(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 530 920 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
**28.08.2019 Bulletin 2019/35**

(21) Application number: **17861678.5**

(22) Date of filing: **22.09.2017**

(51) Int Cl.:
***F02G 1/053** (2006.01)*

(86) International application number:
**PCT/JP2017/034307**

(87) International publication number:
**WO 2018/074143 (26.04.2018 Gazette 2018/17)**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

(30) Priority: **18.10.2016 JP 2016204543**

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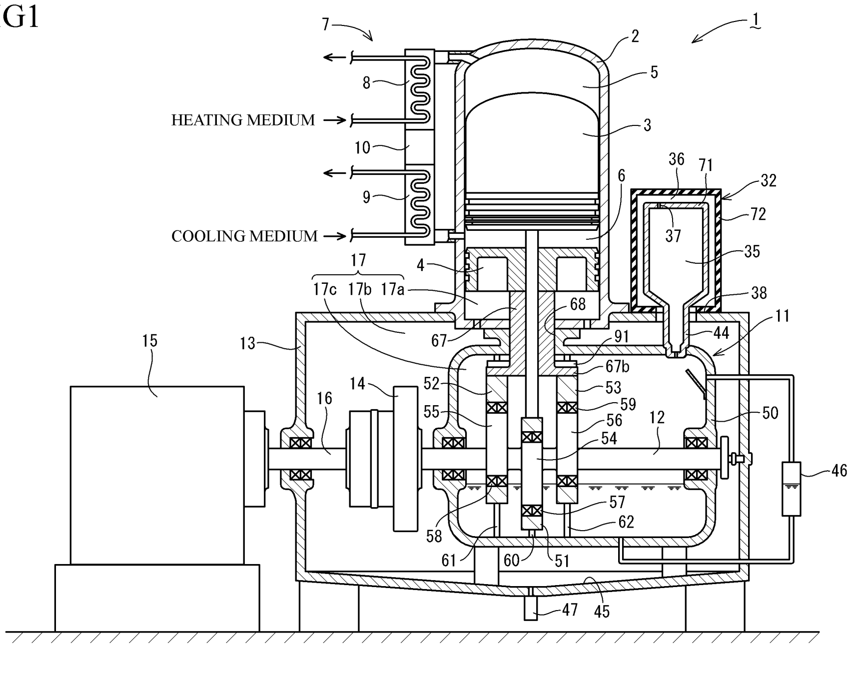
# (54) OUTPUT-DERIVING DEVICE AND STIRLING ENGINE

(57) A power takeout device 11 according to an aspect of the present invention includes: reciprocating parts 51 through 53 coupled to a piston 4; and a crankshaft 12 that is in slidable contact with the reciprocating parts 51 through 53 and rotates by reciprocation of the reciprocating parts 51 through 53. An anti-deformation member 91 made of a material having a specific gravity heavier than those of the reciprocating parts 51 through 53 is fixed to the reciprocating parts 51 through 53.

FIG1

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## Description

### Technical Field

**[0001]** The present invention relates to a power takeout device that convers reciprocating movement to rotation movement and outputs the rotation movement, and a Stirling engine including the power takeout device.

### Background Art

**[0002]** A Stirling engine, for example, has been known as an external combustion engine that outputs a driving force by contraction and expansion of an operating fluid based on a temperature difference by heat from the outside. The Stirling engine moves an operating fluid between a compression chamber and an expansion chamber alternately and repeats expansion and contraction of the operating fluid by a heat exchanger to thereby drive a piston so that heat from the outside is converted to a driving force (see Patent Literatures 1 and 2: PTLs 1 and 2). Examples of such known Stirling engines include an alpha type in which a compression chamber and an expansion chamber are defined in different cylinders, a beta type in which a displacer piston and a power piston are housed in the same cylinder, and a gamma type in which a displacer piston and a power piston are housed in different cylinders.

**[0003]** The Stirling engine includes a power takeout device such as a crank mechanism for converting reciprocating movement of a power piston to rotation movement, and outputs a rotative force to the outside. A Stirling engine described in PTL 1 is configured such that a power takeout device constituted by a crosshead mechanism is disposed below the piston, a cylinder (operating chamber) incorporating a displacer piston and a power piston and a crank chamber (buffer chamber) on which a crankshaft of the crank mechanism is pivotally supported are separated vertically in the same case. A Stirling engine described in PTL 2 is configured such that a power takeout device constituted by a Scotch yoke mechanism is disposed inside a crankcase (buffer chamber) below a cylinder (operating chamber) incorporating a displacer piston and a power piston.

### Citation List

### Patent Literatures

**[0004]** PTL1: Japanese Patent Application Laid-Open No. S63-243574 (1988)

### Summary of Invention

### Technical Problem

**[0005]** The Stirling engine of PTL 1 employs a wet sump lubrication system that supplies lubricating oil to a sliding portion such as a bearing. The Stirling engine of PTL 2 employs a built-in lubrication system in which a sliding portion is constituted by a grease-enclosed part or an oil-impregnated part, for example. In the wet sump lubrication system in PTL 1, a spray of lubricating oil in the buffer chamber might enter the operating chamber to cause, for example, clogging in a heat exchanger that exchanges heat with an operating fluid. On the other hand, in the built-in lubrication system in PTL 2, when power is increased, a withstand load in the sliding portion such as the bearing needs to be increased, and the size of the power takeout device increases in order to reduce a contact pressure in the sliding portion accordingly. Thus, it is difficult to reduce the size of the entire engine.

**[0006]** To prevent or reduce an increase in load by an inertial force, a typical power takeout device is made of a light alloy material such as an aluminium alloy to reduce the weight of the device. In the case where the device is made of a light alloy material, however, a lower rigidity of the light alloy material than that of iron causes deformation of parts of the power takeout device under a load from a piston, and this deformation might affect a behavior of a crank mechanism and, in addition, might cause damage of the device. In addition, since the light alloy material has a linear expansion coefficient larger than that of iron, when the temperature of the power takeout device increases due to the influence of an ambient temperature or abrasion, the part might thermally deform so that problems such as abnormal abrasion in a sliding portion might arise.

**[0007]** The present invention has a technical issue of providing a power takeout device and a Stirling engine improved in consideration of the foregoing circumstances.

### Solution to Problem

**[0008]** An aspect of the present invention provides a power takeout device including: a reciprocating part coupled to a piston; and a crankshaft that is in slidable contact with the reciprocating part and rotates by reciprocation of the reciprocating part, wherein an anti-deformation member made of a material having a specific gravity heavier than that of the reciprocating part is fixed to the reciprocating part.

**[0009]** In the power takeout device, the reciprocating part may include a plurality of reciprocating parts arranged along the crankshaft, and the anti-deformation member may be disposed across the plurality of reciprocating parts.

**[0010]** In the power takeout device, the anti-deformation member may extend in a direction intersecting an axial direction of each of the crankshaft and the piston.

**[0011]** In the power takeout device, the anti-deformation member may have a ring shape whose center axis coincides with an axis of the piston, and may be disposed around a connection portion of the reciprocating part connected to the piston.

**[0012]** In the power takeout device, the reciprocating part may be a yoke portion in which a guide groove penetrates in an axial direction of the crankshaft, the crankshaft may be inserted in the guide groove, and a portion of the crankshaft fitted in the yoke portion may eccentrically rotate based on reciprocation of the yoke portion so that a rotative force is output from the crankshaft.

**[0013]** Another aspect of the present invention provides a Stirling engine including: a piston that reciprocates in a cylinder; a heat exchanger that promotes contraction and expansion of an operating fluid in the cylinder, the heat exchanger being configured to alternately repeat contraction and expansion of the operating fluid in the cylinder to cause the piston to reciprocate; and the power takeout device having any of the above-described configurations, the power takeout device being configured to convert a reciprocation driving force from the piston to a rotative force and output the rotative force.

Advantageous Effects of Invention

**[0014]** According to an aspect of the present invention, the anti-deformation member is disposed on the reciprocating part. Thus, even when a load on the piston increases, the rigid anti-deformation member can suppress deformation of the anti-deformation member. That is, although the reciprocating part tends to deform under a load on the piston, the reciprocating part is pressed by the rigid anti-deformation member made of a material having a heavy specific gravity so that deformation of the reciprocating part can be suppressed. Thus, a rotation operation in the power takeout device can be stabilized, and abnormal abrasion and flaking in a sliding portion caused by, for example, local contact by deformation can be suppressed.

**[0015]** According to an aspect of the present invention, since the anti-deformation member is disposed on the reciprocating part, even when the temperature of the reciprocating part increases, the anti-deformation member having a small linear expansion coefficient can reduce thermal deformation of the reciprocating part. That is, when the temperature of the reciprocating part becomes high by heat from, for example, the piston, the degree of extension of the anti-deformation member is reduced so that the amount of extension of the reciprocating part can be reduced. Accordingly, the amount of shift of the sliding portion in the power takeout device is reduced so that a rotation operation in the power takeout device can be stabilized, and abnormal abrasion and flaking in the sliding portion caused by, for example, local contact by deformation can be suppressed.

Brief Description of Drawings

**[0016]**

[FIG. 1] A cross-sectional side view schematically illustrating a Stirling engine according to an embodiment of the present invention.

[FIG. 2] A cross-sectional front view schematically illustrating the Stirling engine.

[FIG. 3] A cross-sectional side view of a power takeout device in the Stirling engine.

[FIG. 4] An explanatory drawing illustrating a connection structure to a displacer piston in the power takeout device.

[FIG. 5] An explanatory drawing illustrating a connection structure to a power piston in the power takeout device.

[FIG. 6] Explanatory drawings of other examples of a breather in the Stirling engine, where (a) through (c) are schematic cross-sectional views of the breather of the examples.

[FIG. 7] An explanatory drawing illustrating a configuration of a first example of an anti-deformation member in the Stirling engine.

[FIG. 8] An explanatory drawing illustrating a configuration of a second example of the anti-deformation member.

[FIG. 9] An explanatory drawing illustrating another configuration of the anti-deformation member.

[FIG. 10] An explanatory drawing illustrating a configuration of a third example of the anti-deformation member.

[FIG. 11] A schematic cross-sectional view of a Stirling engine according to another embodiment of the present invention.

Description of Embodiments

1. Overall configuration of Stirling engine

**[0017]** An overall configuration of a Stirling engine embodying an aspect of the present invention will be described with reference to the drawings. FIG. 1 is a cross-sectional side view schematically illustrating the Stirling engine. FIG. 2 is a cross-sectional front view schematically illustrating the Stirling engine. In the following description, a beta-type Stirling engine will be described as an example.

**[0018]** As illustrated in FIGs. 1 and 2, in the Stirling engine 1, a cylinder 2 enclosing an operating fluid such as air, a helium gas, or hydrogen incorporates a displacer piston 3 and a power piston 4. The cylinder 2 is configured to be open at one end and closed at the other end. The displacer piston 3 is disposed at the closed end, whereas the power piston 4 is disposed at the open end. In the cylinder 2, an expansion chamber 5 is formed between the closed end and the displacer piston 3, and the compression chamber 6 is formed between the displacer piston 3 and the power piston 4. The expansion chamber 5 and the compression chamber 6 in the cylinder 2 will be referred to collectively as an operating chamber.

**[0019]** The Stirling engine 1 includes a heat exchanger 7 that increases and reduces the temperature of an operating fluid in the operating chamber in the cylinder 2.

The heat exchanger 7 is configured such that a heater 8 that communicates with the expansion chamber 5 and heats an operating fluid by heat entering from the outside and a cooler 9 that communicates with the compression chamber 6 and cools an operating fluid by dissipating heat to the outside are coupled to each other through a regenerator 10 incorporating a matrix that is a porous thermal storage material. When the displacer piston 3 moves toward the open end of the cylinder 2, the operating fluid heated by the heater 8 enters the expansion chamber 5 so that the temperature of the operating fluid increases accordingly. On the other hand, when the displacer piston 3 moves toward the closed end of the cylinder 2, the operating fluid cooled by the cooler 9 enters the compression chamber 6 so that the temperature of the operating fluid decreases, accordingly. Thus, the operating fluid flows in opposite directions between the heat exchanger 7 and the operating chamber in the cylinder 2 so that the internal pressure in the operating chamber of the cylinder 2 changes to promote reciprocation movement of the power piston 4.

**[0020]** To increase a heat transfer area with an external heating medium, the heater 8 is constituted by small tubes, heat collecting fins, and other parts, for example, and increases its temperature when the operating fluid passing through the inside of the heater 8 receives heat from the heating medium. Similarly, the cooler 9 is also constituted by small tubes, heat dissipation fins, and other parts, for example, in order to increase a heat transfer area with an external cooling medium, and reduces its temperature when an operating fluid passing through the cooler 9 dissipates heat to the cooling medium. The regenerator 10 is constituted by, for example, a stack of metal fibers or metal meshes, operating fluid channels arranged in, for example, a honeycomb pattern, or a material incorporating flocculent metal fibers, and functions as a regenerative heat exchanger. That is, while a high-temperature operating fluid flows from the heater 8 to the cooler 9, the regenerator 10 stores heat of the operating fluid, whereas while a low-temperature operating fluid flows from the cooler 9 to the heater 8, the regenerator 10 dissipates stored heat to the operating fluid.

**[0021]** The Stirling engine 1 includes, at the open end of the cylinder 2, a power takeout device 11 that converts a reciprocation operation of the power piston 4 to a rotation operation and outputs a rotative force. The power takeout device 11 pivotally supports, in a crankcase 13, a crankshaft 12 coupled to each of the displacer piston 3 and the power piston 4. An end of the crankshaft 12 serves as an output shaft and is coupled to an input shaft 16 of an electric generator 15 through a flywheel 14 in the crankcase 13. A chamber 17a closer to the open end than the power piston 4 in the cylinder 2 and chambers 17b and 17c in the crankcase 13 define a buffer chamber (rear chamber of the power piston 4) 17.

**[0022]** The displacer piston 3 and the power piston 4 are connected to the crankshaft 12 of the power takeout device 11 to thereby reciprocate in the cylinder 2 with a predetermined phase difference. In this embodiment, the phase difference in reciprocation operation of the displacer piston 3 and the power piston 4 is 90°.

2. Example configuration of power takeout device

**[0023]** A configuration of the power takeout device 11 in the Stirling engine 1 will be described hereinafter with reference to FIGs. 1 through 5. As illustrated in FIGs. 1 through 5, the power takeout device 11 is disposed in a crank box 50 fixed inside the crankcase 13. The power takeout device 11 is constituted by a Scotch yoke mechanism in which crankpins 54 through 56 of the crankshaft 12 are respectively fitted, through bearings 57 through 59, in a plate 51c fixed to a crankshaft guide groove (through groove) 51a of a displacer yoke (reciprocating part) 51 that reciprocates in conjunction with the displacer piston 3 and plates 52c and 53c fixed to crankshaft guide grooves (through grooves) 52a and 53a of power piston yokes (reciprocating parts) 52 and 53 that reciprocate in conjunction with the power piston 4.

**[0024]** As illustrated in FIGs. 1 through 5, the crank box 50 is coupled and supported in the crankcase 13, is coupled to the cylinder 2 inserted in the crankcase 13, and pivotally supports the crankshaft 12. A part of the cylinder 2 is inserted in the crankcase 13, and the crankcase 13 is coupled to the inserted portion of the cylinder 2 to cover the entire crank box 50. That is, the power takeout device 11 is disposed inside the casing having the double structure of the crankcase 13 and the crank box 50. The crankshaft 12 penetrates the crank box 50 to be coupled to the flywheel 14 in the crankcase 13.

**[0025]** As illustrated in FIG. 4, a center portion of the displacer yoke 51 has the crankshaft guide groove 51a elongated in a direction (lateral direction) intersecting the axial directions of the crankshaft 12 and the displacer piston 3. A reciprocation guide hole (through hole) 51b is formed in each of side portions of the displacer yoke 51 sandwiching the crankshaft guide groove 51a, in a direction (longitudinal direction) along the axial direction of the displacer piston 3. A guide shaft 60 fixed to the crank box 50 is inserted in the reciprocation guide hole 51b of the displacer yoke 51 with a linear motion bearing 63 such as a rotary bushing interposed therebetween. The displacer yoke 51 is coupled to one end of a rod 66 that is coupled to the displacer piston 3 at the other end, and reciprocates in the same directions (longitudinal direction) as the reciprocation direction of the displacer piston 3 in conjunction with reciprocation of the displacer piston 3.

**[0026]** As illustrated in FIG. 5, a center portion of the power piston yoke 52 (53) has the crankshaft guide groove 52a (53a) elongated in the lateral direction, and the reciprocation guide hole (through hole) 52b (53b) penetrates each of the side portions sandwiching the crankshaft guide groove 52a (53a) in the longitudinal direction. The guide shaft 61 (62) fixed to the crank box 50 is inserted in the reciprocation guide hole 52b (53b) of the power piston yoke 52 (53) with the linear motion bearing 64 (65) interposed therebetween. The power piston yoke 52 (53) is coupled to one end of a bridge 67 that is coupled to the power piston 4 at the other end, and reciprocates in the longitudinal direction in conjunction with reciprocation of the power piston 4.

**[0027]** As illustrated in FIGs. 3 through 5, through holes 4a and 67a are formed in a direction along the axial direction of the power piston 4 (longitudinal direction) at the centers of the power piston 4 and the bridge 67, and the rod 66 coupled to the displacer piston 3 penetrates the through holes 4a and 67a. The rod 66 is movable relative to the power piston 4 and the bridge 67, and a dynamic sealing mechanism (not shown) of, for example, a mechanical seal, is constituted in a portion of the power piston 4 in which the rod 66 is inserted.

**[0028]** As illustrated in FIGs. 2 through 5, the crankshaft 12 is provided with the crankpin 54 coupled to the rod 66 through the displacer yoke 51, between the crankpins 55 and 56 coupled to the bridge 67 through the power piston yokes 52 and 53. The crankpin 54 is attached to the crankpins 55 and 56 of the same phase with a predetermined phase difference (e.g., 90°). A portion of the crank box 50 coupled to the cylinder 2 has a bridge insertion hole 68 in which the bridge 67 is inserted. The bridge insertion hole 68 of the crank box 50 is formed in a coupling portion between the cylinder 2 and the crank box 50. The bridge 67 reciprocates in conjunction with the power piston 4 in such a manner that a portion of the bridge 67 toward the cylinder 2 is inserted and extracted into/from the bridge insertion hole 68. To reduce variations of the internal pressure caused by volume change with reciprocation of the power piston 4 in the third buffer chamber 17a closer to the open end than the power piston 4 in the cylinder 2, a communication port 17d is disposed between the third buffer chamber 17a and the first buffer chamber 17b.

**[0029]** The displacer piston 3 reciprocates by a rotative force of the crankshaft 12, and an operating fluid moves toward and rearward between the expansion chamber 5 and the compression chamber 6 so that the internal pressure of the operating chamber changes. This pressure change causes the power piston 4 to reciprocate, and this reciprocation driving force is transferred to the power piston yokes 52 and 53 through the bridge 67. Accordingly, the power piston yokes 52 and 53 reciprocate in the longitudinal direction along the guide shafts 61 and 62, respectively. The reciprocation movement of the power piston yokes 52 and 53 causes the crankpins 55 and 56 to reciprocate in the lateral direction in the crankshaft guide grooves 52a and 53a, respectively, while rotating so that the crankshaft 12 rotates. Thus, the power takeout device 11 that has received the reciprocation driving force of the power piston 4 converts the driving force to a rotative force with the Scotch yoke mechanism and outputs the rotative force from the crankshaft 12 to rotate the electric generator 15 through the flywheel 14 and the input shaft 16.

**[0030]** As illustrated in FIGs. 1 through 5, the Stirling engine 1 according to this embodiment employs a wet sump lubrication system in which lubricating oil is supplied to a sliding portion of the power takeout device 11. The crank box 50 is configured as an oil tank for storing lubricating oil, and an oil seal (not shown) is provided not only in a portion in which the crankshaft 12 penetrates but also portions of the coupling portion between the cylinder 2 and the crank box 50 where the bridge 67 is inserted in the bridge insertion hole 68 and the rod 66 is inserted in the through hole 67a. That is, the crank box 50 has a hermetic structure for preventing stored lubricating oil from leaking to the outside. The crankcase 13 includes the first buffer chamber 17b located outside the crank box 50 and the second buffer chamber 17c located inside the crank box 50.

**[0031]** That is, the crankcase 13 has a double structure incorporating the crank box 50, and the crank box 50 encloses lubricating oil. Accordingly, mixing of lubricating oil into the first buffer chamber 17b in the crankcase 13 can be avoided. Accordingly, it is possible to more reliably prevent or reduce entering of lubricating oil into the third buffer chamber 17a, that is, the cylinder 2, from the first buffer chamber 17b through the communication port 17d so that failures and problems in driving caused by, for example, adhesion of lubricating oil to the operating chamber in the cylinder 2, the heat exchanger 7, and other parts can be reduced.

**[0032]** As illustrated in FIGs. 1 and 3, the first buffer chamber 17b in the crankcase 13 communicates with the second buffer chamber 17c in the crank box 50 through a breather 32. The breather 32 is fixed to the crankcase 13 at a position above the oil level of lubricating oil stored in the crank box 50. The breather 32 is divided into a first compartment 35 communicating with the second buffer chamber 17c and a second compartment 36 communicating with the first buffer chamber 17b, and the first compartment 35 and the second compartment 36 communicate with each other through the communication port 37.

**[0033]** With this structure, lubricating oil that has entered the breather 32 is separated from an operating fluid in the first compartment 35, and only the operating fluid flows into the first buffer chamber 17b in the crankcase 13 through the second compartment 36. Accordingly, it is possible to reliably prevent or reduce entering of lubricating oil into the first buffer chamber 17b, and problems in driving caused by, for example, clogging due to adhesion of lubricating oil to the operating chamber in the cylinder 2, the heat exchanger 7, and other parts and mechanical damage can be avoided. The breather 32 has a configuration in which an orifice is formed by reducing the opening area of a box coupled portion 44 coupled to the crank box 50 to reduce entering of lubricating oil from the crank box 50. In addition, the communication port 37 between the first compartment 35 and the second compartment 36 is also constituted by an orifice having a small opening area.

**[0034]** The breather 32 has a double pipe structure in which an inner case 71 coupled to the crank box 50 by the box coupled portion 44 constituting the orifice is covered with an outer case 72 coupled to the crankcase 13 by a case coupled portion 38 that is open at the outer periphery of the box coupled portion 44. In the breather 32, a double opening portion by the case coupled portion 38 and the box coupled portion 44 is disposed at the lowest portion, and the breather 32 is coupled to the crankcase 13 and the crank box 50. The box coupled portion 44 projects from the coupling portion between the case coupled portion 38 and the crankcase 13 toward the inside of the crankcase 13, and is coupled to the crank box 50. The inner case 71 has a communication port 37 in the highest portion opposite to the box coupled portion 44, and causes the first compartment 35 inside the inner case 71 and the second compartment 36 between the inner case 71 and the outer case 72 to communicate with each other.

**[0035]** The inner case 71 (first compartment 35) in the breather 32 is configured such that the volume of the inner case 71 is larger than the amount of volume change in the buffer chamber 17 by reciprocation movement of the power piston 4. The inner case 71 is also configured such that the uppermost portion of the inner case 71 having the communication port 37 is sufficiently higher than the box coupled portion 44. Accordingly, when an operating fluid including lubricating oil flows into the first compartment 35 from the second buffer chamber 17c in the crank box 50 through the box coupled portion 44, lubricating oil is separated from the operating fluid before reaching the communication port 37. Thus, only the operating fluid flows into the first buffer chamber 17b in the crankcase 13 through the second compartment 36 and the case coupled portion 38.

**[0036]** As illustrated in FIGs. 1 through 3, an oil level gauge 46 is disposed outside the crankcase 13 in order to determine the amount of lubricating oil in the crank box 50. Thus, while the Stirling engine 1 is stopped, the oil level of lubricating oil in the oil level gauge 46 is determined so that the amount of lubricating oil in the crank box 50 inside the crankcase 13 can be determined. At this time, if the oil level of the oil level gauge 46 is lower than a predetermined level, it can be determined not only that the amount of lubricating oil in the crank box 50 is insufficient relative to a necessary minimum amount, but also that a part of lubricating oil in the crank box 50 is dropped in the crankcase 13.

**[0037]** As illustrated in in FIGs. 1 through 3, to detect lubricating oil dropped from the crank box 50 into the crankcase 13, an oil leakage detecting part 47 is disposed at the lowest position of a bottom portion 45 of the crankcase 13. The bottom portion 45 of the crankcase 13 shaped such that the bottom portion 45 tilts toward the lowest portion at which the oil leakage detecting part 47 is disposed in order to caused lubricating oil dropped from the crank box 50 to flow toward the location of the oil leakage detecting part 47. Accordingly, in driving of the Stirling engine 1, lubricating oil that has flowed into the oil leakage detecting part 47 can be detected, and a drop of a part of lubricating oil in the crank box 50 into the crankcase 13 can be detected.

**[0038]** As illustrated in FIGs. 1 through 3, an anti-deformation member 91 for preventing deformation of the power piston yokes 52 and 53 and the bridge 67 is disposed in a coupling portion between the power piston yokes 52 and 53 and the bridge 67. Each of the displacer piston 3, the power piston 4, the displacer yoke 51, the power piston yokes 52 and 53, the rod 66, and the bridge 67, for example, is made of a light metal material or a light-metal alloy material having a light specific gravity, such as aluminium, in order to reduce a load on each part of the Stirling engine 1 by an inertial force of reciprocating movement thereof. On the other hand, the anti-deformation member 91 is made of a metal material, such as iron, having a specific gravity heavier than that of metal materials constituting the power piston yokes 52 and 53 and the bridge 67.

**[0039]** The anti-deformation member 91 made of a material having high rigidity can suppress deformation of, for example, the bridge 67 and the power piston yokes 52 and 53 even when the pressure of the compression chamber 6 in the cylinder 2 increases so that loads on the bridge 67 and the power piston yokes 52 and 53 increase through the power piston 4. Thus, abnormal abrasion and peeling (flaking) in the bearings 58 and 59 that are in slidable contact with the crankshaft guide grooves 52a and 53a of the power piston yokes 52 and 53 can be prevented or reduced.

**[0040]** In addition, since positional displacement of relative positions of the linear motion bearings 64 and 65 relative to the guide shafts 61 and 62 can be reduced, a gap (clearance) between the guide shafts 61 and 62 and the linear motion bearings 64 and 65 can be appropriately maintained so that abnormal abrasion and peeling in the guide shafts 61 and 62 and the linear motion bearings 64 and 65 can be prevented or reduced. In addition, the anti-deformation member 91 is made of a metal material having a linear expansion coefficient (thermal expansion coefficient) smaller than that of a light metal material or a light-metal alloy material, and thus, deformation by heat in the bridge 67 and the power piston yokes 52 and 53 can also be reduced.

**[0041]** In this embodiment, to facilitate more reliable separation of lubricating oil from an operating fluid, the breather 32 may be further divided by a plurality of separators 73 each having a communication hole 74 with a small opening area as illustrated in FIG. 6(a), or the box coupled portion 44 may be provided with a baffle 76 as illustrated in FIG. 6(b), or the communication port 37 between the first compartment 35 and the second compartment 36 may be provided with a filter gauze 77 as illustrated in FIG. 6(c).

3-1. First example of anti-deformation member

**[0042]** A first example of the anti-deformation member

91 disposed in the power takeout device 11 will now be described with reference to FIG. 7. As illustrated in FIG. 7, the anti-deformation member 91 of this example is constituted by anti-deformation frames 92 extending in the axial direction of the crankshaft 12 and disposed across the power piston yokes 52 and 53. More specifically, the two anti-deformation frames 92 sandwich the bridge 67 and are fixed to a proximal end flange portion 67b of the bridge 67 coupled to the power piston yokes 52 and 53 with the longitudinal direction of the frames 92 being in parallel with the axial direction of the crankshaft 12.

**[0043]** The anti-deformation frames 92 made of a metal material having high rigidity, such as an iron material, are coupled to the power piston yokes 52 and 53 of a light metal material having low rigidity through the proximal end flange portion 67b of the bridge 67. Thus, even when the compression chamber 6 in the cylinder 2 comes to be under a high pressure so that a load on the power piston 4 increases, the rigid anti-deformation frames 92 can suppress deformation of the bridge 67 and the power piston yokes 52 and 53.

**[0044]** That is, a load on a center portion of the proximal end flange portion 67b is heavier than a load on an outer peripheral portion of the proximal end flange portion 67b coupled to the power piston yokes 52 and 53. Accordingly, deformation of a structure in which the proximal end flange portion 67b of the bridge 67 deforms to tilt the power piston yokes 52 and 53 tends to occur. However, the structure including the bridge 67 and the power piston yokes 52 and 53 is pressed by the rigid anti-deformation frames 92 so that deformation of the structure can be suppressed.

**[0045]** The anti-deformation frames 92 are made of a metal material having a linear expansion coefficient (thermal expansion coefficient) smaller than that of a light metal material or a light-metal alloy material constituting the bridge 67 and the power piston yokes 52 and 53. Thus, even when the temperatures of the bridge 67 and the power piston yokes 52 and 53 are increased by heat from, for example, the cylinder 2, the displacer piston 3, and the power piston 4, the degree of extension of the anti-deformation frames 92 is reduced so that the amount of shift of the bridge 67 and the power piston yokes 52 and 53 can be reduced.

**[0046]** As described above, deformation of the power piston yokes 52 and 53 is suppressed by the presence of the anti-deformation frames 92, and thus, the outer peripheral surfaces of the bearings 58 and 59 can be uniformly brought into slidable contact with the crankshaft guide grooves 52a and 53a along the axial direction. Thus, partial contact of the bearings 58 and 59 can be prevented or reduced so that the contact pressure on the outer peripheral surfaces of the bearings 58 and 59 can be made uniform. Accordingly, a rotation operation in the power takeout device 11 can be stabilized, and abnormal abrasion and flaking in the sliding portion can be suppressed.

3-2. Second example of anti-deformation member

**[0047]** A second example of the anti-deformation member 91 disposed in the power takeout device 11 will now be described with reference to FIG. 8. As illustrated in FIG. 8, the anti-deformation member 91 of this embodiment is constituted by anti-deformation frames 93 extending in a direction intersecting with the axial directions of the crankshaft 12 and the power piston 4 and disposed along surfaces of the power piston yokes 52 and 53 coupled to the bridge 67. More specifically, the anti-deformation frames 93 sandwich the bridge 67 and are fixed to the proximal end flange portion 67b of the bridge 67 coupled to the power piston yokes 52 and 53 with the longitudinal direction of the frames 93 being in parallel with the longitudinal direction of the crankshaft guide grooves 52a and 53a.

**[0048]** The anti-deformation frames 93 made of a metal material having a small linear expansion coefficient, such as an iron material, extend across both side portions in which the guide shafts 61 and 62 penetrate. Thus, even when the temperatures of the bridge 67 and the power piston yokes 52 and 53 are increased by heat from, for example, the cylinder 2, the displacer piston 3, and the power piston 4, the degree of extension of the anti-deformation frames 93 is reduced so that the amount of extension of the bridge 67 and the power piston yokes 52 and 53 can be reduced.

**[0049]** That is, when the temperature of the metal material constituting the power piston yokes 52 and 53 becomes high, the side portions of the power piston yokes 52 and 53 in which the guide shafts 61 and 62 penetrate expand outward so as to increase its width by heat, and tend to shift the reciprocation guide holes 52b and 53b outward. However, the anti-deformation frames 93 having a small linear expansion coefficient reduce the amount of extension so that the amount of shift of the reciprocation guide holes 52b and 53b can be reduced. Accordingly, a change of relative positions of the linear motion bearings 64 and 65 relative to the guide shafts 61 and 62 can be reduced so that reciprocation operations of the power piston yokes 52 and 53 can be stabilized, and abnormal abrasion and flaking in the sliding portion can be suppressed.

**[0050]** The anti-deformation frames 93 made of a metal material having high rigidity, such as an iron material, are coupled to the power piston yokes 52 and 53 of a light metal material having low rigidity through the proximal end flange portion 67b of the bridge 67. Thus, even when the compression chamber 6 in the cylinder 2 comes to be under a high pressure so that a load on the power piston 4 increases, the rigid anti-deformation frames 93 can suppress deformation of the bridge 67 and the power piston yokes 52 and 53.

**[0051]** In this example, the anti-deformation frames 93 are fixed to the proximal end flange portion 67b of the bridge 67. Alternatively, as illustrated in FIG. 9, for example, the anti-deformation frames 93 may be fixed to side surface portions of the power piston yokes 52 and 53 along the crankshaft guide grooves 52a and 53a or may be fixed to the surfaces of the power piston yokes 52 and 53 opposite to the bridge 67. Similar anti-deformation frames 93 may be fixed to, for example, a side surface portion of the displacer yoke 51 so that the amount of deformation of the displacer yoke 51 can also be reduced and an operation of the power takeout device 11 can be further stabilized.

3-3. Third example of anti-deformation member

**[0052]** A third example of the anti-deformation member 91 disposed in the power takeout device 11 will now be described with reference to FIG. 10. As illustrated in FIG. 10, the anti-deformation member 91 of this example is an anti-deformation ring 94 having a ring shape (annular shape such as a polygon, a circle, or an oval) whose center axis coincides with the axis of the piston, and is disposed around a connection portion to the power piston 4. More specifically, the anti-deformation ring 94 is fixed to the proximal end flange portion 67b of the bridge 67 coupled to the power piston yokes 52 and 53 while being disposed coaxially with the bridge 67 inserted in a hole in a center region of the ring 94.

**[0053]** The anti-deformation ring 94 is a combination of the anti-deformation frames 92 of the first example and the anti-deformation frames 93 of the second example, and can reduce the amount of deformation of the power piston yokes 52 and 53 in a direction parallel to the crankshaft 12 and the amount of deformation of the power piston yokes 52 and 53 in a direction orthogonal to the crankshaft 12 and the power piston 4. That is, the anti-deformation ring 94 is made of a metal material having a high rigidity and a small linear expansion coefficient, such as an iron material, so that not only deformation of the power piston yokes 52 and 53 by a load on the power piston 4 but also thermal deformation of the power piston yokes 52 and 53 can be suppressed.

**[0054]** In this embodiment, in a manner similar to the second example illustrated in FIG. 9, the anti-deformation frames 93 may be fixed to side surface portions of the power piston yokes 52 and 53 along the crankshaft guide grooves 52a and 53a or may be fixed to the surfaces of the power piston yokes 52 and 53 opposite to the bridge 67. Similar anti-deformation frames 93 may be fixed to, for example, a side surface portion of the displacer yoke 51.

(Other Embodiments)

**[0055]** The power takeout device 11 of the embodiment described above is incorporated in the crank box 50 in the crankcase 13. Alternatively, as illustrated in FIG. 11, the crank box 50 may be omitted so that the power takeout device 11 is incorporated in the crankcase 13. The cylinder 2 is coupled to the crankcase 13, and a coupling portion of the crankcase 13 coupled to the cylinder 2 has the bridge insertion hole 68 in which the bridge 67 is inserted and fitted. The guide shafts 60 through 62 are fixed to the crankcase 13, and the displacer yoke 51 and the power piston yokes 52 and 53 reciprocate with predetermined phase differences along the guide shafts 60 through 62, respectively.

**[0056]** The configurations of parts of some aspects of the present invention are not limited to those of the illustrated embodiments, but can be variously changed without departing from the gist of the invention. Although the embodiments described above are directed to the beta-type Stirling engines, Stirling engines of other types such as an alpha type and a gamma type may be employed. The power takeout device is not limited to the Scotch yoke mechanism as described in the embodiments, and may be another structure such as a crosshead mechanism. The power takeout device employs the wet sump lubrication system using lubricating oil in the example illustrated above, but may employ a built-in lubrication system in which a sliding portion is constituted by a grease-enclosed part or an oil-impregnated part, for example.

Reference Signs List

**[0057]**

| | |
|---|---|
| 1 | Stirling engine |
| 2 | cylinder |
| 3 | displacer piston |
| 4 | power piston |
| 5 | expansion chamber |
| 6 | compression chamber |
| 7 | heat exchanger |
| 11 | power takeout device |
| 12 | crankshaft |
| 13 | crankcase |
| 50 | crank box |
| 51 | displacer yoke |
| 52 | power piston yoke |
| 53 | power piston yoke |
| 54 | crankpin |
| 55 | crankpin |
| 56 | crankpin |
| 57 | bearing |
| 58 | bearing |
| 59 | bearing |
| 60 | guide shaft |
| 61 | guide shaft |
| 62 | guide shaft |
| 63 | linear motion bearing |
| 64 | linear motion bearing |
| 65 | linear motion bearing |
| 66 | rod |
| 67 | bridge |
| 91 | anti-deformation member |

## Claims

1. A power takeout device comprising:

    a reciprocating part coupled to a piston; and
    a crankshaft that is in slidable contact with the reciprocating part and rotates by reciprocation of the reciprocating part, wherein
    an anti-deformation member made of a material having a specific gravity heavier than that of the reciprocating part is fixed to the reciprocating part.

2. The power takeout device according to claim 1, wherein
the reciprocating part comprises a plurality of reciprocating parts arranged along the crankshaft, and
the anti-deformation member is disposed across the plurality of reciprocating parts.

3. The power takeout device according to claim 1, wherein the anti-deformation member extends in a direction intersecting an axial direction of each of the crankshaft and the piston.

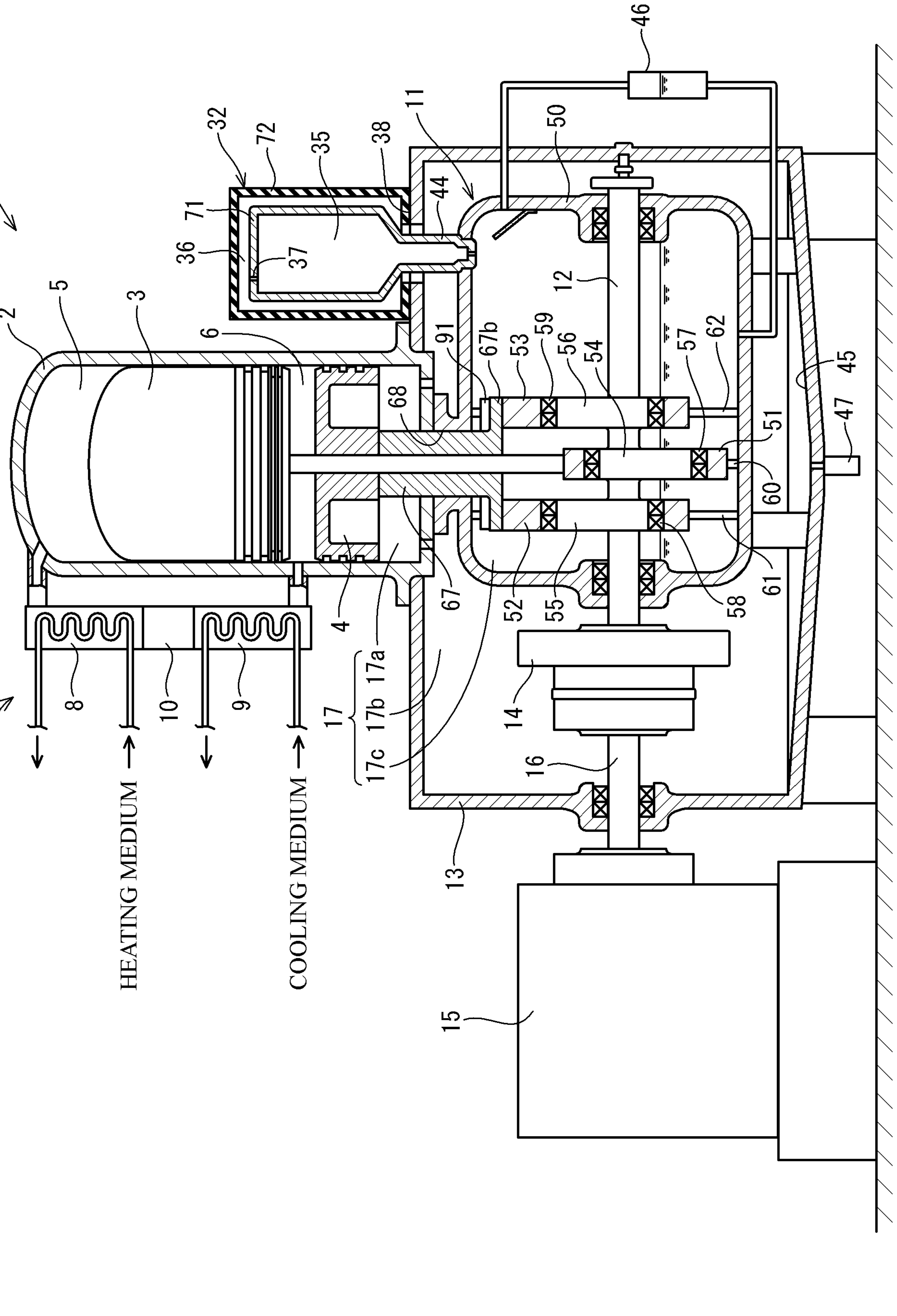
4. The power takeout device according to claim 1, wherein the anti-deformation member has a ring shape whose center axis coincides with an axis of the piston, and is disposed around a connection portion of the reciprocating part connected to the piston.

5. The power takeout device according to claim 1, wherein
the reciprocating part is a yoke portion in which a guide groove penetrates in an axial direction of the crankshaft,
the crankshaft is inserted in the guide groove, and
a portion of the crankshaft fitted in the yoke portion eccentrically rotates based on reciprocation of the yoke portion so that a rotative force is output from the crankshaft.

6. A Stirling engine comprising:

    a piston that reciprocates in a cylinder;
    a heat exchanger that promotes contraction and expansion of an operating fluid in the cylinder, the heat exchanger being configured to alternately repeat contraction and expansion of the operating fluid in the cylinder to cause the piston to reciprocate; and
    the power takeout device according to claim 1, the power takeout device being configured to convert a reciprocation driving force from the piston to a rotative force and output the rotative force.

FIG1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COOLING MEDIUM
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FIG2

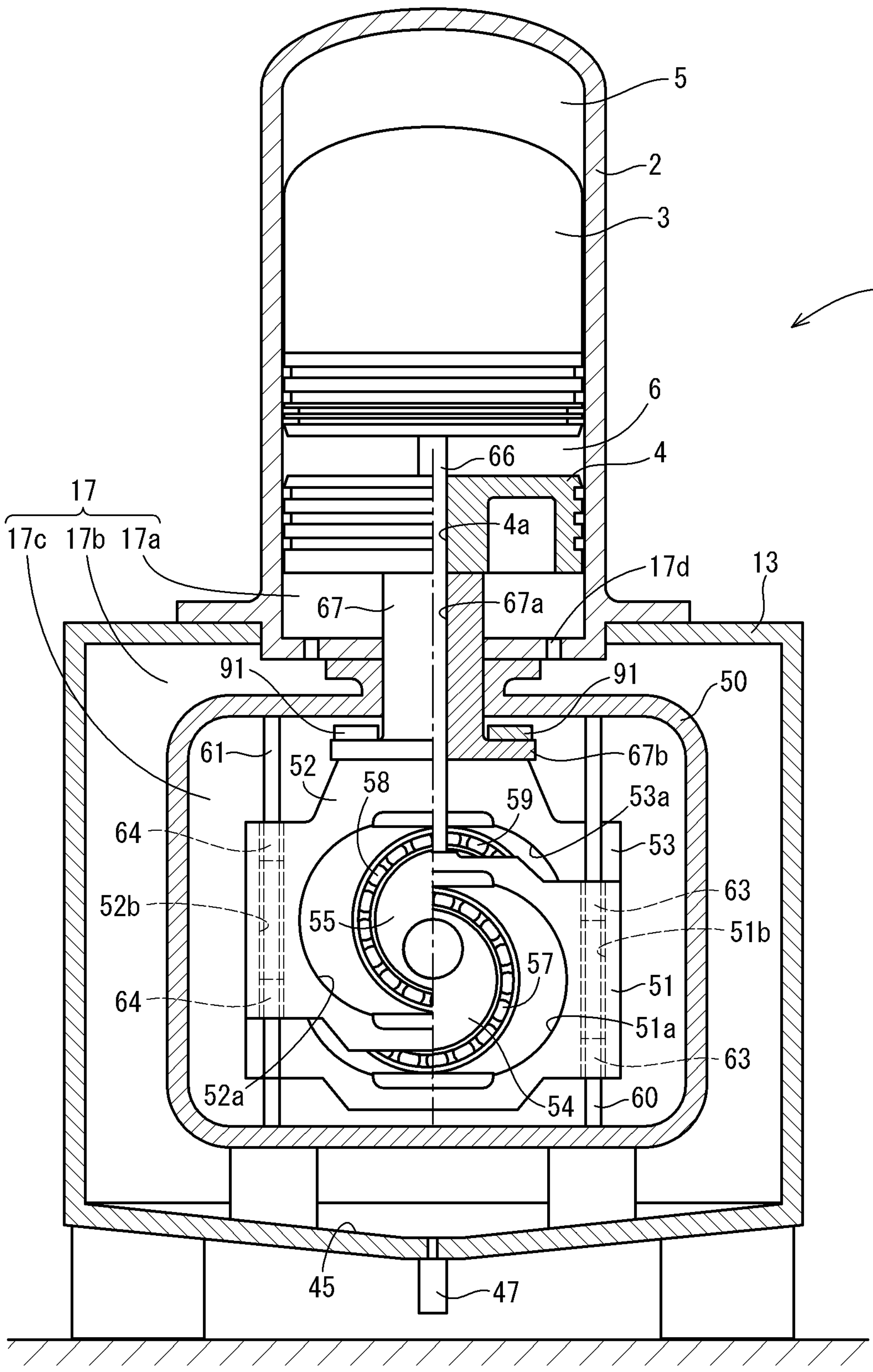
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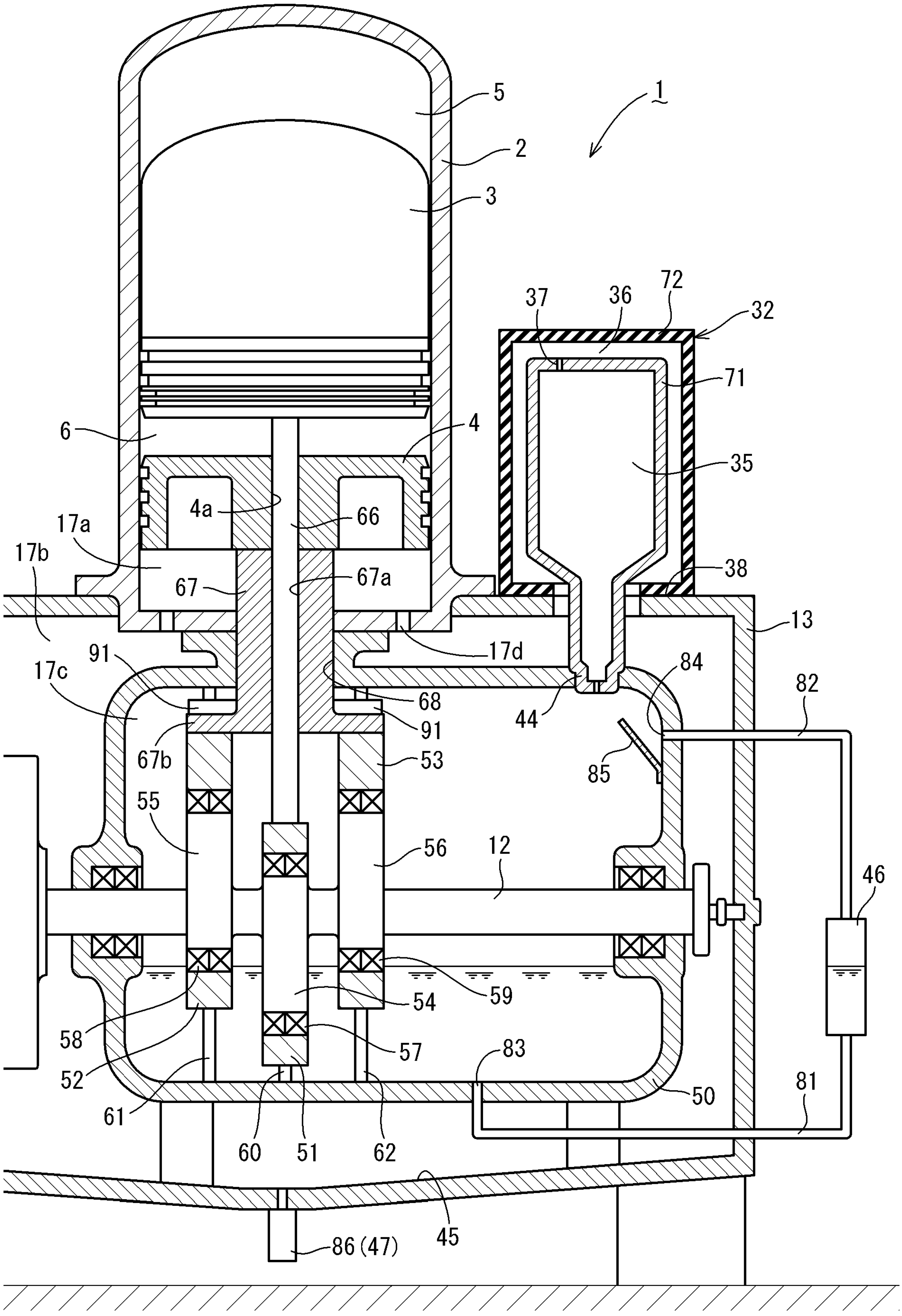
FIG3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17c
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86 (47)

FIG4

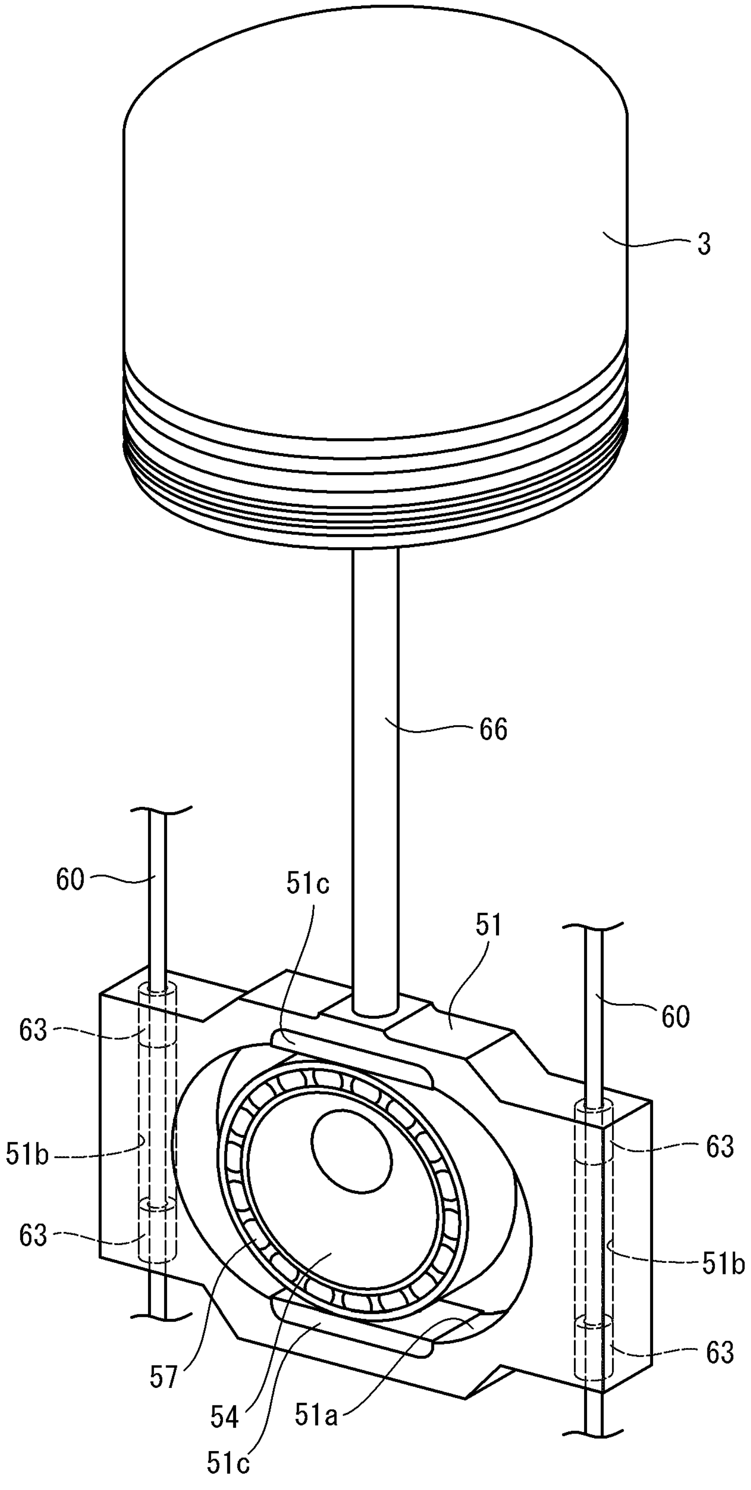

FIG5

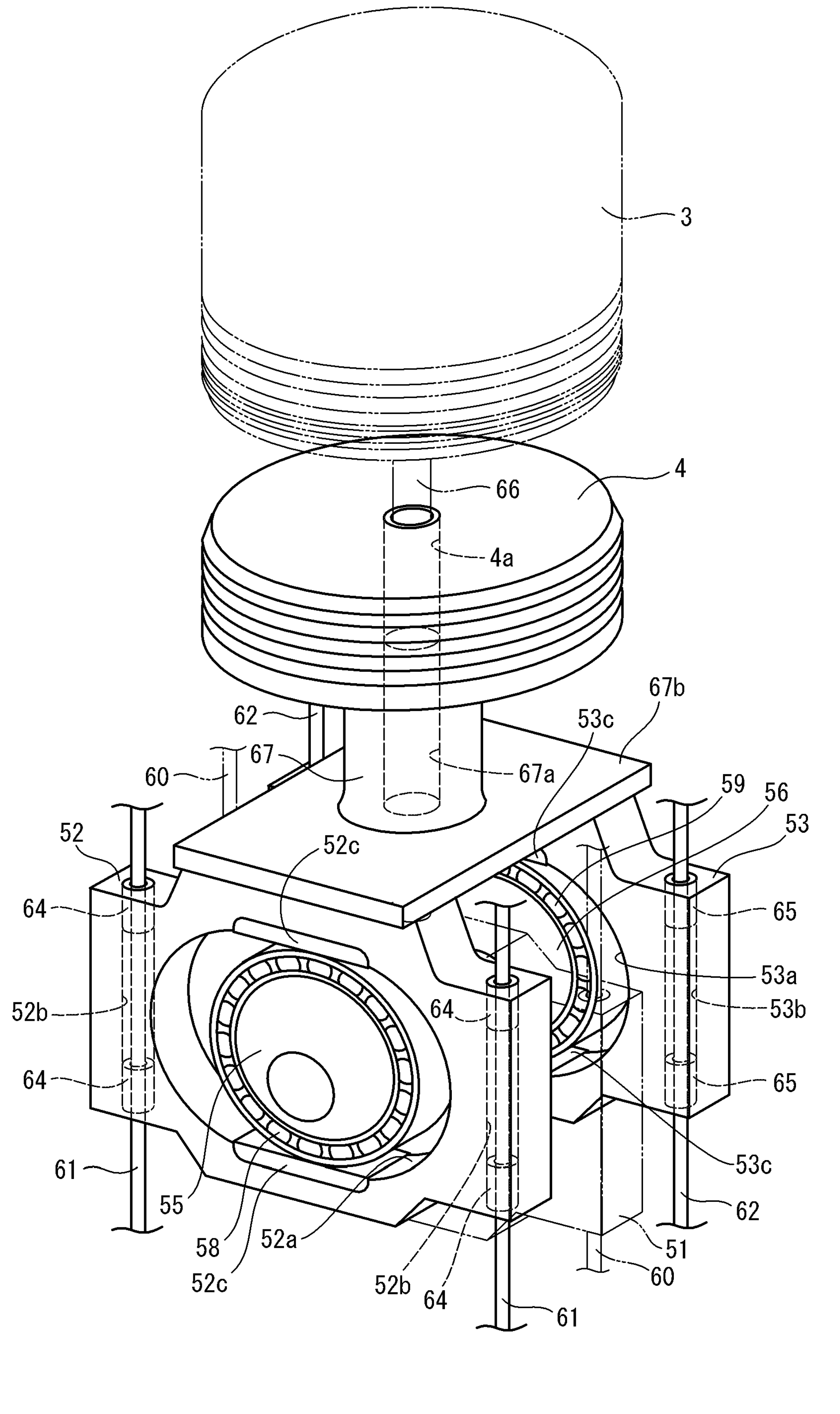
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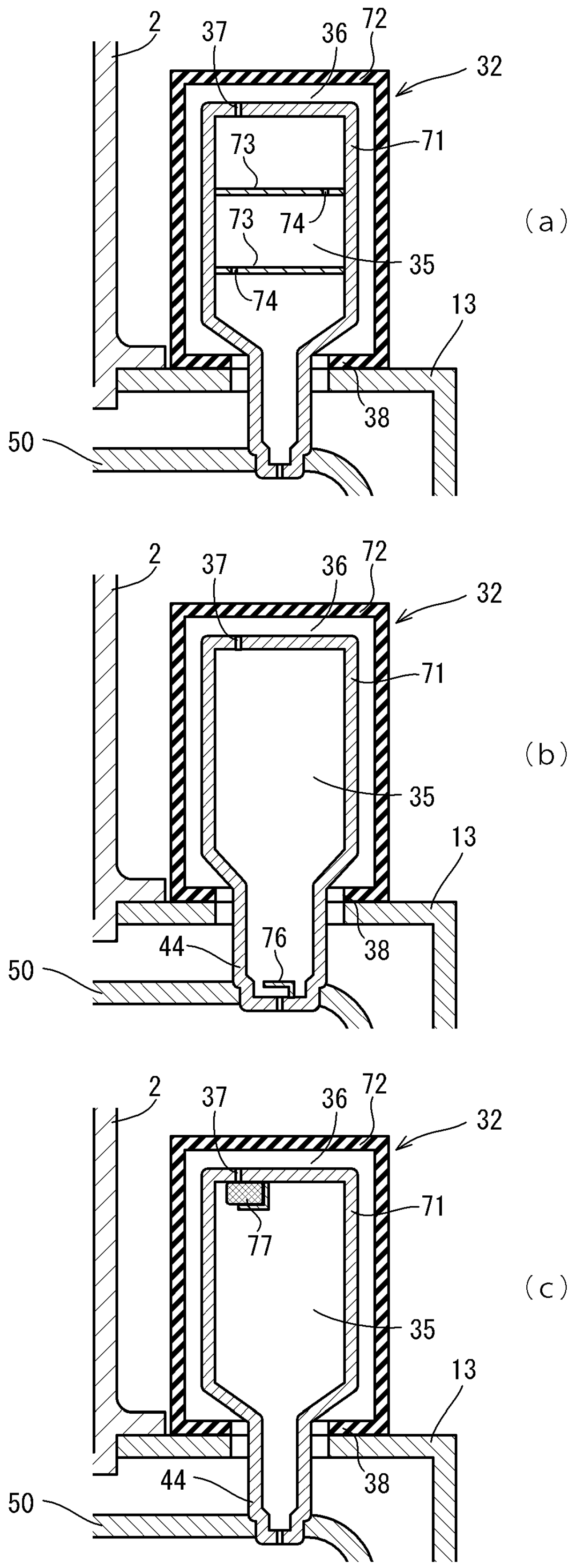
FIG6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(c)

FIG7

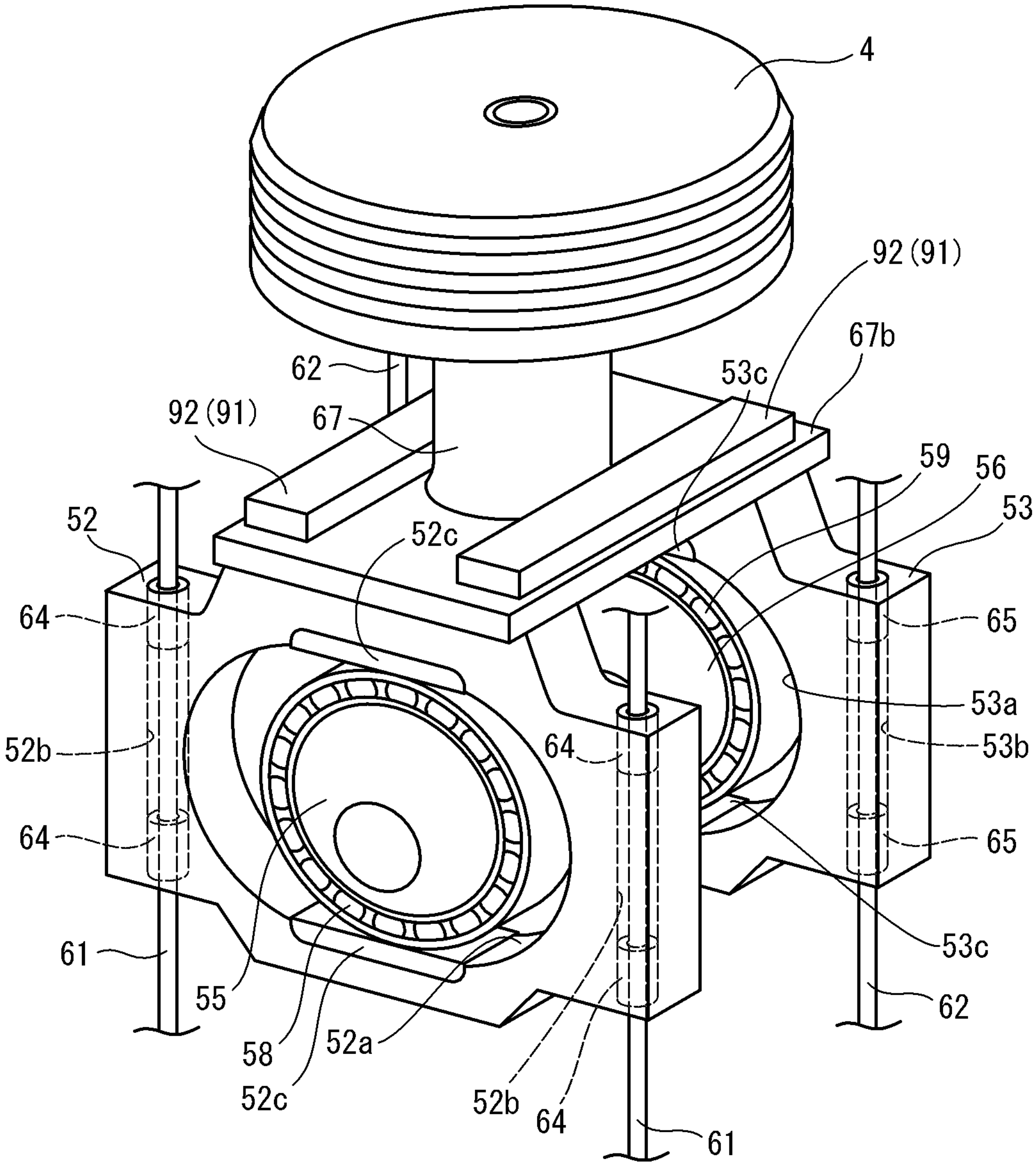
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FIG8

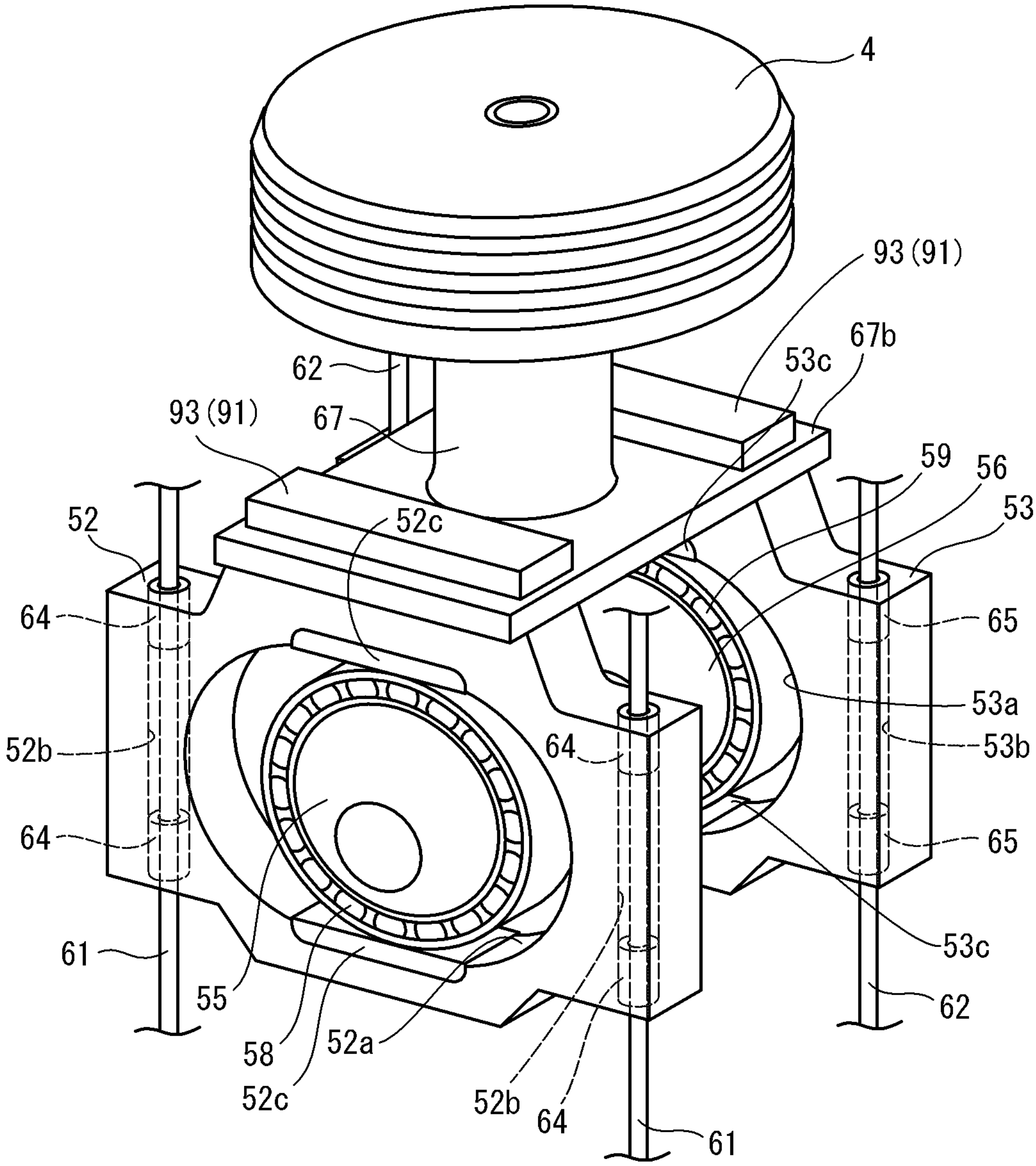
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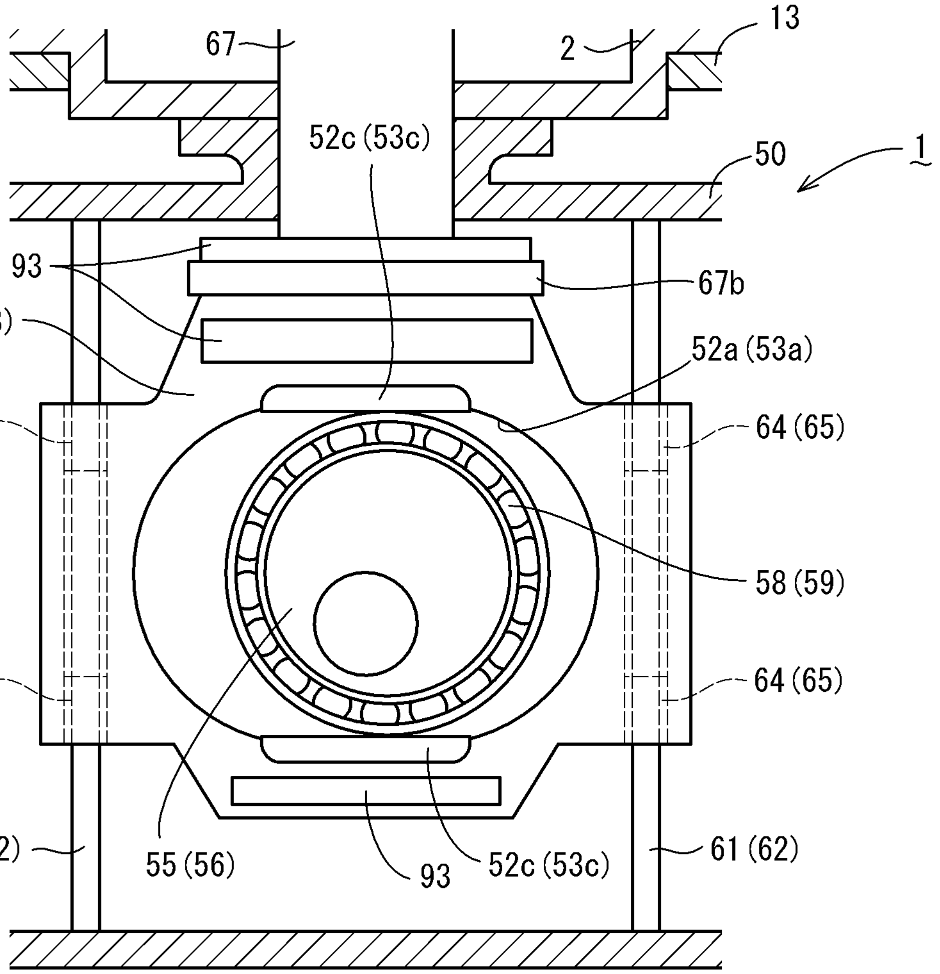
FIG9



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93
52c (53c)
61 (62)

FIG10

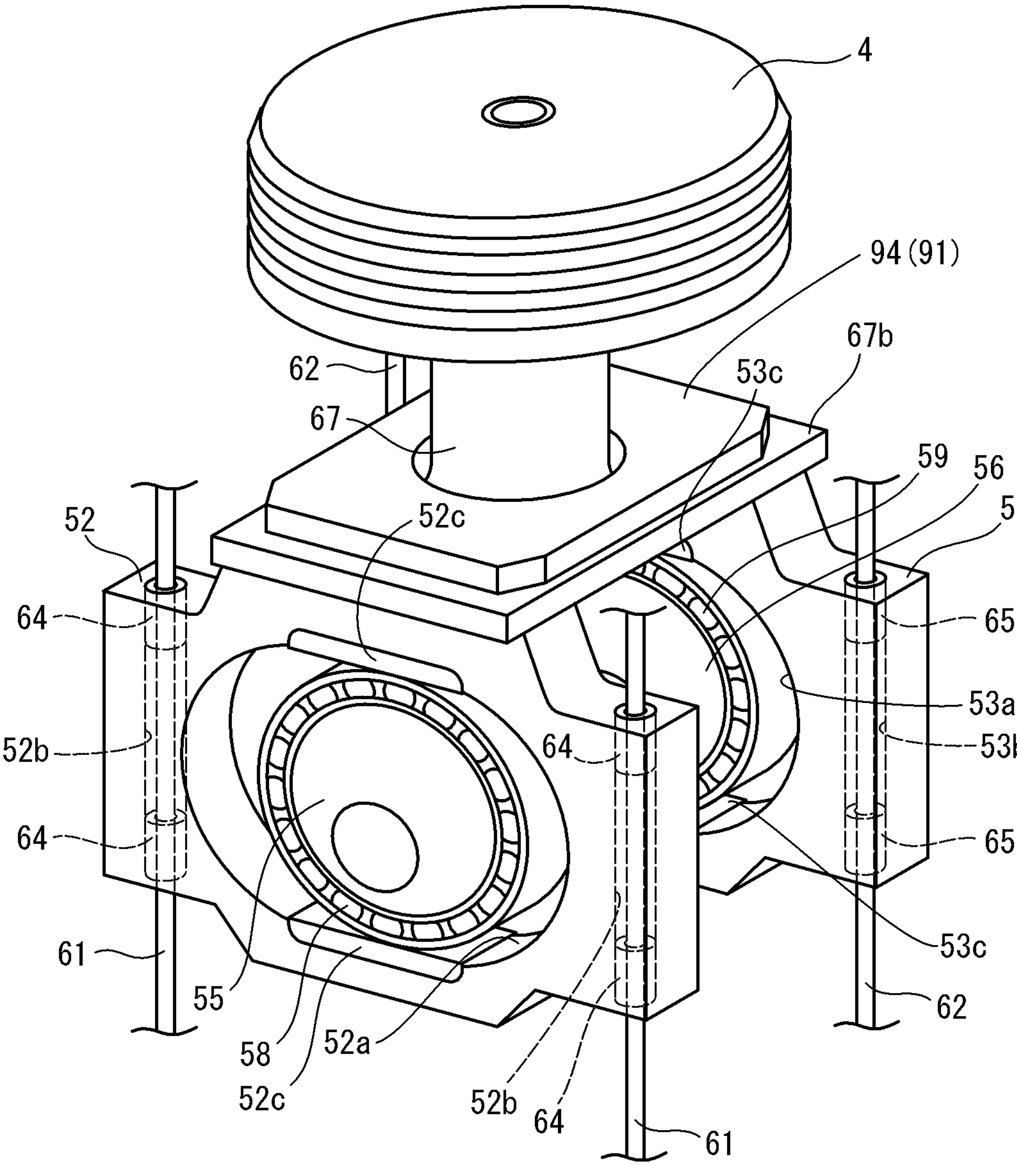
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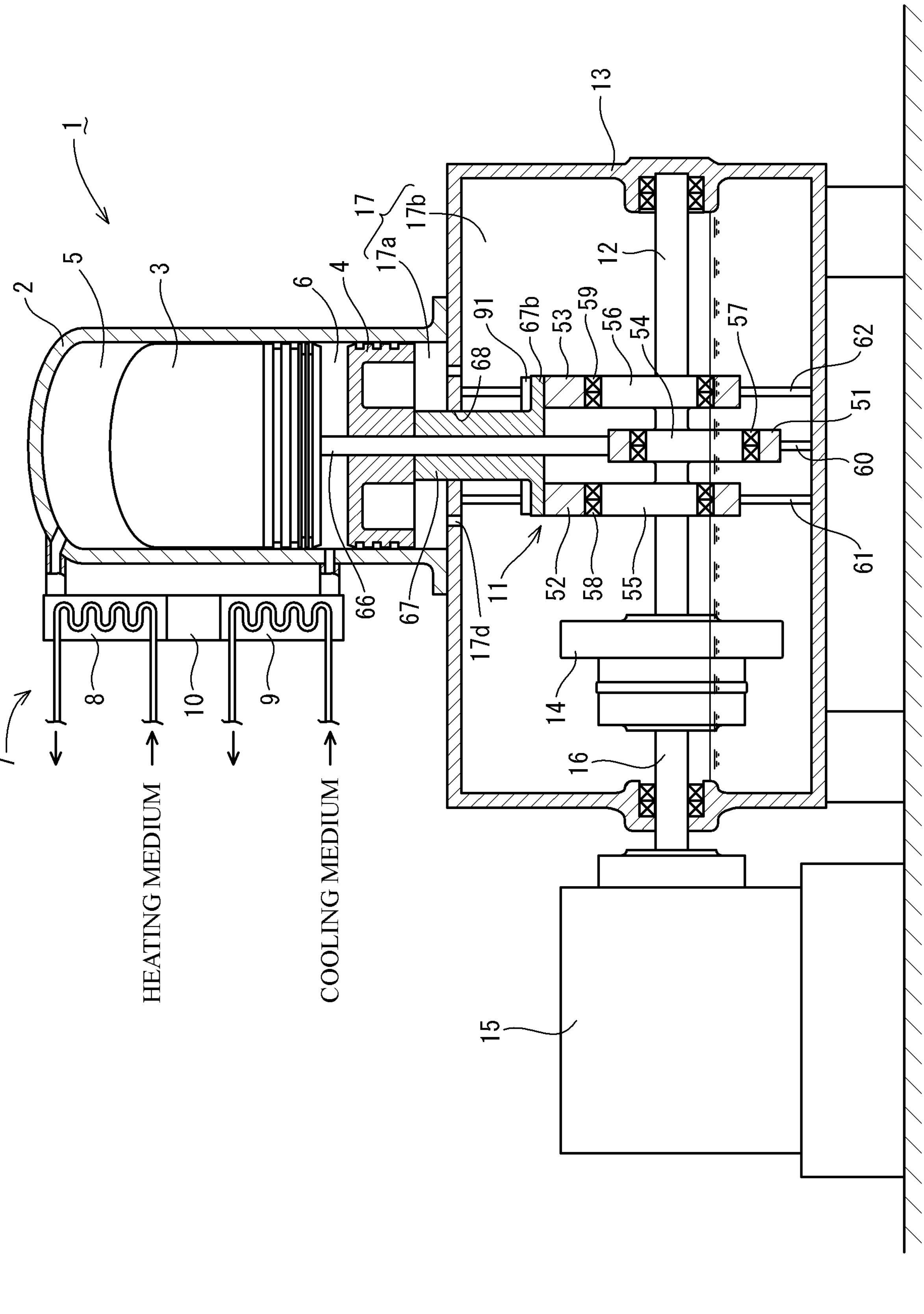
FIG11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HEATING MEDIUM
COOLING MEDIUM

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/034307

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. F02G1/053(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. F02G1/053, F01B9/02, F02B75/32, F16H19/00-31/00, 35/10, 37/00-37/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

| | |
|---|---|
| Published examined utility model applications of Japan | 1922-1996 |
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| Registered utility model specifications of Japan | 1996-2017 |
| Published registered utility model applications of Japan | 1994-2017 |

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI(Derwent Innovation)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br>Y<br>A | JP 2016-504518 A (SCALZO AUTOMOTIVE RESEARCH PTY. LTD.) 12 February 2016, paragraphs [0017], [0026]-[0029], fig. 1, 9-9c & US 2015/0300242 A1, paragraphs [0036], [0046]-[0049], fig. 1, 9-9c & WO 2014/078894 A1 & CN 104919155 A | 1, 3<br>5-6<br>2, 4 |
| Y<br>A | JP 2009-62906 A (ESTIR KK) 26 March 2009, paragraphs [0008]-[0011], fig. 3, 4, 6 (Family: none) | 5-6<br>2, 4 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 27 November 2017 | 12 December 2017 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| Japan Patent Office<br>3-4-3, Kasumigaseki, Chiyoda-ku,<br>Tokyo 100-8915, Japan | Telephone No. |

Form PCT/ISA/210 (second sheet) (January 2015)

## REFERENCES CITED IN THE DESCRIPTION



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- JP S63243574 B **[0004]**