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(54) **MEDICAL MANIPULATOR AND MEDICAL ROBOT SYSTEM**

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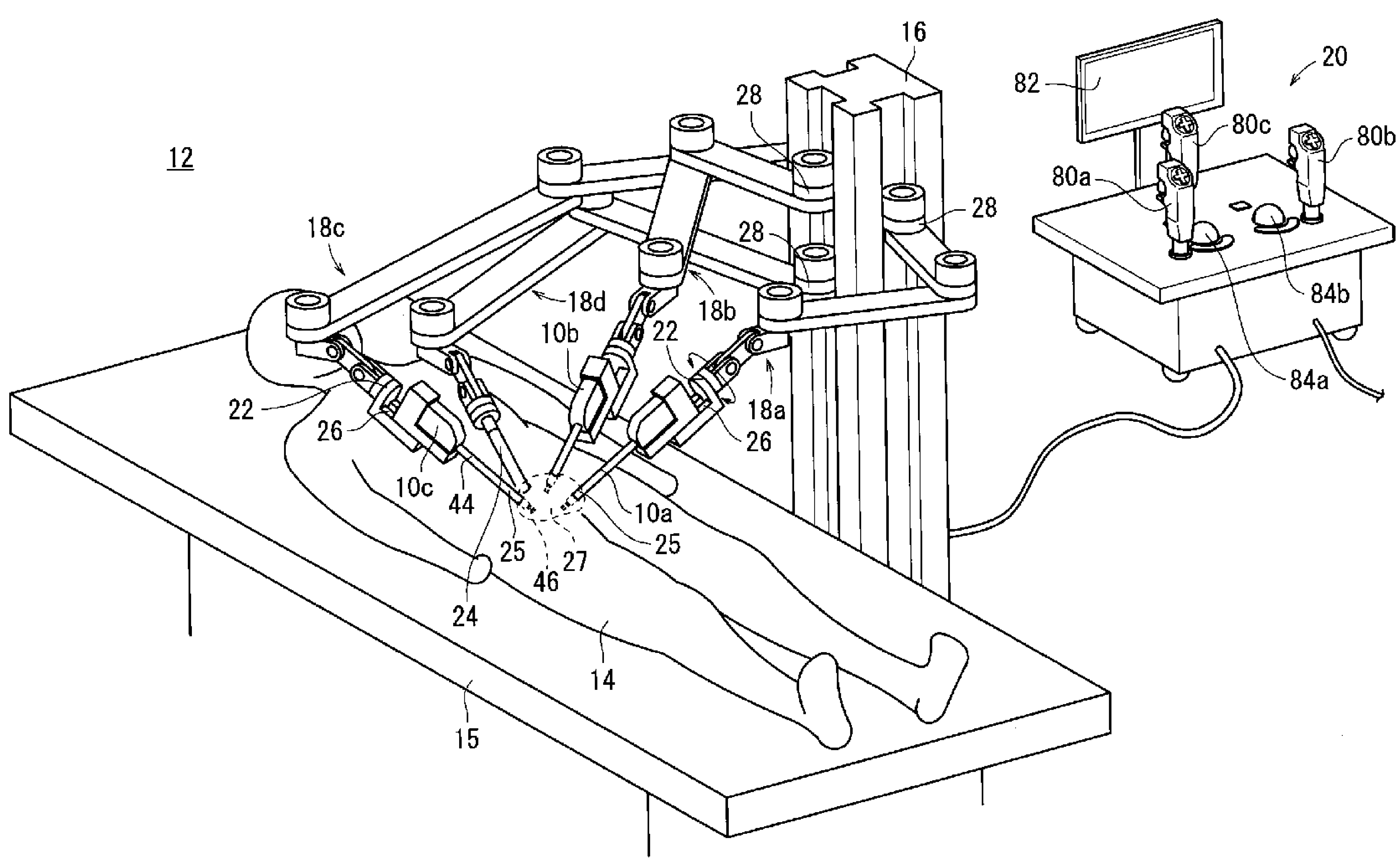
(57) **ABSTRACT**

The present invention relates to a medical manipulator and a medical robot system. The manipulator has a connecting block, a joint shaft, and a distal-end working unit. The distal-end working unit has a gripper, a pitch axis, and a yaw axis which serve as distal-end joints for changing the orientation of the gripper. The gripper, the pitch axis, and the yaw axis are operated by rotors around which wires are wound. The joint shaft has a first intermediate joint and a second intermediate joint which are bendable by the wires which are moved back and forth. Since the manipulator can be bent at the first intermediate joint and the second intermediate joint, the joint shaft can appropriately be placed, and the gripper can be adjusted to an appropriate orientation with respect to an organ by being turned around the pitch axis and the yaw axis.



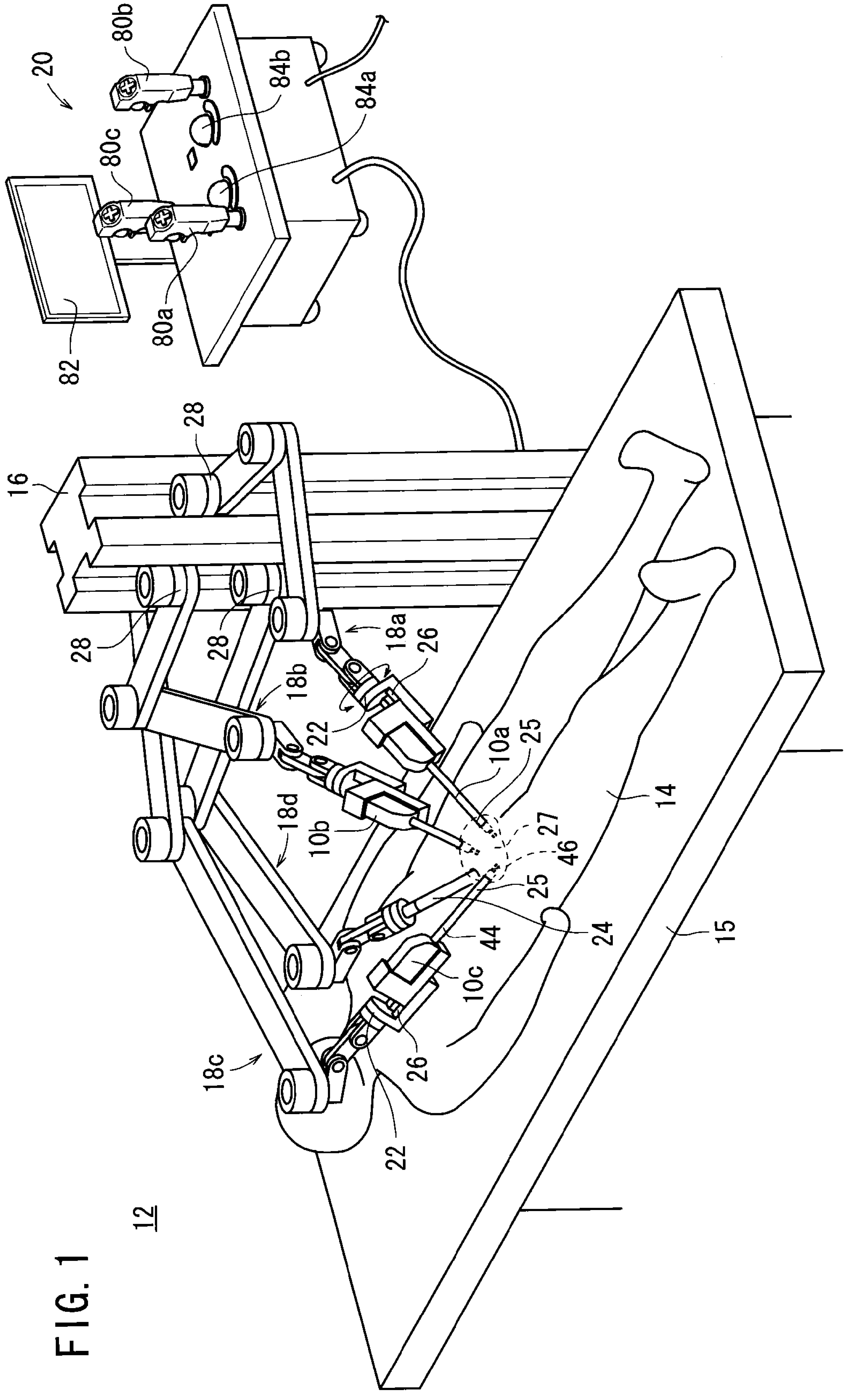

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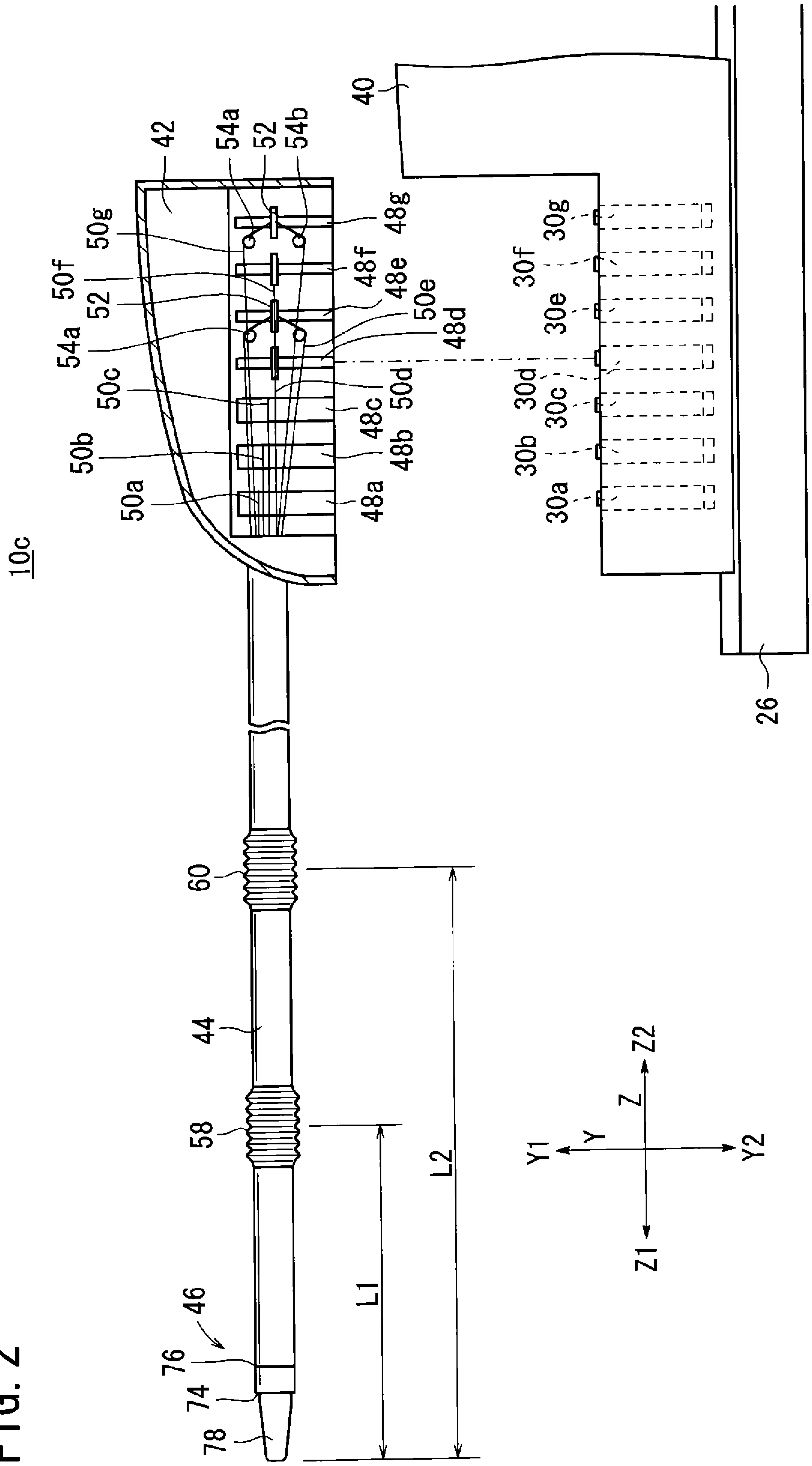
FIG. 1

FIG. 2



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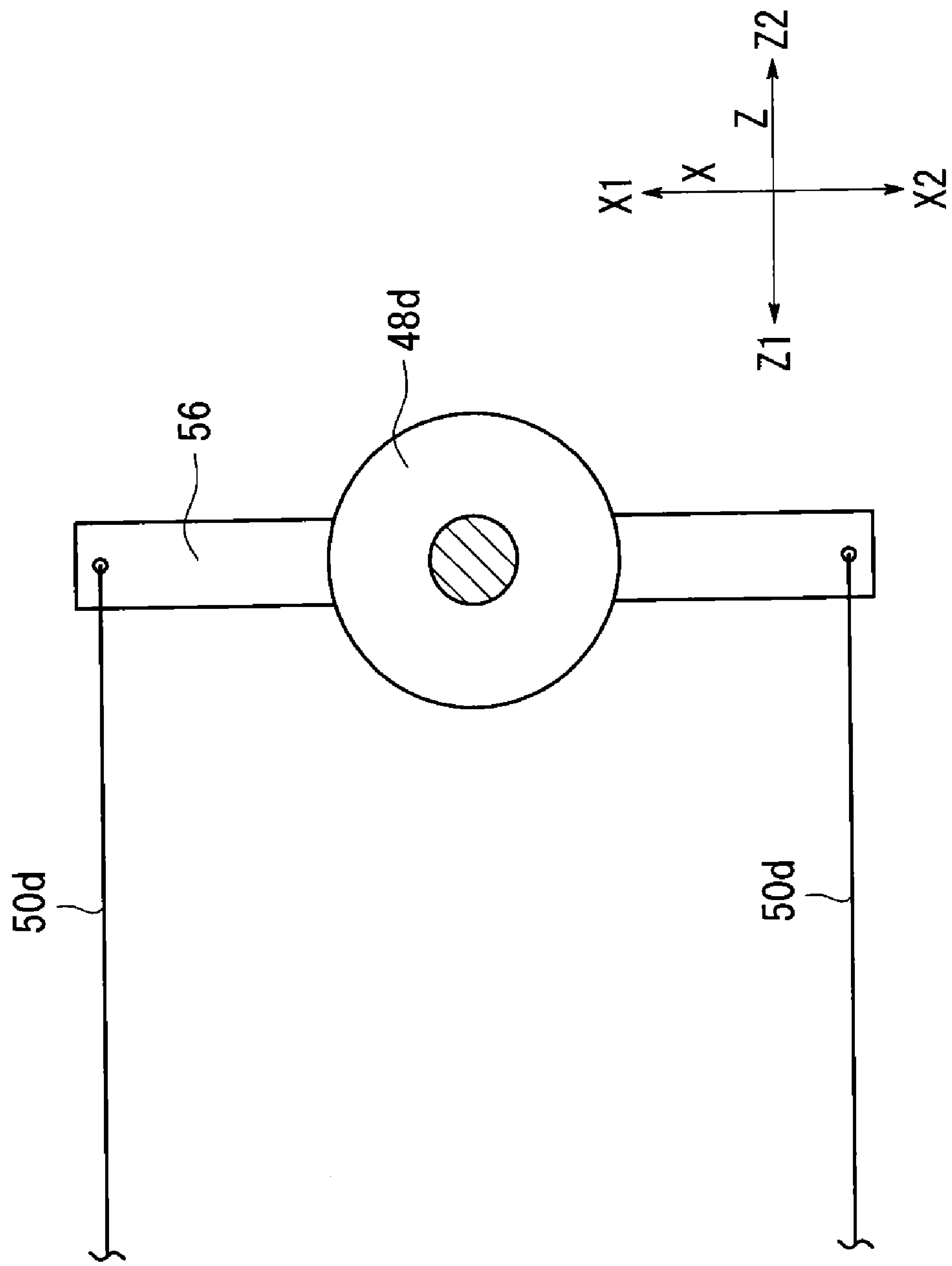


FIG. 3

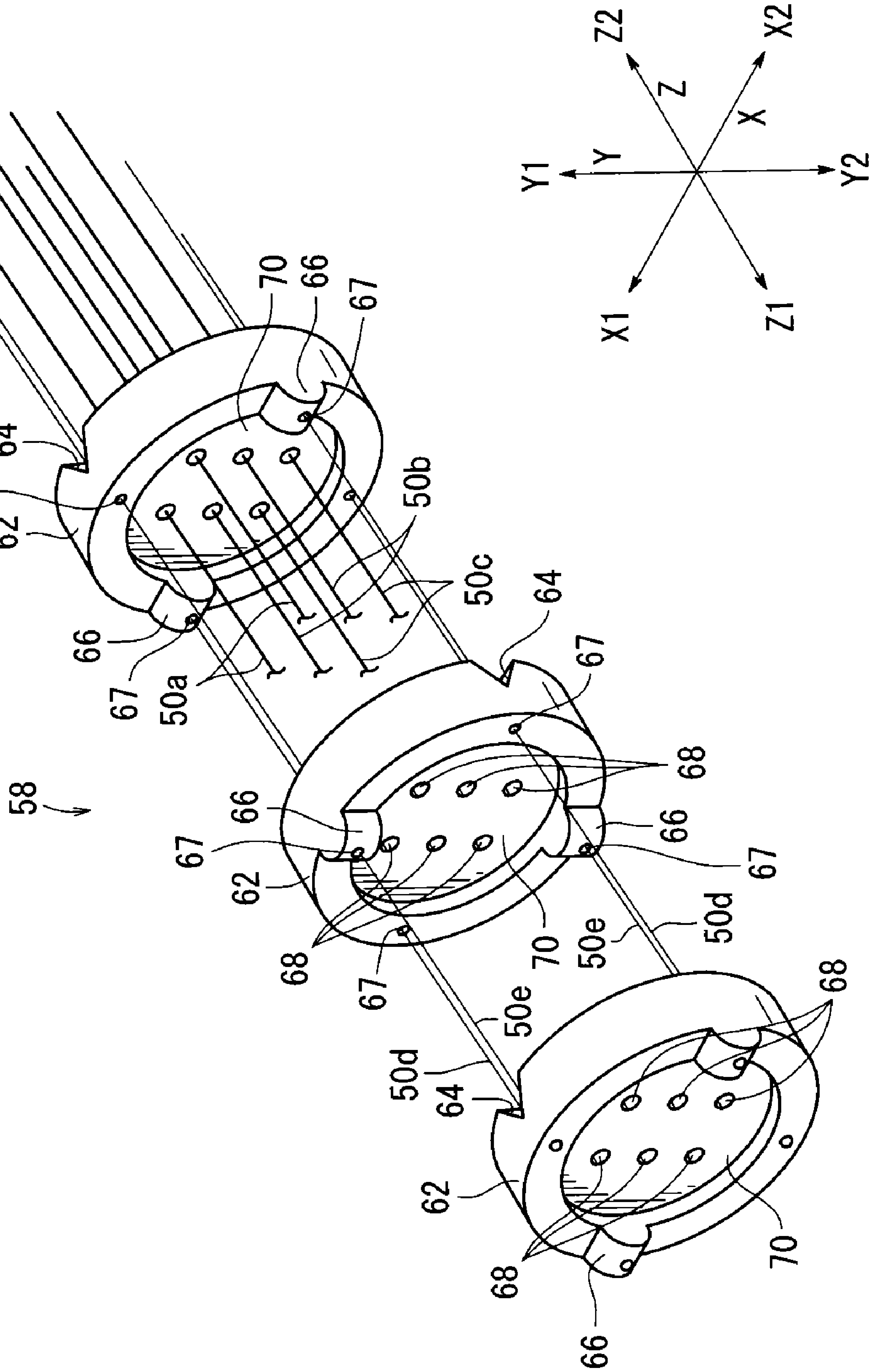


FIG. 4

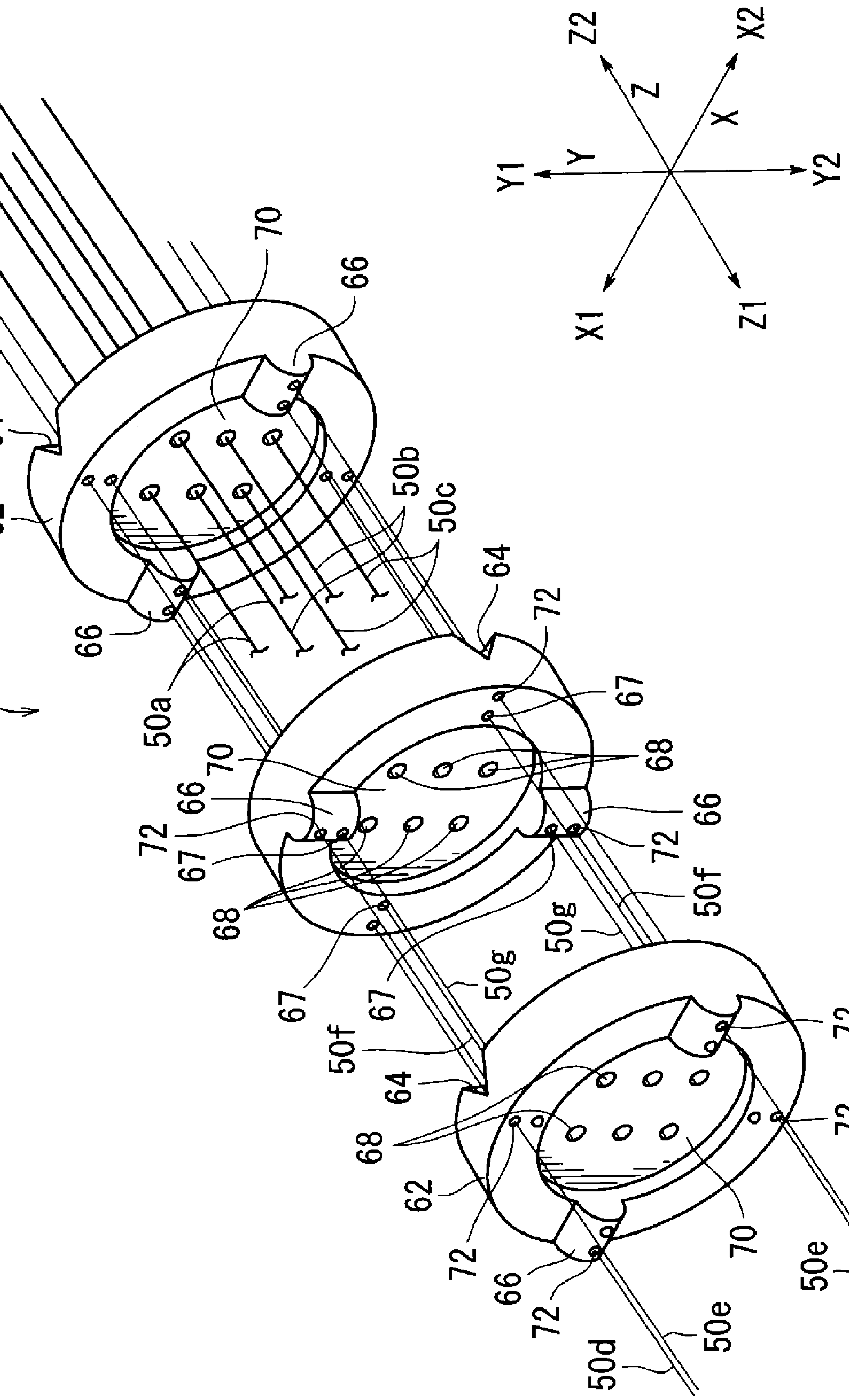

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FIG. 5

FIG. 6

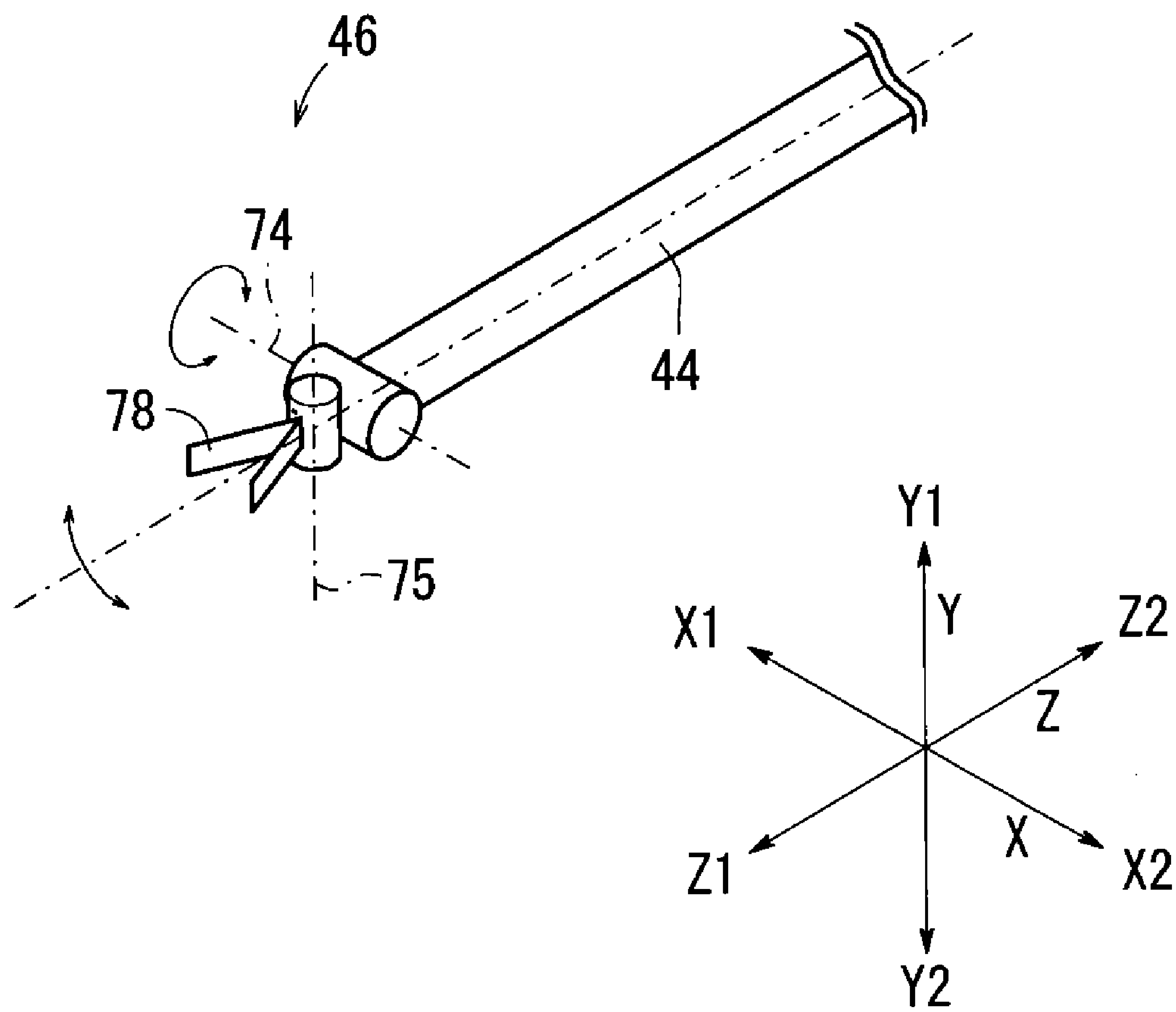

FIG. 7

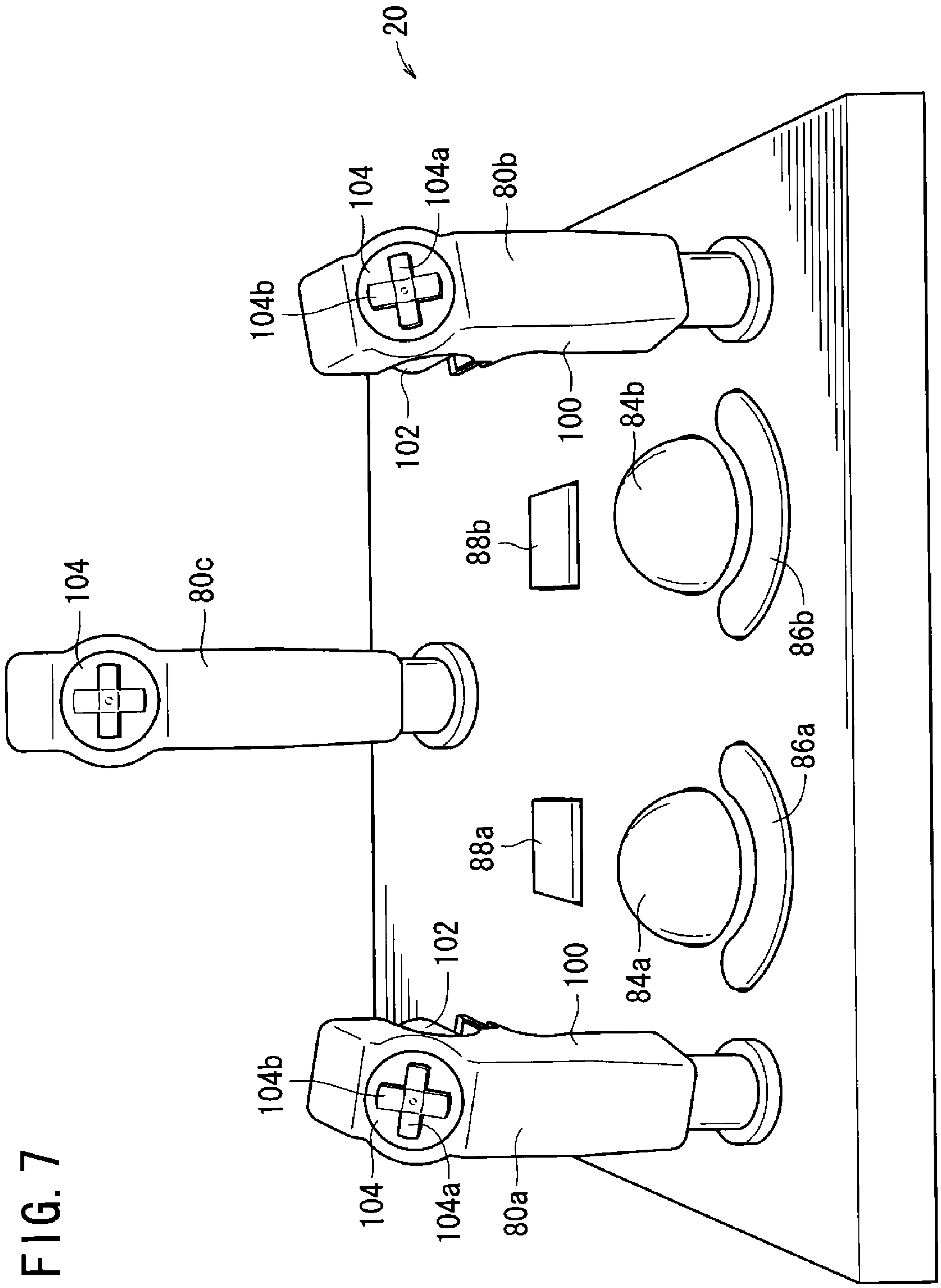
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FIG. 8

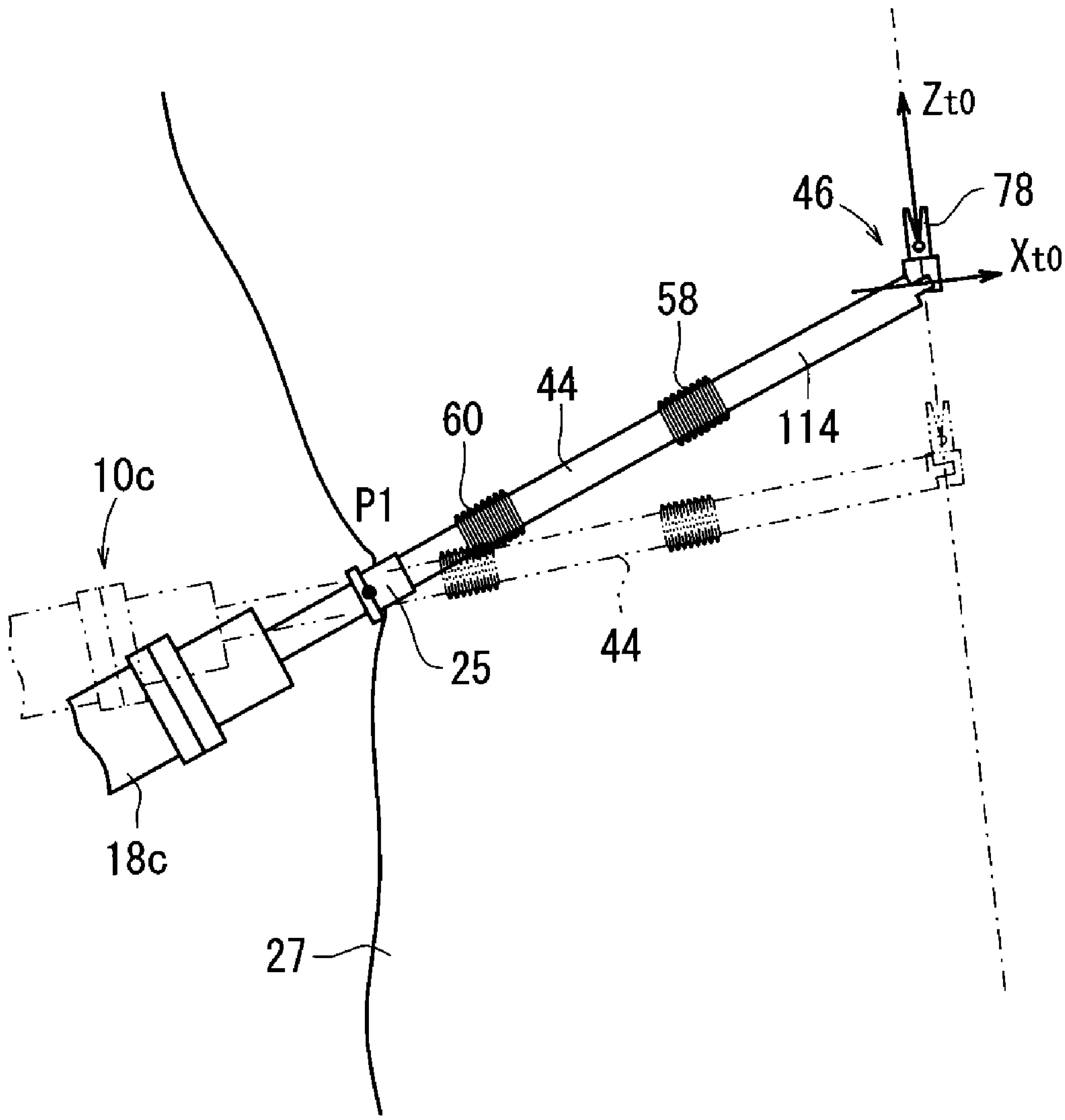


FIG. 9

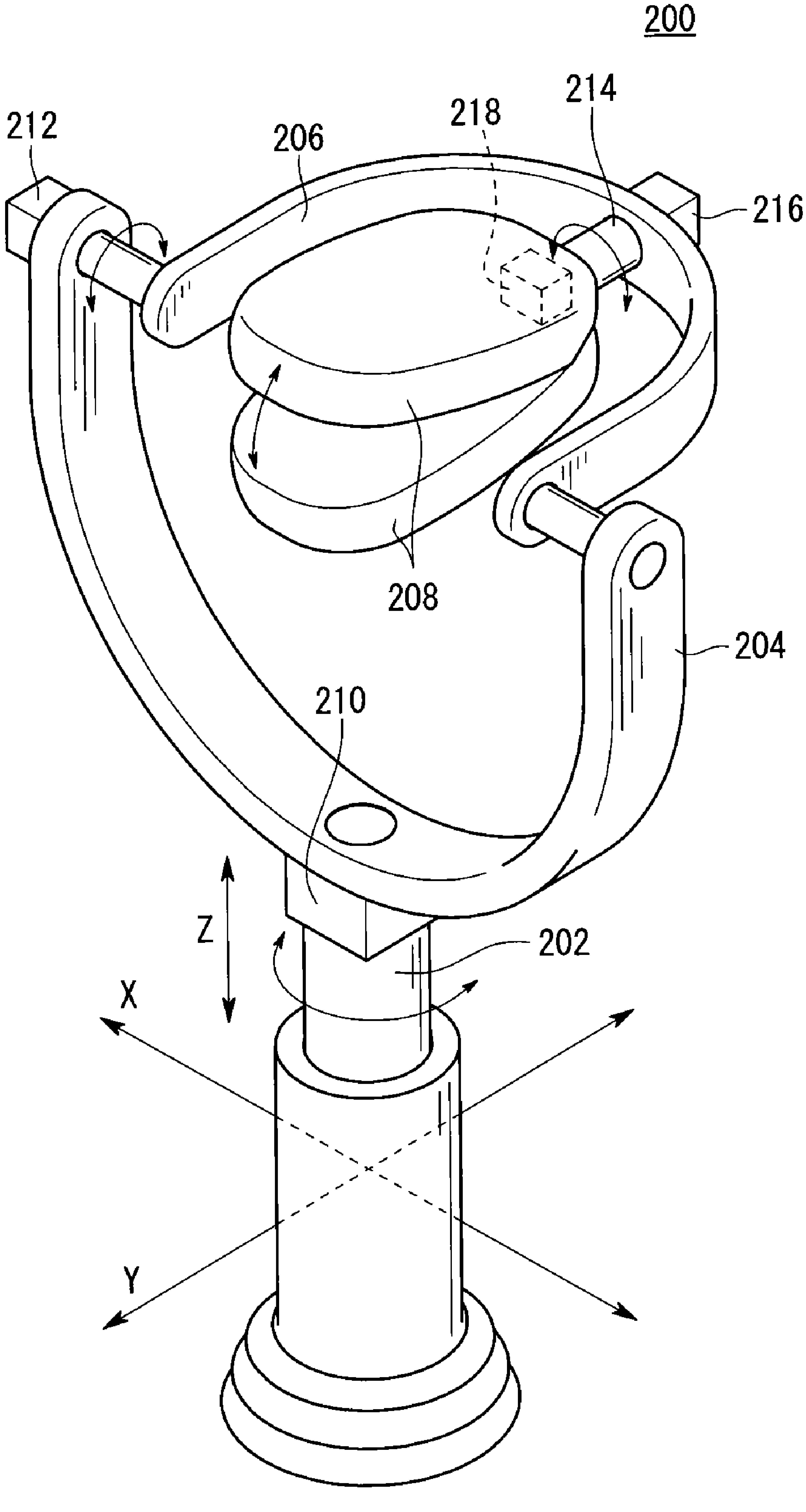


FIG. 10

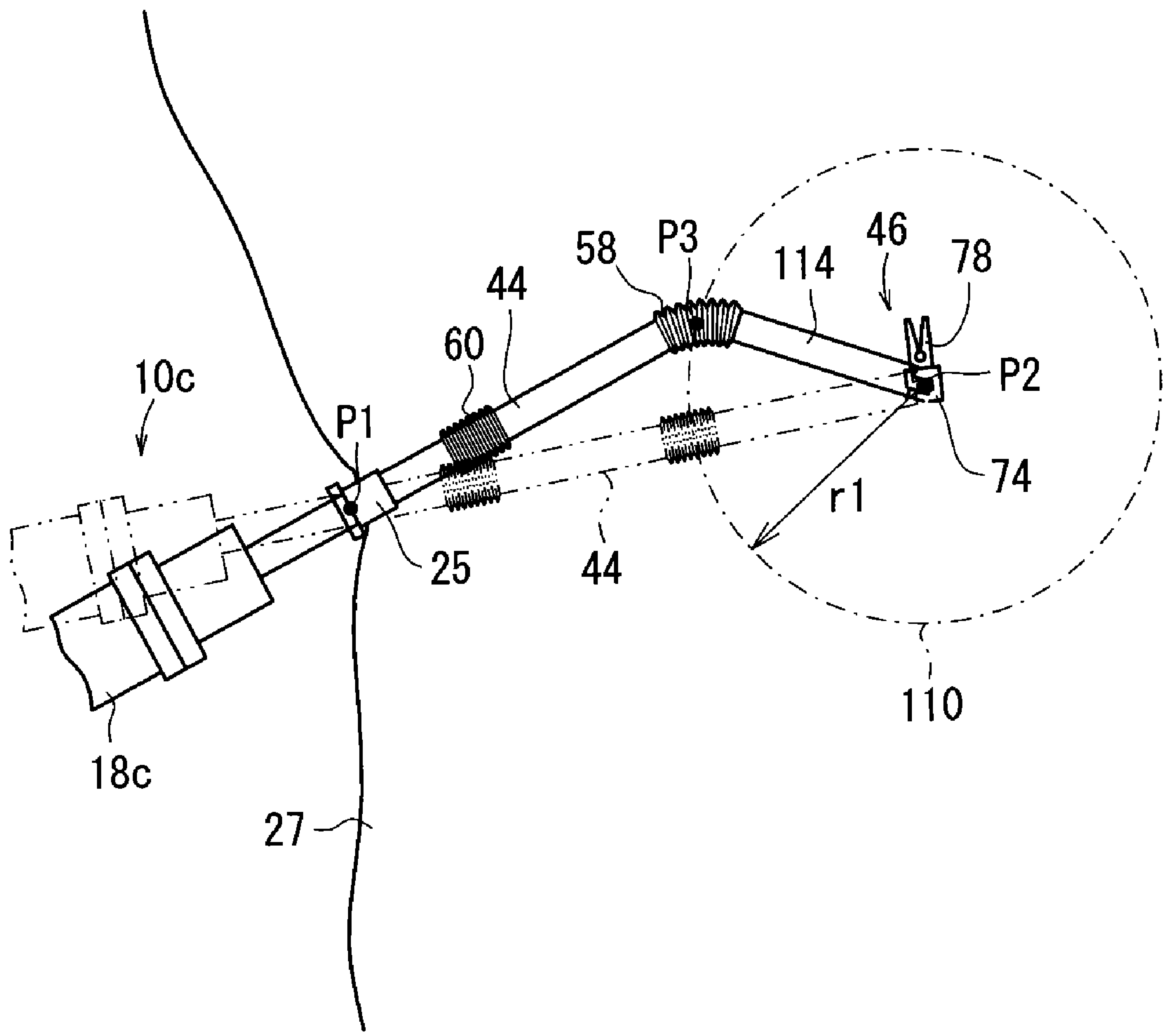


FIG. 11

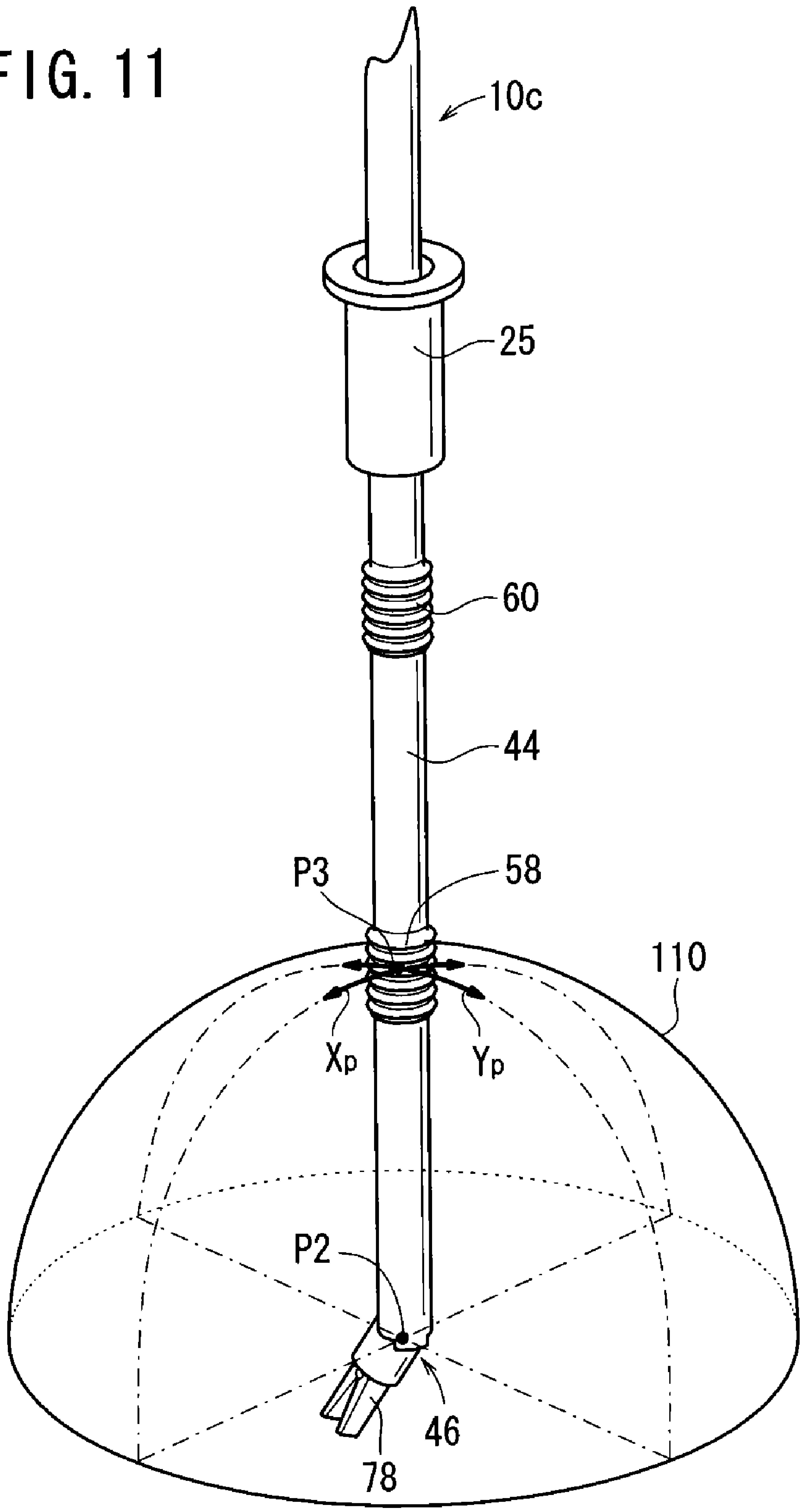


FIG. 12

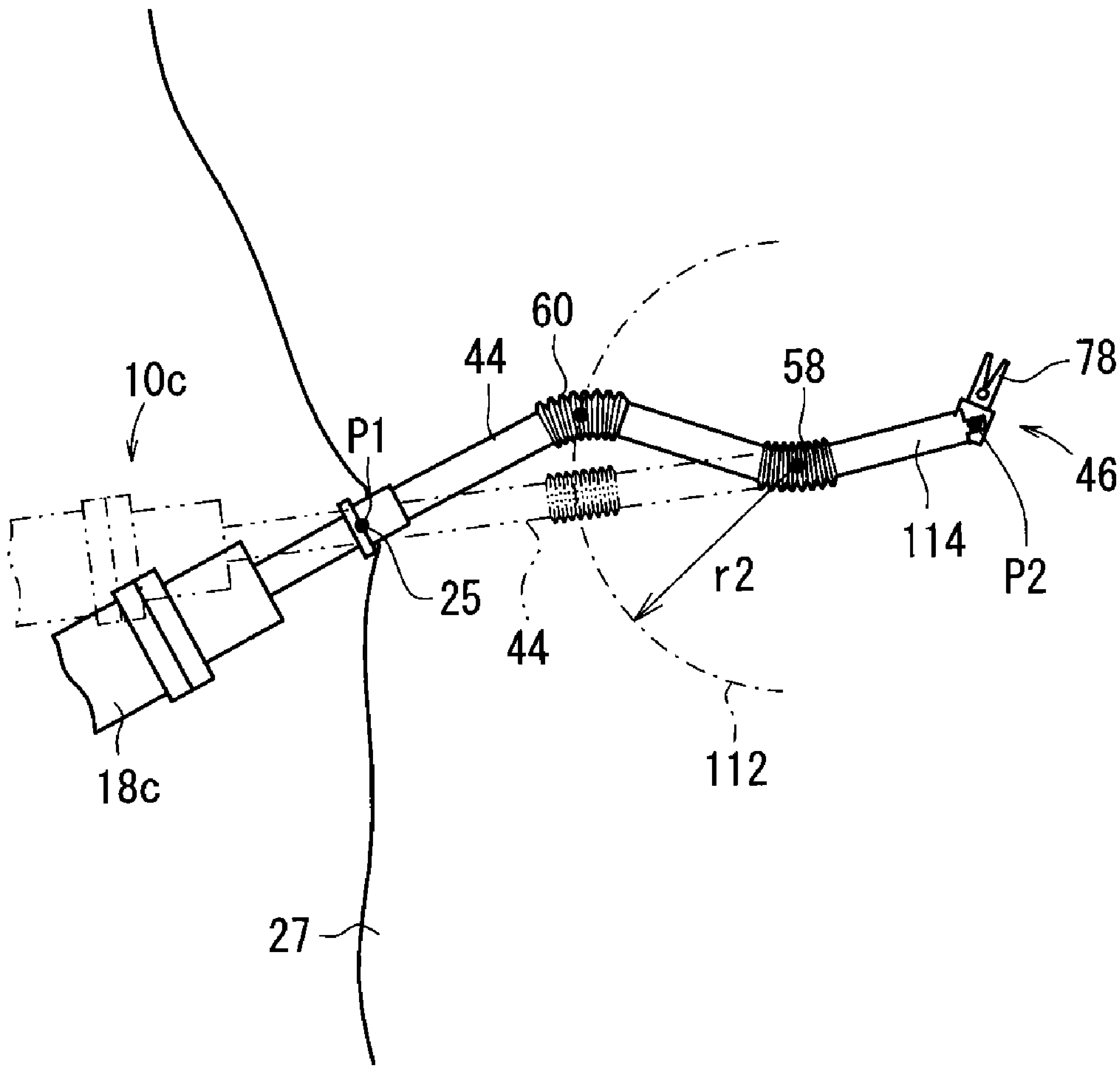


FIG. 13

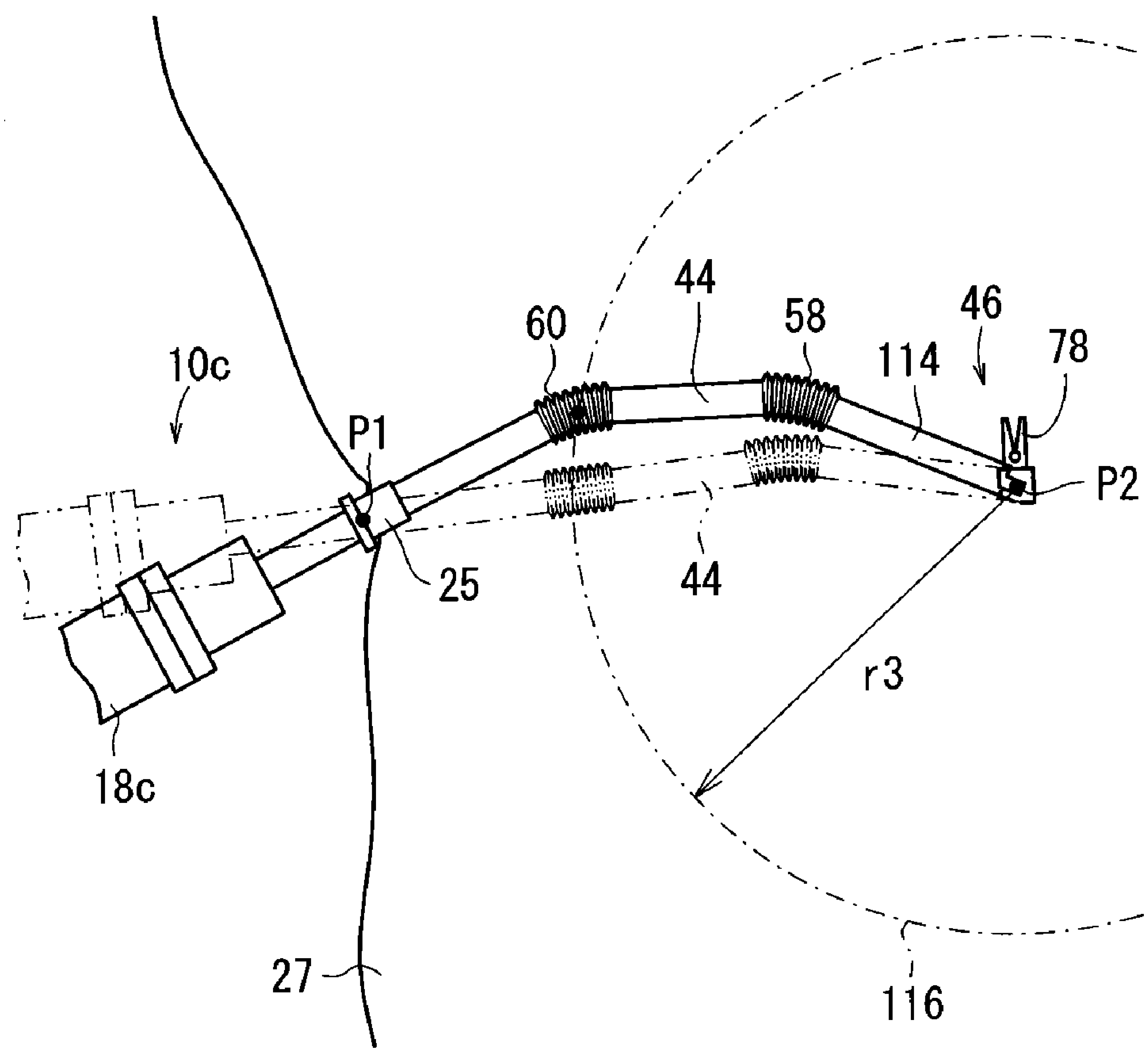


FIG. 14

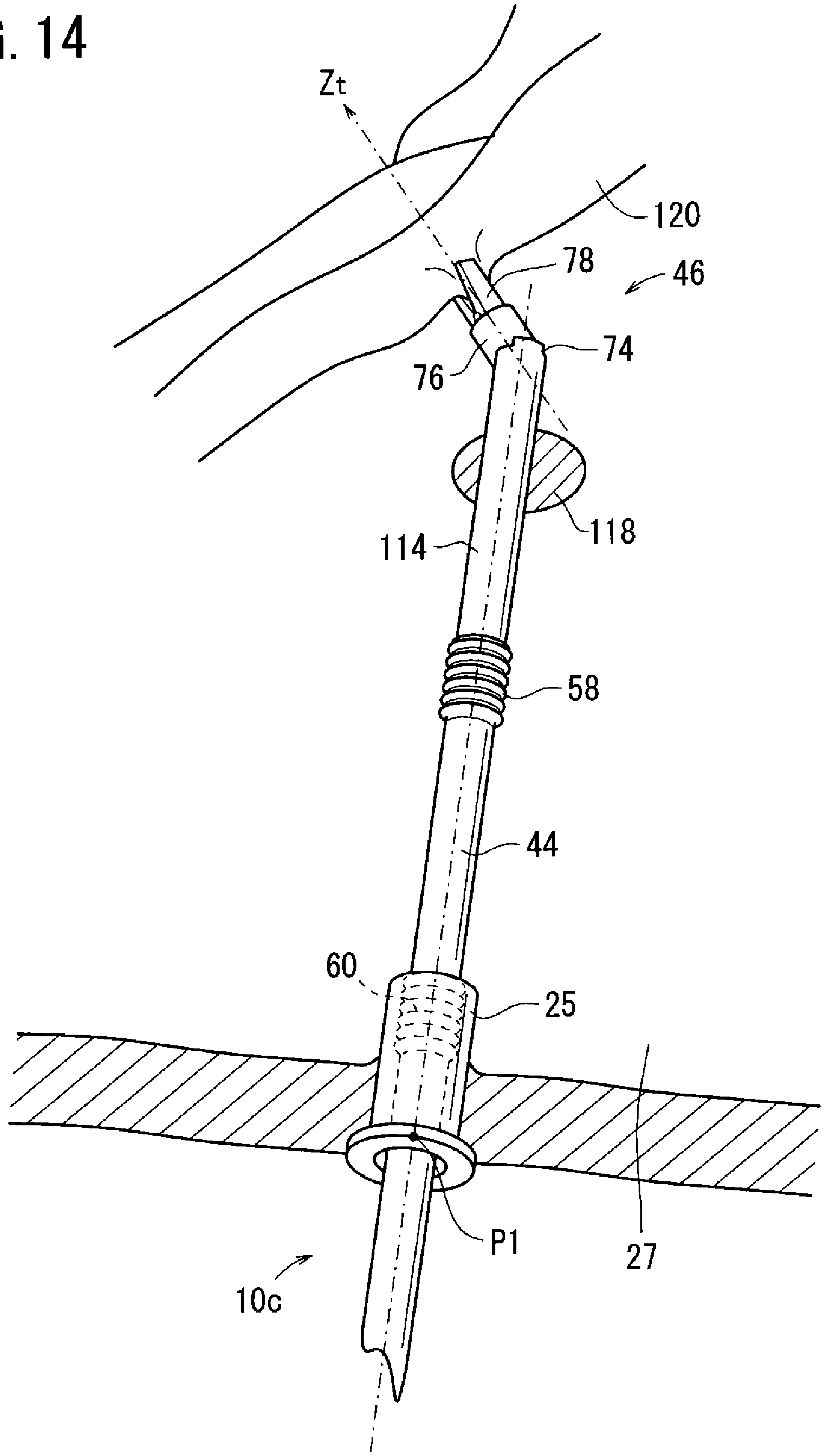


FIG. 15

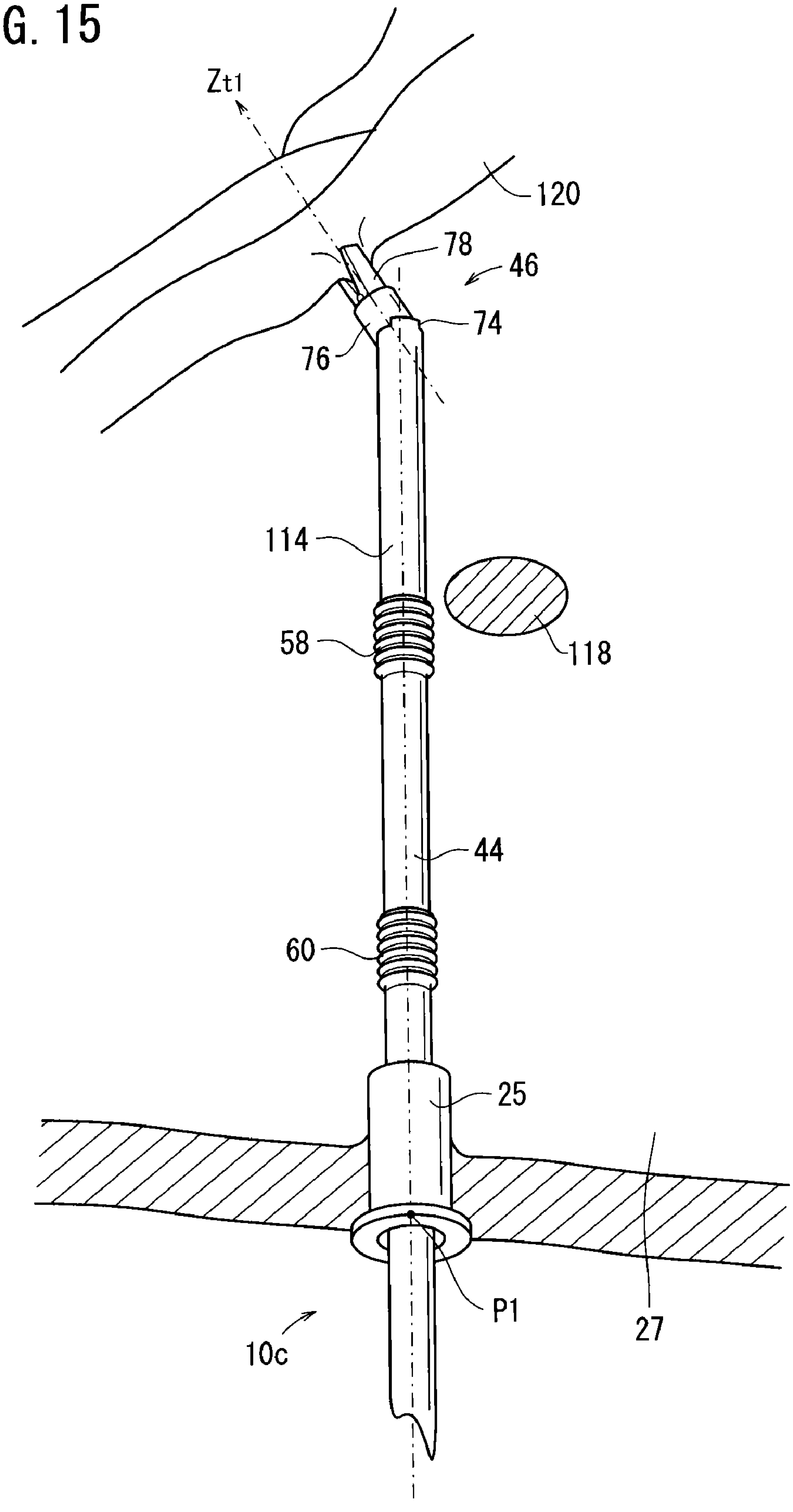


FIG. 16

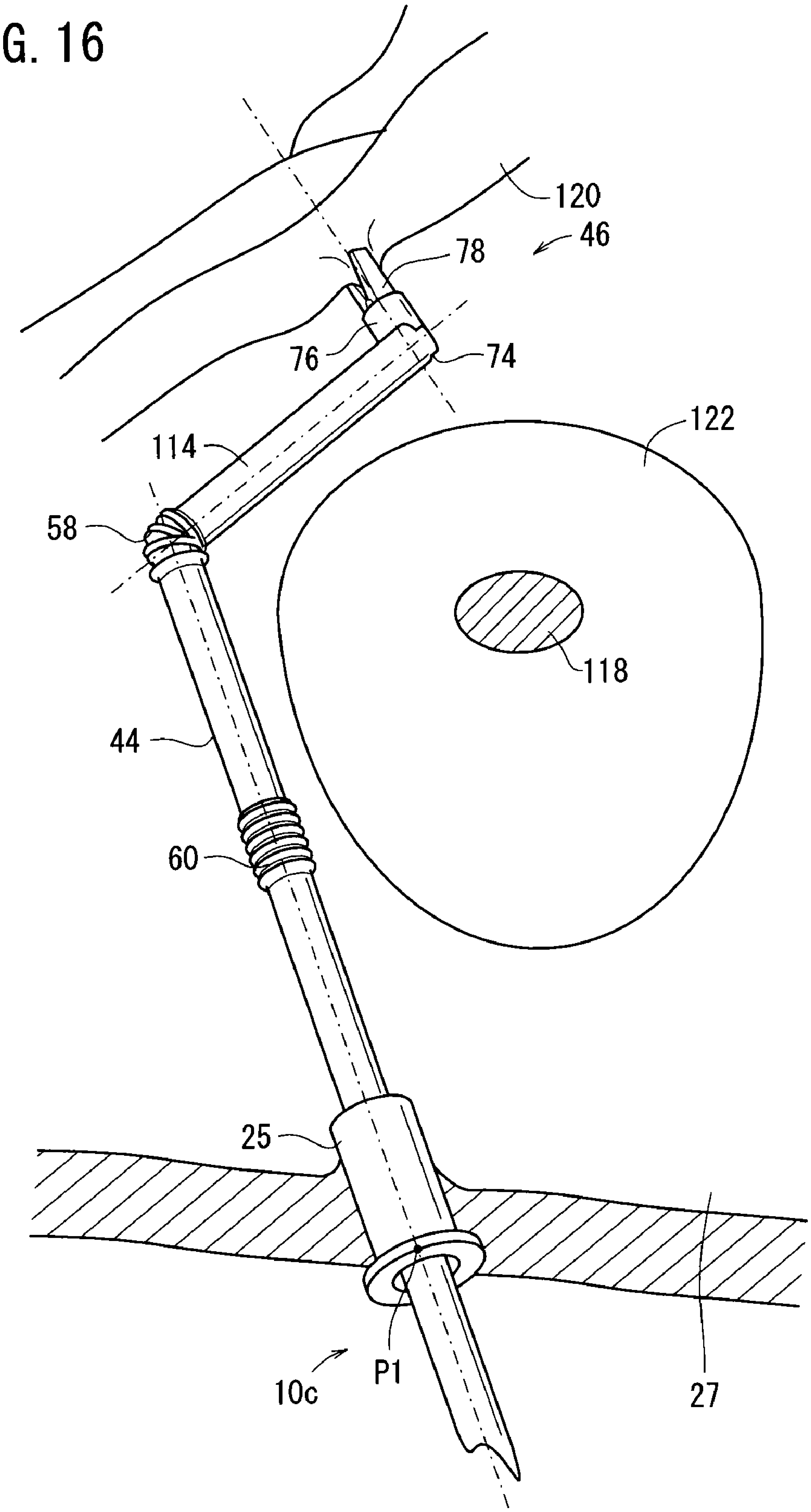
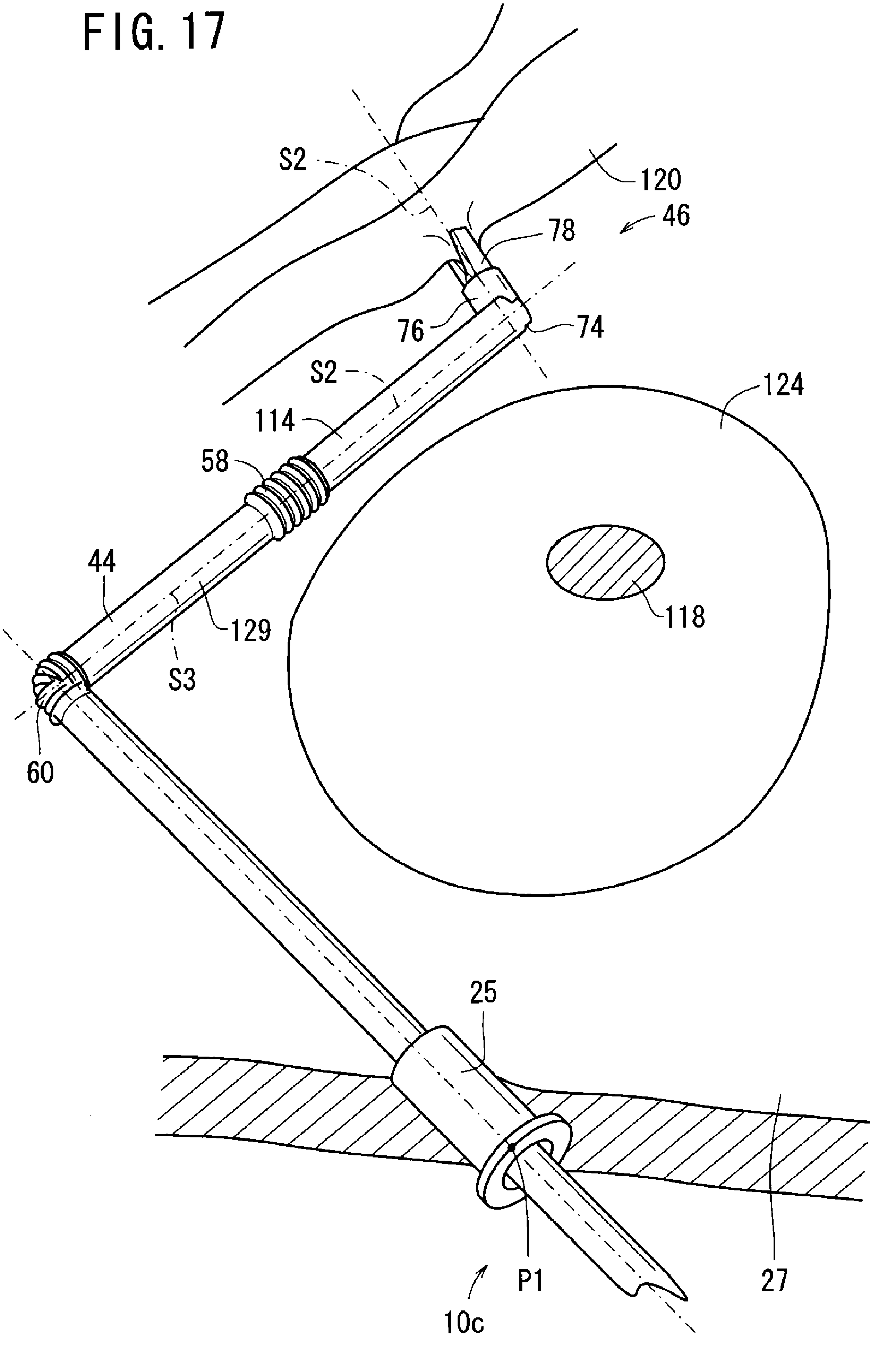


FIG. 17



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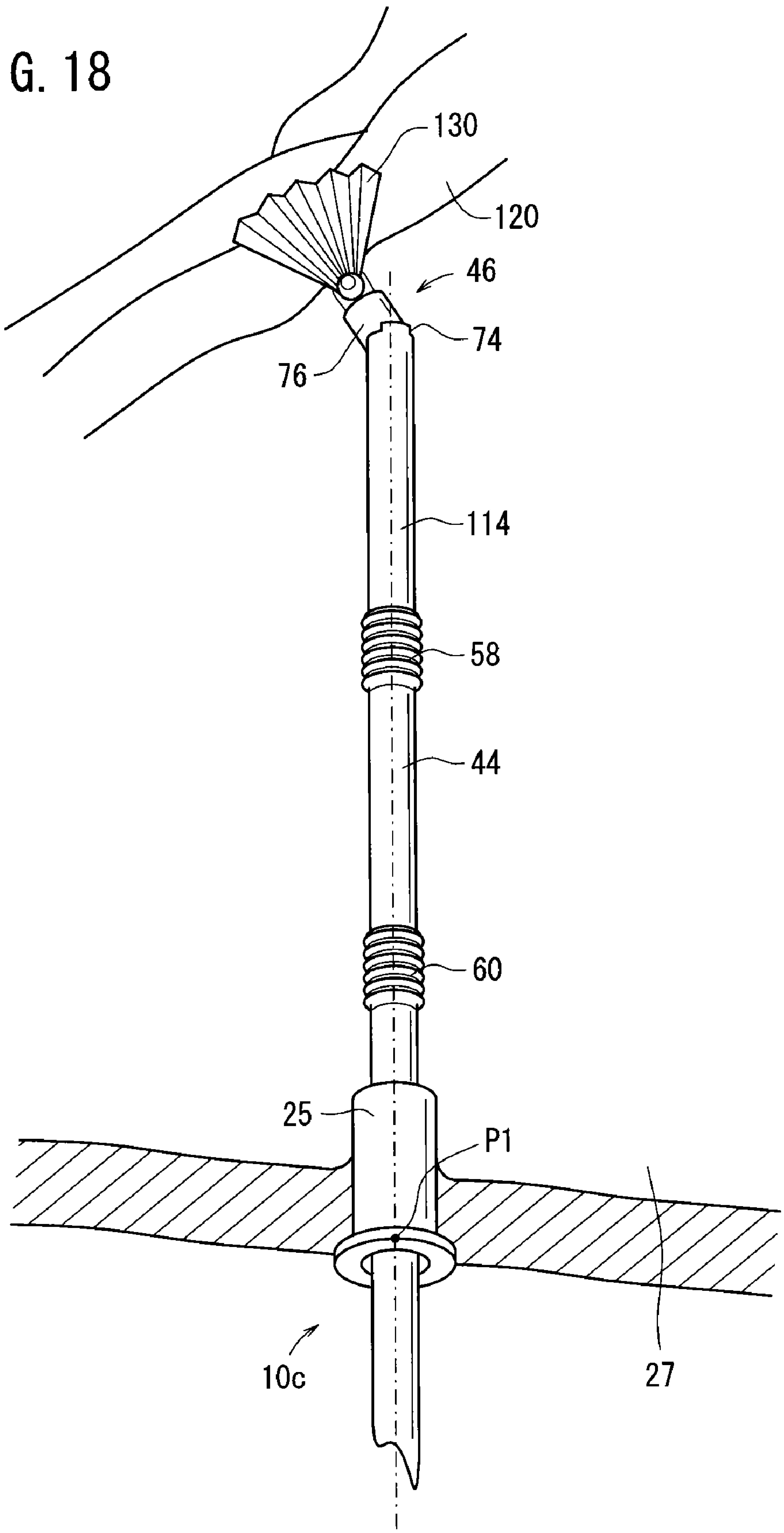

FIG. 19

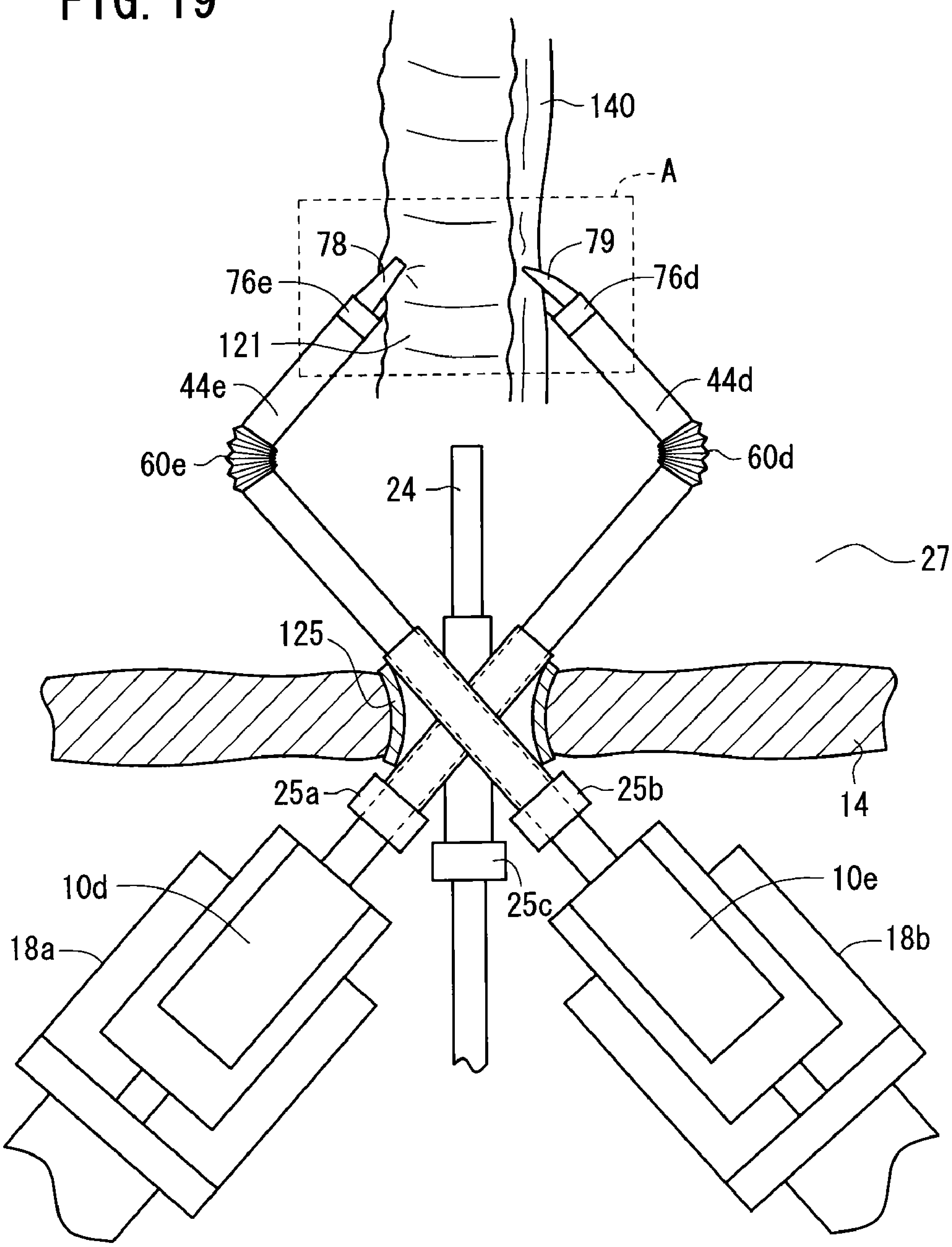
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FIG. 20

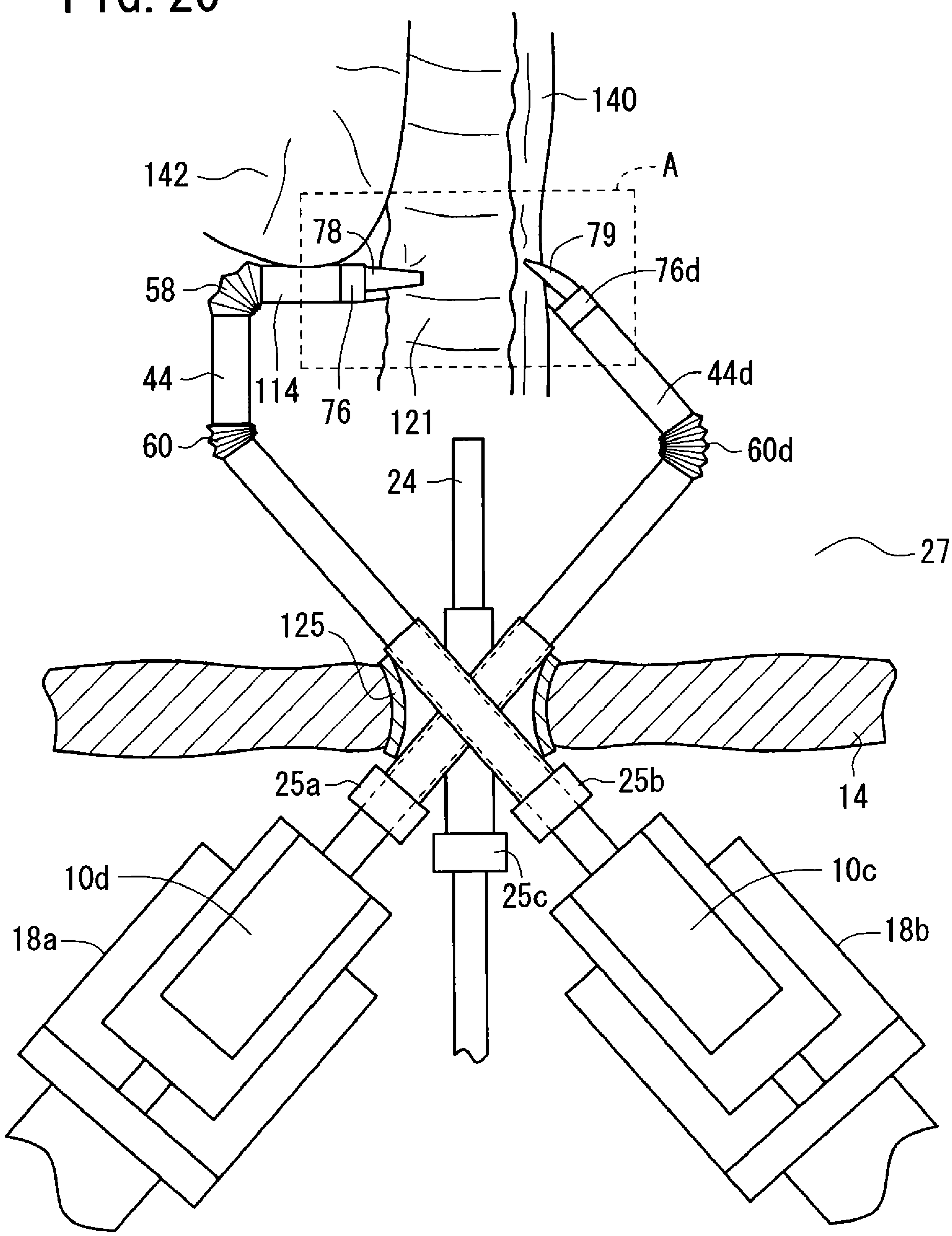

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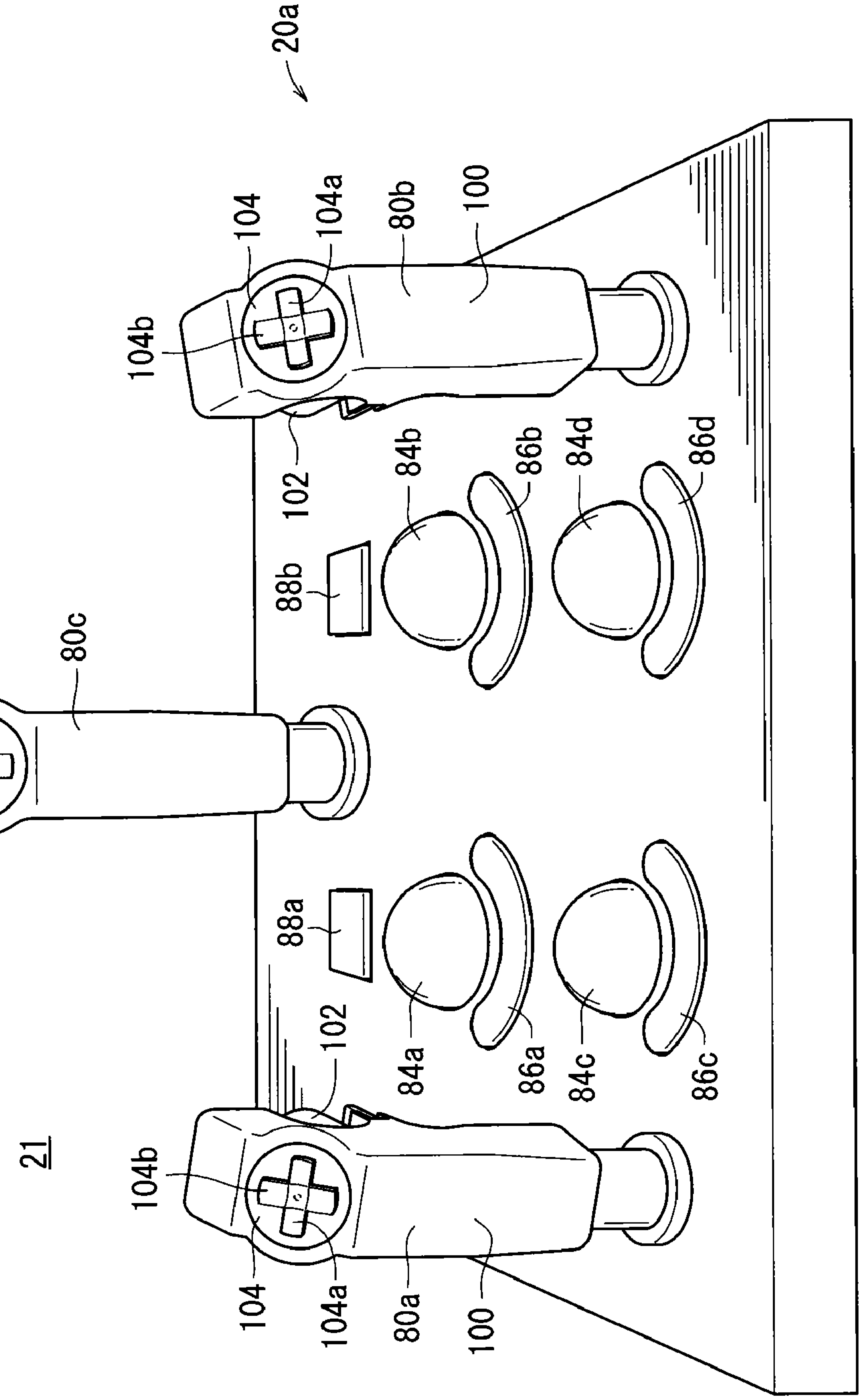
FIG. 21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# MEDICAL MANIPULATOR AND MEDICAL ROBOT SYSTEM

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application is a continuation-in-part and claims the benefit of priority from U.S. application Ser. No. 12/327, 189 filed Dec. 3, 2008, the entire contents of which are hereby incorporated by reference. U.S. application Ser. No. 12/327, 189, claims the benefit of Priority to Japanese Patent Application No. 2007-339211, filed on Dec. 28, 2007.

## BACKGROUND OF THE INVENTION

**[0002]** 1. Field of the Invention

**[0003]** The present invention relates to a medical manipulator having a distal-end joint operable by flexible members that are actuated by actuators, and a medical robot system for actuating such a medical manipulator with a robot arm.

**[0004]** 2. Description of the Related Art

**[0005]** According to a laparoscopic surgical operation process, small holes are opened in the abdominal region, for example, of a patient, and an endoscope and manipulators or forceps are inserted into such holes. The surgeon performs a surgical operation on the patient with the manipulators or forceps, while watching an image captured by the endoscope and displayed on a display monitor. Since the laparoscopic surgical operation process does not require a laparotomy to be performed, the operation is less burdensome on the patient and greatly reduces the number of days required for the patient to spend in the hospital before recovering from the operation and being released from the hospital. Therefore, the range of surgical operations in which the endoscopic surgical operation process may be applied is expected to increase.

**[0006]** As disclosed in Japanese Laid-open Patent Publication No. 2002-102248 and Japanese Laid-open Patent Publication No. 2003-061969, a manipulator system comprises a manipulator and a controller for controlling the manipulator. The manipulator comprises an operating unit, which is manually operated, and a working unit replaceably mounted on the operating unit.

**[0007]** The working unit comprises a long joint shaft and a distal-end working unit (referred to as an "end effector") mounted on the distal end of the joint shaft. The operating unit has motors for actuating the working unit through wires. The wires have proximal end portions wound around respective pulleys. The controller energizes the motors of the operating unit to cause the pulleys to move the wires circulatively.

**[0008]** There has also been proposed a medical robot system for actuating medical manipulators with robot arms (see, for example, U.S. Pat. No. 6,331,181). The medical robot system can be remotely controlled by a master arm, and can be moved in various ways under a programmed control.

**[0009]** The medical robot system has the robot arms, which can selectively be used depending on the surgical technique required. One of the robot arms incorporates an endoscope therein for capturing an image representing the inside of a body cavity, which is capable of being visually confirmed on a display monitor.

**[0010]** According to the laparoscopic surgical operation process, it is desirable to provide a wider operative field in the body cavity being operated on of the patient because the wider operative field allows the manipulators to operate with greater freedom in the body cavity.

**[0011]** The body cavity may contain various organs in addition to the organ as the affected region, which make it difficult to provide a wide operative field in the body cavity. The manipulator on one of the robot arms of medical robot systems may be used as a retractor for retracting an organ or organs other than the affected region to a position out of interference with the surgical operation.

**[0012]** However, when the organ or organs are retracted by the retractor, the retractor itself may be positioned across the body cavity, and present itself as an obstacle in the operative field.

## SUMMARY OF THE INVENTION

**[0013]** It is an object of the present invention to provide a medical manipulator which is capable of keeping a wide operative field in a body cavity and a medical robot system incorporating such a medical manipulator.

**[0014]** A medical manipulator according to an aspect of the present invention includes a rod-shaped member housing therein a first flexible member actuatable by a first actuator and a second flexible member actuatable by a second actuator, the rod-shaped member being flexible at least partly, at least one distal-end joint disposed on a distal end of the rod-shaped member, the distal-end joint being angularly movable by a rotor around which the first flexible member is wound, and at least one intermediate joint disposed on the rod-shaped member more closely to a proximal end thereof than the distal-end joint, the intermediate joint being bendable in response to back-and-forth movement of the second flexible member.

**[0015]** The medical manipulator allows the distal-end joint to perform an appropriate surgical procedure, and also allows the rod-shaped member to be appropriately placed because it can be bent at the intermediate joint, particularly for avoiding physical interference with other medical manipulators. The medical manipulator thus provides a wide operative field in a body cavity.

**[0016]** The rod-shaped member may include at least one guide plate having a hole defined therein through which the first flexible member extends. The guide plate allows the first flexible member to be placed in an appropriate position even when the intermediate joint is bent.

**[0017]** The medical manipulator may be connected to a robot arm, and the robot arm is controlled to insert the rod-shaped member through a trocar into a body cavity and to move back and forth and tilt the rod-shaped member with respect to the trocar. The medical manipulator can thus be appropriately moved with respect to the trocar.

**[0018]** The intermediate joint may include a first intermediate joint and a second intermediate joint which are successively arranged from the distal end of the rod-shaped member. The first intermediate joint may be disposed in a position within a range from 3 cm to 5 cm from the distal end of the rod-shaped member, and the second intermediate joint may be disposed in a position within a range from 7 cm to 12 cm from the distal end of the rod-shaped member. The rod-shaped member can thus be placed appropriately in the body cavity.

**[0019]** A medical robot system according to another aspect of the present invention includes a plurality of first robot arms supporting respective manipulators thereon, a second robot arm supporting an endoscope thereon, and a controller for controlling the first robot arms and the second robot arm, each of the manipulators including a rod-shaped member for insertion through a trocar into a body cavity, and a distal-end working unit mounted on a distal end of the rod-shaped member and having at least one joint, wherein at least one of the manipulators comprises a retractor and has at least one intermediate joint disposed in the rod-shaped member for bending the rod-shaped member.

**[0020]** The medical robot system allows the retractor to retract an organ or the like in a body cavity to a given region for thereby providing a wide operative field in the body cavity. As the rod-shaped member is bendable at the intermediate joint, the rod-shaped member can appropriately be positioned in the body cavity for providing a wider operative field in the body cavity. The rod-shaped member can thus avoid physical interference with other manipulators for performing a surgical procedure with ease.

**[0021]** The retractor may coact with one of the first robot arms connected thereto in a predetermined operation mode for moving the distal-end working unit back and forth while keeping a posture of the distal-end working unit constant, in a coordinate system based on the posture of the distal-end working unit. The retractor can thus easily be operated to retract the organ or the like in the body cavity.

**[0022]** The retractor may coact with one of the first robot arms connected thereto in a predetermined operation mode for bending the intermediate joint while keeping a position and a posture of the distal-end working unit constant. The intermediate joint can thus be bent appropriately with ease.

**[0023]** The medical robot system may further include rotary input means for moving the intermediate joint on a hypothetical sphere or a hypothetical arc around a predetermined reference point on the rod-shaped member, depending on the angular amount by which and the direction in which the rotary input means is angularly moved. The rotary input means allows the user to bend the intermediate joint appropriately with ease and intuitively.

**[0024]** The rotary input means may comprise a trackball for easy operation.

**[0025]** The medical robot system may further include a switch for selectively enabling and disabling the rotary input means. The switch prevents the intermediate joint from being operated carelessly.

**[0026]** A medical robot system according to another aspect of the present invention includes a plurality of first robot arms supporting respective manipulators thereon, a second robot arm supporting an endoscope thereon, and a controller for controlling the first robot arms and the second robot arm, the manipulators and the endoscope being inserted into a body cavity through a common trocar supporting member, wherein each of the manipulators includes a rod-shaped member for insertion through the trocar supporting member into the body cavity, a distal-end working unit mounted on a distal end of the rod-shaped member and having at least one joint, and at least one intermediate joint disposed in the rod-shaped member for bending the rod-shaped member.

**[0027]** With the above structure, when a surgical procedure is performed by single port access, the distal-end working units having the end effectors can be moved closer to each other by bending the rod-shaped members of the two manipulators which intersect with each other at the trocar supporting member, by means of the intermediate joints. Accordingly, for example, an operator can grip an affected region to be treated, with a gripper provided as an end effector at one distal-end working unit, while the operator can perform a procedure (incision etc.) on a portion around the region gripped by the gripper, with scissors provided as an end effector at another distal-end working unit. Additionally, the robot arms do not interfere with each other outside the body of the patient. Thus, a surgical procedure by single port access can be performed suitably.

**[0028]** At least one of the manipulators may serve as a retractor, and the rod-shaped member of the at least one manipulator serving as the retractor may include a plurality of the intermediate joints.

**[0029]** With the above structure, the manipulator serving as a retractor performs an operation (e.g., gripping) on an affected region with the end effector provided at the distal end thereof, while the manipulator pushes aside (retracts) the organ (obstacle to the operative field) with the rod-shaped member having a plurality of intermediate joints. In this manner, one manipulator doubles as a forceps and a retractor. As a result, a surgical procedure can be performed using a smaller number of manipulators. Also, the trocar for a retractor can be omitted, and thus a much less-invasive surgery can be achieved.

**[0030]** The medical robot system may further comprise a monitor for displaying an image captured with the endoscope, first input means which is operated by the left hand of an operator, and second input means which is operated by the right hand of the operator, wherein, when the rod-shaped members of two of the manipulators intersect with each other at the trocar supporting member, the manipulator that is located on the left side on a screen of the monitor is operated based on input operation by the first input means, and the manipulator that is located on the right side on the screen of the monitor is operated based on input operation by the second input means.

**[0031]** With the above structure, even if the manipulators are inserted into the body cavity with the rod-shaped members thereof intersecting with each other, the operator can operate the manipulators intuitively in a manner to fit the feeling of the operator, because operation by the left hand of the operator is reflected on the movement of the manipulator that is located on the left side on the screen, and operation by the right hand of the operator is reflected on the movement of the manipulator that is located on the right side on the screen.

**[0032]** The above and other objects, features, and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings in which preferred embodiments of the present invention are shown by way of illustrative example.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0033]** FIG. **1** is a perspective view of a medical robot system according to a first embodiment of the present invention;

**[0034]** FIG. **2** is a side elevational view, partly in cross section, of a manipulator according to the first embodiment of the present invention;

**[0035]** FIG. **3** is a plan view of a pulley and an arm;

**[0036]** FIG. **4** is an exploded perspective view of a first intermediate joint;

**[0037]** FIG. **5** is an exploded perspective view of a second intermediate joint;

**[0038]** FIG. **6** is a perspective view of a distal-end working unit;

**[0039]** FIG. **7** is a perspective view of a console;

**[0040]** FIG. **8** is a view illustrative of a tool coordinate operation mode;

[0041] FIG. **9** is a perspective view of a master arm;

[0042] FIG. **10** is a view illustrative of a bending motion of the first intermediate joint in an intermediate joint operation mode;

[0043] FIG. **11** is a view illustrative of a hypothetical hemisphere used as a reference for bending the first intermediate joint in the intermediate joint operation mode;

[0044] FIG. **12** is a view illustrative of a bending motion of the second intermediate joint according to a first control process in the intermediate joint operation mode;

[0045] FIG. **13** is a view illustrative of a bending motion of the second intermediate joint according to a second control process in the intermediate joint operation mode;

[0046] FIG. **14** is a perspective view showing the manner in which a gripper of the manipulator grips a large intestine;

[0047] FIG. **15** is a perspective view showing the manner in which the gripper of the manipulator retracts the large intestine;

[0048] FIG. **16** is a perspective view showing the manner in which the first intermediate joint is bent;

[0049] FIG. **17** is a perspective view showing the manner in which the second intermediate joint is bent;

[0050] FIG. **18** is a perspective view of a distal-end action unit having a fan-like mechanism;

[0051] FIG. **19** is a schematic view illustrative of a medical robot system according to a second embodiment of the present invention;

[0052] FIG. **20** is a schematic view illustrative of a medical robot system according to a third embodiment of the present invention; and

[0053] FIG. **21** is a schematic perspective view of a console of the medical robot system according to the third embodiment.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0054] Like or corresponding parts shall be denoted by like or corresponding reference characters throughout the views.

[0055] A medical manipulator and a medical robot system according to embodiments of the present invention will be described below with reference to FIGS. **1** through **21**.

[0056] As shown in FIG. **1**, a medical manipulator **10*c*** and a medical robot system **12** according to a first embodiment of the present invention are particularly suitable for performing a laparoscopic surgical operation on a patient **14**.

[0057] The medical robot system **12** comprises a station **16** disposed near a surgical bed **15**, four robot arms **18*a***, **18*b***, **18*c***, **18*d*** mounted on the station **16**, and a console (controller) **20** for controlling the medical robot system **12** in its entirety. The robot arm **18*c*** will also be referred to as a first robot arm, and the robot arm **18*d*** as a second robot arm. The robot arms **18*a*** through **18*d*** and the console **20** may be connected to each other by a communication means comprising a wired link, a wireless link, a network, or a combination thereof. The console **20** is not required to control the medical robot system **12** in its entirety, but the robot arms **18*a*** through **18*d*** may be feedback-controlled by internal controllers combined with the medical robot system **12**. The robot arms **18*a*** through **18*c*** may be actuated under the control of the console **20** for being operated according to automatic programmed operations or may be manually actuated by respective joysticks **80*a***, **80*b***, **80*c*** on the console **20**. The robot arms **18*a*** through **18*d*** also may be actuated through a combination of automatic programmed operations and manually controlled operations.

[0058] The robot arms **18*a*** through **18*c*** have manipulators **10*a***, **10*b***, **10*c*** disposed respectively on distal ends thereof. The robot arm **18*d*** has an endoscope **24** on the distal end thereof. The manipulators **10*a*** through **10*c*** and the endoscope **24** are inserted into a body cavity **27** of the patient **14** through respective trocars **25**. The station **16** may comprise a plurality of stations supporting the respective robot arms **18*a*** through **18*d***. The manipulators **10*a*** through **10*c*** and the endoscope **24** are removably mounted onto the respective robot arms **18*a*** through **18*d***.

[0059] Each of the robot arms **18*a*** through **18*d*** has an articulated mechanism, e.g., a mechanism with six independent axes. The robot arms **18*a*** through **18*d*** are controlled by the console **20**, so as to set the manipulators **10*a*** through **10*c*** and the endoscope **24** at arbitrary postures and at arbitrary positions, within the operating ranges of the robot arms **18*a*** through **18*d***. The robot arms **18*a*** through **18*c*** have respective joint mechanisms including rotary mechanisms **22** for rotating the manipulators **10*a*** through **10*c*** about respective joints shafts (rod-shaped members) **44**.

[0060] The robot arms **18*a*** through **18*d*** have respective slide mechanisms **26** for moving the manipulators **10*a*** through **10*c*** and the endoscope **24** back and forth along the axes defined by the distal ends thereof, and respective lifting and lowering mechanisms **28**, which are movable vertically along the station **16**. The robot arms **18*a*** through **18*d*** may be structurally identical to each other, or may have different structures depending on the types of manipulators **10*a*** through **10*c*** and the endoscope **24** that are utilized.

[0061] The manipulators **10*a***, **10*b*** mounted respectively on the robot arms **18*a***, **18*b*** serve to perform direct surgical techniques on an affected region of the patient **14**. A gripper, scissors, an electrosurgical knife, for example, are mounted onto distal-end working units of the manipulators **10*a***, **10*b***. The manipulator **10*c*** mounted on the robot arm **18*c*** comprises a retractor for retracting an organ in a body cavity **27** or the like to a given place to allow the surgeon to have a wider operative field.

[0062] Further structural details of the manipulator **10*c*** and a joint between the manipulator **10*c*** and the robot arm **18*c*** will be described below. As shown in FIGS. **2** through **6**, it is assumed that directions established with respect to the manipulator **10*c*** include X directions representing horizontal transverse directions of the manipulator **10*c***, Y directions representing vertical transverse directions of the manipulator **10*c***, and Z directions representing longitudinal directions of the manipulator **10*c***, i.e., a joint shaft (rod-shaped member) **44** thereof. The X directions include an X**1** direction representing a rightward direction as viewed from the front of the manipulator **10*c*** and an X**2** direction representing a leftward direction as viewed from the front of the manipulator **10*c***. The Y directions include a Y**1** direction representing an upward direction and a Y**2** direction representing a downward direction. The Z directions include a Z**1** direction representing a forward direction and a Z**2** direction representing a rearward direction.

[0063] As shown in FIG. **2**, the manipulator **10*c*** is removably mounted on a slider **40**, which is disposed on the distal end of the robot arm **18*c***. The slider **40** is slidable by the slide mechanism **26**. The slider **40** supports seven motors **30*a***, **30*b***, **30*c***, **30*d***, **30*e***, **30*f***, **30*g*** mounted therein in an array along the Z directions. The motors **30*a*** through **30*c*** (first actuator) serve to actuate a distal-end working unit **46**, and the motors

**30***d* through **30***g* (second actuator) serve to actuate a first intermediate joint **58** and a second intermediate joint **60**.

**[0064]** The manipulator **10***c* comprises a connecting block **42** for connection to the slider **40**, a hollow joint shaft **44** extending from the connecting block **42** in the Z**1** direction, and a distal-end working unit **46** mounted on the distal end of the joint shaft **44**.

**[0065]** The connecting block **42** is removably and replaceably mounted on the slider **40** by a removable mounting mechanism. The connecting block **42** supports pulleys **48***a*, **48***b*, **48***c*, **48***d*, **48***e*, **48***f*, **48***g* mounted thereon in an array along the Z directions and held in engagement with the respective motors **30***a* through **38***g*. The motors **30***a* through **30***g* or the pulleys **48***a* through **48***g* have noncircular teeth, while the pulleys **48***a* through **48***g* or the motors **30***a* through **30***g* have noncircular recesses. The noncircular teeth engage with the respective noncircular recesses for transmitting rotation of the motors **30***a* through **30***g* to the pulleys **48***a* through **48***g*.

**[0066]** Wires **50***a*, **50***b*, **50***c*, **50***d*, **50***e*, **50***f*, **50***g* are wound respectively around the pulleys **48***a* through **48***g*. The wires **50***a* through **50***c* (first flexible member) are annular in shape, wherein portions thereof are fixed to the pulleys **48***a* through **48***c* for preventing slippage on the pulleys **48***a* through **48***c*. The wires **50***a* through **50***c* are wound in 1.5 turns around the pulleys **48***a* through **48***c*, and extend in the Z**1** direction inside the joint shaft **44**. When the pulleys **48***a* through **48***c* are rotated about their own axes by the motors **30***a* through **30***c*, one of the two left and right turns of each of the wires **50***a* through **50***c* is wound around the pulley, and the other turn is paid out from the pulley. The wires **50***a* through **50***c* are spaced from each other in the Y directions so as to be held out of interference with each other.

**[0067]** The pulleys **48***e*, **48***g* have respective winding members **52** around which the wires **50***e*, **50***g* (second flexible member) are wound. The connecting block **42** houses therein pairs of idlers **54***a*, **54***b* for guiding the wires **50***e*, **50***g* from the winding members **52** to the joint shaft **44**. The idlers **54***a*, **54***b* in the pairs are disposed in obliquely upward and downward positions that are spaced from the winding members **52** of the pulleys **48***e*, **48***g* in directions between the Z**1** and Y**1** directions and between the Z**1** and Y**2** directions, for guiding the wires **50***e*, **50***g* to upper and lower positions above and below the central axis of the joint shaft **44**.

**[0068]** When the pulleys **48***e*, **48***g* are rotated about their own axes by the motors **30***e*, **30***g*, one of the two upper and lower turns of each of the wires **50***e*, **50***g* is wound around the pulley, and the other turn is paid out from the pulley.

**[0069]** As shown in FIG. **3**, the pulley **48***d* has an arm **56** extending in the X directions, and the wire **50***d* has opposite ends connected to the respective ends of the arm **56**. When the pulley **48***d* is rotated about its own axis by the motor **30***d*, one of the two left and right turns of the wire **50***d* is wound in, and the other turn is wound off. Although not shown, the pulley **48***f* and the wire **50***f* are of a structure identical to the pulley **48***d* and the wire **50***d*. As the wires **50***d*, **50***f* (second flexible member) are not wound around the pulleys **48***d*, **48***f*, the pulleys **48***d*, **48***f* do not operate as pulleys, but are referred to as pulleys for the sake of convenience.

**[0070]** As shown in FIG. **2**, the joint shaft **44** extends from the connecting block **42** in the Z**1** direction, and the distal-end working unit **46** is mounted on the distal end of the joint shaft **44**. The joint shaft **44** has a first intermediate joint **58** and a second intermediate joint **60** which are successively spaced from the distal end thereof. The first intermediate joint **58** and the second intermediate joint **60** are bent when the wires **50***d* through **50***g* are displaced back and forth in the joint shaft **44**. The first intermediate joint **58** may be located in any position (distance L**1** in FIG. **2**) within a range from 3 cm to 5 cm from the distal end of the joint shaft **44** including the distal-end working unit **46**. The second intermediate joint **60** may be located in any position (distance L**2** in FIG. **2**) within a range from 7 cm to 12 cm from the distal end of the joint shaft **44** including the distal-end working unit **46**. With the first intermediate joint **58** and the second intermediate joint **60** being thus positioned, the manipulator **10***c* suitably operates as a retractor in surgical techniques (see FIGS. **14** through **17**) inside the body cavity **27**.

**[0071]** As shown in FIG. **4**, the first intermediate joint **58** comprises a stacked array of joint rings **62** that are angularly movable with respect to each other. In FIG. **4**, the first intermediate joint **58** is shown as comprising three joint rings **62**. However, the number of joint rings **62** is not limited to three, and the first intermediate joint **58** may comprise a suitable number of joint rings **62**, e.g., 4 through 30 joint rings **62**.

**[0072]** Each of the joint rings **62** has a pair of V-shaped grooves **64** defined in one surface thereof in diametrically opposite relation to each other across the center of the joint ring **62**, and also has a pair of semicylindrical ridges **66** disposed on the other surface thereof in diametrically opposite relation to each other across the center of the joint ring **62**. The grooves **64** and the ridges **66** are angularly spaced 90° from each other. Adjacent two of the joint rings **62** are arranged such that their pairs of grooves **64** are angularly spaced 90° from each other, and are also joined to each other such that the ridges **66** of one of the joint rings **62** are inserted in the respective grooves **64** of the other joint ring **62**.

**[0073]** Each of the joint rings **62** has four through holes **67** defined therein at positions of the grooves **64** and the ridges **66**. The wires **50***d*, **50***e* extend respectively through the through holes **67** in the joint rings **62** and have respective tip ends coupled to the joint ring **62** at the distal end side of the first intermediate joint **58** in the Z**1** direction. The joint rings **62** are joined together into a substantially integral assembly.

**[0074]** With the ridges **66** being inserted in the respective grooves **64**, gaps are left between the adjacent ones of the joint rings **62**, allowing the ridges **66** to being angularly moved in the respective grooves **64**. Therefore, the adjacent ones of the joint rings **62** can be angularly moved with respect to each other. Although the joint rings **62** of each adjacent pair are angularly movable through a small angle with respect to each other, the sum of the angles through which the joint rings **62** of all adjacent pairs are angularly movable is large enough to allow the first intermediate joint **58** to be bent through a desired angle, for example, in the range from about 60° to 120°. Accordingly, the distal-end working unit **46** can be bent into an orientation not parallel to the longitudinal axis of the joint shaft **44**.

**[0075]** When the pulleys **48***d*, **48***e* are rotated a given angle about their own axes under the control of the console **20**, the wires **50***d*, **50***e* are displaced back and forth by the corresponding distance for thereby bending the first intermediate joint **58** through a desired angle vertically and horizontally in a plane transverse to the joint shaft **44**. In other words, the first intermediate joint **58** is bent or curved actively by being pulled by the wires **50***d*, **50***e*. The first intermediate joint **58** may be bent in desired directions and with a desired degree of freedom. Although not shown, the outer circumferential surface of each of the joint rings **62** may be covered with a layer made of an elastic or flexible material.

**[0076]** Each of the joint rings **62** has a central guide plate **70** having six guide holes **68** defined therein, through which the wires **50***a*, **50***b*, **50***c* extend. The six guide holes **68** are arranged in three pairs spaced apart in the Y directions, and are arrayed in two vertical rows spaced apart in the X directions. The six guide holes **68** are clustered near the central axis of the guide plate **70**. When the first intermediate joint **58** is not bent, the wires **50***a*, **50***b*, **50***c* extending through the guide holes **68** are not bent, but extend straight. Although the joint rings **62** are shown as having the respective guide plates **70**, at least one of the joint rings **62** may have a central guide plate **70**.

**[0077]** When the first intermediate joint **58** is bent, the wires **50***a* though **50***c* are guided through the guide holes **68** against being unduly displaced or bent, and are held out of contact with each other and remain in respective appropriate positions.

**[0078]** As shown in FIG. **5**, the second intermediate joint **60** is essentially identical in structure to the first intermediate joint **58**, and comprises a stacked array of joint rings **62** each having four additional through holes **72** defined respectively adjacent to the four through holes **67**. The wires **50***f*, **50***g* extend respectively through the through holes **67** in the joint rings **62**, and act in the same manner as the wires **50***d*, **50***e* in the first intermediate joint **58**, for actively bending or curving the second intermediate joint **60**. The wires **50***d*, **50***e* extend respectively through the through holes **72** and further extend toward the first intermediate joint **58** in the Z1 direction.

**[0079]** The first intermediate joint **58** and the second intermediate joint **60** are covered with respective bellows-like or flexible and bendable sheaths. The other portion of the joint shaft **44** than the first intermediate joint **58** and the second intermediate joint **60** is made of a hard material.

**[0080]** As shown in FIG. **6**, the distal-end working unit **46** is mounted on the distal end of the joint shaft **44**, and comprises at least a pulley (rotor) around which the wire **50***a* is wound, a pulley around which the wire **50***b* is wound, and a pulley around which the wire **50***c* is wound. When the wires **50***a*, **50***b*, **50***c* are moved back and forth upon rotation of the pulleys **48***a*, **48***b*, **48***c* in the connecting block **42**, the pulleys in the distal-end working unit **46** are driven to rotate, causing the distal-end working unit **46** to move about three axes. The motions of the distal-end working unit **46** include angular motions about a pitch axis (distal-end joint) **74** and a yaw axis (distal-end joint) **75** and opening and closing motions of a gripper **78**, for example. The gripper **78** comprises a pair of gripper arms, one or both of which are openable. The distal-end working unit **46** may be of the same mechanism as the distal-end working unit of the medical manipulator disclosed in Japanese Laid-Open Patent Publication No. 2003-061969, for example.

**[0081]** Since the first intermediate joint **58**, the second intermediate joint **60**, the pitch axis **74**, the yaw axis **75**, and the gripper **78** can possibly cause a mutual interference, the console **20** calculates an amount of interference and controls the wires **50***a* through **50***g* to move back and forth to compensate for an interfering movement. In other words, the console **20** controls the wires **50***a* through **50***g* such that when it moves one of the movable members, it prevents the other from unnecessarily moving due to such an interfering movement.

**[0082]** The manipulators **10***a*, **10***b* may be of a structure which is free from the first intermediate joint **58**, the second intermediate joint **60**, the motors **30***d* through **30***f*, the wires **50***d* through **50***f*, and the pulleys **48***d* through **48***f* of the manipulator **10***c*, and which is otherwise the same as the manipulator **10***c*. Alternatively, the manipulators **10***a*, **10***b* may be structurally identical to the manipulator **10***c*.

**[0083]** As shown in FIG. **7**, the console **20** has three joysticks **80***a*, **80***b*, **80***c* as manual control units, a display monitor **82** (see FIG. **1**), two trackballs (rotary input means) **84***a*, **84***b*, enable switches **86***a*, **86***b* for enabling or disabling input actions of the trackballs **84***a*, **84***b*, and return switches **88***a*, **88***b*. The display monitor **82** displays information about an endoscopic image captured by the endoscope **24** and other information. The trackballs **84***a*, **84***b* are spaced from each other at a central area on the upper surface of the control table of the console **20**. The return switches **88***a*, **88***b* are disposed behind the respective trackballs **84***a*, **84***b*. The enable switches **86***a*, **86***b* comprise arcuately-shaped momentary switches disposed around respectively partly circumferential surfaces of the trackballs **84***a*, **84***b*.

**[0084]** The operator can operate the joysticks **80***a*, **80***b*, **80***c* to move the robot arms **18***a*, **18***b*, **18***c* individually. The robot arm **18***d* can be operated by another input means, not shown. The joysticks **80***a*, **80***b* are positioned at respective left and right positions where they can easily be operated by the operator. The joystick **80***c* is positioned in a central position behind the joysticks **80***a*, **80***b*.

**[0085]** The joysticks **80***a*, **80***b*, **80***c* are vertically movable, twistable, and tiltable in all directions for moving the robot arms **18***a*, **18***b*, **18***c* according to the joystick motions. When the joysticks **80***a*, **80***b*, **80***c* are released from the hands of the operator, they automatically return to their upright reference orientations shown in FIG. **7** with the robot arms **18***a*, **18***b*, **18***c* being kept in their displaced positions. The joysticks **80***a*, **80***b*, **80***c* are basically identical in structure to each other, and have a handle grip **100** which is gripped by a human hand, a trigger lever **102** which is pushed and pulled mainly by an index finger and a middle finger, and a composite input pad **104** which is gripped mainly by a thumb. When the trigger lever **102** is operated, the gripper **78** is opened and closed. The composite input pad **104** includes horizontal and vertical see-saw switches **104***a*, **104***b* disposed centrally thereof in a crisscross pattern. When the horizontal see-saw switch **104***a* is operated, the distal-end working unit **46** is tilted about the yaw axis **75**, and when the vertical see-saw switch **104***b* is operated, the distal-end working unit **46** is tilted about the pitch axis **74**.

**[0086]** The robot arms **18***a*, **18***b*, **18***c* can be operated in an absolute coordinate (world coordinate) operation mode and a tool coordinate operation mode, for example.

**[0087]** In the absolute coordinate operation mode, the manipulator **10***c* coacts with the robot arm **18***c* (including the slide mechanism **26**) connected thereto based on an input action of the joystick **80***c*. At this time, the position of the distal-end working unit **46** is set based on absolute coordinates depending on the movement of the handle grip **100**, and the orientation of the distal-end working unit **46** is set based on input actions of the see-saw switches **104***a*, **104***b*.

**[0088]** In the tool coordinate operation mode, the manipulator **10***c* coacts with the robot arm **18***c* (including the slide mechanism **26**) connected thereto based on an input action of the joystick **80***c*, for moving the distal-end working unit **46**

back and forth in a constant posture based on a tool coordinate system according to the posture of the distal-end working unit **46**.

**[0089]** For example, as shown in FIG. **8**, according to the posture of the distal-end working unit **46** at the time, a tool coordinate system having orthogonal axes $Zt_0$, $Xt_0$, $Yt_0$ (the axis $Yt_0$ is omitted from illustration) is established, and the distal-end working unit **46** is operated based on the established tool coordinate system. The distal-end working unit **46** is moved from an imaginary-line position to a solid-line position while the gripper **78** is extending along the coordinate axis $Zt_0$. At this time, the position of a hypothetical reference point P**1** at the trocar **25** (pivot point) and the posture of the distal-end working unit **46** are kept constant.

**[0090]** The joysticks **80***a*, **80***b*, **80***c* may be replaced with a master arm **200** shown in FIG. **9**.

**[0091]** As shown in FIG. **9**, the master arm **200** comprises a pivot shaft **202**, a first U-shaped member **204**, a second U-shaped member **206**, and a pair of tongue members **208**. The first U-shaped member **204** is open upwardly and rotatably mounted on the upper end of the pivot shaft **202** for rotation in a horizontal plane. The angle through which the first U-shaped member **204** is rotated with respect to the pivot shaft **202** is detected by a rotation sensor **210** and reflected in the motion of the distal-end working unit **46** about the yaw axis **75**.

**[0092]** The second U-shaped member **206** is smaller in size than the first U-shaped member **204**, and is disposed in the first U-shaped member **204**. The first U-shaped member **204** and the second U-shaped member **206** have their ends rotatably connected to each other. The second U-shaped member **206** is rotatable in a vertical plane with respect to the first U-shaped member **204**. The angle through which the second U-shaped member **206** is rotated with respect to the first U-shaped member **204** is detected by a rotation sensor **212** and reflected in the motion of the distal-end working unit **46** about the pitch axis **74**.

**[0093]** The tongue members **208** are rotatably mounted on an intermediate portion of the second U-shaped member **206** by a shaft **214**. The angle through which the shaft **214** is rotated with respect to the second U-shaped member **206** is detected by a rotation sensor **216** and reflected in the operation of the rotary mechanisms **22** (see FIG. **1**).

**[0094]** The tongue members **208** are openable and closable with respect to, i.e., movable toward and away from, each other about the shaft **214**. The angle through which the tongue members **208** are opened or closed with respect to each other is detected by an internal sensor **218** and reflected in the opening and closing motion of the gripper **78**.

**[0095]** The master arm **200** is displaceable as a whole in the X, Y, and Z directions shown in FIG. **9**. The positions of the master arm **200** in the X, Y, and Z directions with respect to the console **20** can be detected by a sensor, not shown. The master arm **200** may be tilted in the X and Y directions with respect to the console **20** by tilting mechanisms. The detected position of the master arm **200** in the X, Y, and Z directions with respect to the console **20** are reflected in the absolute coordinates of the distal-end working unit **46**. The master arm **200** is thus capable of indicating six parameters with respect to the position and orientation of the distal-end working unit **46**, and also of instructing the gripper **78** to be opened and closed.

**[0096]** When the master arm **200** is released from the operator's hands, the master arm **200** may be returned to its home position shown in FIG. **9** under the bias of resilient members, not shown, with the robot arms **18***a*, **18***b*, **18***c* being kept in their displaced positions.

**[0097]** In the tool coordinate operation mode, the distal-end working unit **46** may be moved along another coordinate axis Zt or in directions along the coordinate axis Zt or in a combination of those directions. In the tool coordinate operation mode, when the master arm **200** is operated, the directions in which the distal-end working unit **46** moves laterally, i.e., the X directions in FIG. **9**, correspond to a coordinate axis Xt, the directions in which the distal-end working unit **46** moves back and forth, i.e., the Y directions in FIG. **9**, correspond to a coordinate axis Yt, and the directions in which the distal-end working unit **46** moves vertically, i.e., in the Z directions in FIG. **9**, correspond to a coordinate axis Zt.

**[0098]** In the tool coordinate operation mode, the posture of the robot arm **18***c* may be determined by setting the position and posture of the distal-end working unit **46**, defining the position of the hypothetical reference point P**1**, and performing known matrix transform calculations. The distal-end working unit **46** may also be operated in the tool coordinate operation mode with the joystick **80***c* or the master arm **200**.

**[0099]** In the tool coordinate operation mode, the distal-end working unit **46** can easily be operated to retract an organ in the body cavity **27**.

**[0100]** The trackball **84***a* serves as an input means for operating the first intermediate joint **58** of the manipulator **10***c*.

**[0101]** Based on an input action of the trackball **84***a* in an intermediate joint operation mode, the manipulator **10***c* coacts with the robot arm **18***c* (including the slide mechanism **26**) connected thereto to bend the first intermediate joint **58** with the distal-end working unit **46** being kept in constant position and posture.

**[0102]** For example, as shown in FIG. **10**, there is assumed a sphere (hypothetical spherical surface) **110** defined around the position P**2** of the distal-end joint (the pitch axis **74** and the yaw axis **75**) of the distal-end working unit **46** at the time, the sphere **110** having a radius equal to the distance r**1** from the position P**2** to the first intermediate joint **58**, and the first intermediate joint **58** (indicated by a point P**3** in FIGS. **10** and **11**) is moved along the surface of the sphere **110** from an imaginary-line position to a solid-line position. At this time, the position of the hypothetical reference point P**1** at the trocar **25** and the position and posture of the distal-end working unit **46** are kept constant.

**[0103]** If the first intermediate joint **58** can be bent either vertically or laterally only, then the first intermediate joint **58** may be moved along a given hypothetical arc instead of the sphere **110**.

**[0104]** In the intermediate joint operation mode, as shown in FIG. **11**, orthogonal coordinate axes Xp, Yp extending across the first intermediate joint **58** along the sphere **110** are established based on the orientation of the distal-end working unit **46** or the orientation of the overall manipulator **10***c* at the time. At this time, when the trackball **84***a* is operated, the directions in which it is angularly moved laterally correspond to the coordinate axis Xp, and the directions in which it is angularly moved back and forth correspond to the coordinate axis Yp. The first intermediate joint **58** is also bendable in all directions other than the coordinate axes Xp, Yp. When the trackball **84***a* is angularly moved in a given direction, the first intermediate joint **58** is bent depending on the direction in which the trackball **84***a* is angularly moved and the angular amount by which the trackball **84***a* is angularly moved. When the trackball **84***a* is stopped, the first intermediate joint **58**

stops being bent. When the first intermediate joint **58** reaches a limit of its bending range in a given direction, a bending command for bending the first intermediate joint **58** further in that direction is disabled.

**[0105]** In the intermediate joint operation mode, another rotary input means may be employed rather than the trackball **84***a*. For example, the joystick **80***c* may be employed such that the directions in which it is tilted laterally correspond to the coordinate axis Xp and the directions in which it is tilted back and forth correspond to the coordinate axis Yp.

**[0106]** In the intermediate joint operation mode, the posture of the robot arm **18***c* may be determined by setting the position and posture of the distal-end working unit **46**, defining the positions of the hypothetical reference point P**1** and the first intermediate joint **58**, and performing known matrix transform calculations.

**[0107]** For operating the first intermediate joint **58**, the enable switch **86***a* is pressed to enable the trackball **84***a*. If the enable switch **86***a* is not pressed, then the trackball **84***a* remains disabled, and the first intermediate joint **58** is prevented from being moved when the trackball **84***a* is operated carelessly.

**[0108]** When the return switch **88***a* is pressed, the first intermediate joint **58** automatically returns to a zero-bend-angle state (see FIG. **2**) at a predetermined speed. With the first intermediate joint **58** in the zero-bend-angle state, the joint shaft **44** can easily be pulled out of the trocar **25**. The return switch **88***a* is a momentary switch which is enabled only when it is pressed. When the return switch **88***a* is released, the returning motion of the first intermediate joint **58** is interrupted, allowing the operator to confirm the state of the first intermediate joint **58**.

**[0109]** In the intermediate joint operation mode, the second intermediate joint **60** can also be bent by the trackball **84***b*, the enable switch **86***b*, and the return switch **88***b*. The trackball **84***b*, the enable switch **86***b*, and the return switch **88***b* operate in the same manner as the trackball **84***a*, the enable switch **86***a*, and the return switch **88***a*.

**[0110]** The second intermediate joint **60** can be controlled according to a plurality of control processes, which can be selected. According to a first control process, as shown in FIG. **12**, there is assumed a sphere **112** around the first intermediate joint **58**, the sphere **112** having a radius equal to the distance r**2** from the first intermediate joint **58** to the second intermediate joint **60**, and the second intermediate joint **60** is moved along the surface of the sphere **112** from an imaginary-line position to a solid-line position. At this time, the position of the hypothetical reference point P**1** at the trocar **25**, the position and posture of the distal-end working unit **46**, and the position and posture of a link **114** extending from the point P**2** to the first intermediate joint **58** are kept constant. According to the first control process, the first intermediate joint **58** is also bent in coaction with the second intermediate joint **60** as it is bent.

**[0111]** According to a second control process, as shown in FIG. **13**, there is assumed a sphere **116** defined around the position P**2** of the distal-end joint (the pitch axis **74** and the yaw axis **75**) of the distal-end working unit **46** at the time, the sphere **116** having a radius equal to the distance r**3** from the position P**2** to the second intermediate joint **60**, and the second intermediate joint **60** is moved along the surface of the sphere **116** from an imaginary-line position to a solid-line position. At this time, the position of the hypothetical reference point P**1** at the trocar **25** and the position and posture of the distal-end working unit **46** are kept constant. According to the second control process, the first intermediate joint **58** remains bent.

**[0112]** The first intermediate joint **58** and the second intermediate joint **60** may automatically be moved according to a program or a teaching process, rather than being controlled based on the operation of the trackballs **84***a*, **84***b*.

**[0113]** Operation of the manipulator **10***c* and the medical robot system **12** thus constructed will be described below.

**[0114]** First, a gas is introduced around the affected region of the patient to form the body cavity **27**, and the distal-end working units **46** and the joint shaft **44** of the manipulator **10***c* are inserted through the trocar **25**. The state in the body cavity **27** is confirmed based on an endoscopic image captured by the endoscope **24** that has been inserted into the body cavity **27**.

**[0115]** Prior to a surgical technique to be performed on an affected region **118**, other organs that exist around the affected region **118** are retracted to given regions to provide a wide operative field in the body cavity **27**.

**[0116]** For example, as shown in FIG. **14**, for retracting a large intestine **120**, the distal-end working unit **46** is bent around the pitch axis **74** and the yaw axis **75** into an orientation substantially perpendicularly to an appropriate portion of the large intestine **120**. Thereafter, the gripper **78** grips the large intestine **120** lightly.

**[0117]** Then, as shown in FIG. **15**, the distal-end working unit **46** is moved forward to retract the large intestine **120** to a deeper region. At this time, in order to keep the distal-end working unit **46** and the gripped portion of the large intestine **120** oriented relatively to each other, the distal-end working unit **46** may be pushed in the direction of a coordinate axis Zt**1** in the tool coordinate operation mode (see FIG. **8**).

**[0118]** By thus retracting the large intestine **120**, the large intestine **120** is sufficiently spaced from the affected region **118**, allowing the surgeon to perform a surgical operation on the affected region **118**. The manipulator **10***c* thus acts as a retractor. In some instances, even when the large intestine **120** is retracted away from the affected region **118** by the manipulator **10***c*, the manipulator **10***c* may be positioned across the body cavity **27**, failing to provide a wide operative field in the body cavity **27**.

**[0119]** To avoid the above difficulty, at least one of the first intermediate joint **58** and the second intermediate joint **60** of the manipulator **10***c* is bent.

**[0120]** For example, as shown in FIG. **16**, in the intermediate joint operation mode, the first intermediate joint **58** is bent to make the link **114** substantially parallel to the large intestine **120**. Thus, the joint shaft **44** is spaced from the affected region **118**, providing a wide operative field **122** around the affected region **118**. The surgeon finds it easy to perform a surgical procedure on the affected region **118** with the other manipulators **10***a*, **10***b*. As a result, the time required to perform the surgical operation may be shortened.

**[0121]** Although the wide operative field **122** is provided simply by bending the first intermediate joint **58**, the second intermediate joint **60** may instead be bent to provide a wider operative field **124**, as shown in FIG. **17**. For bending the second intermediate joint **60**, one or both of the first control process (see FIG. **12**) and the second control process (see FIG. **13**) may be carried out.

**[0122]** In this case, it is assumed that the distal-end working unit **46** has an axis S**1**, the link **114** has an axis S**2**, and a link **129** extending from the first intermediate joint **58** to the second intermediate joint **60** has an axis S3. The second intermediate joint **60** may be bent such that the axes S2, S3 are held in alignment with each other.

**[0123]** For retracting the large intestine **120**, it may not be gripped by the gripper **78**, but may be engaged and pushed by a distal-end action unit **130** (see FIG. **18**) having a folding-fan-like mechanism. The distal-end action unit **130** may comprise a membrane extending between two openable gripper arms. Since the distal-end action unit **130** does not grip the large intestine **120**, it is less detrimental to the large intestine **120**. When the distal-end action unit **130** is folded by closing the openable gripper arms, it can easily be inserted through the trocar **25**.

**[0124]** With the manipulator **10***c* according to the present embodiment, the gripper **78** can be adjusted in orientation about the pitch axis **74** and the yaw axis **75** of the distal-end joint for performing an appropriate surgical procedure on the affected region. If the manipulator **10***c* is used as a retractor, then the gripper **78** can appropriately be oriented to an organ such as the large intestine **120**. Furthermore, since the joint shaft **44** of the manipulator **10***c* can be bent at the first intermediate joint **58** and the second intermediate joint **60**, the joint shaft **44** can be appropriately placed around the affected region to provide a wide operative field in the body cavity **27**. Particularly, the bendable joint shaft **44** is preferable to avoid physical interference with the other manipulators **10***a*, **10***b* in the body cavity **27**.

**[0125]** The manipulator **10***c* is connected to the robot arm **18***c*, and the robot arm **18***c* coacts with the manipulator **10***c* to move the manipulator **10***c* back and forth and tilt the manipulator **10***c* with respect to the reference point P1 at the trocar **25** for achieving appropriate manipulator motions.

**[0126]** With the medical robot system **12** according to the present embodiment, the manipulator **10***c* is used to retract an organ or organs in the body cavity **27** to a given region to provide a wide operative field in the body cavity **27**. Inasmuch as the joint shaft **44** is bendable at the first intermediate joint **58** and the second intermediate joint **60**, the joint shaft **44** can appropriately be positioned in the body cavity **27** to provide a wider operative field in the body cavity **27** and also to avoid physical interference with the other manipulators **10***a*, **10***b* for allowing the surgeon to perform a surgical procedure with ease.

**[0127]** The first intermediate joint **58** and the second intermediate joint **60** are movable on a hypothetical sphere or a hypothetical arc around a given reference point depending on the angular amount by which and the direction in which the trackballs **84***a*, **84***b* are angularly moved. The trackballs **84***a*, **84***b* allow the operator to bend the first intermediate joint **58** and the second intermediate joint **60** appropriately with ease and also intuitively in a manner to fit the feeling of the operator.

**[0128]** FIG. **19** is a schematic view illustrative of a medical robot system according to a second embodiment of the present invention. FIG. **19** shows manipulators **10***d*, **10***e* and an endoscope **24**, which are constituent elements of the medical robot system.

**[0129]** The medical robot system according to the second embodiment differs from the medical robot system **10** according to the first embodiment in that the manipulator **10***d* having a different structure from the manipulator **10***a* is provided at the distal end of the robot arm **18***a* and the manipulator **10***e* having a different structure from the manipulator **10***b* is provided at the distal end of the robot arm **18***b*.

**[0130]** A rod-shaped member **44**d of the manipulator **10***d* has an intermediate joint **60***d* in an intermediate portion thereof, and a rod-shaped member **44**e of the manipulator **10***e* has an intermediate joint **60***e* in an intermediate portion thereof. The intermediate joints **60***d*, **60***e* have the same structure as the first intermediate joint **58** shown in FIGS. **2** and **4**. More specifically, the manipulators **10***d*, **10***e* have such a structure that the second intermediate joint **60** is eliminated from the manipulator **10** shown in FIG. **2**. In the structure shown in FIG. **19**, an end effector provided at the distal end of the manipulator **10***d* is configured as scissors **79**, and an end effector provided at the distal end of the manipulator **10***e* is configured as a gripper **78**.

**[0131]** The manipulators **10***d*, **10***e* can be operated using operation input means shown in FIG. **7**. More specifically, an operator operates joysticks (first and second input means) **80***a*, **80***b* to move and open/close distal-end working units **76***d*, **76***e* of the manipulators **10***d*, **10***e* and change the posture thereof. Further, the operator can operate trackballs **84***a*, **84***b* to move the intermediate joints **60***d*, **60***e*. Incidentally, the trackballs **84***a*, **84***b* may be omitted. In this case, a switch may be provided to select an object(s) to be operated, and the operator may operate the joysticks **80***a*, **80***b* to move the intermediate joints **60***d*, **60***e*.

**[0132]** As shown in FIG. **19**, the manipulators **10***d*, **10***e* and the endoscope **24** are inserted into a body cavity **27** of a patient **14** through a common trocar supporting member **125**. The operator captures images of an affected region and its peripheral portions with the endoscope **24**, while performs a given surgical procedure on the affected region with the end effectors (gripper **78** and scissors **79**) provided at the distal end of the manipulators **10***d*, **10***e*. That is, the medical robot system according to the second embodiment enables the operator to perform a surgical procedure by single port access.

**[0133]** More specifically, the trocar supporting member **125** has a plurality of holes (three holes in the present embodiment), into which the trocars **25***a* to **25***c* are hermetically inserted, respectively. The trocars **25***a*, **25***b* are adapted for the manipulators **10***d*, **10***e*, whereas the trocar **25***c* is adapted for the endoscope **24**. If the outer diameter of the rod-shaped members **44***d*, **44***e* of the manipulators **10***d*, **10***e* has the same size as the inner diameter of the endoscope **24**, the trocars **25***a*, **25***b* and the trocar **25***c* may have the same structure.

**[0134]** A laparoscopic surgical operation process is performed using the medical robot system according to the second embodiment by single port access in the following manner.

**[0135]** First, the trocar supporting member **125** is inserted into the patient **14**. Next, the trocars **25***a*, **25***b* for the manipulators **10***d*, **10***e* and the trocar **25***c* for the endoscope **24** are inserted into the trocar supporting member **125**. Then, the two manipulators **10***d*, **10***e* and the endoscope **24** are inserted into the body cavity **27** of the patient **14** through the trocars **25***a*, **25***b*, **25***c*, respectively. In this case, as shown in FIG. **19**, the rod-shaped members **44***d*, **44***e* of the manipulators **10***d*, **10***e* are straightened, and then they are inserted such that the rod-shaped members **44***d*, **44***e* intersect with each other.

**[0136]** After the rod-shaped members **44***d*, **44***e* are inserted to a certain extent, the intermediate joints **60***d*, **60***e* are bent in such a direction that the end effectors (gripper **78** and scissors **79**) approach each other. Next, an observing point of the endoscope **24** is secured in order that images of a portion to be treated and the distal-end working units **76***d*, **76***e* can be captured with the endoscope **24**. Then, the operator performs a given surgical procedure on the portion to be treated, with the end effectors. In a surgical example shown in FIG. **19**, a tissue **121** within the body cavity **27** is gripped with the gripper **78**, while a membranous tissue **140** near the tissue **121** is cut out with the scissors **79**.

**[0137]** With the medical robot system according to the second embodiment, when a surgical procedure is performed by single port access, the distal-end working units **76** having the end effectors can be moved closer to each other by bending the rod-shaped members **44***d*, **44***e* of the two manipulators **10***d*, **10***e* which intersect with each other at the trocar supporting member **125**, by means of the intermediate joints **60***d*, **60***e*. Thus, a surgical procedure by single port access can be performed suitably.

**[0138]** As shown in FIG. **19**, when the rod-shaped members **44***d*, **44***e* of the manipulators **10***d*, **10***e* intersect with each other, the proximal end portion of the manipulator **10***d* is located on the left side, while the proximal end portion of the manipulator **10***e* is located on the right side. Accordingly, the positional relation of the proximal end portions is opposite to the positional relation of the distal-end working units **76***d*, **76***e*. For easier understanding, the field of view of the endoscope **24** (image captured with the endoscope **24**), i.e., the area that is displayed on the screen of the monitor **82** (see FIG. **1**), is represented by reference character A. As described above, the proximal end of the manipulator **10***d* is located on the left side whereas the distal-end working unit **76***d* of the manipulator **10***d* is located on the right side on the screen of the monitor **82**. Similarly, the proximal end of the manipulator **10***e* is located on the right side whereas the distal-end working unit **76***e* of the manipulator **10***e* is located on the left side on the screen of the monitor **82**.

**[0139]** If the left joystick **80***a* in FIG. **7** always serves to operate the left manipulator **10***d* and the right joystick **80***b* always serves to operate the right manipulator **10***e*, an operator has to operate the joysticks **80***a*, **80***b* while imagining a positional relation that is left-and-right reverse to the positional relation of the distal-end working units **76***d*, **76***e* on the screen. Accordingly, the operator can not operate the manipulators intuitively.

**[0140]** Thus, when the manipulators **10***d*, **10***e* are inserted into the body cavity **27** such that the rod-shaped members **44***d*, **44***e* intersect with each other, the console **20** (see FIG. **1**) may control operation of the manipulators **10***d*, **10***e* in a left-and-right reverse operation mode to be described below. In the left-and-right reverse operation mode, the console **20** operates the manipulator **10***e* whose distal-end working unit **76***e* is located on the left side on the screen of the monitor **82**, based on input operation of the left joystick **80***a*, while the console **20** operates the manipulator **10***d* whose distal-end working unit **76***d* is located on the right side on the screen of the monitor **82**, based on input operation of the right joystick **80***b*.

**[0141]** By setting the left-and-right reverse operation mode, even if the manipulators **10***d*, **10***e* are inserted into the body cavity **27** with the rod-shaped members **44***d*, **44***e* intersecting with each other, the operator can operate the manipulators intuitively in a manner to fit the feeling of the operator, because operation by the left hand of the operator is reflected on the movement of the manipulator **10***e* whose distal-end working unit **76***e* is located on the left side on the screen, and operation by the right hand of the operator is reflected on the movement of the manipulator **10***d* whose distal-end working unit **76***d* is located on the right side on the screen.

**[0142]** In this case, a switch may be provided onto the console **20**, for enabling/disabling the left-and-right reverse operation mode, and the operator may manually operate the switch to cause the console to control operation of the manipulators in the left-and-right reverse operation mode.

**[0143]** Alternatively, the console **20** may determine whether the rod-shaped members **44***d*, **44***e* intersect with each other or not, based on the positional coordinates of the manipulators **10***d*, **10***e*, and when the console **20** determines that the rod-shaped members **44***d*, **44***e* intersect with each other, the console **20** may automatically set the left-and-right reverse operation mode. In this case, the operator does not need to determine by oneself whether the rod-shaped members **44***d*, **44***e* intersect with each other or not, and burden on the operator is thus reduced.

**[0144]** FIG. **20** is a schematic view illustrative of a medical robot system according to a third embodiment of the present invention. FIG. **20** shows manipulators **10***c*, **10***d* and an endoscope **24**, which are constituent elements of the medical robot system.

**[0145]** The medical robot system according to the third embodiment is a medical robot system in which the manipulator **10***c* (see FIG. **2**) of the medical robot according to the first embodiment, instead of the manipulator **10***e*, is applied to the medical robot system according to the second embodiment. The manipulator **10***d* that is provided at the distal end of the robot arm **18***a* has the same structure as the manipulator **10***d* according to the second embodiment.

**[0146]** As described above, the manipulator **10***c* has the first intermediate joint **58** and the second intermediate joint **60**, and accordingly the rod-shaped member **44** can be bent at two points. Thus, the manipulator **10***c* has greater flexibility to its possible shape, compared to the manipulator **10***e* (see FIG. **19**). The trocar supporting member **125** and the trocars **25***a* to **25***c* have the same structures as the trocar supporting member **125** and the trocars **25***a* to **25***c* shown in FIG. **19**, respectively.

**[0147]** The manipulators **10***c*, **10***d* can be operated by means of operation input means **21** of a console **20***a* shown in FIG. **21**. The console **20***a* having the operation input means **21** differs from the console **20** shown in FIG. **7** in that the console **20***a* further comprises two trackballs **84***c*, **84***d* and two enable switches **86***c*, **86***d*. More specifically, an operator can operate the joysticks **80***a*, **80***b* to move and open/close distal-end working units **76**, **76***d* of the manipulators **10***c*, **10***d* and change the posture thereof, and also operate the trackballs **84***a* to **84***d* to actuate the intermediate joint **60***d*, the first intermediate joint **58** and the second intermediate joint **60**.

**[0148]** The console **20***a* can execute the left-and-right reverse operation mode, as with the console **20** according to the second embodiment. Accordingly, when the manipulators **10***c*, **10***d* intersect with each other, the manipulator **10***c* whose distal-end working unit **76** is located on the left side is operated based on input operation by the left joystick **80***a*, and the manipulator **10***d* whose distal-end working unit **76***d* is located on the right side is operated based on input operation by the right joystick **80***b*. In this case, one (e.g., trackball **84***a* at the back) of the two left trackballs **84***a*, **84***c* serves to operate the first intermediate joint **58**, while the other trackball (e.g., trackball **84***c* at the front) serves to operate the second intermediate joint **60**. Further, one of the two right trackballs **84***b*, **84***d* serves to operate the intermediate joint **60***d*.

**[0149]** When the manipulators **10***c*, **10***d* do not intersect with each other, the manipulator **10***d* is operated based on input operation by the left joystick **80***a*, while the manipulator **10***c* is operated based on input operation by the right joystick **80***b*. In this case, one of the two left trackballs **84***a*, **84***c* serves to operate the intermediate joint **60***d*. Also, one (e.g., trackball **84***b* at the back) of the two right trackballs **84***b*, **84***d* serves to operate the first intermediate joint **58**, and the other trackball (e.g., trackball **84***d* at the front) serves to operate the second intermediate joint **60**.

**[0150]** Incidentally, as with the operation input means of the console **20** shown in FIG. **7**, the trackballs **84***a*, **84***b* may be provided on the left side and on the right side, respectively. In this case, a switch may be provided to select an object to be operated based on input operation by each of the trackballs **84***a*, **84***b*. For example, the switch may be configured such that the operator can switch between one mode where operation by the trackball **84***a* (or the trackball **84***b*) is reflected on the movement of the intermediate joint **60***d* and anther mode where operations by the trackballs **84***a*, **84***b* are reflected on the movements of the first and second intermediate joints **58**, **60**, respectively.

**[0151]** A laparoscopic surgical operation process is performed using the medical robot system according to the third embodiment by single port access in the following manner. First, the trocar supporting member **125** is inserted into the patient **14**. Next, the trocars **25***a*, **25***b* for the manipulators **10***c*, **10***d* and the trocar **25***c* for the endoscope **24** are inserted into the trocar supporting member **125**. Then, the two manipulators **10***c*, **10***d* and the endoscope **24** are inserted into the body cavity **27** of the patient **14** through the trocars **25***a*, **25***b*, **25***c*, respectively. In this case, as shown in FIG. **20**, the rod-shaped members **44**, **44***d* of the manipulators **10***c*, **10***d* are straightened, and then they are inserted such that the rod-shaped members **44**, **44***d* intersect with each other.

**[0152]** After the rod-shaped members **44**, **44***d* are inserted to a certain extent, the first and second intermediate joints **58**, **60** of the manipulator **10***c* are bent, so that an organ **142** (obstacle to an operative field) is pushed aside (retracted) with the rod-shaped member **44** (link **114** in FIG. **20**) for a wider operative field. After the wider operative field has been thus secured, the intermediate joint **60***d* of the rod-shaped member **44***d* are bent and the first and second intermediate joints **58**, **60** are further bent so as to move the end effectors closer to each other.

**[0153]** Next, an observing point of the endoscope **24** is secured in order that images of a portion to be treated and the distal-end working units **76**, **76***d* can be captured with the endoscope **24**. Then, the operator performs a given surgical procedure on the portion to be treated, with the end effectors. In a surgical example shown in FIG. **20**, a tissue **121** within the body cavity **27** is gripped with the gripper **78**, while a membranous tissue **140** near the tissue **121** is cut out with the scissors **79**.

**[0154]** With the medical robot system according to the third embodiment, the distal-end working units **76**, **76***d* having the end effectors can be moved closer to each other by operation of the intermediate joint **60***d* and the first and second intermediate joints **58**, **60**. Thus, in the third embodiment, a surgical procedure can be performed suitably by single port access, as in the second embodiment.

**[0155]** Also, with the third embodiment, the manipulator **10***c* serving as a retractor performs an operation (e.g., gripping) on an affected region with the end effector provided at the distal end thereof, while the manipulator **10***c* pushes aside the organ **142** (obstacle to the operative field) with the rod-shaped member **44** having a plurality of intermediate joints. In this manner, one manipulator **10***c* doubles as a forceps and a retractor. As a result, a surgical procedure can be performed using a smaller number of manipulators. Also, the trocar for a retractor can be omitted, and thus a much less-invasive surgery can be achieved.

**[0156]** Although certain preferred embodiments of the present invention have been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.

What is claimed is:

**1**. A medical manipulator comprising:

a rod-shaped member housing therein a first flexible member actuatable by a first actuator and a second flexible member actuatable by a second actuator, said rod-shaped member being flexible at least partly;

at least one distal-end joint disposed on a distal end of said rod-shaped member, said distal-end joint being angularly movable by a rotor around which said first flexible member is wound; and

at least one intermediate joint disposed on said rod-shaped member more closely to a proximal end thereof than said distal-end joint, said intermediate joint being bendable in response to back-and-forth movement of said second flexible member.

**2**. A medical manipulator according to claim **1**, wherein said rod-shaped member includes at least one guide plate having a hole defined therein through which said first flexible member extends.

**3**. A medical manipulator according to claim **1**, which is connected to a robot arm, wherein said robot arm is controlled to insert said rod-shaped member through a trocar into a body cavity and to move back and forth and tilt said rod-shaped member with respect to said trocar.

**4**. A medical manipulator according to claim **1**, wherein said intermediate joint includes a first intermediate joint and a second intermediate joint which are successively arranged from the distal end of said rod-shaped member;

said first intermediate joint is disposed in a position within a range from 3 cm to 5 cm from the distal end of said rod-shaped member; and

said second intermediate joint is disposed in a position within a range from 7 cm to 15 cm from the distal end of said rod-shaped member.

**5**. A medical robot system comprising:

a plurality of first robot arms supporting respective manipulators thereon;

a second robot arm supporting an endoscope thereon; and

a controller for controlling said first robot arms and said second robot arm;

each of said manipulators including a rod-shaped member for insertion through a trocar into a body cavity, and a distal-end working unit mounted on a distal end of said rod-shaped member and having at least one joint;

wherein at least one of said manipulators comprises a retractor and has at least one intermediate joint disposed in said rod-shaped member for bending said rod-shaped member.

**6**. A medical robot system according to claim **5**, wherein said retractor coacts with one of said first robot arms connected thereto in a predetermined operation mode for moving said distal-end working unit back and forth while keeping a posture of the distal-end working unit constant, in a coordinate system based on the posture of said distal-end working unit.

**7**. A medical robot system according to claim **5**, wherein said retractor coacts with one of said first robot arms connected thereto in a predetermined operation mode for bending said intermediate joint while keeping a position and a posture of said distal-end working unit constant.

**8**. A medical robot system according to claim **7**, further comprising:

rotary input means for moving said intermediate joint on a hypothetical sphere or a hypothetical arc around a predetermined reference point on said rod-shaped member, depending on an angular amount by which and a direction in which said rotary input means is angularly moved.

**9**. A medical robot system according to claim **8**, wherein said rotary input means comprises a trackball.

**10**. A medical robot system according to claim **8**, further comprising:

a switch for selectively enabling and disabling said rotary input means.

**11**. A medical robot system comprising:

a plurality of first robot arms supporting respective manipulators thereon;

a second robot arm supporting an endoscope thereon; and

a controller for controlling said first robot arms and said second robot arm;

said manipulators and said endoscope being inserted into a body cavity through a common trocar supporting member,

wherein each of said manipulators includes a rod-shaped member for insertion through said trocar supporting member into said body cavity, a distal-end working unit mounted on a distal end of said rod-shaped member and having at least one joint, and at least one intermediate joint disposed in said rod-shaped member for bending said rod-shaped member.

**12**. A medical robot system according to claim **11**, wherein at least one of said manipulators serves as a retractor, and said rod-shaped member of said at least one manipulator serving as the retractor includes a plurality of said intermediate joints.

**13**. A medical robot system according to claim **11**, further comprising:

a monitor for displaying an image captured with said endoscope;

first input means which is operated by the left hand of an operator; and

second input means which is operated by the right hand of said operator,

wherein, when said rod-shaped members of two of said manipulators intersect with each other at said trocar supporting member, said manipulator that is located on the left side on a screen of said monitor is operated based on input operation by said first input means, and said manipulator that is located on the right side on said screen of said monitor is operated based on input operation by said second input means.

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