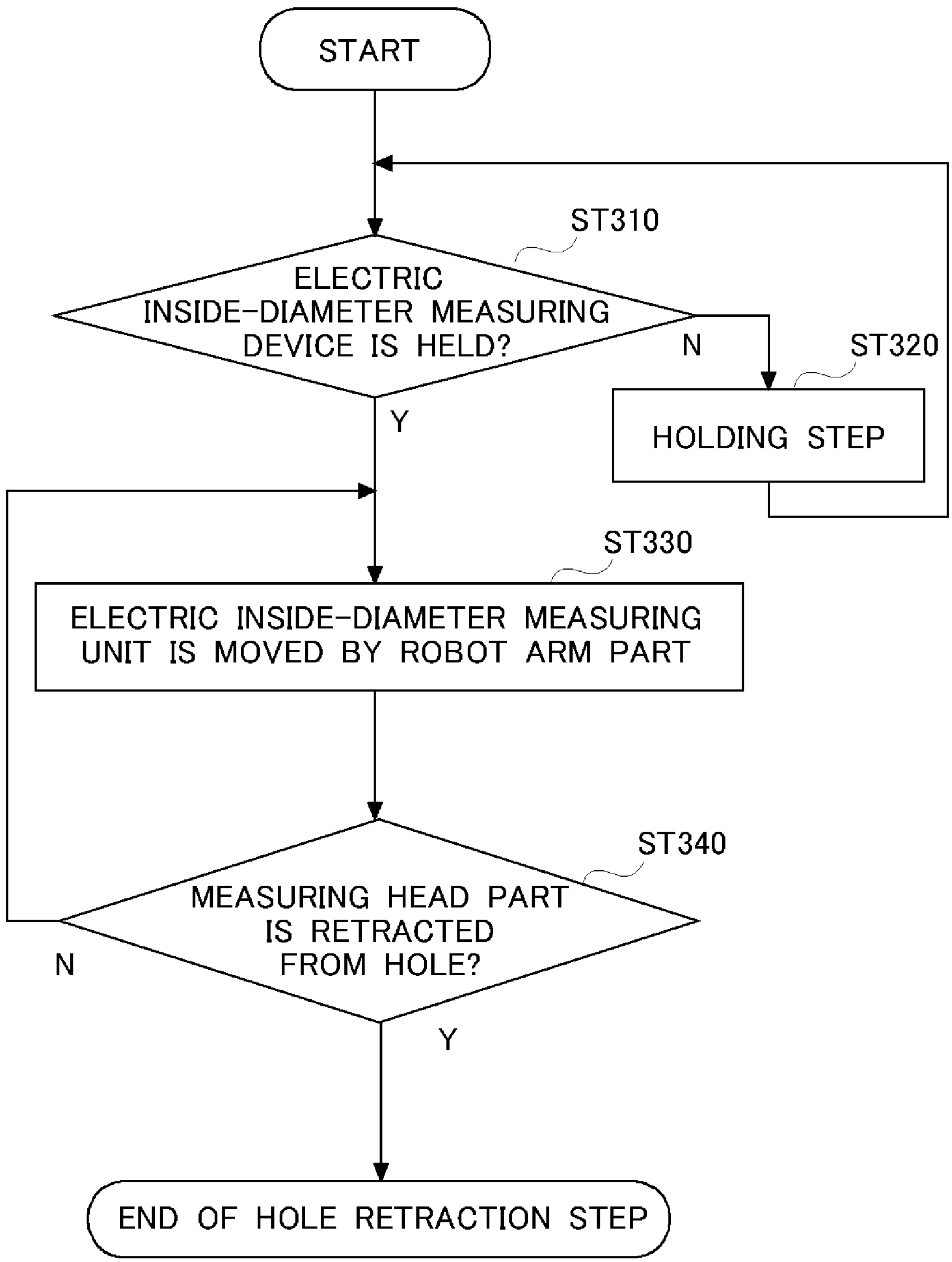

Fig. 19

SECOND EXEMPLARY EMBODIMENT
MEASUREMENT STEP

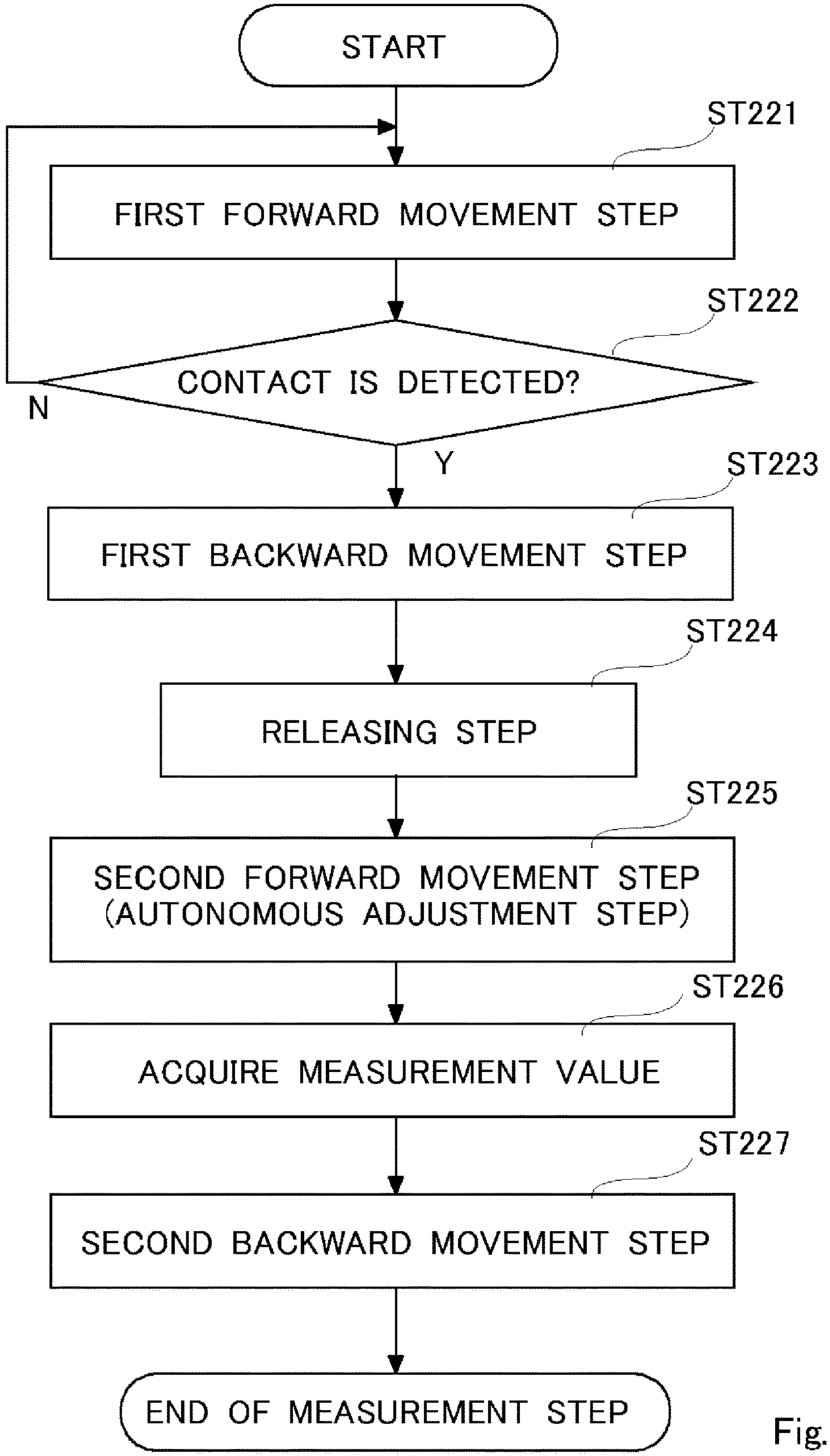

Fig. 20

THIRD EXEMPLARY EMBODIMENT
MEASUREMENT STEP

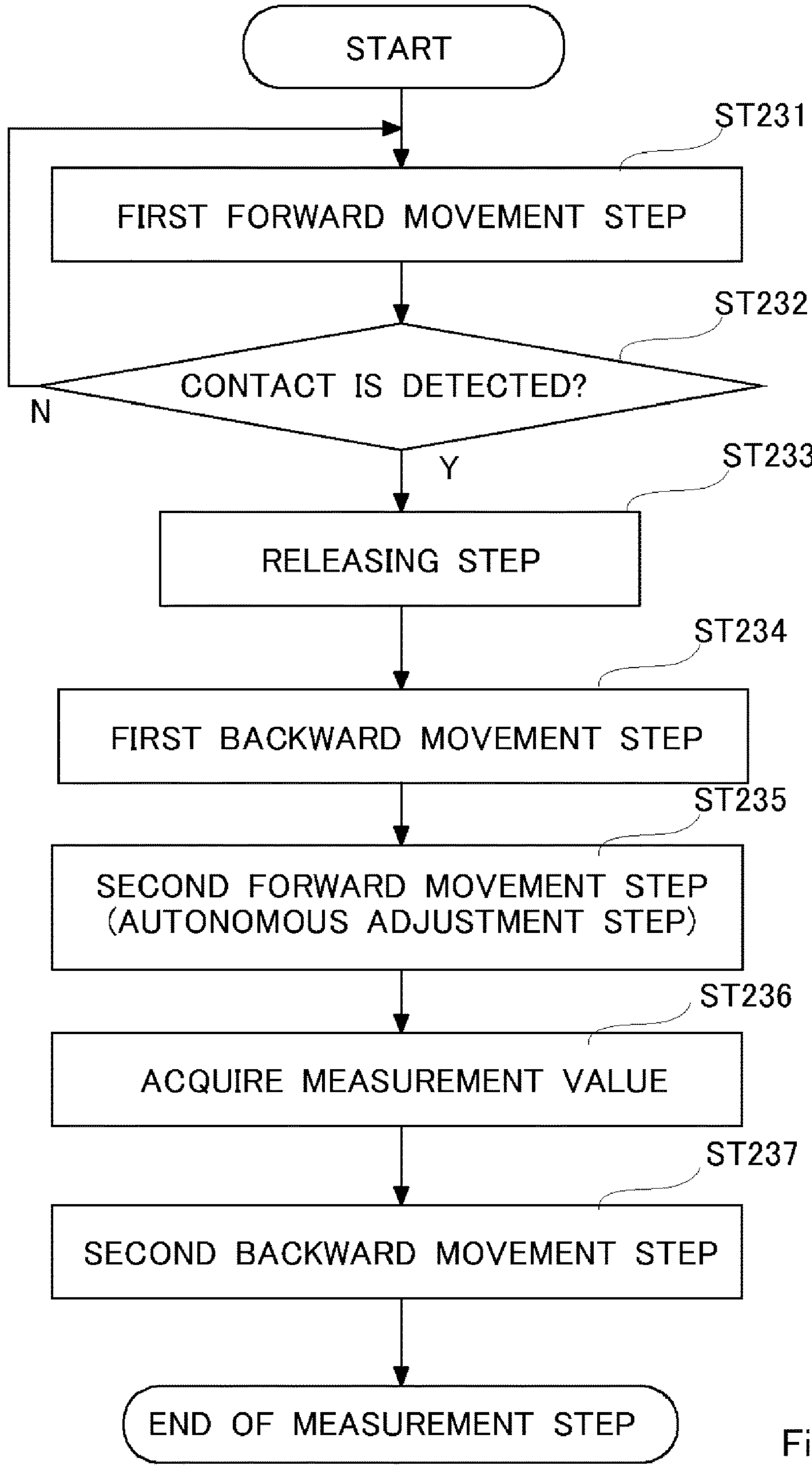

Fig. 21

FOURTH EXEMPLARY EMBODIMENT

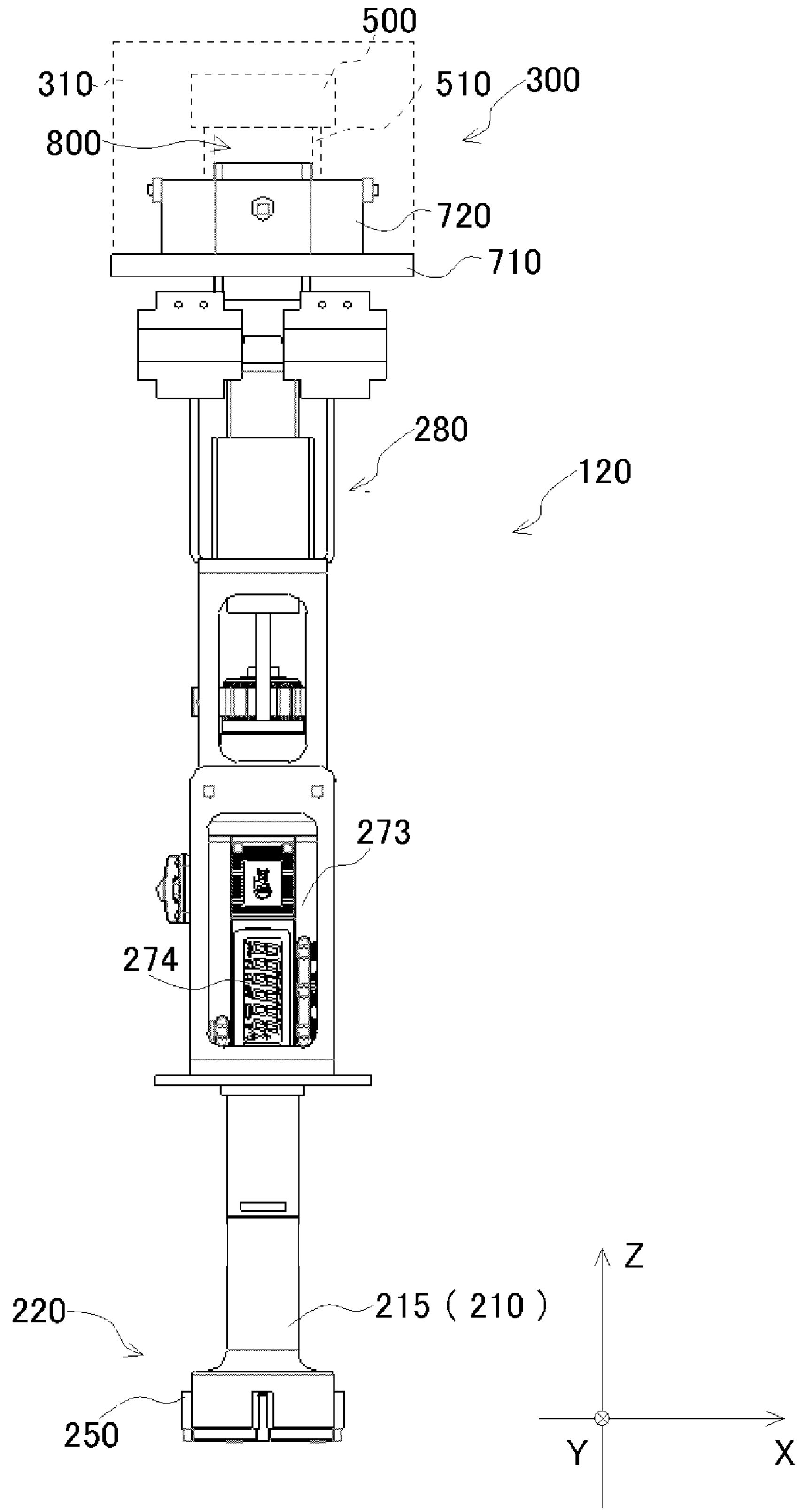

Fig. 22

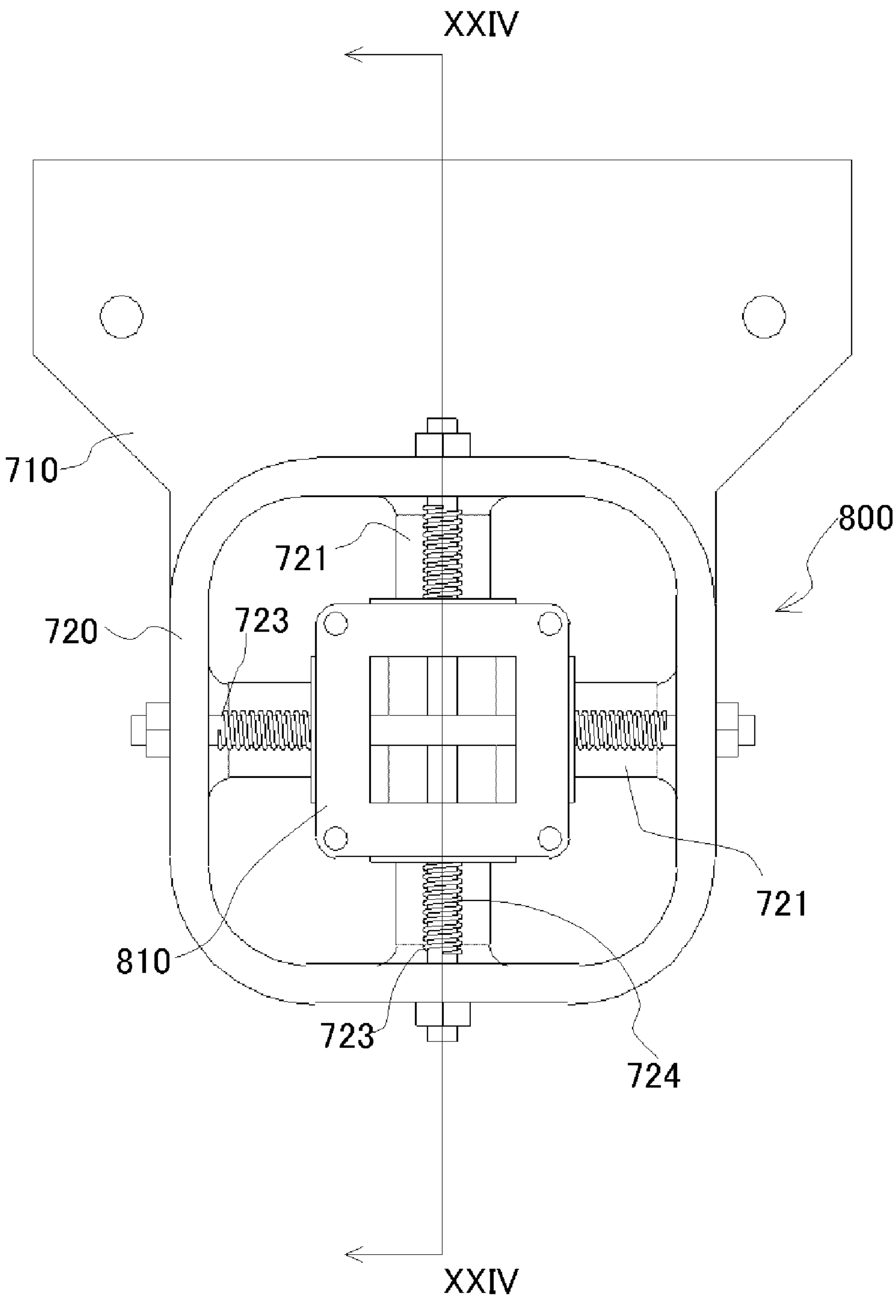

Fig. 23

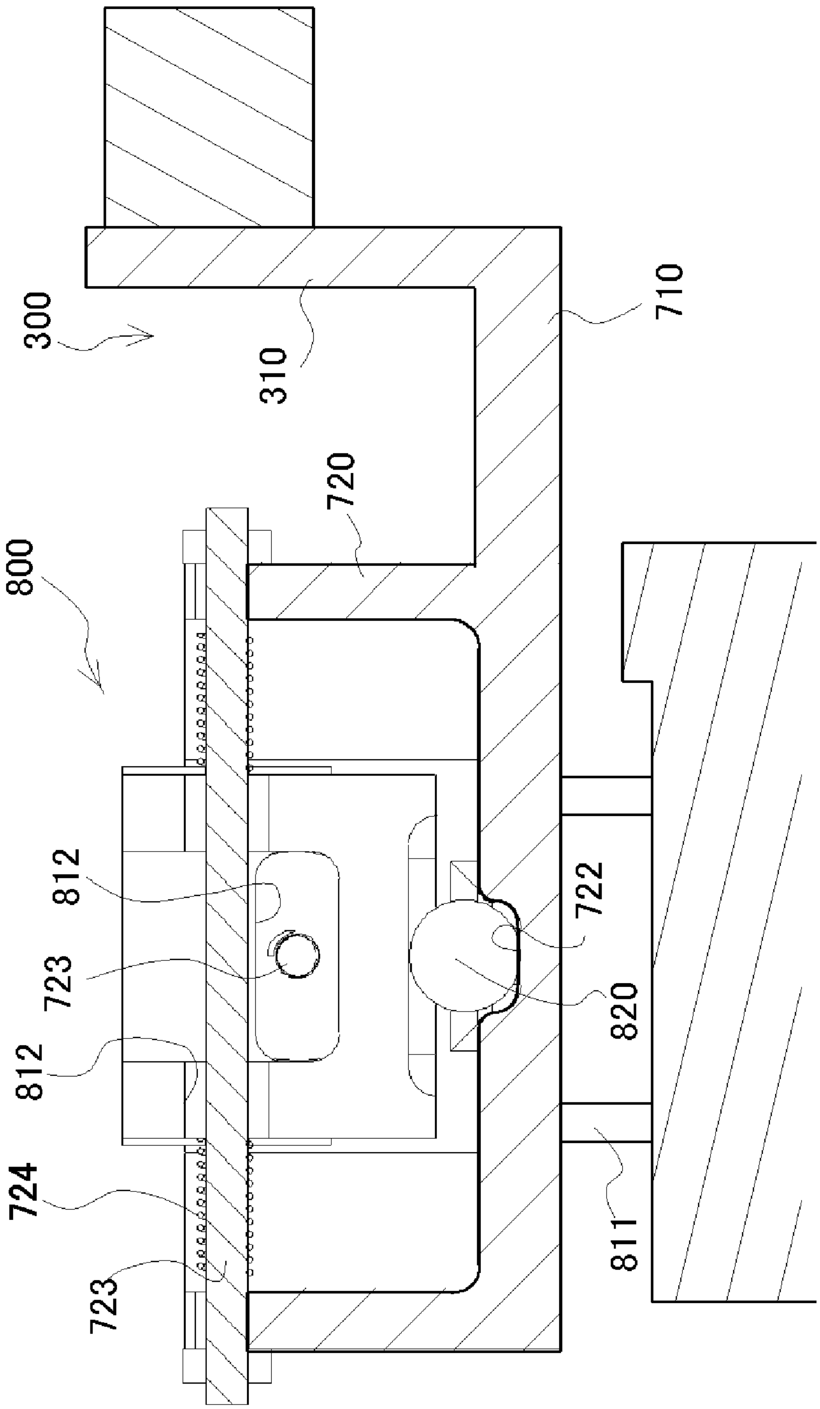

Fig. 24

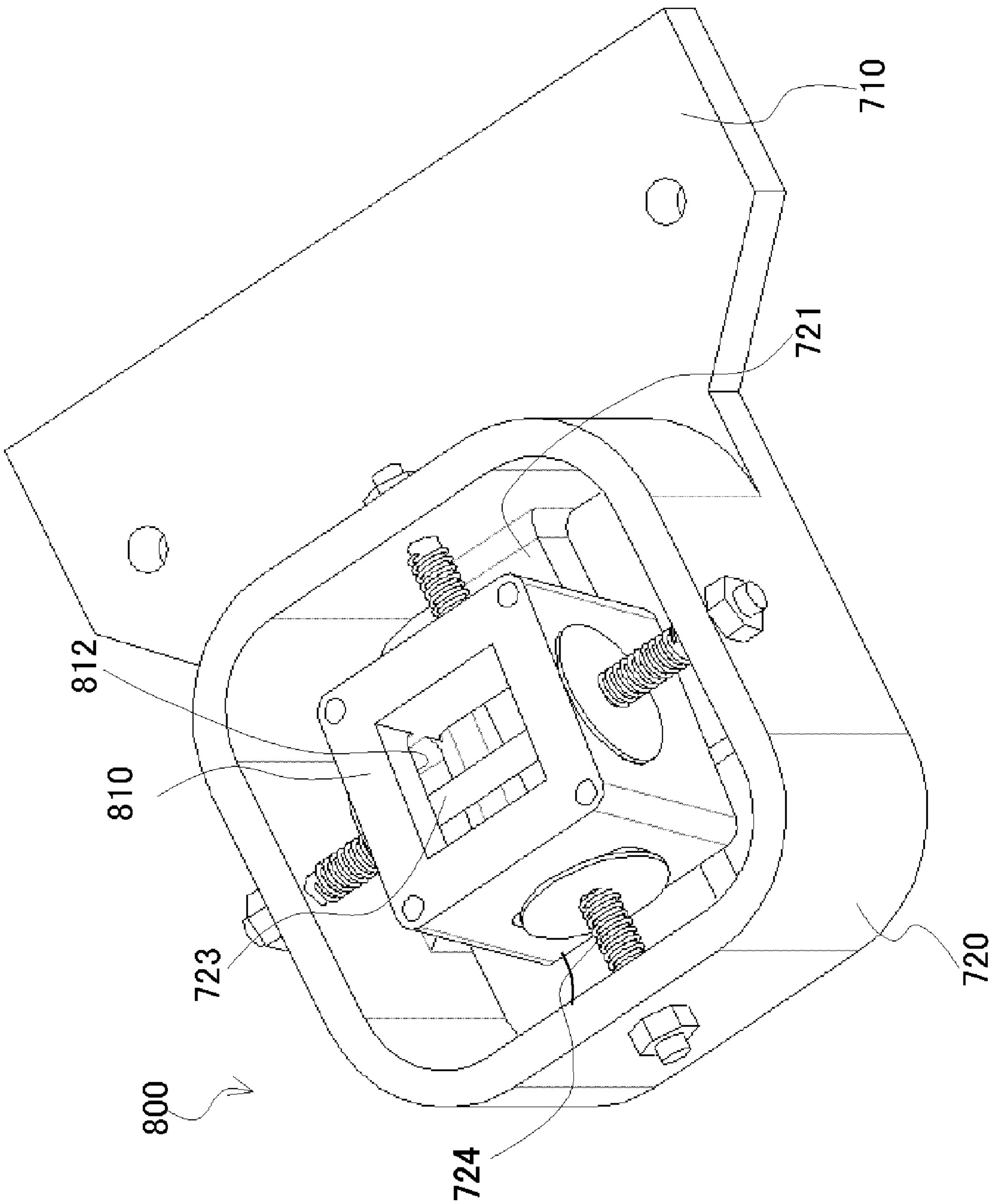

Fig. 25

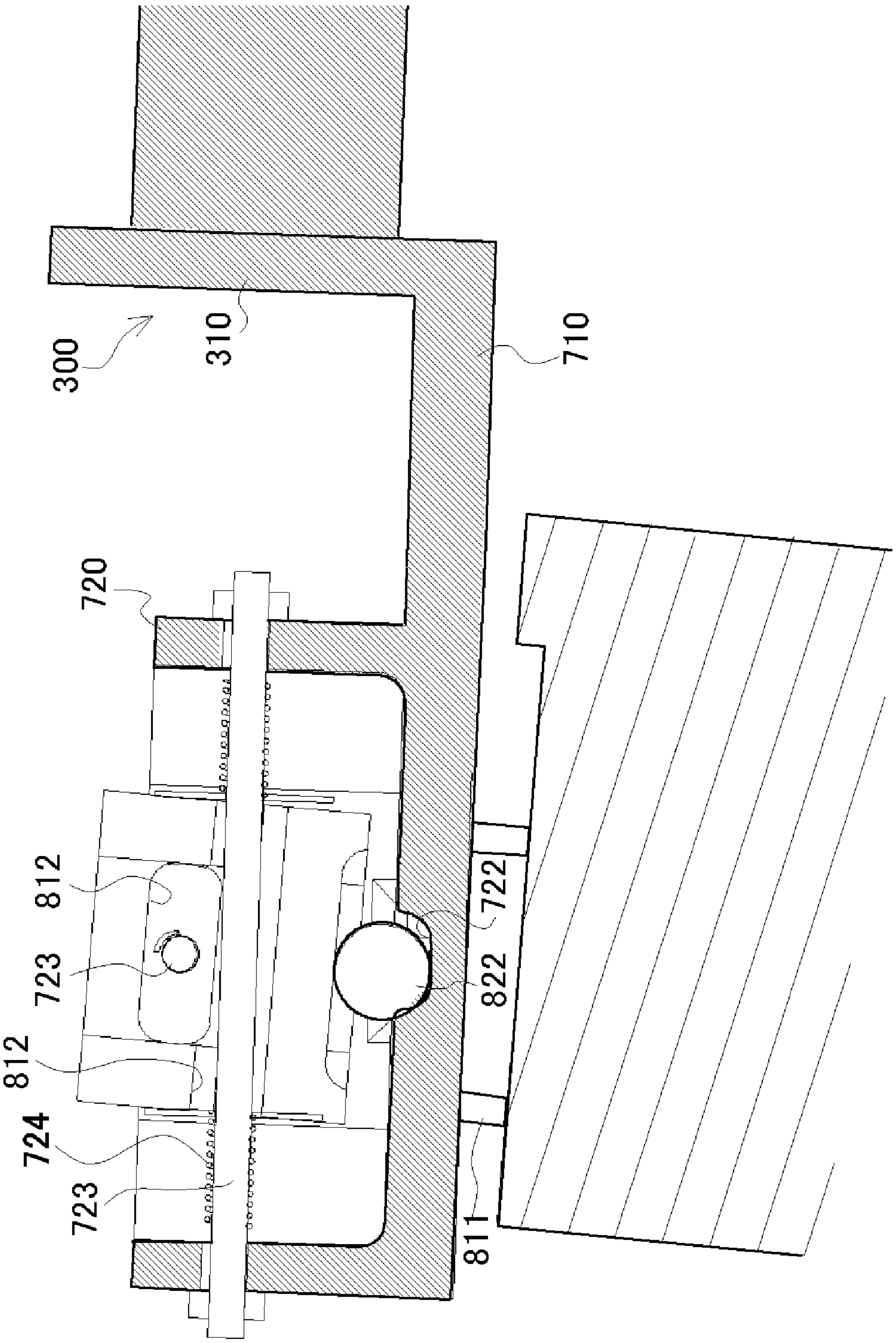

Fig. 26

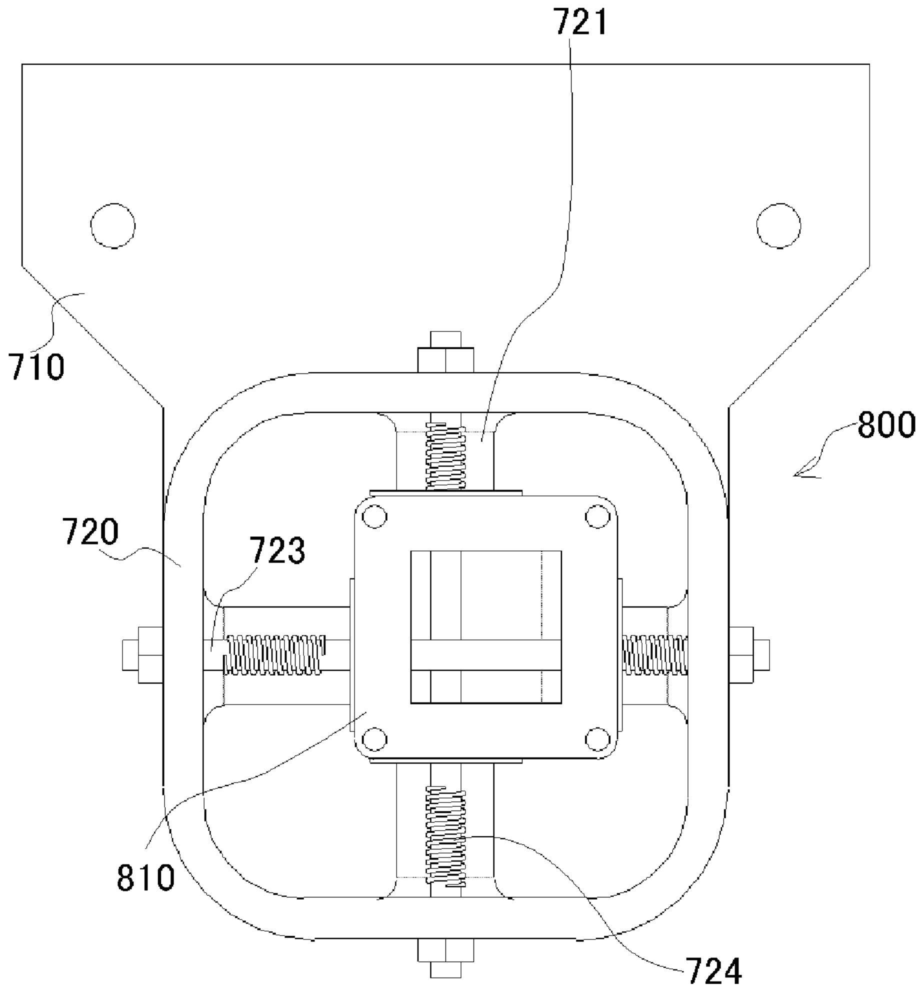

Fig. 27

FIFTH EXEMPLARY EMBODIMENT

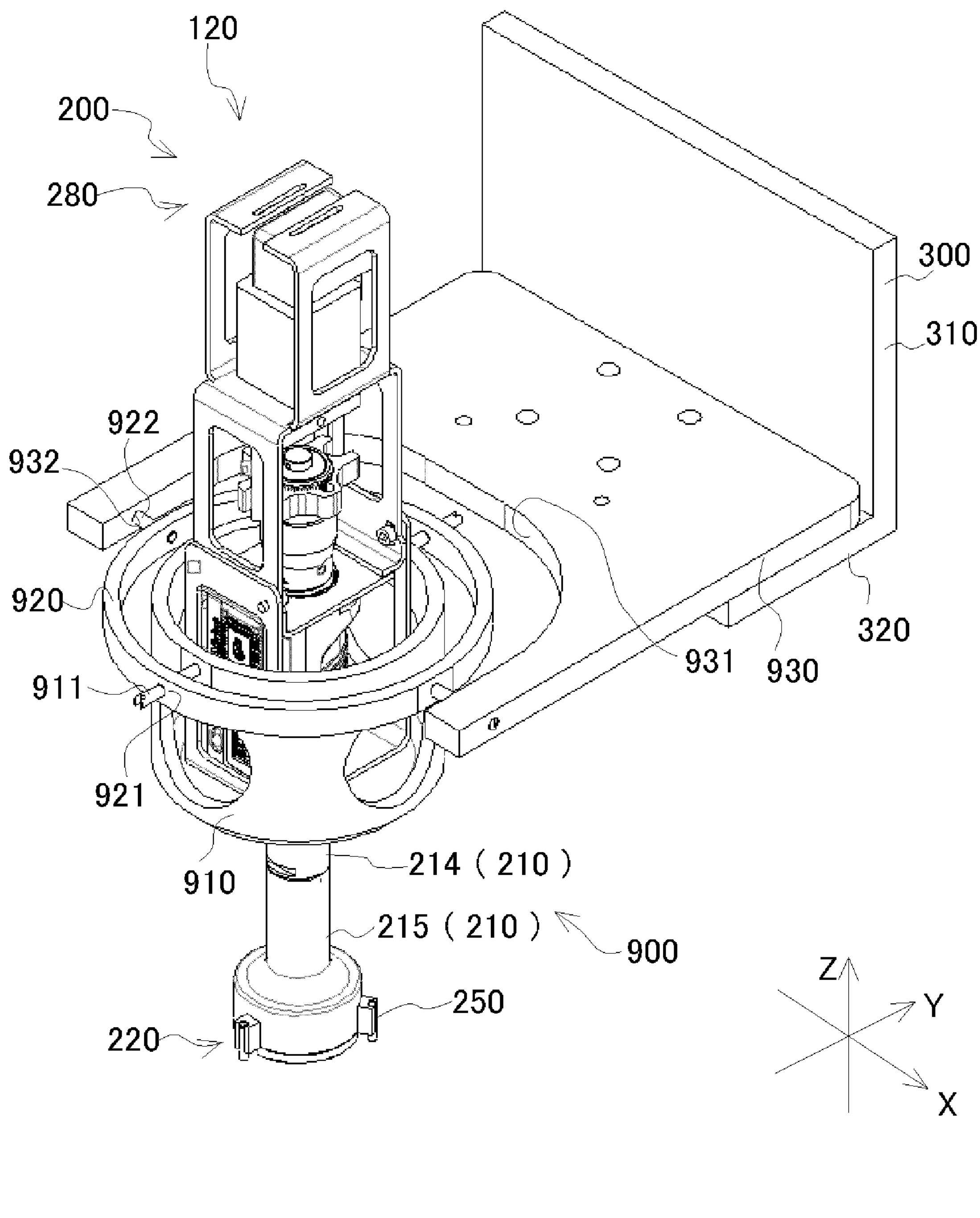

Fig. 28

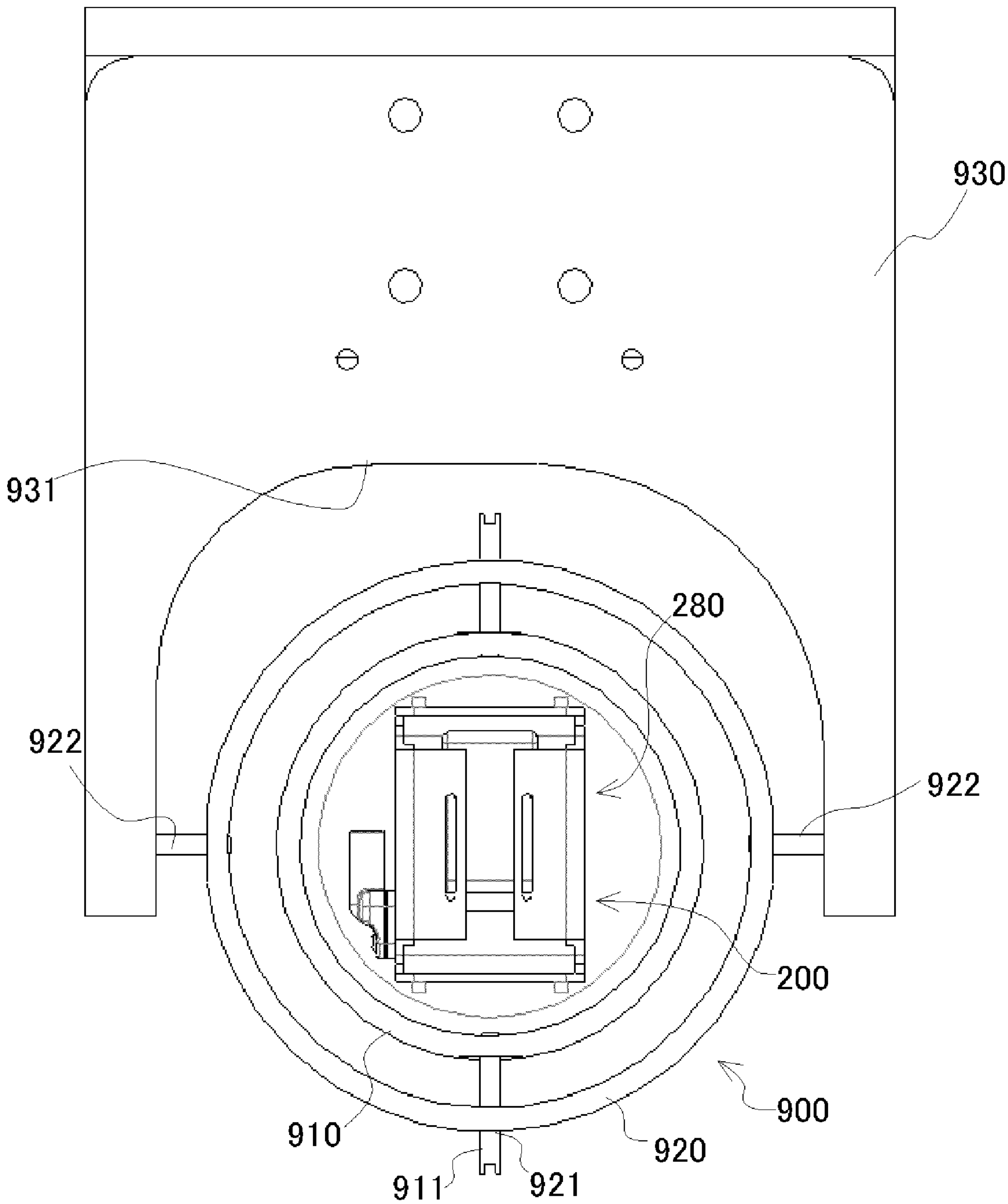

Fig. 29

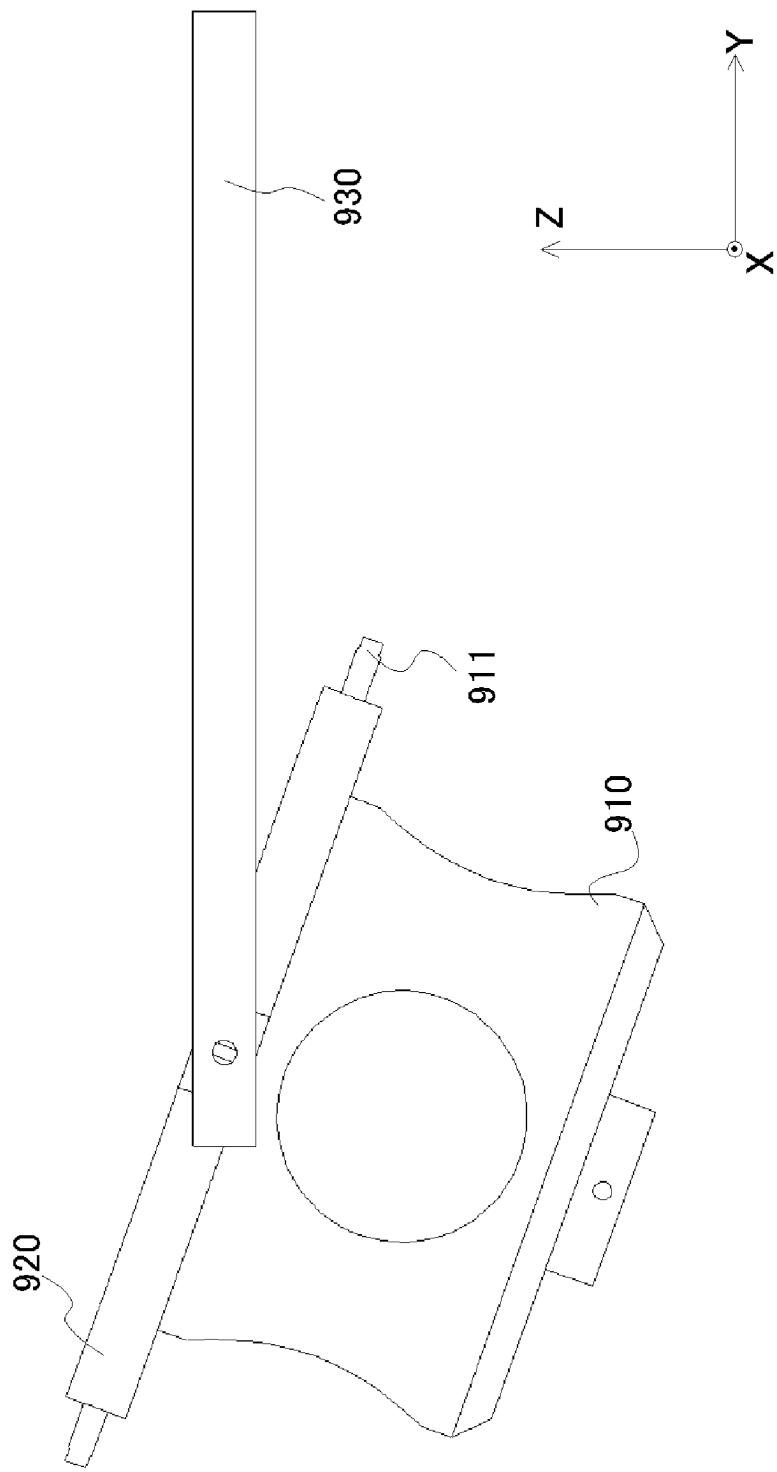

Fig. 30

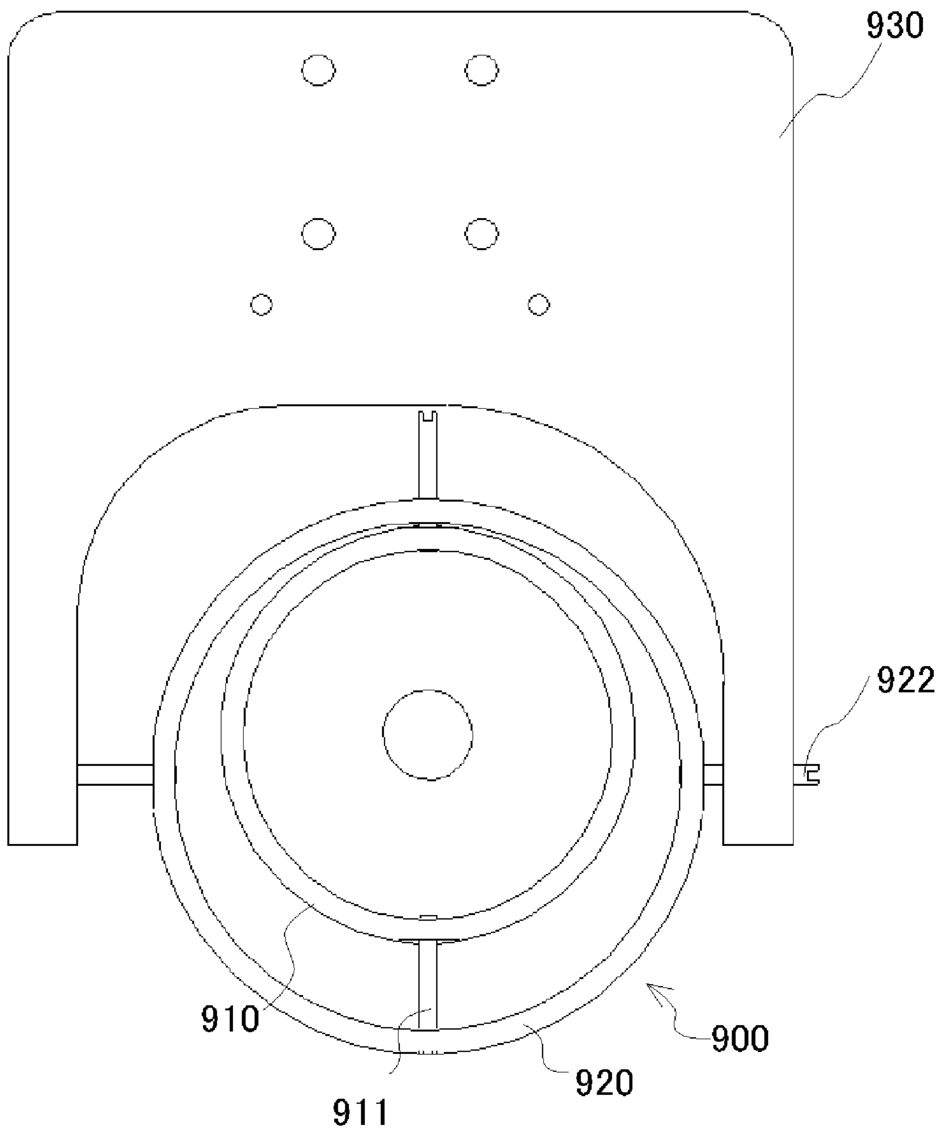

Fig. 31

SIXTH EXEMPLARY EMBODIMENT

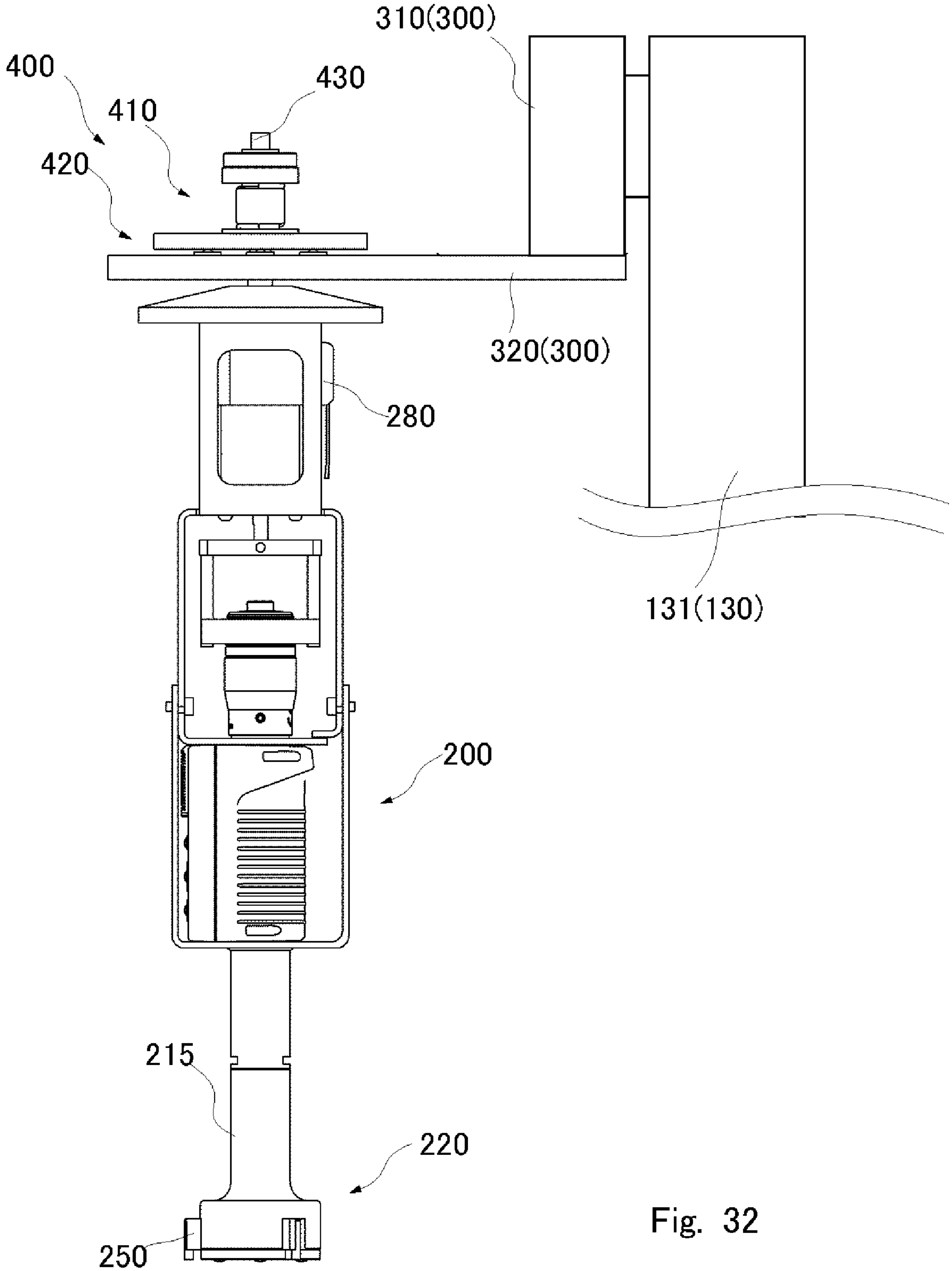

Fig. 32

SIXTH EXEMPLARY EMBODIMENT

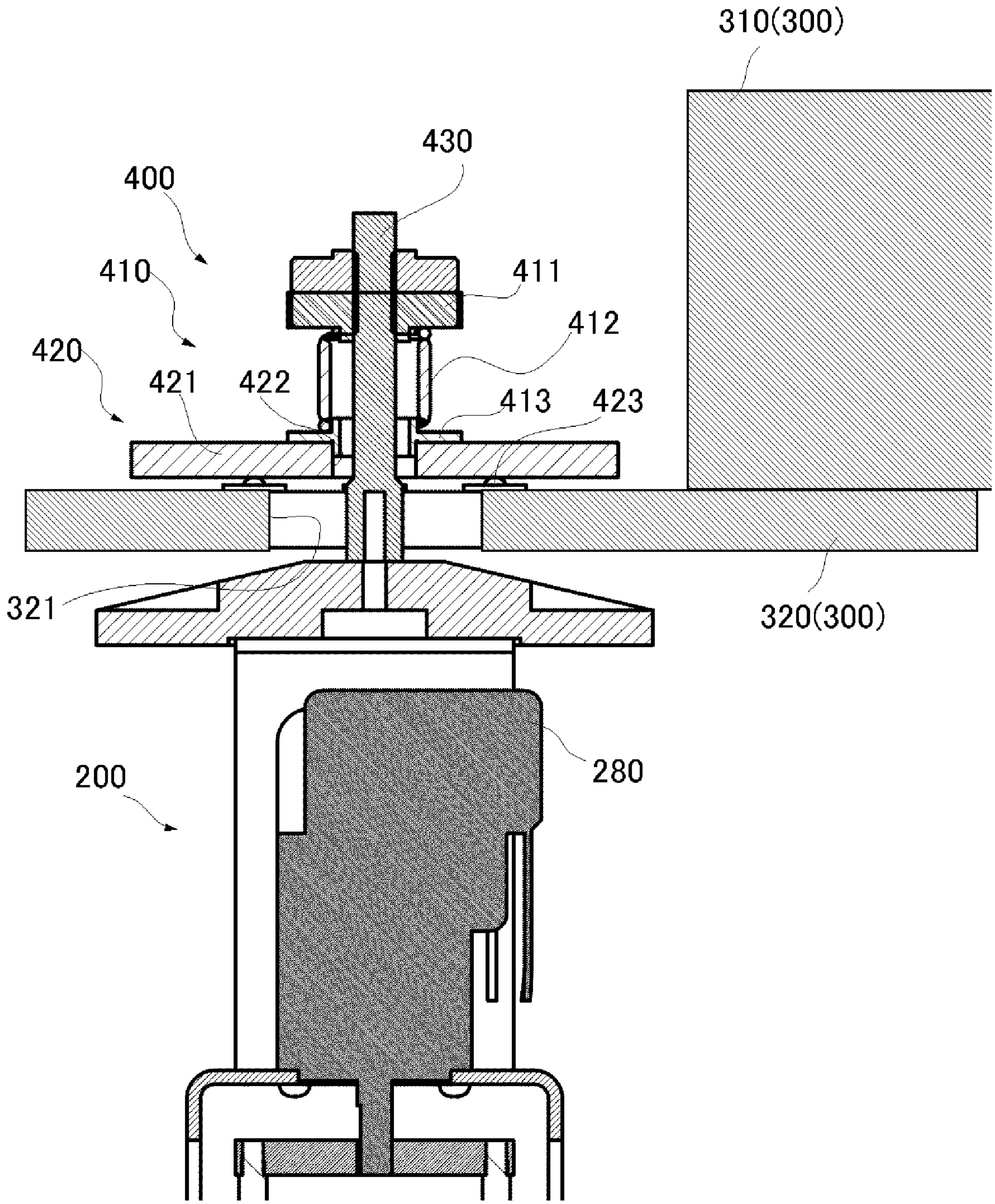

Fig. 33

INSIDE-DIAMETER MEASURING UNIT, FLOATING JOINT MECHANISM UNIT, AND MEASURING UNIT

INCORPORATION BY REFERENCE

This application is based upon and claims the benefit of priority from JP patent application No. 2022-049141, filed on Mar. 24, 2022 (DAS code BE25), the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an inside-diameter measuring unit, a floating joint mechanism part, and a measuring unit.

2. Description of Related Art

Measuring devices for measuring the inside diameter of holes are inside-diameter measuring devices, such as hole tests, cylinder gauges, and Borematic (registered trademark) (see, for example, Patent Literature 1: JP 2010-19783 A). However, when using such an inside-diameter measuring device, manual measurement is inevitably required, because its contact point must be moved forward and backward or centering is performed to some extent while the inside-diameter measuring device is inserted in a hole. Therefore, it takes a lot of manpower and time to check the machining accuracy of a hole with such an inside-diameter measuring device.

As an alternative to manual measurement, an air micrometer is an inside-diameter measuring apparatus that automates inside-diameter measurement at production sites (see, for example, Patent Literature 2: JP H8-14871). The air micrometer, which is simply inserted into a hole and blows air out, is a suitable measuring apparatus for automating inside-diameter measurement among the current options.

Patent Literature 1: JP 2010-19783 A

Patent Literature 2: JP H8-14871

SUMMARY OF THE INVENTION

However, air micrometers also have the following disadvantages.

First, air micrometers are very expensive because of their structure. In addition, an air compressor needs to be prepared and maintained. In terms of measurement capability, the repeatability of air micrometers is limited due to their structure, and their measurement range is extremely short (a few hundred micrometers).

A common problem with manual measurement using manual measuring devices has been the demand to automate measurement as inexpensively as possible.

There is a need for a measuring unit that is inexpensive, easy to use, and can automate measurement and a control method for automatic measurement.

For example, there is a need for an inside-diameter measuring unit that is inexpensive, easy to use, and can automatically measure hole diameters and a control method for automatic inside-diameter measurement.

An inside-diameter measuring unit according to an exemplary embodiment of the present invention includes:

an inside-diameter measuring part including a contact point configured to move forward and backward in a direction perpendicular to a cylinder axis of a cylinder case part, the inside-diameter measuring part configured to bring the contact point into contact with an inner wall of a hole to be measured to measure an inside diameter of the hole while the inside-diameter measuring part is inserted in the hole;

a support frame part configured to support the inside-diameter measuring part; and

a floating joint part interposed between the support frame part and the inside-diameter measuring part to allow relative translation and rotation of the inside-diameter measuring part with respect to the support frame part, wherein

the floating joint part includes:

a rotation-allowing mechanism part configured to allow the rotation of the inside-diameter measuring part with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the inside-diameter measuring part with respect to the support frame part

the rotation-allowing mechanism part includes a flexible body configured to allow deformation in a direction in which the inside-diameter measuring part is inclined

the translation-allowing mechanism part includes a translation body configured to allow translation of the inside-diameter measuring part in a direction intersecting the cylinder axis of the cylinder case part

the flexible body has one end coupled to the inside-diameter measuring part

the flexible body has the other end coupled to the translation body, and

the translation body is supported in such a manner as to be translatable with respect to the support frame part.

In an exemplary embodiment of the present invention, it is preferable that

the support frame part includes a support base part

the support base part includes a first insertion hole through which the inside-diameter measuring part is inserted

the translation body includes a second insertion hole through which

the inside-diameter measuring part is inserted

the inside-diameter measuring part is supported while being inserted in the first insertion hole and the second insertion holes, and

the floating joint part includes a bearing provided around the first insertion hole and the second insertion hole between the translation body and the support base part to allow translation of the translation body with respect to the support base part.

In an exemplary embodiment of the present invention, it is preferable that

the first insertion hole has a larger diameter than a diameter of the second insertion hole

the diameter of the first insertion hole has a size allowing the translation of the inside-diameter measuring part, and

the diameter of the second insertion hole has a size allowing the inclination of the inside-diameter measuring part.

In an exemplary embodiment of the present invention, it is preferable that the flexible body is an elastic body provided to surround the inside-diameter measuring part between the inside-diameter measuring part and the translation body.

In an exemplary embodiment of the present invention, it is preferable that the elastic body is a spring provided to surround the inside-diameter measuring part.

In an exemplary embodiment of the present invention, it is preferable that

the translation body is disposed above the support base part

the flexible body has a lower end coupled to the translation body as the other end, and

the flexible body has an upper end coupled to the inside-diameter measuring part as the one end.

In an exemplary embodiment of the present invention, it is preferable that a position at which the one end of the flexible body is coupled to the inside-diameter measuring part corresponds to a center of gravity of the inside-diameter measuring part.

In an exemplary embodiment of the present invention, it is preferable that the inside-diameter measuring unit further includes an electric drive unit configured to move the contact point forward and backward.

In an exemplary embodiment of the present invention, it is preferable that

the inside-diameter measuring unit further includes a restriction means for clamping the inside-diameter measuring part from a direction intersecting the cylinder axis, wherein

the restriction means is configured to clamp and hold the inside-diameter measuring part when the inside-diameter measuring part is not inserted in the hole to be measure, and to release the inside-diameter measuring part when the inside-diameter measuring part is inserted in the hole to be measured.

In an exemplary embodiment of the present invention, it is preferable that the inside-diameter measuring part is supported by the support frame part via the floating joint part when the cylinder axis is oriented in a vertical direction as a reference position.

In an exemplary embodiment of the present invention, it is preferable that the support frame part couples the inside-diameter measuring part to a moving means for moving the inside-diameter measuring part.

A floating joint mechanism part according to an exemplary embodiment of the present invention is a floating joint mechanism part interposed between an object to be supported and a support frame part configured to support the object to be supported, the floating joint mechanism part configured to allow relative translation and rotation of the object to be supported with respect to the support frame part, the floating joint mechanism part includes:

a rotation-allowing mechanism part configured to allow the rotation of the object to be supported with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the object to be supported with respect to the support frame part, wherein

the rotation-allowing mechanism part includes a flexible body configured to allow deformation in a direction in which the object to be supported is inclined

the translation-allowing mechanism part includes a translation body configured to allow translation of the object to be supported

the flexible body has one end coupled to the object to be supported

the flexible body has the other end coupled to the translation body, and

the translation body is supported in such a manner as to be translatable with respect to the support frame part.

A measuring unit according to an exemplary embodiment of the present invention includes:

a measuring part configured to bring a contact point into contact with an object to be measured to measure a dimension of the object to be measured;

a support frame part configured to support the measuring part; and

a floating joint part interposed between the support frame part and the measuring part to allow relative translation and rotation of the measuring part with respect to the support frame part, wherein

the floating joint part includes:

a rotation-allowing mechanism part configured to allow the rotation of the measuring part with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the measuring part with respect to the support frame part

the rotation-allowing mechanism part includes a flexible body configured to allow deformation in a direction in which the measuring part is inclined

the translation-allowing mechanism part includes a translation body configured to allow translation of the measuring part

the flexible body has one end coupled to the measuring part

the flexible body has the other end coupled to the translation body, and

the translation body is supported in such a manner as to be translatable with respect to the support frame part.

An inside-diameter measuring unit according to an exemplary embodiment of the present invention includes:

an inside-diameter measuring part including a contact point configured to move forward and backward in a direction perpendicular to a cylinder axis of a cylinder case part, the inside-diameter measuring part configured to bring the contact point into contact with an inner wall of a hole to be measured to measure an inside diameter of the hole while the inside-diameter measuring part is inserted in the hole;

a support frame part configured to support the inside-diameter measuring part; and

a floating joint part interposed between the support frame part and the inside-diameter measuring part to allow relative translation and rotation of the inside-diameter measuring part with respect to the support frame part, wherein

the floating joint part includes:

a coupling block fixedly coupled to the inside-diameter measuring part and configured to be translated and rotated integrally with the inside-diameter measuring part;

a rotation-allowing mechanism part configured to allow rotation of the coupling block with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the coupling block in a direction parallel to a plane perpendicular to the cylinder axis with respect to the support frame part

the rotation-allowing mechanism part includes a sphere disposed between the coupling block and the support frame part, and

the translation-allowing mechanism part includes:

a guide shaft provided to either one of the coupling block and the support frame part and extending in the direction parallel to the plane perpendicular to the cylinder axis; and

a guide hole provided in the other one of the coupling block and the support frame part to receive the guide shaft and allow the guide shaft to slide in the direction parallel to the plane perpendicular to the cylinder axis.

In an exemplary embodiment of the present invention, it is preferable that

the guide shaft is one of two guide shafts, and

the two guide shafts are provided in mutually orthogonal directions in the plane perpendicular to the cylinder axis.

In an exemplary embodiment of the present invention, it is preferable that

the support frame part includes a support ring part surrounding the coupling block in the plane perpendicular to the cylinder axis

the support ring part is provided with the two guide shafts, and

the coupling block includes a guide hole configured to receive the two guide shafts and allow translation and rotation of the coupling block.

In an exemplary embodiment of the present invention, it is preferable that

the coupling block is disposed above an upper end of the inside-diameter measuring part, and

the inside-diameter measuring part is supported by the support frame part while being suspended from the support frame part via the floating joint part.

In an exemplary embodiment of the present invention, it is preferable that a position at which the two guide shafts intersect is on an extension of the cylinder axis of the inside-diameter measuring part.

In an exemplary embodiment of the present invention, it is preferable that the inside-diameter measuring unit further includes an electric drive unit configured to move the contact point forward and backward.

In an exemplary embodiment of the present invention, it is preferable that

the inside-diameter measuring unit further includes a restriction means for clamping the inside-diameter measuring part or the coupling block to hold the inside-diameter measuring part, wherein

the restriction means is configured to hold the inside-diameter measuring part when the inside-diameter measuring part is not inserted in a hole to be measured, and to release the inside-diameter measuring part when the inside-diameter measuring part is inserted in the hole to be measured.

In an exemplary embodiment of the present invention, it is preferable that the inside-diameter measuring part is supported by the support frame part via the floating joint part when the cylinder axis is oriented in a vertical direction as a reference position.

In an exemplary embodiment of the present invention, it is preferable that the support frame part couples the inside-diameter measuring part to a moving means for moving the inside-diameter measuring part.

A floating joint mechanism part according to an exemplary embodiment of the present invention is a floating joint mechanism part interposed between an object to be supported and a support frame part configured to support the object to be supported, the floating joint mechanism part configured to allow relative translation and rotation of the object to be supported with respect to the support frame part, the floating joint mechanism part includes:

a coupling block fixedly coupled to the object to be supported and configured to be translated and rotated integrally with the object to be supported;

a rotation-allowing mechanism part configured to allow rotation of the coupling block with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the coupling block with respect to the support frame part

the rotation-allowing mechanism part includes a sphere disposed between the coupling block and the support frame part, and

the translation-allowing mechanism part includes:

a guide shaft provided to either one of the coupling block and the support frame part and extending in a direction of guiding translation; and

a guide hole provided in the other one of the coupling block and the support frame part to receive the guide shaft and allow the guide shaft to slide.

A measuring unit according to an exemplary embodiment of the present invention includes:

a measuring part configured to bring a contact point into contact with an object to be measured to measure a dimension of the object to be measured;

a support frame part configured to support the measuring part; and

a floating joint part interposed between the support frame part and the measuring part to allow relative translation and rotation of the measuring part with respect to the support frame part, wherein

the floating joint part includes:

a coupling block fixedly coupled to the measuring part and configured to be translated and rotated integrally with the measuring part;

a rotation-allowing mechanism part configured to allow rotation of the coupling block with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the coupling block with respect to the support frame part

the rotation-allowing mechanism part includes a sphere disposed between the coupling block and the support frame part, and

the translation-allowing mechanism part includes:

a guide shaft provided to either one of the coupling block and the support frame part and extending in a direction of guiding translation; and

a guide hole provided in the other one of the coupling block and the support frame part to receive the guide shaft and allow the guide shaft to slide.

An inside-diameter measuring unit according to an exemplary embodiment of the present invention includes:

an inside-diameter measuring part including a contact point configured to move forward and backward in a direction perpendicular to a cylinder axis of a cylinder case part, the inside-diameter measuring part configured to bring the contact point into contact with an inner wall of a hole to be measured to measure an inside diameter of the hole while the inside-diameter measuring part is inserted in the hole;

a support frame part configured to support the inside-diameter measuring part; and

a floating joint part interposed between the support frame part and the inside-diameter measuring part to allow relative translation and rotation of the inside-diameter measuring part with respect to the support frame part, wherein

the floating joint part includes:

a first floating coupling body fixedly coupled to the inside-diameter measuring part and configured to be translated and rotated integrally with the inside-diameter measuring part;

a second floating coupling body configured to support the first floating coupling body to allow translation and rotation of the first floating coupling body; and

a third floating coupling body configured to support the second floating coupling body to allow translation and rotation of the second floating coupling body, and

the third floating coupling body is fixedly attached to the support frame part.

In an exemplary embodiment of the present invention, it is preferable that

the second floating coupling body supports the first floating coupling body via a first coupling shaft extending in a first direction parallel to a plane perpendicular to the cylinder axis, the first coupling shaft configured to allow axially forward and backward movement and axial rotation, and

the third floating coupling body supports the second floating coupling body via a second coupling shaft extending in a direction perpendicular to the first direction in the plane perpendicular to the cylinder axis, the second coupling shaft configured to allow axially forward and backward movement and axial rotation.

In an exemplary embodiment of the present invention, it is preferable that

the first floating coupling body is ring shaped or cylinder shaped and provided to surround the inside-diameter measuring part in the direction perpendicular to the cylinder axis, and

the second floating coupling body is ring shaped or cylinder shaped and provided to surround the first floating coupling body in the direction perpendicular to the cylinder axis.

In an exemplary embodiment of the present invention, it is preferable that a position at which a first virtual straight line being a virtual extension of the first coupling shaft and a second virtual straight line being a virtual extension of the second coupling shaft intersect is substantially aligned with a center of gravity of the inside-diameter measuring part.

In an exemplary embodiment of the present invention, it is preferable that the inside-diameter measuring unit further includes an electric drive unit configured to move the contact point forward and backward.

In an exemplary embodiment of the present invention, it is preferable that

the inside-diameter measuring unit further includes a restriction means for clamping the inside-diameter measuring part from a direction intersecting the cylinder axis, wherein

the restriction means is configured to clamp and hold the inside-diameter measuring part when the inside-diameter measuring part is not inserted in a hole to be measured, and to release the inside-diameter measuring part when the inside-diameter measuring part is inserted in the hole to be measured.

In an exemplary embodiment of the present invention, it is preferable that the inside-diameter measuring part is supported by the support frame part via the floating joint part when the cylinder axis is oriented in a vertical direction as a reference position.

A floating joint mechanism part according to an exemplary embodiment of the present invention is a floating joint mechanism part interposed between an object to be supported and a support frame part configured to support the object to be supported, the floating joint mechanism part configured to allow relative translation and rotation of the object to be supported with respect to the support frame part, the floating joint mechanism part includes:

a first floating coupling body fixedly coupled to the object to be supported and configured to be translated and rotated integrally with the object to be supported;

a second floating coupling body configured to support the first floating coupling body to allow translation and rotation of the first floating coupling body; and

a third floating coupling body configured to support the second floating coupling body to allow translation and rotation of the second floating coupling body, wherein

the third floating coupling body is fixedly attached to the support frame part.

A measuring unit according to an exemplary embodiment of the present invention includes:

a measuring part configured to bring a contact point into contact with an object to be measured to measure a dimension of the object to be measured;

a support frame part configured to support the measuring part; and

a floating joint part interposed between the support frame part and the measuring part to allow relative translation and rotation of the measuring part with respect to the support frame part, wherein

the floating joint part includes:

a first floating coupling body fixedly coupled to the measuring part and configured to be translated and rotated integrally with the measuring part;

a second floating coupling body configured to support the first floating coupling body to allow translation and rotation of the first floating coupling body; and

a third floating coupling body configured to support the second floating coupling body to allow translation and rotation of the second floating coupling body, and

the third floating coupling body is fixedly attached to the support frame part.

A control method of an automatic inside-diameter measuring apparatus, the automatic inside-diameter measuring apparatus including:

an inside-diameter measuring part including a contact point configured to move forward and backward in a direction perpendicular to a cylinder axis of a cylinder case part, an electric drive unit configured to move the contact point forward and backward, and a displacement detection part configured to detect displacement of the contact point;

a moving means for relatively moving the inside-diameter measuring part with respect to an object to be measured to insert and retract the inside-diameter measuring part into and from a hole to be measured; and

a control unit configured to control operation of the inside-diameter measuring part and the moving means, the control method includes:

a hole insertion step of inserting, by the moving means, the inside-diameter measuring part into the hole to be measured;

a measurement step of bringing the contact point into contact with an inner wall of the hole to measure an inside diameter of the hole; and

a hole retraction step of retracting the inside-diameter measuring part from the hole by the moving means.

In an exemplary embodiment of the present invention, it is preferable that

the automatic inside-diameter measuring apparatus further includes:

a support frame part configured to support the inside-diameter measuring part and to couple the inside-diameter measuring part to the moving means; and

a floating joint part interposed between the support frame part and the inside-diameter measuring part to allow relative translation and rotation of the inside-diameter measuring part with respect to the support frame part

the hole insertion step including temporarily stopping drive of the moving means after the inside-diameter measuring part is inserted by the moving means into the hole to be measured, and

the measurement step includes an autonomous adjustment step of autonomously adjusting, by the inside-diameter measuring part, a position and posture of the inside-diameter measuring part itself to align the cylinder axis of the cylinder case part with an axis of the hole to be measured while the inside-diameter measuring part is relatively displaced with respect to the support frame part by a reaction force applied to the inside-diameter measuring part from the inner wall of the hole to be measured when the electric drive unit moves the contact point forward and brings the contact point into contact with the inner wall of the hole to be measured.

In an exemplary embodiment of the present invention, it is preferable that

the automatic inside-diameter measuring apparatus further includes a restriction means for clamping the inside-diameter measuring part from a direction intersecting the cylinder axis

the restriction means is configured to switch between a holding state and a release state of the inside-diameter measuring part by performing a holding step of clamping and restricting the inside-diameter measuring part and a release step of releasing the restriction of the inside-diameter measuring part

the restriction means maintains the holding state of the inside-diameter measuring part during the hole insertion step and the hole retraction step, and

the measurement step includes performing, by the restriction means, the releasing step before the autonomous adjustment step to release the restriction of the inside-diameter measuring part.

In an exemplary embodiment of the present invention, it is preferable that

the control unit includes a drive control unit configured to control the electric drive unit

the measurement step includes:

a first forward movement step of moving, by the drive control unit, the contact point forward until the contact point is brought into first contact with the inner wall of the hole to be measured;

a backward movement step of moving, by the drive control unit, the contact point backward slightly in an opposite direction after the first forward movement step; and

a second forward movement step of moving, by the drive control unit, the contact point forward again after the backward movement step to perform the autonomous adjustment step.

In an exemplary embodiment of the present invention, it is preferable that the releasing step is performed before the first forward movement step.

In an exemplary embodiment of the present invention, it is preferable that the releasing step is performed after the first forward movement step.

In an exemplary embodiment of the present invention, it is preferable that

a constant pressure mechanism configured to regulate an upper limit of the reaction force applied to the contact point from the inner wall of the hole to be measured is provided in a force transmission path from the electric drive unit to the contact point, and

the drive control unit terminates the second forward movement step when the constant pressure mechanism is activated.

In an exemplary embodiment of the present invention, it is preferable that

the automatic inside-diameter measuring apparatus further includes a collision detection part configured to detect that the inside-diameter measuring part has collided with an object, and

the hole insertion step is stopped when the collision detection part detects a collision.

A control method of an automatic measuring apparatus, the automatic measuring apparatus including:

a measuring part including a contact point provided to move forward and backward with respect to a fixed element, an electric drive unit configured to move the contact point forward and backward, and a displacement detection part configured to detect displacement of the contact point;

a moving means for relatively moving the measuring part with respect to an object to be measured to bring the measuring part closer to or in contact with the object to be measured; and

a control unit configured to control operation of the measuring part and the moving means, the control method includes:

an approaching step of bringing, by the moving means, the measuring part closer to the object to be measured;

a measurement step of bringing the contact point into contact with the object to be measured to measure a dimension of the object to be measured; and

a retraction step of retracting, by the moving means, the measuring part from the object to be measured.

In an exemplary embodiment of the present invention, it is preferable that

the automatic measuring apparatus further includes:

a support frame part configured to support the measuring part and to couple the measuring part to the moving means; and

a floating joint part interposed between the support frame part and the measuring part to allow relative translation and rotation of the measuring part with respect to the support frame part

the approaching step including temporarily stopping drive of the moving means after the measuring part is brought, by the moving means, closer to or into contact with the object to be measured, and

the measurement step includes an autonomous adjustment step of autonomously adjusting, by the measuring part, a position and posture of the measuring part itself while the measuring part is relatively displaced with respect to the support frame part by a reaction force applied to the measuring part from object to be measured when the electric drive unit moves the contact point forward and brings the contact point into contact with object to be measured.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an external view of an entire automatic inside-diameter measuring apparatus;

FIG. **2** is an external perspective view of an electric inside-diameter measuring unit when viewed from a slightly front side;

FIG. **3** is an external perspective view of the side of the electric inside-diameter measuring unit when viewed from a slightly rear side;

FIG. **4** is a front view of the electric inside-diameter measuring unit;

FIG. **5** is a cross-sectional view for showing the internal structure of an electric inside-diameter measuring device;

FIG. **6** is an exploded view of a floating joint part according to an first exemplary embodiment;

FIG. **7** is a cross-sectional view of the floating joint part according to the first exemplary embodiment;

FIG. **8** is a view for explaining a function of the floating joint part for adjusting the position and posture of the electric inside-diameter measuring device according to the first exemplary embodiment;

FIG. **9** is a view for explaining the function of the floating joint part for adjusting the position and posture of the electric inside-diameter measuring device according to the first exemplary embodiment;

FIG. **10** is a view for explaining the function of the floating joint part for adjusting the position and posture of the electric inside-diameter measuring device according to the first exemplary embodiment;

FIG. **11** is a view for explaining the function of the floating joint part for adjusting the position and posture of the electric inside-diameter measuring device according to the first exemplary embodiment;

FIG. **12** is a view for explaining the function of the floating joint part for adjusting the position and posture of the electric inside-diameter measuring device according to the first exemplary embodiment;

FIG. **13** is an exploded view of a collision detection part;

FIG. **14** is a perspective view of the collision detection part when viewed from a slightly rear side;

FIG. **15** is a functional block diagram of a control unit;

FIG. **16** is a flowchart of the overall operation of automatic inside-diameter measurement;

FIG. **17** is a flowchart showing an operating procedure of a hole insertion step (ST**100**);

FIG. **18** is a flowchart showing an operating procedure of a measurement step (ST**200**);

FIG. **19** is a flowchart showing an operating procedure of a hole retraction step (ST**300**);

FIG. **20** is a flowchart showing an operating procedure of a measurement step according to a second exemplary embodiment;

FIG. **21** is a flowchart showing an operating procedure of a measurement step according to a third exemplary embodiment;

FIG. **22** is a front view of an electric inside-diameter measuring unit according to a fourth exemplary embodiment;

FIG. **23** is a top view (plan view) of a floating joint part according to the fourth exemplary embodiment;

FIG. **24** is a cross-sectional view taken along the XXIV-XXIV line in FIG. **23**;

FIG. **25** is a perspective view when a coupling block according to the fourth exemplary embodiment is rotated and displaced with respect to a support frame part (support base part);

FIG. **26** is a cross-sectional view when the coupling block according to the fourth exemplary embodiment is rotated and displaced with respect to the support frame part (support base part);

FIG. **27** is a top view (plan view) when the coupling block according to the fourth exemplary embodiment is horizontally translated;

FIG. **28** is a perspective view of an electric inside-diameter measuring unit according to a fifth exemplary embodiment;

FIG. **29** is a top view (plan view) of the electric inside-diameter measuring unit according to the fifth exemplary embodiment;

FIG. **30** is a view when a first floating coupling cup according to the fifth exemplary embodiment is rotated around an X-axis;

FIG. **31** is a view when the first floating coupling cup according to the fifth exemplary embodiment is translated in a horizontal plane;

FIG. **32** is an exterior side view according to a sixth exemplary embodiment; and

FIG. **33** is an enlarged cross-sectional view of a floating joint part according to the sixth exemplary embodiment.

DETAILED DESCRIPTION

Exemplary embodiments of the present invention are illustrated and described with reference to the reference signs assigned to the elements in the drawings.

First Exemplary Embodiment

In the following, a first exemplary embodiment of the present invention is described.

The present exemplary embodiment describes an automatic inside-diameter measuring apparatus **100** that automates the measurement of the inside diameter (hole diameter) of a hole to be measured.

(Automatic Inside-Diameter Measuring Apparatus)

FIG. **1** is an external view of the entire automatic inside-diameter measuring apparatus **100**.

The automatic inside-diameter measuring apparatus **100** includes a measuring-apparatus main body **110** and a control unit **140** that controls the overall operation.

(Measuring-Apparatus Main Body **110**)

The measuring-apparatus main body **110** includes an electric inside-diameter measuring unit **120** that measures the hole diameter of an object to be measured, and a multi-joint robot arm part (robot arm part) **130** as a moving means for moving the electric inside-diameter measuring unit **120**.

(Electric Inside-Diameter Measuring Unit **120**)

The electric inside-diameter measuring unit **120** is attached to and held by a hand part **131**, which is the tip of the robot arm part **130**. The electric inside-diameter measuring unit **120** is inserted into a hole that is an object to be measured to measure the inside diameter. In addition, the electric inside-diameter measuring unit **120** has a function to autonomously adjust its own position and posture to accurately measure a hole that is an object to be measured.

The configuration of the electric inside-diameter measuring unit **120** is described.

FIG. **2** is an external perspective view of the electric inside-diameter measuring unit **120** when viewed from a slightly front side.

FIG. **3** is an external perspective view of the side of the electric inside-diameter measuring unit **120** when viewed from a slightly rear side.

FIG. **4** is a front view of the electric inside-diameter measuring unit **120**.

The electric inside-diameter measuring unit **120** includes an electric inside-diameter measuring device (object to be supported) **200**, a support frame part **300**, a floating joint part (floating joint mechanism part) **400**, a restriction means **500**, a collision detection part **600**, and a force sensor part **132**.

(Electric Inside-Diameter Measuring Device **200**)

The electric inside-diameter measuring device **200** is an electric version of the rod feed of an existing manual inside-diameter measuring device (for example, Hole test).

FIG. **5** is a cross-sectional view for showing the internal structure of the electric inside-diameter measuring device **200**.

The electric inside-diameter measuring device **200** includes a cylinder case part (fixed element) **210**, a rod **230**, a thimble part **240**, a contact point (movable element) **250**, a displacement detection part **260**, an outer case part **270**, a display unit **273**, and an electric drive unit **280**.

The cylinder case part **210** is a case having a cylindrical shape as a whole.

The rod **230** moves axially forward and backward inside the cylinder case part **210**.

The cylinder case part **210** includes an upper cylinder case part **211** constituting an upper part, a middle cylinder case part **213** constituting a middle part, a lower cylinder case part **214** constituting a lower part, and a head cylinder part **215** constituting a measuring head part **220**.

The middle cylinder case part **213** is attached to the lower end of the upper cylinder case part **211**, the lower cylinder case part **214** is attached to the lower end of the middle cylinder case part **213**, and the head cylinder part **215** is attached to the lower end of the lower cylinder case part **214**.

The rod **230** is a long rod-shaped body as a whole. The rod **230** includes an upper rod **231** and a lower rod **233**. The upper rod **231** is a spindle and has a feed screw (male thread) **232** on the outer surface of its base end (upper end side). The upper cylinder case part **211** has a female thread **212**, and the feed screw **232** is screwed with the female thread **212**.

The thimble part **240** is provided at the base end (upper end side) of the upper rod **231**.

The thimble part **240** includes a thimble sleeve **241**, a ratchet sleeve **242**, and a coil spring **243**.

The thimble sleeve **241** is fitted externally to the base end of the upper rod **231** (rod **230**) by a tapered surface fit and is adhered to the base end of the upper rod **231** (rod **230**).

The ratchet sleeve **242** is a cylindrical body provided above the thimble sleeve **241**, and the coil spring **243** is interposed between the thimble sleeve **241** and the ratchet sleeve **242**. A push screw is screwed onto the base end face of the upper rod **231**, and the ratchet sleeve **242** is pushed by the head flange of the push screw. At this time, the coil spring **243** is sandwiched between the ratchet sleeve **242** and the thimble sleeve **241**.

Between the ratchet sleeve **242** and the thimble sleeve **241**, a ratchet mechanism (not shown) is provided. Here, the rotation direction of the ratchet sleeve **242**, the thimble sleeve **241**, or the rod **230** in the direction of feeding the rod **230** downward (in the direction of protruding the contact point **250**) is a positive rotation direction. In contrast, the rotation direction of the ratchet sleeve **242**, the thimble sleeve **241**, or the rod **230** in the direction of feeding the rod **230** upward (the direction in which the contact point **250** is moved backward) is a negative rotation direction. The ratchet mechanism allows the ratchet sleeve **242** to idle against the thimble sleeve **241** in the positive rotation direction and does not allow the ratchet sleeve **242** to idle in the negative rotation direction.

When the ratchet sleeve **242** is subjected to (positive) rotary operation, the rotation of the ratchet sleeve **242** is transmitted to the rod **230** via the coil spring **243** and the thimble sleeve **241**.

There is an upper limit to the force (rotational force) transmitted from the ratchet sleeve **242** to the rod **230**. That is, if the rod **230** is attempted to be rotated with a force exceeding the frictional force (static frictional force) acting between the ratchet sleeve **242**, the coil spring (load regulating elastic body) **243**, and the thimble sleeve **241**, the ratchet mechanism causes the ratchet sleeve **242** to idle against the thimble sleeve **241**. The thimble part **240** constitutes a constant pressure mechanism that regulates the upper limit of the force (measuring force) acting between an object to be measured and the contact point **250**. Conversely, a predetermined force (measuring force), which can be defined by the indentation amount of the push screw, is generated between the object to be measured and the contact point **250**, and when the contact point **250** applies the predetermined force (measuring force) to the object to be measured, the reaction force is applied to the contact point **250**, that is, the electric inside-diameter measuring device **200**.

The lower rod **233** is provided inside the head cylinder part **215**.

The upper end of the lower rod **233** is in contact with the lower end of the upper rod **231**. The lower end of the lower rod **233** is conical.

The contact point **250** is provided in the head cylinder part **215** to move forward and backward in a direction perpendicular to the axial direction of the rod **230**.

Three contact points **250** are provided at 120° intervals in the head cylinder part **215**. Each contact point **250** has a thin round shaft tip **252** made of carbide at its outer end. When each contact point **250** moves forward in the protruding direction, the round shaft tip **252** is brought into contact with the inner wall of the object to be measured.

The inner end side of each contact point **250** is formed with a tapered surface **251**, and the tapered surface **251** is brought into contact with the conical surface of the lower rod **233**. The conical surface of the lower rod **233** and the tapered surface **251** of each contact point **250** constitute a displacement direction conversion means for changing the direction of force and displacement to a right angle.

Inside the head cylinder part **215**, a spring **216** (for example, plate spring) corresponding to each contact point **250** is provided, one end of the plate spring **216** is fixed to the inner wall of the head cylinder part **215**, and the other end of the plate spring **216** is fixed to the contact point **250**.

Each plate spring **216** biases the corresponding contact point **250** in the direction of being accommodated in the head cylinder part **215**. When the rod **230** is pulled upward by an external force, the force of the plate spring **216** causes the contact point **250** to follow the rod **230** and to move in the direction of entering the head cylinder part **215**.

The part of the head cylinder part **215** (the tip end part of the inside-diameter measuring device) where the contact point **250** is protruded and accommodated is also referred to as the measuring head part **220**.

The displacement detection part **260** is provided inside the middle cylinder case part **213** to detect displacement of the upper rod **231**.

The displacement detection part **260** is what is called a rotary encoder including a rotor **261** provided to rotate integrally with the upper rod **231**, a stator **262** that counts the rotation of the rotor **261**, and a signal processing calculation unit (not shown). The detection method of the displacement detection part **260** is not particularly limited, and examples of the displacement detection part **260** include a photoelectric encoder, a capacitive encoder, an electromagnetic induction encoder, a magnetic encoder, and the like.

The outer case part **270** is an outer cylinder part that covers the outside of the cylinder case part **210**. The outer case part **270** is provided to cover the electric inside-diameter measuring device **200** above the middle of the lower cylinder case part **214**. The outer case part **270** is constituted by two parts of an outer case body part **271** that accommodates the middle part thereinside and an outer case upper part **272** that accommodates the upper part thereinside. The outer case body part **271** is a cylindrical body that covers the entire middle cylinder case part **213** corresponding to the middle part of the electric inside-diameter measuring device **200**, as well as the upper end side of the lower cylinder case part **214** and the lower end side of the upper cylinder case part **211**.

The outer case upper part **272** is a cylindrical body connected to the upper end of the outer case body part **271** and covers the upper cylinder case part **211** constituting the upper part of the electric inside-diameter measuring device **200**.

The display unit **273** includes a display part **274** and is attached to the side openings of the middle cylinder case part **213** and the outer case body part **271** to close the openings. The display part **274** is the digital display part **274** (for example, a liquid crystal display panel or an organic EL display panel) fitted into the central area of the display unit **273**. The display part **274** shows measurement values and other information calculated by the signal processing calculation unit (not shown).

The display unit **273** is provided with a connector, and measurement values calculated by the signal processing calculation unit (not shown) are output externally.

The electric drive unit **280** is a drive unit that rotates the ratchet sleeve **242** of the thimble part **240**. The electric drive unit **280** is attached above the outer case upper part **272**. The electric drive unit **280** is, for example, a motor, and the rotational output of the motor is transmitted to the ratchet sleeve **242** via a power transmission mechanism (a gear train, a coupling belt, a coupling shaft, a coupling link, or the like).

The operation of the electric inside-diameter measuring device **200** is basically the same as that of an existing manual inside-diameter measuring device, except that the rod is fed by the electric drive unit **280**.

When the rod **230** is moved forward and backward by electric power, the contact points **250** are protruded from and accommodated in the head cylinder part **215** in accordance with the movement of the lower rod **233**. By detecting the displacement (position) of the rod **230** when the three contact points **250** are in even contact with the inner wall of a hole to be measured, the inside diameter of the hole to be measured is obtained as a measurement value.

(Support Frame Part **300**)

The support frame part **300** is an L-shaped member in side view and includes a support column part **310** and a support base part **320**. The support base part **320** is attached to the lower end of the support column part **310** at right angles in the vertical direction.

The support column part **310** is adjacent and parallel to the electric inside-diameter measuring device **200**. The restriction means **500** is provided on the front face side of the support column part **310**, and the restriction means **500** switches between holding and releasing of the electric inside-diameter measuring device **200**. This point is described later.

The support base part **320** is provided by being bent in an L-shape from the lower end of the support column part **310** toward the electric inside-diameter measuring device **200**.

The support base part **320** includes a first insertion hole **321** through which the head cylinder part **215** of the electric inside-diameter measuring device **200** is inserted. The electric inside-diameter measuring device **200** is attached in such a manner that the upper part above the lower cylinder case part **214** is placed on the support base part **320** via the floating joint part **400** while the head cylinder part **215** has passed through the first insertion hole **321**.

(Floating Joint Part **400**)

The floating joint part **400** is described.

FIG. **6** is an exploded view of the floating joint part **400**.

FIG. **7** is a cross-sectional view of the floating joint part **400**.

The floating joint part **400** is a joint (or coupling mechanism) that allows rotation of the electric inside-diameter measuring device **200** with respect to the support frame part **300** and also allows horizontal translation of the electric inside-diameter measuring device **200** with respect to the support frame part **300**. Even if there is an axial misalignment (inclination and distortion) between the electric inside-diameter measuring device **200** and a hole to be measured, the floating joint part **400** allowing rotation and translation allows the electric inside-diameter measuring device **200** to autonomously adjust its own position and posture.

The floating joint part **400** includes a rotation-allowing mechanism part **410** and a translation-allowing mechanism part **420**.

The rotation-allowing mechanism part **410** includes a first spring holder **411**, a spring (coil spring) **412** (flexible body or elastic body), and a second spring holder **413**. The first spring holder **411** and the second spring holder **413** are roughly ring-shaped, with a flange extending radially outward from the ring.

As shown in the cross-sectional view in FIG. **7**, the first spring holder **411** is fitted externally to the outer surface of the lower cylinder case part **214** at the upper side of the lower cylinder case part **214**, and the first spring holder **411** is thereby fixedly attached to the electric inside-diameter measuring device **200**. Here, the lower end face of the outer case body part **271** and the first spring holder **411** are continuously integrated, and the position where the first spring holder **411** is attached to the electric inside-diameter measuring device **200** is fixedly regulated.

As one embodiment, the first spring holder **411** may be installed in such a manner that the height (position) of the first spring holder **411** corresponds to the height (position) of the center of gravity of the electric inside-diameter measuring device **200**. For example, the first spring holder **411** is installed in such a manner that the height (position) of the first spring holder **411** is approximately the same as the height (position) of the center of gravity of the electric inside-diameter measuring device **200**. Alternatively, the first spring holder **411** may be installed in such a manner that the height (position) of the first spring holder **411** is within 20%, 15%, 10%, or 5% (of the length of the electric inside-diameter measuring device in the vertical direction) above or below the height (position) of the center of gravity of the electric inside-diameter measuring device **200**.

The upper end of the coil spring **412** is received by the first spring holder **411** while the coil spring **412** accommodates the lower cylinder case part **214** (electric inside-diameter measuring device **200**) thereinside. The lower end of the coil spring **412** is received by the second spring holder **413**.

As one embodiment, instead of one coil spring **412**, a plurality of elastic bodies or springs may be provided to surround the electric inside-diameter measuring device **200** (at equal angular intervals).

Although it is better for the spring to have a larger diameter (for the distance between the spring and the center axis of the electric inside-diameter measuring device to be larger) to support the electric inside-diameter measuring device, if the diameter of the spring is too large (the distance between the spring and the center axis of the electric inside-diameter measuring device is too large), the measurement pressure of the inside-diameter measuring device alone cannot autonomously adjust the posture of the electric inside-diameter measuring device to scan the axis of the hole. If the diameter of the spring is to be increased (the distance between the spring and the center axis of the electric inside-diameter measuring device is to be increased), the spring constant (modulus of elasticity) should be decreased. If the diameter of the spring is to be reduced (the distance between the spring and the center axis of the electric inside-diameter measuring device is to be reduced), the spring constant (modulus of elasticity) may be slightly increased. Although the elastic spring is described in the exemplary embodiment, the member coupling the first spring holder **411** and the second spring holder **413** may be a flexible member without elasticity instead of the coil spring **412**, as long as the posture adjustment in the rotational direction of the electric inside-diameter measuring device can be allowed.

The second spring holder **413** is coupled to the translation-allowing mechanism part **420**.

As shown in the cross-sectional view in FIG. **7**, a ring hole **414** of the second spring holder **413** has a slight length (height) in the axial direction, and the diameter of the ring hole **414** is slightly larger than the cylinder case part **210** (lower cylinder case part **214**) of the electric inside-diameter measuring device **200** to the extent that it allows the inclination of the electric inside-diameter measuring device **200**. The ring hole **414** may be a tapered hole **414** where the ring hole increases in diameter toward the upper side or lower side.

The translation-allowing mechanism part **420** includes a horizontal plate (translation body) **421** and a ball roller (bearing) **423**.

The horizontal plate **421** is a plate provided above the support base part **320**. The horizontal plate **421** includes a second insertion hole **422** through which the electric inside-diameter measuring device **200** (lower cylinder case part **214**) is inserted. The second spring holder **413** is fitted into the second insertion hole **422** from above. That is, the rotation-allowing mechanism part **410** is on the horizontal plate **421**, and the electric inside-diameter measuring device **200** is supported by the rotation-allowing mechanism part **410**. In other words, the electric inside-diameter measuring device **200** is supported on the horizontal plate **421** with the rotation-allowing mechanism part **410** interposed.

The ball roller **423** is provided on the upper face of the support base part **320**. Here, four ball rollers **423** are installed at 90-degree intervals around the first insertion hole **321** and the second insertion hole **422**, and the horizontal plate **421** is placed on the ball rollers **423**.

The horizontal plate **421** placed on the ball rollers **423** can move horizontally with very little force, almost without friction. On the other hand, to deform the coil spring **412** (elastic body) as the rotation-allowing mechanism part **410** requires a force to resist the elastic force. Therefore, in the present exemplary embodiment, when a force (rotational or translational force) acts on the electric inside-diameter measuring device **200**, the translation-allowing mechanism part **420** relatively has priority in displacement.

The operation of adjusting the position and posture of the electric inside-diameter measuring device **200** by the action of the floating joint part **400** is described with reference to FIGS. **8** to **12**.

For example, FIG. **8** shows a case assuming that a hole to be measured has been machined with a deviation from the design value and that the hole that should have been drilled vertically has an inclination and is slightly deviated from the position of the design value to the right in the drawing. The electric inside-diameter measuring unit **120** is moved to the hole by the robot arm part **130**, and the measuring head part **220** is inserted into the hole. Even if the drive control of the robot arm part **130** is accurate, there is a deviation in position and angle between the axis of the electric inside-diameter measuring device **200** and the axis of the hole to be measured, because the hole to be measured is deviated from the design value.

Now, in order to accurately measure the inside diameter of a hole to be measured, all the three contact points **250** need be brought into even contact with the inside wall of the hole to be measured.

First, the electric drive unit **280** drives the rod **230** to move the rod **230** downward. Then, the tip (cone) of the lower rod **233** protrudes the contact points **250**, and one of the three contact points **250** closer to the inner wall of the hole to be measured is brought into contact with the inner wall of the hole to be measured.

As the lower rod **233** continues to protrude the contact points **250**, a reaction force is applied to the contact points **250** from the inside wall of the hole. This reaction force causes the electric inside-diameter measuring device **200** to be pushed in the opposite direction. The reaction force pushes near the lower end of the lower rod **233** from the contact points **250**, but the displacement of the horizontal plate **421** occurs first before the deformation of the coil spring **412** of the rotation-allowing mechanism part **410**. Thus, as shown in FIGS. **9** and **10**, the displacement of the horizontal plate **421** first absorbs the axial misalignment between the electric inside-diameter measuring device **200** and the hole to be measured.

The first insertion hole **321** of the support base part **320** has a diameter large enough to allow horizontal movement of the electric inside-diameter measuring device **200**.

At the time of FIG. **9** (FIG. **10**), the axal inclination is not yet aligned between the electric inside-diameter measuring device **200** and the hole to be measured. When the lower rod **233** continues to protrude the contact points **250** from the state shown in FIG. **9** (FIG. **10**), the tips (round shafts) of the contact points **250** are brought into contact with the inner wall of the hole, and at this time (because of the length of the three round shafts), the reaction force applied to the electric inside-diameter measuring device **200** from the inner wall of the hole to be measured has a moment of rotation. At this time, the reaction force from the inner wall of the hole deforms the coil spring **412** of the rotation-allowing mechanism part **410** as shown in FIGS. **11** and **12**, and the inclination of the electric inside-diameter measuring device **200** is adjusted to align the axis of the electric inside-diameter measuring device **200** with the axis of the hole to be measured. The ring hole **414** of the second spring holder **413** allows the inclination of the electric inside-diameter measuring device **200**.

Eventually, when the three contact points **250** push against the inner wall of the hole to be measured with the predetermined measuring pressure, the floating joint part **400** (the rotation-allowing mechanism part **410** and the translation-allowing mechanism part **420**) allows the electric inside-diameter measuring device **200** to autonomously adjust its own position and posture to accurately measure the inside diameter of the hole to be measured. In other words, once the robot arm part **130** is able to insert the measuring head part **220** of the electric inside-diameter measuring device **200** into the hole to be measured, the inside diameter of the hole can be accurately measured through automatic posture adjustment without the need for manual sensory adjustment or advanced feedback control.

(Restriction Means **500**)

The restriction means **500** is provided to the support frame part **300** (support column part **310**) to hold and support the electric inside-diameter measuring device **200**. The restriction means **500** includes two clamping pieces **510** that clamp the electric inside-diameter measuring device **200** from a direction perpendicular to the axis as shown, for example, in FIGS. **2** and **3**. Here, the clamping pieces **510** clamp the outer case body part **271** from both sides. The clamping pieces **510** are movable, and the restriction means **500** can switch between a hold state of the electric inside-diameter measuring device **200** and a release state in which the holding is released.

Even though the clamping pieces **510** are opened to release the electric inside-diameter measuring device **200**, the gap between each clamping piece **510** and the electric inside-diameter measuring device **200** is preferably limited to a predetermined upper limit (about 5 mm or 10 mm) to regulate any large displacement (translation or inclination) of the electric inside-diameter measuring device **200** beyond the limit.

The electric inside-diameter measuring device **200** is placed on the support base part **320** (support frame part **300**) via the floating joint part **400**.

In order for the electric inside-diameter measuring device **200** to be able to autonomously adjust its posture according to a hole to be measured with its own measuring pressure, the floating joint part **900** needs to be soft (softness or flexibility). Therefore, if the electric inside-diameter measuring device **200** is simply placed on the floating joint part **400**, the electric inside-diameter measuring device **200** can swing unsteadily, be inclined greatly, or fall down, depending on the rigidity (softness) of the floating joint part **400**.

From a safety point of view, it is undesirable that the electric inside-diameter measuring device **200** swings or falls down. In addition, if the posture of the electric inside-diameter measuring device **200** is not fixed, the position of the measuring head part **220** is unstable, and the robot arm part **130** cannot be able to insert the measuring head part **220** of the electric inside-diameter measuring device **200** into the hole to be measured.

For these reasons, when the electric inside-diameter measuring device **200** is not inserted in a hole to be measured, the restriction means **500** clamps and holds the electric inside-diameter measuring device **200**. Then, when the measuring head part **220** of the electric inside-diameter measuring device **200** is inserted in a hole to be measured, the restriction means **500** releases the electric inside-diameter measuring device **200** in order for the electric inside-diameter measuring device **200** to be able to autonomously change and adjust its posture (to perform autonomous adjustment) by the floating joint part **400**.

(Collision Detection Part **600**)

The collision detection part **600** detects that the electric inside-diameter measuring device **200** has collided with something with a force greater than a predetermined force.

FIG. **13** is an exploded view of the collision detection part.

FIG. **14** is a perspective view of the collision detection part when viewed from a slightly rear side.

The collision detection part **600** is provided between the rear side of the support column part **310** and the hand part **131** of the robot arm part **130**. Here, the collision detection part **600** detects that a large force is applied to the electric inside-diameter measuring device **200** in the direction of being pushed upward from below in the Z direction (vertical direction) when the electric inside-diameter measuring device **200** approaches an object (for example, a workpiece) from above the object and collides with the workpiece. That is, the collision detection direction of the collision detection part **600** is almost parallel to the direction when the electric inside-diameter measuring device **200** approaches a hole to be measured.

The collision detection part **600** includes a fixed plate **601**, a mounting plate **602**, a linear guide **610**, a biasing means **620**, and a contact sensor **630**.

The fixed plate **601** is attached directly or indirectly to the hand part **131** of the robot and is fixedly provided to the hand part **131**. Here, the force sensor part **132** is provided between the hand part **131** of the robot and the collision detection part **600**. Therefore, the collision detection part **600** is attached to the hand part **131** of the robot arm part **130** via the force sensor part **132**.

The mounting plate **602** is attached directly or indirectly to the rear face of the support column part **310** and is fixedly provided to the support column part **310** (support frame part **300**). The linear guide **610** is provided between the fixed plate **601** and the mounting plate **602** and guides the moving direction of the mounting plate **602** with respect to the fixed plate **601** in the vertical direction. The linear guide **610** includes a groove frame body **611** having a groove in the vertical direction and a slide body **612** that slides in the groove of the groove frame body **611** in the vertical direction. Here, the groove frame body **611** is attached to the fixed plate **601**, and the slide body **612** is attached to the mounting plate **602**.

The biasing means is two coil springs **620**.

One end of each coil spring **620** is fastened to the fixed plate **601**, and the other end of the coil spring **620** is fastened to the mounting plate **602**. Each coil spring **620** constantly biases the mounting plate **602** in the direction of pulling down the mounting plate **602** with respect to the fixed plate **601**. That is, the position of the mounting plate **602** when the mounting plate **602** is lowered vertically downward with respect to the fixed plate **601** by its own weight, the weight of the electric inside-diameter measuring device **200**, and the force of the coil spring **620** is a reference position.

The contact sensor **630** includes a contact detection block **631** provided to the fixed plate **601** and a ball plunger **632** provided to the mounting plate **602**. As shown in FIG. **14**, when the mounting plate **602** is in the reference position with respect to the fixed plate **601**, the ball plunger **632** on the mounting plate **602** is in contact with (fitting into) the contact detection block **631**.

Here, it is assumed that, for example, the position of a hole machined in a workpiece is deviated significantly from the design value.

In this state, when the robot arm part **130** attempts to insert the electric inside-diameter measuring device **200** into the hole to be measured from above, the measuring head part **220** of the electric inside-diameter measuring device **200** hits the workpiece. The electric inside-diameter measuring device **200** (measuring head part **220**) is deviated from the hole and hits the workpiece, and the electric inside-diameter measuring device **200** (measuring head part **220**) is pushed further into the workpiece. Then, when a force exceeding the gravitational force of the electric inside-diameter measuring device **200** and the biasing force of the biasing means (coil spring **620**) are applied to the collision detection part **600**, the mounting plate **602** slides upward and the ball plunger **632** of the mounting plate **602** is removed from the contact detection block **631**. The contact sensor **630** transmits a signal (collision detection signal) when the contact detection block **631** detects the separation of the ball plunger **632** (or when the contact detection block **631** can no longer detect the contact of the ball plunger **632**).

When the collision detection part **600** detects that the electric inside-diameter measuring device **200** has collided with something, the control unit **140** immediately stops the operation of the robot arm part **130**.

(Force Sensor Part **132**)

The force sensor part **132** is, for example, a 6-axis (forces in **3** orthogonal axial directions and rotational forces around the axes) force sensor. While the collision detection part **600** is specialized to detect a force pushed up from below in the vertical direction (Z-direction), the force sensor part **132** detects forces applied to the electric inside-diameter measuring device **200** in all directions.

The multi-joint robot arm part **130** is what is called a robot arm and moves the hand part **131**, which is the tip of the robot arm part **130**, three-dimensionally with the vertical and horizontal rotational drive axes. The hand part **131** of the robot arm part **130** is coupled to the support frame part **300** via the force sensor part **132** and the collision detection part **600**. The force sensor part **132** detects that the electric inside-diameter measuring device **200** has collided with an object with an unexpected force exceeding a predetermined force in directions where the collision detection part **600** does not detect collisions (that is, in directions other than the vertical direction (Z direction)). When the force sensor part **132** detects an unexpected collision of the electric inside-diameter measuring device **200**, the control unit **140** immediately stops the operation of the robot arm part **130**. This further ensures safety.

(Control Unit **140**)

FIG. **15** is a functional block diagram of the control unit **140**. The control unit **140** may be implemented by hardware or software incorporated into a computer (a computer terminal including a central processing unit (CPU), a ROM or a RAM storing predetermined programs) that is connected to the measuring-apparatus main body **110** by wired or wireless communication.

An operation control program (measuring part program) is installed in the computer terminal, and the measurement operation of the measuring-apparatus main body **110** is controlled by executing the program. The method of supplying the program is not limited. The program may be installed by inserting a (nonvolatile) recording medium recording the program directly into the computer, or a reading device that reads the information on the recording medium may be attached externally to the computer to install the program into the computer from the reading device. Alternatively, the program may be supplied to the computer via a communication line, such as the Internet, a LAN cable, or a telephone line, or wirelessly.

The control unit **140** includes a measurement operation control unit **150**, a robot arm drive control unit **160**, and a central control unit **170**.

The measurement operation control unit **150** controls the measurement operation of the electric inside-diameter measuring device **200**.

The measurement operation control unit **150** includes a restriction control unit **151**, a drive control unit **152**, and a measurement value acquisition unit **153**.

The restriction control unit **151** controls the opening and closing operation of the clamping pieces **510** of the restriction means **500** to control the timing of holding and releasing of the electric inside-diameter measuring device **200**.

The drive control unit **152** controls the drive of the electric drive unit **280** to control the forward and backward movement of the rod **230**, that is, the forward and backward movement of the contact points **250**.

The measurement value acquisition unit **153** acquires a measurement value of the electric inside-diameter measuring device **200**. That is, the measurement value acquisition unit **153** receives a sensor value of the displacement detection part **260** to acquire the measurement value of the inside diameter of a hole to be measured from the displacement (position) of the rod **230**.

The robot arm drive control unit **160** controls the operation of the robot arm part **130**.

The central control unit **170** integrally controls the measurement operation control unit **150** and the robot arm drive control unit **160**.

(Operation of Controlling Automatic Inside-Diameter Measuring Apparatus **100**)

The following describes a series of operations in which the measuring-apparatus main body **110** (the electric inside-diameter measuring unit **120** and the robot arm part **130**) automatically measures the inside diameter of a hole to be measured under the control of the control unit **140**.

FIG. **16** is a flowchart of the overall operation of automatic inside-diameter measurement (automatic inside-diameter measurement operation).

A workpiece (object to be measured) having a hole (hole to be measured) is conveyed by a conveyor belt or rail in a production line and brought to a predetermined position in front of the measuring-apparatus main body **110** (the electric inside-diameter measuring unit **120** and the robot arm part **130**).

The automatic inside-diameter measuring apparatus **100** automatically sequentially performs inside-diameter measurement on the inside diameters of holes that are designated (set) as objects to be measured among workpieces (objects to be measured) to be conveyed. The position (coordinates) of a hole to be measured among the workpieces (objects to be measured) has been set (stored) as part of the measuring part program in the central control unit **170**. Alternatively, the inside-diameter measurement may be performed automatically sequentially while searching for a hole to be measured by image recognition using a separate camera or the like.

The first exemplary embodiment assumes that a hole to be measured is a hole drilled to have an opening on the top face in the vertical direction, and the electric inside-diameter measuring device **200** is inserted into the hole from above while maintaining a roughly vertical orientation.

The automatic inside-diameter measurement operation includes a hole insertion step (approaching step) (ST**100**), a measurement step (ST**200**), and a hole retraction step (retraction step) (ST**300**).

The hole insertion step (ST**100**) is a step of moving the electric inside-diameter measuring unit **120** by the robot arm part **130** and inserting the measuring head part **220** of the electric inside-diameter measuring device **200** into a hole to be measured (in other words, approaching a workpiece from above the workpiece).

FIG. **17** is a flowchart showing an operating procedure of the hole insertion step (ST**100**).

In the hole insertion step (ST**100**), first, the destination (target coordinates) of the electric inside-diameter measuring device **200** by the robot arm part **130** is set to the hole to be measured (ST**110**).

Then, it is confirmed that the electric inside-diameter measuring device **200** is restricted by the restriction means **500** (ST**120**).

In the present exemplary embodiment, the state in which the restriction means **500** restricts (holds) the electric inside-diameter measuring device **200** is a default state (which may be paraphrased as a standard state or a reference state). However, since the holding by the restriction means **500** can be released after the electric inside-diameter measuring device **200** is maintained or replaced, the holding state needs to be confirmed. Then, when the electric inside-diameter measuring device **200** is not held (ST**120**: NO), the restriction control unit **151** transmits a signal to perform a holding step (ST**130**) by the restriction means **500**. By restricting (holding) the electric inside-diameter measuring device **200** while the robot arm part **130** moves the electric inside-diameter measuring unit **120**, the robot arm part **130** can stably safely move the electric inside-diameter measuring device **200**.

The drive of the robot arm part **130** is started (ST**140**) to move the electric inside-diameter measuring unit **120**, and the measuring head part **220** of the electric inside-diameter measuring device **200** is inserted into the hole to be measured.

At this time, for example, if the machining position of the hole to be measured is deviated from the design value, the electric inside-diameter measuring device **200** (measuring head part **220**) can unexpectedly collide with the workpiece.

In this regard, the robot arm drive control unit **160** monitors signals from the collision detection part **600** and the force sensor part **132** (ST**150**). If a collision between the electric inside-diameter measuring device **200** (measuring head part **200**) and the workpiece is detected (ST**150**: YES), the drive of the robot arm part **130** is immediately stopped (emergency stop) (ST**180**). Thereafter, the central control unit **170** may report the abnormality to an operator.

When the measuring head part **220** of the electric inside-diameter measuring device **200** is inserted into the hole to be measured and reaches the target coordinates, the drive of the robot arm part **130** is temporarily stopped (ST**170**).

Next, the procedure proceeds to the measurement step (ST**200**).

FIG. **18** is a flowchart showing an operating procedure of the measurement step (ST**200**).

In the measurement step (ST**200**), first, the holding by the restriction means **500** is released (ST**211**) to put the electric inside-diameter measuring device **200** in a released state. This makes the electric inside-diameter measuring device **200** in a state of being supported by the support frame part **300** via the floating joint part **400**, allowing autonomous adjustment of the position and posture of the electric inside-diameter measuring device **200**.

Then, the drive control unit **152** transmits a drive signal to drive the electric drive unit **280**.

First, a first forward movement step (ST**220**) is performed. The first forward movement step (ST**220**) is a step of moving the contact points **250** forward until the contact points **250** are brought into first contact with the inner wall of the hole to be measured. The electric drive unit **280** (for example, a motor) is driven to move the rod **230** forward (in this case, downward) to move the contact points **250** forward toward the inner wall of the hole. In the first forward movement step (ST**220**), the motor is driven at high speed to move the rod **230** and the contact points **250** as fast as possible to improve measurement efficiency. (For example, if the rod **230** is a screw feed, the rotational speed of the rod **230** is 100 rpm to 200 rpm. In terms of the speed at which the rod **230** or the contact points **250** move, the speed may be 10 μm/s to 20 μm/s.)

As the contact points **250** move forward toward the inner wall of the hole, the contact points **250** are brought into contact with the inner wall of the hole.

Here, in the present exemplary embodiment, the number of contact points **250** is three. If the axis of the electric inside-diameter measuring device **200** and the axis of the hole to be measured are perfectly aligned, the three contact points **250** can be brought into contact with the inner wall of the hole at the same time, but there is a gap between the axis of the electric inside-diameter measuring device **200** and the axis of the hole to be measured because of the driving error of the robot arm part **130** and the machining error of the workpiece. In this case, any one of the three contact points **250** is brought into first contact with the inner wall of the hole. When any one of the three contact points **250** has been brought into contact with the inner wall of the hole (ST**213**: YES), the first forward movement step (ST**212**) is immediately stopped, and the procedure proceeds to a first backward movement step (ST**214**). The fact that the contact points **250** have been brought into contact with the inner wall of the hole may be confirmed by, for example, calculating the motor torque from the applied current (applied voltage) of the motor to determine that (one of) the contact points (has) have brought into contact with the inner wall of the hole when the torque exceeds a predetermined value.

In the first backward movement step (ST**214**), the rod **230** and the contact points **250** are moved backward slightly in the opposite direction. This avoids the contact points **250** from digging into the inner wall of the hole due to its momentum after the contact points **250** have been brought into contact with the inner wall of the hole in the first forward movement step (ST**212**).

The distance for moving the contact points **250** backward in the first backward movement step (ST**214**) is very small, for example, 0.001 mm to 0.01 mm.

The speed of backward movement of the contact points **250** in the first backward movement step (ST**214**) may be as fast as possible. For example, if the rod **230** is a screw feed, the rotational speed of the rod **230** is 100 rpm to 200 rpm.

In terms of the speed at which the rod **230** or the contact points **250** move, the speed may be 10 μm/s to 20 μm/s.

After the contact points **250** are moved backward slightly in the first backward movement step (ST**214**), the contact points **250** are moved forward again in a second forward movement step (ST**215**). In the second forward movement step (ST**215**), the contact points **250** are moved forward slowly (at a low speed with fine movement).

The feed speed of the contact points **250** in the second forward movement step (ST**215**) is preferably slow (micro-motion). For example, if the rod **230** is a screw feed, the rotational speed of the rod **230** is 10 rpm to 20 rpm. In terms of the speed at which the rod **230** or the contact points **250** move, the speed may be 1 μm/s to 2 μm/s.

The position and inclination of the electric inside-diameter measuring device **200** are autonomously adjusted by the reaction force of the contact points **250** pushing against the inner wall of the hole. The action of the autonomous adjustment of the position and inclination of the electric inside-diameter measuring device **200** by the floating joint part **400** allowing translation and rotation is as described above.

When the three contact points **250** are in even contact with the inner wall of the hole with the predetermined measuring pressure, the autonomous adjustment of the position and inclination of the electric inside-diameter measuring device **200** is completed. When the three contact points **250** are in contact with the inner wall of the hole with the predetermined measuring pressure, the ratchet mechanism (constant pressure mechanism) is activated. That is, the electric drive unit **280** rotates and drives the thimble part **240** (ratchet sleeve **242**) until the ratchet mechanism (constant pressure mechanism) is activated, which causes the contact points **250** to be in even contact with the inner wall of the hole with the predetermined measuring pressure.

The second forward movement step (ST**215**) can be rephrased as an autonomous adjustment step.

In this state, the displacement detection part **260** detects the displacement (position) of the rod **230**. The measurement value acquisition unit **153** acquires the inside diameter of the hole from the displacement (position) of the rod **230** (ST**216**).

After the measurement value is acquired, the contact points **250** are moved backward in a second backward movement step (ST**217**) to separate the contact points **250** from the inner wall of the hole.

After the measurement step (ST**200**), the electric inside-diameter measuring device **200** is retracted from the hole to be measured in the hole retraction step (ST**300**).

FIG. **19** is a flowchart showing an operation procedure of the hole retraction step (ST**300**). In the hole retraction step (ST**300**), first, the electric inside-diameter measuring device **200** is restricted (held) by the restriction means **500** (ST**320**), and then the robot arm part **130** moves the electric inside-diameter measuring unit **120** to be retracted from the hole (ST**330**).

This completes the measurement of the inside diameter of one hole. Until measurement of all the holes to be measured is completed, ST**100** to ST**300** are repeated (ST**400**).

In this manner, according to the present exemplary embodiment, the inside diameter of a hole can be automatically measured by the electric inside-diameter measuring unit (electric inside-diameter measuring device **200** and the robot arm part **130**) without the need for a person to hold and operate the inside-diameter measuring device.

Second Exemplary Embodiment

The above first exemplary embodiment assumes that a hole to be measured is drilled in the vertical direction.

A second exemplary embodiment describes a case in which the automatic inside-diameter measuring apparatus **100** automatically measures the inside diameter of a hole to be measured even when the hole to be measured is inclined from the vertical direction.

FIG. **20** is a flowchart showing an operating procedure of a measurement step according to the second exemplary embodiment.

Since a hole to be measured is inclined with respect to the vertical direction, in the hole insertion step (ST**100**) of inserting the electric inside-diameter measuring device **200** into the hole by the robot arm part **130**, the electric inside-diameter measuring device **200** is inserted into the hole while being inclined to align the inclination of the hole. Then, since the electric inside-diameter measuring device **200** is inclined, if the holding of the electric inside-diameter measuring device **200** by the restriction means **500** is released, the electric inside-diameter measuring device **200** can be greatly displaced (translated and inclined) by the flexibility of the floating joint part **400**.

If the electric inside-diameter measuring device **200** is greatly displaced (translated and inclined), the measuring head part **220** can collide with the inner wall of the hole. In addition, once the electric inside-diameter measuring device **200** is greatly displaced (translated and inclined) in the direction of gravitational force, it can be time-consuming and difficult to autonomously recover from the displacement (translation and inclination) only by the reaction force of the measuring pressure.

Therefore, in the measurement step according to the second exemplary embodiment, a first forward movement step (ST**221**) is performed before a releasing step (ST**224**). That is, after performing the first forward movement step (ST**221**) and detecting that the contact points **250** (one of the contact points **250**) have been brought into contact with the inner wall of the hole (ST**222**: YES), the contact points **250** are moved slightly backward (a first backward movement step (ST**223**)). The releasing step (ST**224**) is performed in this state.

By performing he first forward movement step (ST**221**) first, the contact points **250** are in contact with the inner wall of the hole. Since at least one of the contact points **250** is in contact with the inner wall of the hole, it can be expected that the electric inside-diameter measuring device **200** is not greatly displaced (translated and inclined) even if the holding by the restriction means **500** is released. This allows the automatic inside-diameter measurement to be properly performed even for inclined holes to be measured.

Third Exemplary Embodiment

In the second exemplary embodiment (flowchart in FIG. **20**), the releasing step (ST**224**) is performed after the first backward movement step (ST**223**), but the releasing step (ST**224**) may be performed before the first backward movement (ST**223**).

As shown in the flowchart in FIG. **21**, when it is detected, in a first forward movement step (ST**231**), that the contact points **250** have been brought into contact with the inner wall of a hole (ST**232**: YES), the forward movement of the contact points **250** is immediately stopped.

In this state, a releasing step (ST**233**) is performed. Then, after the contact points **250** are once moved backward (a first backward movement step (ST**234**)), the contact points **250** are moved forward again to bring the contact points **250** into even contact with the inner wall of the hole with the predetermined measuring pressure while the autonomous adjustment of the position and posture of the electric inside-diameter measuring device **200** is activated. In this order of operation, automatic inside-diameter measurement can still be properly performed on the inside diameter of an inclined hole to be measured, as in the second exemplary embodiment,.

Fourth Exemplary Embodiment

A fourth exemplary embodiment is described.

The basic configuration in the fourth exemplary embodiment is similar to that in the first exemplary embodiment, but the structure of a floating joint part (floating joint mechanism part) **800** is characterized.

FIG. **22** is a front view of the electric inside-diameter measuring unit **120** according to the fourth exemplary embodiment.

FIG. **23** is a top view (plan view) of the floating joint part **800** according to the fourth exemplary embodiment.

FIG. **24** is a cross-sectional view taken along the line XXIV-XXIV in FIG. **23**.

In the fourth exemplary embodiment, the electric inside-diameter measuring device **200** is supported to be suspended from the support frame part **300** via the floating joint part **800** in a posture in which its axis (cylinder axis or rod axis) is vertical.

The support frame part **300** in the fourth exemplary embodiment is an L-shaped member in a side view, as in the first exemplary embodiment, and includes a support column part **310** and a support base part **710**.

Here, the support base part **710** has an annular shape having a horizontally-orthogonal wall to form a vertical hole (cylindrical hole).

Since the annular wall surrounds and supports the floating joint part **800**, the annular wall is referred to as a support ring part **720**. On the lower side face of the support ring part **720**, two beams **721** that are bridged in the front-rear and left-right directions and intersect crosswise are provided. As shown in the cross-sectional view in FIG. **24**, a recessed part **722** is provided at the intersection of the beams **721**.

The floating joint part **800** according to the fourth exemplary embodiment includes a coupling block **810**.

The coupling block **810** is fixedly coupled to the electric inside-diameter measuring device **200**, and is translated and rotated integrally with the electric inside-diameter measuring device **200**.

The coupling block **810** is provided inside the support ring part **720** and surrounded by the wall of the support ring part **720** on the beams **721**. The coupling block **810** is square prism-shaped (cube or rectangular). From the four corners of the lower end face of the coupling block **810**, four suspension rods **811** are vertically suspended, and the suspension rods **811** are coupled to the upper end of the electric inside-diameter measuring device **200**. That is, the electric inside-diameter measuring device **200** is suspended from the coupling block **810** via the suspension rods **811**.

As a rotation-allowing mechanism part of the floating joint part **800**, a sphere **820** is provided between the coupling block **810** and the support base part **710**.

The sphere **820** is placed in the recessed part **722** of the support base part **710**, and the coupling block **810** is placed on the top of the sphere **820**.

The coupling block **810** placed on the sphere **820** allows rotation of the coupling block **810**.

FIG. **25** is a perspective view when the coupling block **810** is rotated and displaced with respect to the support frame part **300** (support base part **710**).

FIG. **26** is a cross-sectional view when the coupling block **810** is rotated and displaced with respect to the support frame part **300** (support base part **710**).

The bottom face of the coupling block **810** is provided with a platform (a ring-shaped, protruding edge) to prevent the coupling block **810** from coming off the sphere **820**. Although pins may be used instead of the sphere if they only allow rotation of the coupling block **810**, it is preferable to use the sphere **820** because it does not inhibit the translation of the coupling block **810**.

The support ring part **720** is provided with two guide shafts **723** that extend horizontally and intersect crosswise. The coupling block **810** is provided with two guide holes **812** in the front-rear and left-right directions to receive the two crossed guide shafts **723**. The guide holes **812** are formed into long holes to allow the guide shafts **723** to guide the horizontal translation of the coupling block **810**.

FIG. **27** is a top view (plan view) when the coupling block **810** is translated in the horizontal direction.

The guide holes **812** also have some width in the height direction in order for the guide shafts **723** not to inhibit the coupling block **810** from rotating.

In order to center (balance) the normal position of the coupling block **810**, four springs (coil springs) **724** are interposed between the coupling block **810** and the inner wall of the support ring part **720**. Here, the springs (coil springs) **724** are disposed between the coupling block **810** and the inner wall of the support ring part **720** by winding the springs (coil springs) **724** around the guide shafts **723**.

Here, the guide shafts **723** and the guide holes **812** constitute a translation-allowing mechanism part that allows translation of the coupling block **810**.

The translation-allowing mechanism part may be constituted by providing the guide shafts to the coupling block **810** and providing the guide holes in the support ring part **720**.

The restriction means **500** may directly restrict the electric inside-diameter measuring device **200** by clamping the electric inside-diameter measuring device **200** itself with the clamping pieces **510**, as in the first exemplary embodiment, or may indirectly restrict the electric inside-diameter measuring device **200** by restricting the coupling block **810**, for example.

The floating joint part **800** according to the fourth exemplary embodiment also allows translation and rotation of the electric inside-diameter measuring device **200** with respect to the support frame part **300**. That is, even if there is an axial misalignment (inclination and distortion) between the electric inside-diameter measuring device **200** and a hole to be measured, the floating joint part **800** allowing the rotation and translation allows the electric inside-diameter measuring device **200** to autonomously adjust its own position and posture.

Compared with the floating joint part **400** according to the first exemplary embodiment, the floating joint part **800** according to the fourth exemplary embodiment has fewer components because the coupling block **810** is a block that combines rotation and translation.

Even if the floating joint part **800** according to the fourth exemplary embodiment is attached to the electric inside-diameter measuring device **200**, the overall size increase can be suppressed. For example, since the floating joint part **800** according to the fourth exemplary embodiment is small in size, even if the floating joint part **800** according to the fourth exemplary embodiment is disposed above the electric inside-diameter measuring device **200**, the increase in the overall size of the electric inside-diameter measuring unit **120** is suppressed and does not have an extreme effect on the variation of the center of gravity. Therefore, by disposing the floating joint part **800** above the electric inside-diameter measuring device **200** instead of disposing the floating joint part on the side of the electric inside-diameter measuring device **200**, the automatic inside-diameter measuring apparatus **100** according to the fourth exemplary embodiment is suitable for automatic inside-diameter measurement for deep holes, such as measurement of the inside diameter near the bottom of a deep hole.

Fifth Exemplary Embodiment

A fifth exemplary embodiment is described.

The basic configuration in the fifth exemplary embodiment is similar to that in the first exemplary embodiment, but the structure of a floating joint part (floating joint mechanism part) **900** is characterized.

FIG. **28** is a perspective view of the electric inside-diameter measuring unit **120** according to the fifth exemplary embodiment.

FIG. **29** is a top view (plan view) of the electric inside-diameter measuring unit **120** according to the fifth exemplary embodiment.

In the fifth exemplary embodiment, the electric inside-diameter measuring device **200** is supported by the support frame part **300** via the floating joint part **900** in a posture in which its axis (the cylinder axis or the axis of the rod **230**) is vertical.

The structure of the floating joint part **900** according to the fifth exemplary embodiment is described below.

The floating joint part **900** includes a first floating coupling body **910**, a second floating coupling body **920**, and a third floating coupling body **930**.

The first floating coupling body **910** is cup-shaped and is referred to as the first floating coupling cup **910**. The electric inside-diameter measuring device **200** is received inside the cup-shaped interior, and the first floating coupling cup **910** and the electric inside-diameter measuring device **200** are fixedly coupled. The measuring head part **220** corresponding to the lower cylinder case part **214** and the head cylinder part **215** of the electric inside-diameter measuring device **200** protrudes downward from the bottom of the first floating coupling cup **910**. The first floating coupling cup **910** includes a first coupling shaft **911** protruding on both sides in the front-rear direction (Y-axis).

The second floating coupling body **920** is a ring-shaped member and is referred to as the second floating coupling ring **920**. The second floating coupling ring **920** is provided to surround the first floating coupling cup **910** in a direction perpendicular to the axis of the electric inside-diameter measuring device **200**. The second floating coupling ring **920** includes a hole provided in the front-rear direction (Y-axis direction). This hole is for bearing the first coupling shaft **911** of the first floating coupling cup **910** and referred to as a first coupling hole **921**. The first coupling hole **921** allows the first coupling shaft **911** to rotate about the axis and the first coupling shaft **911** to slide in the axial direction. That is, the electric inside-diameter measuring device **200** and the first floating coupling cup **910** can be translated in the front-rear direction (Y-axis direction) and be rotated around the Y-axis with respect to the second floating coupling ring **920**.

The second floating coupling ring **920** is provided with a second coupling shaft **922** protruding on both sides in the left-right direction (X-axis).

The third floating coupling body **930** is a horizontally-parallel plate member that supports the second floating coupling ring **920** to allow translation and rotation of the second floating coupling ring **920**, and is referred to as the third floating coupling plate **930**. The third floating coupling plate **930** includes a U-shaped depressed (recessed) curved part **931** to receive the electric inside-diameter measuring device **200** in the horizontal direction. At the tips of the arms constituting both sides of the curved part **931**, holes drilled in the left-right direction (X-axis) are provided.

Each hole is for bearings the second coupling shaft **922** of the second floating coupling ring **920**, and is referred to as a second coupling hole **932**. The second coupling hole **932** allows the second coupling shaft **922** to rotate about the axis and the second coupling shaft **922** to slide in the axial direction. That is, the electric inside-diameter measuring device **200**, the first floating coupling cup **910**, and the second floating coupling ring **920** can be translated in the left-right direction (X-axis direction) and rotated about the X-axis with respect to the third floating coupling plate **930**.

The third floating coupling plate **930** is coupled to the support base part **710** of the support frame part **300**.

When considering a first virtual straight line, which is a virtual extension of the first coupling shaft **911**, and a second virtual straight line, which is a virtual extension of the second coupling shaft **922**, the intersection of the first and second virtual lines is preferably substantially aligned with the center of gravity of the electric inside-diameter measuring device **200**.

The floating joint part **900** according to the fourth exemplary embodiment also allows translation and rotation of the electric inside-diameter measuring device **200** with respect to the support frame part **300**. That is, even if there is an axial misalignment (inclination and distortion) between the electric inside-diameter measuring device **200** and a hole to be measured, the floating joint part **900** allowing the rotation and translation allows the electric inside-diameter measuring device **200** to autonomously adjust its own position and posture.

FIG. **30** is a view when the first floating coupling cup **910** is rotated about the X axis.

FIG. **31** is a view when the first floating coupling cup **910** is translated in the horizontal plane.

For ease of viewing the drawings, the electric inside-diameter measuring device **200** is omitted in FIGS. **30** and **31**.

With the structure of the floating joint part **900** according to the fifth exemplary embodiment, it is easier to align the rotation axis and translation axis with the center of gravity of the electric inside-diameter measuring device **200**. This makes the posture of the electric inside-diameter measuring device **200** more stable.

As described above, according to the present invention, inside-diameter measurement, which has been operated manually, can be automated, which enables full automation of the inside-diameter measurement. Automatic in-line measurement of hole diameters can be introduced in machining factories or the like, and is expected to significantly improve production efficiency.

Sixth Exemplary Embodiment

A sixth exemplary embodiment is described.

FIG. **32** is a side view of the overall appearance according to the sixth exemplary embodiment.

FIG. **33** is an enlarged cross-sectional view of a floating joint part according to the sixth exemplary embodiment.

The basic configuration in the sixth exemplary embodiment is similar to that in the first exemplary embodiment, but a floating joint part **400** is disposed above the electric inside-diameter measuring device **200** in the sixth exemplary embodiment. That is, the electric inside-diameter measuring device **200** is supported to be suspended from the support frame part **300** via the floating joint part **400**. The configuration is substantially the same as that in the first exemplary embodiment, except that almost the entire electric inside-diameter measuring device **200** is below the support frame part **300** and is suspended and supported from the support frame part **300**. In the sixth exemplary embodiment (FIGS. **32** and **33**), the same reference signs are assigned to the elements corresponding to the first exemplary embodiment.

In FIGS. **32** and **33**, a suspension rod **430** that suspends the electric inside-diameter measuring device **200** extends toward the top of the electric inside-diameter measuring device **200**. The suspension rod **430** is on the central axis of the electric inside-diameter measuring device **200**, and the suspension rod **430** is fixedly coupled to the electric inside-diameter measuring device **200**. (The electric inside-diameter measuring device (electric inside-diameter measuring part) **200** may be interpreted to include the suspension rod **430**.) The suspension rod **430** passes through the first insertion hole **321** of the support base part **320**, and the first spring holder **411** is coupled to the upper end of the suspension rod **430**. The floating joint part **400** is constituted between the first spring holder **411** and the support base part **320**. That is, the floating joint part **400** is roughly constituted by a ball roller **423** provided in the support base part **320**, a horizontal plate (translation body) **421** provided to be translated by the ball roller **423**, the second spring holder **413** provided in the second insertion hole **422** of the horizontal plate (translation body) **421**, and the coil spring **412** disposed between the first spring holder **411** and the second spring holder **413**.

Similarly to the first exemplary embodiment, the sixth exemplary embodiment with this configuration and arrangement enables the operation of autonomously adjusting the position and posture of the electric inside-diameter measuring device **200** by the action of the floating joint part **400**. In addition, according to the sixth exemplary embodiment, the floating joint part **400** is disposed above the electric inside-diameter measuring device **200**, which make it suitable for automatic inside-diameter measurement for deep holes, such as measurement of the inside diameter near the bottom of a deep hole.

The present invention is not limited to the above exemplary embodiments, and can be appropriately modified without departing from the gist.

In the description of the above exemplary embodiments, when the rod **230** is driven, in addition to screw feeding by rotation, a linear motion may be used to pull the rod **230** up and down.

In the above exemplary embodiments, a multi-joint robot arm is described as an example of a moving means, but the moving means does not need to be a large-scale device, but may be a one-dimensional driving apparatus with an up-and-down elevation mechanism. For example, the one-dimensional driving apparatus includes a column, a slider that slides along the column, a motor that drives the slider, and a power transmission mechanism (a ball screw, a belt pulley, or the like) that couples the motor and the slider.

In the above exemplary embodiments, what is called a hole test (Borematic (registered trademark)) is described as an example of the structure of the tip of the inside-diameter measuring part, but any inside-diameter measuring device with the contact point **250** that moves forward and backward in conjunction with the rod **230** to be brought into contact with the inside wall is applicable. For example, in the case of the head of a cylinder gauge, the head includes one contact point **250** that moves forward and backward, an anvil that is coaxially opposed to the contact point **250** for centering, and guide heads on both sides in the orthogonal direction.

In the above exemplary embodiments, an inside-diameter measuring device (inside-diameter measuring part) is described as an example of a measuring device (measuring part). However, instead of an inside-diameter measuring device (inside-diameter measuring part), a contact-type measuring device (measuring part) that measures the dimensions (inside and outside dimensions) of a workpiece (object to be measured) may be used.

If a measuring device (measuring part) is provided with a movable element (which is variously called as a contact point, a measuring jaw, a spindle, or the like) that is displaceable with respect to a fixed element and measures the dimensions of a workpiece by bringing the contact point into contact with the workpiece or by clamping the workpiece with the contact point, such a measuring device is applicable to the above exemplary embodiment. The measuring device (measuring part) can autonomously adjust its position or posture by the floating joint part (floating joint mechanism part) using the reaction force applied to the contact point from the workpiece when the contact point is in contact with the workpiece with a predetermined measuring pressure, or when the contact point clamps the workpiece with a predetermined measuring pressure. (Therefore, the direction in which the translation-allowing mechanism part allows translation of an object to be supported (measuring device) is approximately parallel to the direction in which the contact point is brought into contact with the workpiece (or approximately parallel to the direction of the reaction force applied to the measuring device from the workpiece).) Examples of the measuring device (measuring part) include calipers, micrometer heads, micrometers, digital dial gauges (indicators), test indicators (lever-type dial gauges), and the like.

In the first, fourth, and fifth exemplary embodiments, different types of floating joint parts **400**, **800**, and **900** have been described, respectively. They may be used individually or in combination.

For example, the floating joint part **400** according to the first exemplary embodiment may be installed on the side of the electric inside-diameter measuring device **200**, and the floating joint part **800** according to the fourth exemplary embodiment may be further installed above the electric inside-diameter measuring device **200**.

Similarly, for example, the floating joint part **900** according to the fifth exemplary embodiment may be installed on the side of the electric inside-diameter measuring device **200**, and the floating joint part **800** according to the fourth exemplary embodiment may be further installed above the electric inside-diameter measuring device **200**.

Because of the length of an inside-diameter measuring device, if the inside-diameter measuring device is supported by a flexible joint, the inside-diameter measuring device sways unsteadily, inclines greatly, or slides back and forth or left and right, and is difficult to stabilize.

On the other hand, if the rigidity of the joint is increased, autonomous position and posture adjustment cannot be performed only with weak measuring pressure, which needs to introduce advanced feedback control, and the like. However, this requires the introduction of an expensive system and a long time for position and posture adjustment. Therefore, by coupling and supporting the inside-diameter measuring device at two points of the side and the top of the inside-diameter measuring device with appropriate floating joint parts, it is expected that stability can be achieved while flexibility of the joints can be maintained.

The above exemplary embodiments assume that the electric inside-diameter measuring device is inserted into a hole from the top of the hole while a nearly vertical posture is maintained, but the electric inside-diameter measuring device may be used in a horizontal posture as well as the vertical posture, or it may approach a workpiece (hole to be measured) from below to top in an upside-down vertical posture.

100 Automatic inside-diameter measuring apparatus
110 Measuring-apparatus main body
120 Electric inside-diameter measuring unit
200 Electric inside-diameter measuring device
210 Cylinder case part
211 Upper cylinder case part
212 Female thread
213 Middle cylinder case part
214 Lower cylinder case part
215 Head cylinder part
216 Plate spring
220 Measuring head part
230 Rod
231 upper rod
232 Feed screw
233 Lower rod
240 Thimble part
241 Thimble sleeve
242 Ratchet sleeve
243 Coil spring (load regulation elasticity)
250 Contact point
251 Tapered surface
252 Round shaft tip
260 Displacement detection part
261 Rotor
262 Stator
270 Outer case part
271 Outer case body part
272 Outer case upper part
273 Display unit
274 Display part
280 Electric drive unit
300 Support frame part
310 Support column part
320 Support base part
321 First insertion hole
400 Floating joint part (floating joint mechanism part)
410 Rotation-allowing mechanism part
411 First spring holder
412 Coil spring
413 Second spring holder
414 Ring hole
420 Translation-allowing mechanism part
421 Horizontal plate
422 Second insertion hole
423 Ball roller
430 Suspension rod
500 Restriction means
510 Clamping piece
600 Collision detection part
601 Fixed plate
602 Mounting plate
610 Linear guide
611 Groove frame
612 Slide body
620 Coil spring
630 Contact sensor
631 Contact detection block
632 Ball plunger
132 Force sensor part
130 Multi-joint robot arm part (robot arm part)
131 Hand part
140 Control unit
150 Measurement operation control unit
151 Restriction control unit
152 Drive control unit
153 Measurement value acquisition unit
160 Robot arm drive control unit
170 Central control unit
710 Support base part
720 Support ring part
721 Beam
722 Recessed part
723 Guide shaft
724 Spring (coil spring)
800 Floating joint part (floating joint mechanism part)
810 Coupling block
811 Suspension rod
812 Guide hole
820 Sphere
900 Floating joint part (floating joint mechanism part)
910 First floating coupling cup (first floating coupling body)
911 First coupling shaft
920 Second floating coupling ring (second floating coupling body)
921 First coupling hole
922 Second coupling shaft
930 Third floating coupling plate (third floating coupling body)
931 Curved part
932 Second coupling hole

The invention claimed is:

1. An inside-diameter measuring unit comprising:

an inside-diameter measuring part including a contact point configured to move forward and backward in a direction perpendicular to a cylinder axis of a cylinder case part, the inside-diameter measuring part configured to bring the contact point into contact with an inner wall of a hole to be measured to measure an inside diameter of the hole while the inside-diameter measuring part is inserted in the hole;

a support frame part configured to support the inside-diameter measuring part; and

a floating joint part interposed between the support frame part and the inside-diameter measuring part to allow relative translation and rotation of the inside-diameter measuring part with respect to the support frame part, wherein

the floating joint part includes:

a rotation-allowing mechanism part configured to allow the rotation of the inside-diameter measuring part with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the inside-diameter measuring part with respect to the support frame part

the rotation-allowing mechanism part includes a flexible body configured to allow deformation in a direction in which the inside-diameter measuring part is inclined the translation-allowing mechanism part includes a translation body configured to allow translation of the inside-diameter measuring part in a direction intersecting the cylinder axis of the cylinder case part

the flexible body has one end coupled to the inside-diameter measuring part

the flexible body has the other end coupled to the translation body, and

the translation body is supported in such a manner as to be translatable with respect to the support frame part.

2. The inside-diameter measuring unit according to claim **1**, wherein

the support frame part includes a support base part

the support base part includes a first insertion hole through which the inside-diameter measuring part is inserted

the translation body includes a second insertion hole through which the inside-diameter measuring part is inserted

the inside-diameter measuring part is supported while being inserted in the first insertion hole and the second insertion holes, and

the floating joint part includes a bearing provided around the first insertion hole and the second insertion hole between the translation body and the support base part to allow translation of the translation body with respect to the support base part.

3. The inside-diameter measuring unit according to claim **2**, wherein

the first insertion hole has a larger diameter than a diameter of the second insertion hole

the diameter of the first insertion hole has a size allowing the translation of the inside-diameter measuring part, and

the diameter of the second insertion hole has a size allowing the inclination of the inside-diameter measuring part.

4. The inside-diameter measuring unit according to claim **1**, wherein the flexible body is an elastic body provided to surround the inside-diameter measuring part between the inside-diameter measuring part and the translation body.

5. The inside-diameter measuring unit according to claim **4**, wherein the elastic body is a spring provided to surround the inside-diameter measuring part.

6. The inside-diameter measuring unit according to claim **1**, wherein

the translation body is disposed above the support base part

the flexible body has a lower end coupled to the translation body as the other end, and

the flexible body has an upper end coupled to the inside-diameter measuring part as the one end.

7. The inside-diameter measuring unit according to claim **1**, wherein a position at which the one end of the flexible body is coupled to the inside-diameter measuring part corresponds to a center of gravity of the inside-diameter measuring part.

8. The inside-diameter measuring unit according to claim **1**, further includes an electric drive unit configured to move the contact point forward and backward.

9. The inside-diameter measuring unit according to claim **1**, further includes a restriction means for clamping the inside-diameter measuring part from a direction intersecting the cylinder axis, wherein

the restriction means is configured to clamp and hold the inside-diameter measuring part when the inside-diameter measuring part is not inserted in the hole to be measured, and to release the inside-diameter measuring part when the inside-diameter measuring part is inserted in the hole to be measured.

10. The inside-diameter measuring unit according to claim **1**, wherein the inside-diameter measuring part is supported by the support frame part via the floating joint part when the cylinder axis is oriented in a vertical direction as a reference position.

11. The inside-diameter measuring unit according to claim **1**, wherein the support frame part couples the inside-diameter measuring part to a moving means for moving the inside-diameter measuring part.

12. A floating joint mechanism part interposed between an object to be supported and a support frame part configured to support the object to be supported, the floating joint mechanism part configured to allow relative translation and rotation of the object to be supported with respect to the support frame part, the floating joint mechanism part comprising:

a rotation-allowing mechanism part configured to allow the rotation of the object to be supported with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the object to be supported with respect to the support frame part, wherein

the rotation-allowing mechanism part includes a flexible body configured to allow deformation in a direction in which the object to be supported is inclined

the translation-allowing mechanism part includes a translation body configured to allow translation of the object to be supported

the flexible body has one end coupled to the object to be supported

the flexible body has the other end coupled to the translation body, and

the translation body is supported in such a manner as to be translatable with respect to the support frame part.

13. A measuring unit comprising:

a measuring part configured to bring a contact point into contact with an object to be measured to measure a dimension of the object to be measured;

a support frame part configured to support the measuring part; and

a floating joint part interposed between the support frame part and the measuring part to allow relative translation and rotation of the measuring part with respect to the support frame part, wherein

the floating joint part includes:

a rotation-allowing mechanism part configured to allow the rotation of the measuring part with respect to the support frame part; and

a translation-allowing mechanism part configured to allow translational displacement of the measuring part with respect to the support frame part

the rotation-allowing mechanism part includes a flexible body configured to allow deformation in a direction in which the measuring part is inclined

the translation-allowing mechanism part includes a translation body configured to allow translation of the measuring part

the flexible body has one end coupled to the measuring part

the flexible body has the other end coupled to the translation body, and the translation body is supported in such a manner as to be translatable with respect to the support frame part.

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