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### Elastic unit

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#### Abstract

This elastic unit is provided with: a shaft-like member that extends in one direction and that is connected to a force point acted on by an external force; an enclosure member that has an internal space and that is penetrated by the shaft-like member; a bearing that is provided at a point of contact between the shaft-like member and the enclosure member so that the shaft-like member is movable with respect to the enclosure member; a plate member that is provided inside the internal space of the enclosure member so as to protrude from the shaft-like member; and at least one or more elastic members sandwiched between the enclosure member and the plate member.

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## Background/Summary

### CROSS REFERENCE TO RELATED APPLICATIONS

(1) This application is a U.S. National Phase of International Patent Application No. PCT/JP2019/040160 filed on Oct. 11, 2019, which claims priority benefit of Japanese Patent Application No. JP 2018-222011 filed in the Japan Patent Office on Nov. 28, 2018. Each of the above-referenced applications is hereby incorporated herein by reference in its entirety.

### FIELD

(2) The present disclosure relates to an elastic unit.

### BACKGROUND

(3) In recent years, the development of actuators for driving each of the parts of a robot device is also advancing with the progress in developing robot devices. As an example of such actuators, linear actuators that perform driving in a linear motion direction are known.

(4) Linear actuators are capable of causing a motor which performs rotational movement, or the like, to generate thrust without using a mechanical transformation mechanism such as a gear, and are therefore highly anticipated as actuators that possess superior controllability.

(5) For example, Patent Literature 1 below discloses a series elastic actuator in which an elastic unit is further provided between a force point and a linear-motion drive unit in order to stabilize force control of the linear actuator.

### CITATION LIST

#### Patent Literature

(6) Patent Literature 1: U.S. Pat. No. 5,650,704

### SUMMARY

#### Technical Problem

(7) However, the structure of the elastic unit provided between the force point and the linear-motion drive unit is not adequately investigated in the foregoing Patent Literature 1. Therefore, by

further investigating the specific structure of the elastic unit used in the series elastic actuator, an elastic unit which is more lightweight and of superior maintainability can potentially be achieved.

**Solution to Problem**

(8) According to the present disclosure, an elastic unit is provided that includes: a shaft-like member that extends in one direction and that is connected to a force point acted on by an external force; an enclosure member that has an internal space and that is penetrated by the shaft-like member; a bearing that is provided at a point of contact between the shaft-like member and the enclosure member so that the shaft-like member is movable with respect to the enclosure member; a plate member that is provided inside the internal space of the enclosure member so as to protrude from the shaft-like member; and at least one or more elastic members sandwiched between the enclosure member and the plate member.

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## **Description**

### **BRIEF DESCRIPTION OF DRAWINGS**

- (1) FIG. 1 is an explanatory diagram schematically illustrating an overview of a series elastic actuator.
- (2) FIG. 2 is a schematic diagram illustrating the structure of an elastic unit according to a first embodiment of the present disclosure.
- (3) FIG. 3 is a schematic diagram illustrating the operation of the elastic unit when an external force is applied to a force point.
- (4) FIG. 4 is a schematic diagram illustrating the structure of an elastic unit according to a comparative example.
- (5) FIG. 5 is a schematic diagram illustrating the structure of an elastic unit according to a first modification example.
- (6) FIG. 6 is a block diagram illustrating a function configuration for changing the elastic modulus of the elastic unit according to a second modification example.
- (7) FIG. 7 is a schematic diagram illustrating the structure of an elastic unit according to a third modification example.
- (8) FIG. 8 is a schematic diagram illustrating the structure of an elastic unit according to a fourth modification example.
- (9) FIG. 9 is a schematic diagram illustrating the structure of an elastic unit according to a fifth modification example.
- (10) FIG. 10 is a schematic diagram illustrating the structure of an elastic unit according to a sixth modification example.
- (11) FIG. 11 is a schematic diagram illustrating a robot device to which the elastic unit or series elastic actuator according to the first embodiment of the present disclosure is applied.

### **DESCRIPTION OF EMBODIMENTS**

(12) A preferred embodiment of the present disclosure will be described in detail hereinbelow with reference to the appended drawings. Note that, in the present specification and drawings, redundant descriptions of components having substantially the same function configuration are omitted by assigning the same reference signs.

(13) Note that the description will be given in the following order. 1. Overview of series elastic actuator 2. Structure of elastic unit 3. Modification examples 4. Applied example

#### **1. Overview of Series Elastic Actuator**

(14) First, an overview of the series elastic actuator to which the elastic unit according to a first embodiment of the present disclosure is applied will be described with reference to FIG. 1. FIG. 1 is an explanatory diagram schematically illustrating an overview of a series elastic actuator.

(15) As illustrated in FIG. 1, a series elastic actuator 10 is provided with a force point 200, an

elastic unit **100**, a linear motion part **300**, and a linear-motion drive unit **400**, for example.

(16) The linear-motion drive unit **400** is a drive device for generating motive power to move the linear motion part **300** in one direction. The linear-motion drive unit **400** may be any well-known drive device as long as same enables the linear motion part **300** to move in one direction, and may, for example, be a solenoid that transforms an electromagnetic force into linear motion, a power cylinder that transforms pressure such as hydraulic pressure, air pressure, or water pressure into linear motion, or a linear actuator that uses a linear motor, or the like. Alternatively, the linear-motion drive unit **400** may be a drive device with which rotational motion generated by a motor or the like is transformed to linear motion by means of a mechanical structure such as a gear or a ball screw.

(17) The linear motion part **300** is a member that moves in one direction due to motive power from the linear-motion drive unit **400** and is provided connected to the linear-motion drive unit **400**. More specifically, the linear motion part **300** may be configured from an expandable section **310** that expands in one direction due to the motive power from the linear-motion drive unit **400**; and a storage section **320** that stores the expandable section **310** during expansion/compression. Note that the linear motion part **300** may be integrated with the linear-motion drive unit **400**.

(18) The elastic unit **100** is a member that is provided between the linear motion part **300** and the force point **200** and that absorbs, using an elastic force, an external force applied to the force point **200**. The elastic unit **100** is capable of preventing an external force (that is, a shock or the like) applied to the force point **200** from being directly transmitted to the linear motion part **300**, and hence the linear motion part **300** can be protected from a shock or the like applied to the force point **200**.

(19) Furthermore, the elastic unit **100** is capable of transforming the energy of the external force applied to the force point **200** into elastic deformation energy, and therefore by measuring the magnitude of the elastic deformation resulting from the transformation, the size of the external force applied to the force point **200** can also be measured. In this case, the elastic unit **100** is capable of functioning as a force detection sensor.

(20) The force point **200** is a member that causes a force to act externally due to the driving of the series elastic actuator **10**. Therefore, an external force acts on the force point **200** as an externally-acting counterforce. In the case of the series elastic actuator **10**, the external force applied to the force point **200** is absorbed by the elastic unit **100**, and hence damage to the linear motion part **300** or the linear-motion drive unit **400** caused by the external force can be mitigated.

(21) There are no particular limitations on the structure of the force point **200**, rather, same may be a rotation bearing that enables connection of a member that rotatably turns about the force point **200**, for example. In such a case, the series elastic actuator **10** is capable of transforming the linear motion of the force point **200** into rotational motion, and hence is capable of functioning as an actuator that rotates a joint of an arm section or a leg section of a robot device.

(22) The technology according to the present disclosure is applied to a series elastic actuator **10** in which the elastic unit **100** is provided between the force point **200** and the linear-motion drive unit **400** as mentioned earlier. According to the technology of the present disclosure, it is possible to provide the elastic unit **100** with a more lightweight and robust structure. The elastic unit **100** according to the first embodiment of the present disclosure will be described hereinbelow in more specific terms.

## 2. Structure of Elastic Unit

(23) Next, the structure of the elastic unit **100** according to the present embodiment will be described with reference to FIG. 2. FIG. 2 is a schematic diagram illustrating the structure of the elastic unit **100** according to the present embodiment.

(24) As illustrated in FIG. 2, the elastic unit **100** is provided with a shaft-like member **111**, an enclosure member **140**, bearings **121**, **122**, a plate member **112**, elastic members **131**, **132**, an encoder detection unit **151**, an encoder unit **152**, and a connecting portion **160**.

(25) The shaft-like member **111** is a member that is connected to the force point **200** and that extends like a shaft in one direction. The shaft-like member **111** is provided so as to penetrate the enclosure member **140** (described subsequently), and is provided so as to be movable by the bearings **121**, **122** with respect to the enclosure member **140**. Thus, the shaft-like member **111** is capable of moving independently of the enclosure member **140** due to an external force applied to the force point **200**. Therefore, the direction of extension of the shaft-like member **111** is the detection direction of the external force applied to the force point **200**.

(26) Note that a stopper (not illustrated) may also be provided at the other end of the shaft-like member **111** on the opposite side from the one end where the force point **200** is provided. The stopper comes into contact with the bearing **122** or the enclosure member **140** when the shaft-like member **111** moves excessively due to the external force applied to the force point **200**, thereby preventing further movement of the shaft-like member **111**. Thus, the stopper is capable of preventing an excessive load on the elastic unit **100** due to the external force applied to the force point **200**.

(27) The enclosure member **140** is a member that has an internal space and that stores, in the internal space, the principal members of the elastic unit **100**. The shape of the enclosure member **140** may be a cylindrical shape or a prism shape the height direction of which is the direction of extension of the shaft-like member **111**, for example, or may be an isotropic shape such as a spherical shape or polyhedral shape. As described earlier, the shaft-like member **111** is provided so as to penetrate the enclosure member **140** via the bearings **121**, **122**.

(28) The bearings **121**, **122** are each provided at a point of contact between the shaft-like member **111** and the enclosure member **140** and support the shaft-like member **111** so that same is movable with respect to the enclosure member **140**. More specifically, the bearing **121** is provided on the surface of the enclosure member **140** on the side where the force point **200** is provided, and the bearing **122** is provided on the surface of the enclosure member **140** on the opposite side from the side where the force point **200** is provided.

(29) The bearings **121**, **122** function as radial bearings that support the load of the shaft-like member **111** that performs a reciprocating motion in one direction due to the external force applied to the force point **200**. The structure of the bearings **121**, **122** may be any kind of structure as long as same enables the shaft-like member **111** to move with respect to the enclosure member **140**, and may be any structure, namely, that of a rolling bearing, a slide bearing, a magnetic bearing, or a fluid bearing.

(30) The elastic unit **100** according to the present embodiment is capable of extending the distance between the bearings **121**, **122** without increasing the size of the elastic unit **100** (that is, the width of the elastic unit **100**) that is oriented orthogonal to the direction in which the external force acts. Thus, the elastic unit **100** according to the present embodiment enables a structure which is more robust with respect to the moment load due to the external force applied to the force point **200** to be realized.

(31) The plate member **112** is a member that is provided inside the internal space of the enclosure member **140** so as to protrude from the shaft-like member **111**. More specifically, the plate member **112** may be a disc-shaped or prism-shaped member that orthogonally intersects the direction of extension of the shaft-like member **111**. The plate member **112** moves in conjunction with the shaft-like member **111** due to the external force applied to the force point **200**, thereby extending/compressing the elastic members **131**, **132** sandwiched between the plate member **112** and the enclosure member **140**. Thus, the elastic unit **100** is capable of transforming the energy of the external force applied to the force point **200** into elastic deformation energy of the elastic members **131**, **132**.

(32) The elastic members **131**, **132** are members that are elastically deformable in the direction of extension of the shaft-like member **111** and are provided sandwiched between the plate member **112** and the enclosure member **140**. More specifically, the elastic members **131**, **132** are each

provided on the two main surfaces of the plate member **112**. For example, the elastic member **131** may be provided on the main surface of the plate member **112** on the side where the force point **200** is provided, and the elastic member **132** may be provided on the main surface of the plate member **112** on the opposite side from the side where the force point **200** is provided. Note that the moduli of elasticity of the elastic members **131**, **132** (the spring constants in the case of coil springs) may be the same as each other or may be different from each other.

(33) Here, the elastic members **131**, **132** may be hollow-shaped so as to surround the periphery of the shaft-like member **111**. Accordingly, the elastic members **131**, **132** enable the shaft-like member **111** to be arranged in the internal space, and hence the elastic unit **100** can be further miniaturized due to more effective utilization of the space between the elastic members and the shaft-like member **111**. For example, the elastic members **131**, **132** are coil springs, and the shaft-like member **111** may be provided so as to penetrate the center of the helical shape of the coil springs. Thus, the elastic members **131**, **132** enable the space between the elastic members and the shaft-like member **111** to be utilized more effectively, and hence the elastic unit **100** can be further miniaturized.

(34) Note that, as long as the elastic members **131**, **132** are members that can be elastically deformed in the direction of extension of the shaft-like member **111**, it is understood that the elastic members may be members other than coil springs. For example, the elastic members **131**, **132** may be a multilayered wave ring, a rubber or elastomeric material, or a jamming structural body, or the like. Even when the elastic members **131**, **132** are such members, the elastic members **131**, **132** are arranged so as to surround the periphery of the shaft-like member **111**, thereby enabling the elastic unit **100** to be further miniaturized.

(35) The encoder detection unit **151** and the encoder unit **152** detect the motion amounts of the shaft-like member **111** and plate member **112** with respect to the enclosure member **140**. More specifically, the encoder detection unit **151** and the encoder unit **152** are so-called optical linear encoders that detect the motion amount of the plate member **112** with respect to the enclosure member **140**. For example, the encoder unit **152** is a glass substrate formed with an evenly spaced grid scale, and may be provided on the edge of the plate member **112**. Furthermore, the encoder detection unit **151** is a light detection device that projects light onto the encoder unit **152** from a predetermined position and that detects reflected light from the encoder unit **152**, and may be provided on the internal space side of the enclosure member **140** so as to lie opposite the encoder unit **152**.

(36) Accordingly, because the amount of reflected light changes due to the grid scale of the encoder unit **152**, the encoder detection unit **151** detects the amount by which the reflected light from the encoder unit **152** changes, thus making it possible to detect how much of the grid scale of the encoder unit **152** has passed the light projection position. Therefore, the encoder detection unit **151** and the encoder unit **152** are capable of detecting the motion amount of the plate member **112** with respect to the enclosure member **140**. The motion amount of the plate member **112** with respect to the enclosure member **140** measured by the encoder detection unit **151** and the encoder unit **152** can be used to derive the size of the external force applied to the force point **200**, for example.

(37) The connecting portion **160** is a member that is provided on the side of the enclosure member **140** opposite the side where the force point **200** is provided, and that connects the elastic unit **100** to the linear motion part **300** or the linear-motion drive unit **400**. There are no particular limitations on the shape or installation position of the connecting portion **160** as long as same enables the elastic unit **100** to be connected to the linear motion part **300** or the linear-motion drive unit **400**.

(38) The elastic unit **100** according to the present embodiment has a structure which is connected directly to the linear motion part **300** by the connecting portion **160**. Thus, the elastic unit **100** is capable of facilitating connection to or removal from the linear motion part **300** or the linear-motion drive unit **400**, and hence the mass productivity and maintainability of the series elastic actuator **10** can be improved.

(39) The operation of the elastic unit **100** when an external force is applied to the force point **200** will be described next with reference to FIG. **3**. FIG. **3** is a schematic diagram illustrating the operation of the elastic unit **100** when an external force is applied to the force point **200**.

(40) As illustrated in FIG. **3**, when an external force  $F$  is applied to the force point **200**, the shaft-like member **111** connected to the force point **200** and the plate member **112** protruding from the shaft-like member **111** are pushed in in the direction of extension of the shaft-like member **111**. Thus, one of the elastic members **131**, **132** between the pushed-in plate member **112** and the fixed enclosure member **140** is expanded, while the other of the elastic members is compressed.

(41) Here, the elastic members **131**, **132** are coil springs, and the respective spring constants thereof are  $k_1$  and  $k_2$ , respectively. When the direction in which the external force  $F$  acts is the same as the direction of extension of the shaft-like member **111**, the whole of the external force  $F$  is dissipated in elastically deforming the elastic members **131**, **132**, and the elastic members **131**, **132** are in a state of being expanded or compressed, respectively, from a natural length state. Supposing that the motion amount of the plate member **112** from a case where the elastic members **131**, **132** are in an unloaded state is  $\Delta x_f$ , the relationship of equation 1 below is established between the external force  $F$  and the motion amount  $\Delta x_f$  of the plate member **112**.

$$F=(k_1+k_2).\text{Math}.\Delta x_f \quad \text{Equation 1}$$

(42) Hence, the motion amount  $\Delta x_f$  of the plate member **112** can be measured by the encoder detection unit **151** and the encoder unit **152**, and it is possible to calculate the magnitude of the external force  $F$  applied to the force point **200** by performing a calculation using the spring constants  $k_1$  and  $k_2$  of the elastic members **131**, **132** set at the design stage. Thus, the elastic unit **100** is capable of causing the series elastic actuator **10** to execute highly accurate force control or damping control by feeding back the calculated external force  $F$  and motion amount  $\Delta x_f$  to the linear-motion drive unit **400** or the like.

(43) Next, the superiority of the elastic unit **100** according to the present embodiment will be described by referring to the structure of an elastic unit **900** according to the comparative example illustrated in FIG. **4**. FIG. **4** is a schematic diagram illustrating the structure of the elastic unit **900** according to the comparative example.

(44) As illustrated in FIG. **4**, the elastic unit **900** according to the comparative example is provided with a force point **200**, a bearing plate **971**, linear motion shafts **911**, a bottom plate **972**, bearings **921**, a plate member **912**, elastic members **931**, **932**, and connecting portions **961**, **961**, for example.

(45) The linear motion shafts **911** are respectively provided in the direction in which the external force from the force point **200** acts, and are coupled to each other by the bearing plate **971** connected to the force point **200**, and by the bottom plate **972**. The linear motion shafts **911** are provided so as to penetrate the plate member **912** (described subsequently), and are provided so as to be movable with respect to the plate member **912** due to the bearings **921**. Thus, the linear motion shafts **911**, the bearing plate **971**, and the bottom plate **972** are capable of moving independently of the plate member **912** due to the external force applied to the force point **200**.

(46) The bearings **921** are each provided at a point of contact between the linear motion shafts **911** and the plate member **912** and support the linear motion shafts **911** such that same are movable with respect to the plate member **912**. That is, the bearings **921** function as radial bearings that support the load of the linear motion shafts **911** that perform a reciprocating motion in one direction due to the external force applied to the force point **200**.

(47) The plate member **912** is penetrated by the linear motion shafts **911** via the bearings **921** and is provided parallel to the bearing plate **971** and plate member **912**. Furthermore, elastic members **931**, **932**, which are elastically deformable in the direction of extension of the linear motion shafts **911**, are respectively provided sandwiched between the plate member **912**, and the bearing plate **971** and the plate member **912**.

(48) The connecting portions **961**, **962** are respectively provided on the two sides of the plate



member **912** so as to sandwich the plate member **912** therebetween, and connects the elastic unit **900** to the linear motion part **300** or the linear-motion drive unit **400**. In the case of the elastic unit **900**, the linear motion shafts **911**, the bearing plate **971**, and the bottom plate **972** are capable of moving as a result of an external force being applied to the force point **200**. Hence, the connecting portions **961**, **962**, which connect the elastic unit **900** to the linear motion part **300** or linear-motion drive unit **400**, are connected to the plate member **912** which is not movable even when an external force is applied to the force point **200**.

(49) In the case of the elastic unit **900** according to the comparative example, when an external force is applied to the force point **200**, the bearing plate **971** connected to the force point **200**, the linear motion shafts **911**, and the bottom plate **972** are pushed in in the direction of extension of the linear motion shafts **911**. Due to this configuration, one of the elastic members **931**, **932**, which is between the pushed in the bearing plate **971** and the bottom plate **972**, and the fixed plate member **912**, is compressed, while the other of the elastic members is expanded. Thus, the elastic unit **900** according to the comparative example is capable of transforming the energy of the external force applied to the force point **200** into elastic deformation energy of the elastic members **931**, **932**. Furthermore, by detecting the motion amount of the bearing plate **971** and the bottom plate **972** with respect to the plate member **912**, the elastic unit **900** according to the comparative example is capable of calculating the magnitude of the external force applied to the force point **200**.

(50) Nevertheless, in the case of the elastic unit **900** according to the comparative example, the bearings **921** movably supporting the linear motion shafts **911** are arranged in a direction orthogonally intersecting the direction in which external force acts. Hence, when the distance between the bearings **921** is extended in order to improve the robustness to a moment load exerted by the external force applied to the force point **200**, the size of the elastic unit **900** in a direction orthogonally intersecting the direction in which the external force acts (that is, the width of the elastic unit **900**) then increases.

(51) Additionally, in the case of the elastic unit **900** according to the comparative example, because the connecting portions **961**, **962** are connected to the lateral surfaces of the plate member **912**, the width of the elastic unit **900** is further increased by the connecting portions **961**, **962**. Moreover, in the case of the elastic unit **900**, because a connection is formed between the elastic unit **900** and the linear motion part **300** or linear-motion drive unit **400** due to the plate member **912** being sandwiched between the connecting portions **961**, **962**, this connection cannot easily be broken. Hence, the series elastic actuator **10** using the elastic unit **900** according to the comparative example exhibits reduced mass productivity and maintainability.

(52) As can be seen when referring to the elastic unit **900** according to the comparative example, despite the elastic unit **100** according to the present embodiment having a smaller width and being more compact, the elastic unit **100** is capable of exhibiting improved robustness to a moment load on the force point **200**. Moreover, the elastic unit **100** according to the present embodiment enables the connection with the linear motion part **300** or linear-motion drive unit **400** to be formed using a simpler structure. Thus, the elastic unit **100** according to the present embodiment enables improvements in the mass productivity and maintainability of the series elastic actuator **10**.

### 3. Modification Examples

(53) Modification examples of the elastic unit **100** according to the present embodiment will be described hereinbelow with reference to FIGS. **5** to **10**.

#### First Modification Example

(54) First, the structure of an elastic unit **100A** according to a first modification example will be described with reference to FIG. **5**. FIG. **5** is a schematic diagram illustrating the structure of the elastic unit **100A** according to the first modification example.

(55) As illustrated in FIG. **5**, the elastic unit **100A** is provided with a shaft-like member **111A**, an enclosure member **140A**, bearings **122**, a plate member **112**, elastic members **131A**, **132**, an encoder detection unit **151**, an encoder unit **152**, and a connecting portion **160**. The configuration,

to which the same reference signs as in FIG. 2 are assigned, is substantially the same as the configuration described with reference to FIG. 2, and hence a description thereof is omitted here. (56) The elastic unit **100A** according to the first modification example differs from the elastic unit **100** illustrated in FIG. 2 in that the force point **200** exists in an internal space of the enclosure member **140A**.

(57) More specifically, the force point **200** is provided connected to the plate member **112**, and the shaft-like member **111A** is connected to the force point **200** via the plate member **112**. Furthermore, in order to enable an external force to act on the force point **200**, an opening is provided in one surface of the enclosure member **140A**, and the elastic members **131A** are configured from a plurality of coil springs, and each arranged in the vicinity of the force point **200**.

(58) In the case of the elastic unit **100A** according to the first modification example, the length of the shaft-like member **111A** connected to the force point **200** can be made shorter, and therefore the moment load acting on the shaft-like member **111A** from the force point **200** can be further reduced.

(59) Note that, although coil springs are illustrated in FIG. 5 as the elastic members **131A**, **132**, the elastic members **131A**, **132** are not limited to or by this example. As mentioned earlier, it is understood that the elastic members **131A**, **132** may be an elastic member such as a multilayered wave ring, or a rubber or elastomeric material.

#### Second Modification Example

(60) Next, an elastic unit **100B** according to a second modification example will be described with reference to FIG. 6. FIG. 6 is a block diagram illustrating a function configuration for changing the elastic modulus of the elastic unit **100B** according to the second modification example.

(61) In the case of the elastic unit **100B** according to the second modification example, the elastic members **131**, **132** are provided using jamming structural bodies. A jamming structural body is a structural body that, by utilizing the jamming transitions of powder particles, enables control of an elastic modulus according to the clogging of the powder particles. Hence, the elastic unit **100B** controls the internal pressure of the internal space of the enclosure member **140** and enables the elastic modulus of the elastic members **131**, **132** to be changed by changing the clogging of powder particles of elastic members **131**, **132** which are jamming structural bodies.

(62) More specifically, a regulator **20** is a valve for pressure adjustment, and a compressor **30** is a compressor for pumping a gas. The elastic unit **100B** according to the second modification example feeds, via the regulator **20**, a gas which has been compressed by the compressor **30** into the interior of the enclosure member **140**, and is thus capable of controlling the internal pressure of the internal space of the enclosure member **140** and of controlling the elastic modulus of the elastic members **131**, **132**.

#### Third Modification Example

(63) Next, the structure of an elastic unit **100C** according to a third modification example will be described with reference to FIG. 7. FIG. 7 is a schematic diagram illustrating the structure of the elastic unit **100C** according to the third modification example.

(64) As illustrated in FIG. 7, the elastic unit **100C** is provided with a shaft-like member **111**, an enclosure member **140C**, bearings **121**, **122**, a plate member **112**, elastic members **131**, **132**, a reflective plate **153C**, a ranging sensor **154C**, and a connecting portion **160**. The configuration, to which the same reference signs as in FIG. 2 are assigned, is substantially the same as the configuration described with reference to FIG. 2, and hence a description thereof is omitted here.

(65) The elastic unit **100C** according to the third modification example differs from the elastic unit **100** illustrated in FIG. 2 in that the motion amounts of the shaft-like member **111** and plate member **112** with respect to the enclosure member **140C** are detected by the reflective plate **153C** and the ranging sensor **154C**.

(66) More specifically, the enclosure member **140C** is provided, on the other end side of the shaft-like member **111**, with an internal space **142C** inside which the ranging sensor **154C** is provided, in

addition to the internal space **141C** inside which the shaft-like member **111**, the plate member **112**, and the elastic members **131**, **132** are provided. The ranging sensor **154C** is a sensor that measures the distance from the other end of the shaft-like member **111**. For example, the ranging sensor **154C** may project light onto the reflective plate **153C** provided at the other end of the shaft-like member **111** and measure the distance from the other end of the shaft-like member **111** on the basis of the time taken for the projected light to be reflected by the reflective plate **153C** and to return. (67) In the case of the elastic unit **100C** according to the third modification example, although the measurement accuracy is lower than that of an optical linear encoder, the motion amounts of the shaft-like member **111** and plate member **112** can be detected by a lower-cost ranging sensor **154C**. Thus, the elastic unit **100C** according to the third modification example enables a reduction in the manufacturing costs of the series elastic actuator **10**.

#### Fourth Modification Example

(68) Next, the structure of an elastic unit **100D** according to a fourth modification example will be described with reference to FIG. 8. FIG. 8 is a schematic diagram illustrating the structure of the elastic unit **100D** according to the fourth modification example.

(69) As illustrated in FIG. 8, the elastic unit **100D** is provided with a shaft-like member **111**, an enclosure member **140**, bearings **121**, **122**, a plate member **112**, elastic members **131**, **132**, a force detection sensor **500D**, and a connecting portion **160**. The configuration, to which the same reference signs as in FIG. 2 are assigned, is substantially the same as the configuration described with reference to FIG. 2, and hence a description thereof is omitted here.

(70) The elastic unit **100D** according to the fourth modification example differs from the elastic unit **100** illustrated in FIG. 2 in that the shaft-like member **111** is provided with the force detection sensor **500D**, which detects the magnitude of the external force applied to the force point **200**. The force detection sensor **500D** is a force sensor that uses a strain gauge, for example, and is capable of directly measuring the magnitude of the external force applied to the force point **200**.

(71) The elastic unit **100D** according to the fourth modification example is capable of directly measuring the magnitude of the external force applied to the force point **200** without the involvement of the elastic members **131**, **132**. Accordingly, the elastic unit **100D** is capable of measuring the magnitude of the external force applied to the force point **200** without damage caused by friction or the like, and therefore enables the force detection accuracy to be improved. Furthermore, because the elastic unit **100D** according to the fourth modification example enables shocks applied to the force point **200** to be absorbed by the elastic members **131**, **132**, the probability of damage to the force detection sensor **500D**, which is vulnerable to shocks, can be reduced.

#### Fifth Modification Example

(72) Next, the structure of an elastic unit **100E** according to a fifth modification example will be described with reference to FIG. 9. FIG. 9 is a schematic diagram illustrating the structure of the elastic unit **100E** according to the fifth modification example.

(73) As illustrated in FIG. 9, the elastic unit **100E** is provided with a shaft-like member **111**, an enclosure member **140**, bearings **121**, **122**, a plate member **112E**, elastic members **131E**, **132E**, a strain sensor **113E**, and a connecting portion **160**. The configuration, to which the same reference signs as in FIG. 2 are assigned, is substantially the same as the configuration described with reference to FIG. 2, and hence a description thereof is omitted here.

(74) The elastic unit **100E** according to the fifth modification example differs in that the plate member **112E** is flexible and in that the magnitude of the external force applied to the force point **200** is calculated by using the strain sensor **113E** to detect the amount of bending of the plate member **112E**.

(75) More specifically, the plate member **112E** is flexible due to being formed with a thin structure or due to being formed from a flexible material such as plastic. Thus, when an external force is applied to the force point **200**, the plate member **112E** then bends as the shaft-like member **111**

moves and without elastically deforming the elastic members **131E**, **132E**. Hence, by using the strain sensor **113E**, which is a strain gauge or the like, the magnitude of the external force applied to the force point **200** can be calculated by detecting the amount of bending of the plate member **112E**. Note that, in the case of the elastic unit **100E** according to the fifth modification example, the elastic members **131E**, **132E** are not provided in order to detect the magnitude of the external force, rather, same are provided in order to absorb shocks applied to the force point **200**.

(76) The elastic unit **100E** according to the fifth modification example employs the plate member **112E**, which is flexible, and the strain sensor **113E**, and is thus capable, even with a more compact configuration, of detecting the magnitude of the external force applied to the force point **200**.

Furthermore, the elastic unit **100E** according to the fifth modification example utilizes the bending of the plate member **112E** to enable detection of the magnitude of the external force applied to the force point **200** without considering hysteresis of the elastic members **131E**, **132E**.

#### Sixth Modification Example

(77) Next, the structure of an elastic unit **100F** according to a sixth modification example will be described with reference to FIG. **10**. FIG. **10** is a schematic diagram illustrating the structure of the elastic unit **100F** according to the sixth modification example.

(78) As illustrated in FIG. **10**, the elastic unit **100F** is provided with a shaft-like member **111**, an enclosure member **140F**, bearings **121**, **122**, a plate member **112**, elastic members **131F**, **132F**, a reflective plate **153F**, a ranging sensor **154F**, and a connecting portion **160**. The configuration, to which the same reference signs as in FIG. **2** are assigned, is substantially the same as the configuration described with reference to FIG. **2**, and hence a description thereof is omitted here.

(79) The elastic unit **100F** according to the sixth modification example differs from the elastic unit **100** illustrated in FIG. **2** in that the elastic members **131F**, **132F** differ from each other in size and in that the reflective plate **153F** and the ranging sensor **154F** are provided in a space amounting to the difference in size of the elastic members **131F**, **132F**.

(80) More specifically, the elastic members **131F**, **132F** have mutually different elastic moduli and therefore differ from each other in size. Hence, an empty space due to miniaturization of the elastic member **131F** is formed around the elastic member **131F**, which is smaller in size than the elastic member **132F**. In the elastic unit **100F** according to the sixth modification example, the motion amounts of the shaft-like member **111** and plate member **112** are detected by providing the ranging sensor **154F** on the enclosure member **140F**-side of the empty space and by providing the reflective plate **153F** on the plate member **112**-side. For example, the ranging sensor **154F** projects light onto the reflective plate **153F** provided on one main side of the plate member **112** and is capable of measuring the distance from the plate member **112** on the basis of the time taken for the projected light to be reflected by the reflective plate **153F** and to return.

(81) In the elastic unit **100F** according to the sixth modification example, the size of either of the elastic members **131F**, **132F** can be miniaturized, thereby enabling the elastic unit **100F** to be further miniaturized. Furthermore, in the case of the elastic unit **100F** according to the sixth modification example, although the measurement accuracy is lower than that of an optical linear encoder, the motion amounts of the shaft-like member **111** and plate member **112** can be detected by a lower-cost ranging sensor **154F**. Thus, the elastic unit **100F** according to the sixth modification example enables a reduction in the manufacturing costs of the series elastic actuator **10**.

#### 4. Applied Example

(82) Next, an applied example of the elastic unit **100** or the series elastic actuator **10** according to the present embodiment will be described with reference to FIG. **11**. FIG. **11** is a schematic diagram illustrating a robot device **1** to which the elastic unit **100** or the series elastic actuator **10** according to the present embodiment is applied.

(83) The elastic unit **100** or the series elastic actuator **10** according to the present embodiment may be applied to a multi-joint link mechanism of an articulated arm mechanism of a robot device like that illustrated in FIG. **11**, for example.

(84) More specifically, the series elastic actuator **10** may be applied to a drive unit for driving the joints of a multi-joint link mechanism. Furthermore, the elastic unit **100** may be applied to a shock absorbing part or a force detection unit provided in the links of a multi-joint link mechanism.

(85) Moreover, the elastic unit **100** or the series elastic actuator **10** according to the present embodiment may also be applied to a multi-joint link mechanism for the legs of a legged robot device.

(86) Although preferred embodiments of the present disclosure have been described in detail hereinabove with reference to the accompanying drawings, the technical scope of the present disclosure is not limited to or by such examples. It will be apparent to a person having ordinary knowledge in the technical field of the present disclosure that various modification or revision examples are conceivable within the scope of the technical ideas described in the claims and that such modification or revision examples are naturally understood to fall within the technical scope of the present disclosure.

(87) Furthermore, the effects described in the present specification are merely illustrative or exemplary and are not restrictive. That is, the technology according to the present disclosure can afford other advantageous effects that would be apparent to a person skilled in the art from the description of the present specification in addition to or instead of the foregoing advantageous effects.

(88) Note that the following configurations also belong to the technical scope of the present disclosure.

(89) (1)

(90) An elastic unit, comprising: a shaft-like member that extends in one direction and that is connected to a force point acted on by an external force; an enclosure member that has an internal space and that is penetrated by the shaft-like member; a bearing that is provided at a point of contact between the shaft-like member and the enclosure member so that the shaft-like member is movable with respect to the enclosure member; a plate member that is provided inside the internal space of the enclosure member so as to protrude from the shaft-like member; and at least one or more elastic members sandwiched between the enclosure member and the plate member.

(2)

(91) The elastic unit according to (1), wherein the elastic member is provided so as to surround the periphery of the shaft-like member.

(3)

(92) The elastic unit according to (2), wherein the elastic member is a coil spring, and wherein the shaft-like member is provided so as to penetrate the center of the helical shape of the coil spring.

(4)

(93) The elastic unit according to (2), wherein the elastic member is a jamming structural body that enables the elastic modulus to fluctuate under the internal pressure of the internal space of the enclosure member.

(5)

(94) The elastic unit according to any one of (1) to (4), wherein the elastic member is provided respectively on the two main sides of the plate member.

(6)

(95) The elastic unit according to (5), wherein the elastic members provided respectively on the two main sides have mutually different elastic moduli.

(7)

(96) The elastic unit according to any one of (1) to (6), further comprising: a motion amount sensor that measures the motion amounts of the plate member and the shaft-like member with respect to the enclosure member.

(8)

(97) The elastic unit according to (7), wherein the motion amount sensor is an optical or magnetic

linear encoder.

(9)

(98) The elastic unit according to (7), wherein the motion amount sensor is a ranging sensor that measures the distance between the plate member or the shaft-like member, and the enclosure member.

(10)

(99) The elastic unit according to (7), wherein the elastic unit calculates the magnitude of the external force applied to the force point on the basis of the motion amounts measured by the motion amount sensor.

(11)

(100) The elastic unit according to any one of (1) to (6), wherein the plate member further comprises: a strain sensor that is flexible and that detects bending of the plate member.

(12)

(101) The elastic unit according to any one of (1) to (6), further comprising: a force detection sensor that is provided to the shaft-like member and that detects the external force acting on the force point.

(13)

(102) The elastic unit according to any one of (1) to (12), wherein a stopper that limits the motion amount of the shaft-like member with respect to the enclosure member is provided at the other end of the shaft-like member on the opposite side from the one end where the force point is provided.

(14)

(103) The elastic unit according to any one of (1) to (13), wherein the force point is a rotation bearing to which a member that rotatably turns about the force point is connected.

(15)

(104) The elastic unit according to any one of (1) to (14), wherein the enclosure member is further provided with a linear-motion drive unit that linearly moves the enclosure member in the direction of extension of the shaft-like member.

#### REFERENCE SIGNS LIST

(105) **1** ROBOT DEVICE **10** SERIES ELASTIC ACTUATOR **20** REGULATOR **30** COMPRESSOR **100** ELASTIC UNIT **111** SHAFT-LIKE MEMBER **112** PLATE MEMBER **121**, **122** BEARING **131**, **132** ELASTIC MEMBER **140** ENCLOSURE MEMBER **151** ENCODER DETECTION UNIT **152** ENCODER UNIT **160** CONNECTING SECTION **200** FORCE POINT **300** LINEAR MOTION UNIT **310** EXPANDABLE SECTION **320** STORAGE SECTION **400** LINEAR-MOTION DRIVE UNIT

## Claims

1. An elastic unit, comprising: a shaft member that extends in a direction and that is connected to a force point acted on by an external force; an enclosure member that has an internal space and that is penetrated by the shaft member; a bearing that is at a point of contact between the shaft member and the enclosure member so that the shaft member is movable with respect to the enclosure member; a plate member inside the internal space of the enclosure member, wherein the plate member protrudes from the shaft member, the plate member comprises a strain sensor that is flexible, and the strain sensor is configured to detect bending of the plate member; a first elastic member between the enclosure member and the plate member; and a motion amount sensor inside the internal space of the enclosure member, wherein the motion amount sensor is configured to measure a distance between one of the plate member and the enclosure member or the shaft member and the enclosure member.

2. The elastic unit according to claim 1, wherein the first elastic member surrounds a periphery of the shaft member.

3. The elastic unit according to claim 2, wherein the first elastic member is a coil spring, and the shaft member penetrates a center of a helical shape of the coil spring.
  4. The elastic unit according to claim 2, wherein the first elastic member is a jamming structural body configured to enable an elastic modulus of the first elastic member to fluctuate under an internal pressure of the internal space of the enclosure member.
  5. The elastic unit according to claim 1, further comprising a second elastic member, wherein the first elastic member is on a first side of the plate member, and the second elastic member is on a second side of the plate member.
  6. The elastic unit according to claim 5, wherein the first elastic member and the second elastic member have mutually different elastic moduli.
  7. The elastic unit according to claim 1, wherein the motion amount sensor is one of an optical linear encoder or a magnetic linear encoder.
  8. The elastic unit according to claim 1, wherein the motion amount sensor is a ranging sensor.
  9. The elastic unit according to claim 1, wherein the elastic unit is configured to calculate a magnitude of the external force based on the distance measured by the motion amount sensor.
  10. The elastic unit according to claim 1, further comprising a force detection sensor in the shaft member, wherein the force detection sensor is configured to detect the external force that acts on the force point.
  11. The elastic unit according to claim 1, further comprising a stopper configured to limit a motion amount of the shaft member, wherein the force point is at a first end of the shaft member, and the stopper is at a second end of the shaft member opposite to the first end.
  12. The elastic unit according to claim 1, wherein the force point is a rotation bearing to which a member that rotatably turns about the force point is connected.
  13. The elastic unit according to claim 1, wherein the enclosure member includes a linear-motion drive unit configured to linearly move the enclosure member in the direction in which the shaft member extends.
  14. An elastic unit, comprising: a shaft member that extends in a direction and that is connected to a force point acted on by an external force; an enclosure member that has an internal space and that is penetrated by the shaft member; a bearing that is at a point of contact between the shaft member and the enclosure member so that the shaft member is movable with respect to the enclosure member; a plate member inside the internal space of the enclosure member, wherein the plate member protrudes from the shaft member, the plate member comprises a strain sensor that is flexible, and the strain sensor is configured to detect bending of the plate member; and at least one elastic member between the enclosure member and the plate member.
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