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(54) PUMP DEVICE

(57) [Object] To provide a pump device capable of achieving a further reduction in power consumption.

[Solving Means] A pump device (1) according to an embodiment of the present invention includes a drive motor (M), a first pump unit for evacuation (11) including a first pump chamber and a first piston (21v), and a second pump unit for pressurization (12) including a second pump chamber and a second piston (21c). The second piston (21c) has a phase advanced with a rotational phase difference (φ) of more than 0° and less than 80° with respect to the first piston (21v).

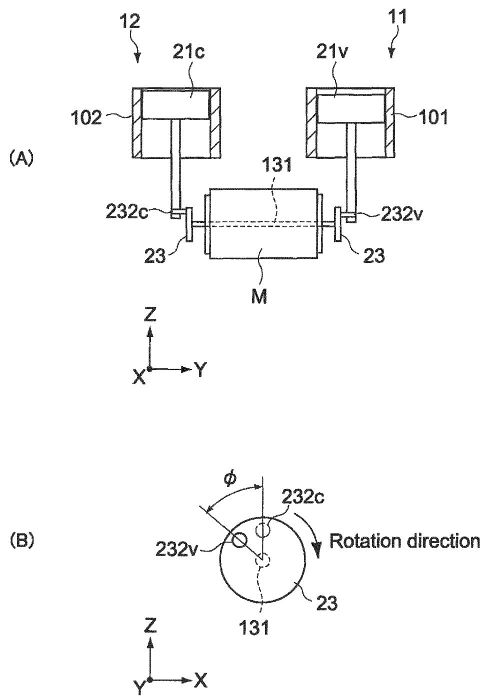


FIG.6

EP 2 832 998 A1

Description

Technical Field

[0001] The present invention relates to a pump device including a vacuum pump and a pressurizing pump.

Background Art

[0002] An oscillating-piston-type pump as a type of vacuum pump is known as a reciprocating-type pump that alternately performs suction and discharge of air inside a pump chamber by a piston reciprocating within a cylinder, and is widely used as a vacuum pump or a pressurizing pump, for example.

[0003] Meanwhile, a complex type of pump device including two pistons for evacuation and for pressurization, which are simultaneously driven by a common motor, is also known. As a method of driving this type of pump device, there are known a method of causing the two pistons to reciprocate in opposite phases and a method of causing the two pistons to reciprocate in the same phase (see, for example, Patent Document 1 below).

[0004] The former method, that is, a drive method of causing both the pistons to reciprocate with rotation phases thereof being made different by 180° has an advantage that a dynamic balance of each pump can be successfully maintained and vibrations of the whole of the pump device can be reduced. On the other hand, the latter method, that is, a drive method of simultaneously moving both the pistons to a top dead center or a bottom dead center can reduce a load fluctuation of a drive source and achieve a stable operation of the pump device.

[0005] Patent Document 1: Japanese Patent Application Laid-open No. Hei 7-310651

Disclosure of the Invention

Problem to be solved by the Invention

[0006] In recent years, there has been a demand for a reduction in power consumption of the pump device, and it is desirable to further reduce power consumption also in the complex-type pump device described above.

[0007] In view of the circumstances as described above, it is an object of the present invention to provide a pump device capable of achieving a further reduction in power consumption.

Means for solving the Problem

[0008] In order to achieve the object described above, according to an embodiment of the present invention, there is provided a pump device including a drive motor, a first pump unit for evacuation, and a second pump unit for pressurization.

[0009] The drive motor includes a first drive shaft and a second drive shaft. The drive motor is configured to be capable of rotating the first drive shaft and the second drive shaft in synchronization about a first axis.

[0010] The first pump unit includes a first piston that reciprocates in a direction of a second axis orthogonal to the first axis by a rotation of the first drive shaft, and a first pump chamber that has an internal pressure changing in accordance with a reciprocating movement of the first piston.

[0011] The second pump unit includes a second piston that reciprocates in the direction of the second axis by a rotation of the second drive shaft, and a second pump chamber that has an internal pressure changing in accordance with a reciprocating movement of the second piston. The second piston has a phase advanced with a rotational phase difference of more than 0° and less than 80° with respect to the first piston.

Brief Description of Drawings

[0012]

[Fig. 1] Fig. 1 is a perspective view of a pump device seen from the front side according to an embodiment of the present invention.

[Fig. 2] Fig. 2 is a perspective view of the pump device seen from the back side.

[Fig. 3] Fig. 3 is a right side view of the pump device.

[Fig. 4] Fig. 4 is a left side view of the pump device.

[Fig. 5] Fig. 5 is a vertical cross-sectional view showing a part of a configuration of a vacuum pump unit and a drive unit of the pump device.

[Fig. 6] Fig. 6 is a schematic view for describing a relationship between an eccentric shaft on the vacuum pump unit side and an eccentric shaft on the pressurizing pump unit side of the pump device, in which (A) is a front view and (B) is a side view seen from the vacuum pump unit side.

[Fig. 7] Fig. 7 shows results of an experiment when the pump device is driven such that the internal pressure of a pump chamber in a vacuum stage and the internal pressure of a pump chamber in a pressurizing stage have the same phase, in which (A) shows time changes in internal pressure of the pump chamber and in piston position in the vacuum stage, (B) shows time changes in internal pressure of the pump chamber and in piston position in the pressurizing stage, and (C) shows a composite waveform of a pressure waveform of the pump chamber in the vacuum stage and a pressure waveform of the pump chamber in the pressurizing stage.

[Fig. 8] Fig. 8 shows results of an experiment when the pump device is driven such that the internal pressure of the pump chamber in the vacuum stage and the internal pressure of the pump chamber in the pressurizing stage have opposite phases, in which (A) shows time changes in internal pressure of the pump chamber and in piston position in the vacuum stage, (B) shows time changes in internal pressure of the pump chamber and in piston position in the pressurizing stage, and (C) shows a composite waveform of a pressure waveform of the pump chamber in the vacuum stage and a pressure waveform of the pump chamber in the pressurizing stage.

[Fig. 9] Fig. 9 shows results of an experiment showing a relationship between a rotational phase difference of a piston of the pressurizing stage with respect to a piston of the vacuum stage and a consumption current of a motor.

Best Mode(s) for Carrying Out the Invention

[0013] The internal pressure of a pump chamber in an oscillating-type piston pump periodically changes by a reciprocating movement of a piston. For example, when the piston moves from a bottom dead center to a top dead center, the volume of the pump chamber decreases and thus the internal pressure transfers to an increasing direction, and when the piston moves from the top dead center to the bottom dead center, the volume of the pump chamber increases and thus the internal pressure transfers to a decreasing direction. At that time, in the case of a vacuum pump, the internal pressure of the pump chamber changes within a pressure range (negative pressure) equal to or lower than an atmospheric pressure, and in the case of a pressurizing pump, the internal pressure of the pump chamber changes within a pressure range (positive pressure) equal to or higher than the atmospheric pressure.

[0014] However, according to an experiment by the inventors of the present invention, it was found that even in the case where the piston for a vacuum pump and the piston for a pressurizing pump are caused to reciprocate in the same phase as described above, the internal pressures of both the pump chambers are synchronized with each other and do not change, and a phase difference in pressure change is caused between both of the pump chambers. Further, it was found that even when the rotation phases of both the pistons are controlled such that changes in internal pressure of both the pump chambers in the vacuum pump and the pressurizing pump have the same phase, the load of a motor is not reduced to a minimum value.

[0015] In this regard, in order to achieve a further reduction in power consumption of a pump device, according to the present invention, the following pump device is configured.

[0016] Specifically, according to an embodiment of the present invention, there is provided a pump device including a drive motor, a first pump unit for evacuation, and a second pump unit for pressurization.

[0017] The drive motor includes a first drive shaft and a second drive shaft. The drive motor is configured to be capable of rotating the first drive shaft and the second drive shaft in synchronization about a first axis.

[0018] The first pump unit includes a first piston that reciprocates in a direction of a second axis orthogonal to the first axis by a rotation of the first drive shaft, and a first pump chamber that has an internal pressure changing in accordance with a reciprocating movement of the first piston.

[0019] The second pump unit includes a second piston that reciprocates in the direction of the second axis by a rotation of the second drive shaft, and a second pump chamber that has an internal pressure changing in accordance with a reciprocating movement of the second piston. The second piston has a phase advanced with a rotational phase difference of more than 0° and less than 80° with respect to the first piston.

[0020] According to an experiment by the inventors of the present invention, in the first pump unit for evacuation, a top dead center of the piston and a pressure peak position of the pump chamber almost coincided with each other, while in the second pump unit for pressurization, a top dead center of the piston and a pressure peak position of the pump chamber did not coincide with each other. In particular, in the second pump unit, it was found that the pump chamber reaches a pressure peak before the piston arrives at the top dead center.

[0021] The rotational phase difference can be appropriately set in the range of more than 0° and less than 80°. For example, a stable reduction effect of power consumption is obtained in the range of 40°±30°, and a further reduction effect of power consumption is obtained in the range of 40°±15°. In such a manner, the rotational phase difference is optimized and thus the pump device can be stably operated at low power consumption.

[0022] Hereinafter, an embodiment of the present invention will be described with reference to the drawings.

[0023] Figs. 1 to 4 are outer appearance views each showing a pump device according to an embodiment of the present invention. Fig. 1 is a perspective view seen from the front side, Fig. 2 is a perspective view seen from the back side, Fig. 3 is a right side view, and Fig. 4 is a left side view.

[0024] A pump device 1 of this embodiment includes a vacuum pump unit 11 (first pump unit) as a vacuum stage, a pressurizing pump unit 12 (second pump unit) as a pressurizing stage, and a drive unit 13 that drives in common the vacuum pump unit 11 and the pressurizing pump unit 12. For example, the pump device 1 is used as a booster blower of gas used in a fuel cell system or as a vacuum and pressurizing pump used in a medical analyzer.

[0025] The vacuum pump unit 11 and the pressurizing pump unit 12 typically have a common configuration and are each configured as an oscillating piston pump in this embodiment.

[0026] The pump device 1 includes a pump case 100 including a first casing 101 that constitutes a part of the vacuum pump unit 11, a second casing 102 that constitutes a part of the pressurizing pump unit 12, and a third casing 103 that constitutes a part of the drive unit 13.

[0027] Fig. 5 is a vertical cross-sectional view showing a part of a configuration of the vacuum pump unit 11 and the drive unit 13. In Fig. 5, an X axis, a Y axis, and a Z axis represent three axis directions that are orthogonal to one another. It should be noted that the pressurizing pump unit 12 has the same configuration as that of the vacuum pump unit 11, and thus the vacuum pump unit 11 will be mainly described here.

[0028] The vacuum pump unit 11 includes the first casing 101, a piston 21, a connecting rod 22 (rod member), and an eccentric member 23.

[0029] The first casing 101 includes a case body 110, a cylinder 111, a pump head 112, and a pump head cover 113. The case body 110, the cylinder 111, the pump head 112, and the pump head cover 113 are mutually integrated so as to be stacked in a Z-axis direction.

[0030] The case body 110 is connected to the third casing 103 that contains a motor M, and includes a through-hole 110h through which the connecting rod 22 passes. The case body 110 includes a fixing portion 110a that fixes a bearing 32, the bearing 32 rotatably supporting a drive shaft 131 of the motor M, and a cylindrical portion 110b that contains a coil 132 of the motor M. The drive shaft 131 is disposed parallel to a Y-axis direction (first axis direction) and rotates about the Y axis by the drive of the motor M. The bearing 32 is disposed between the main body of the motor M and the eccentric member 23.

[0031] The cylinder 111 is disposed between the case body 110 and the pump head 112 and contains the piston 21 so as to be slidable in the Z-axis direction. The pump head 112 is disposed between the cylinder 111 and the pump head cover 113 and includes a suction valve 112a and a discharge valve 112b. The pump head cover 113 is disposed on the pump head 112 and includes a suction chamber 113a that communicates with a suction port 114a and a discharge chamber 113b that communicates with a discharge port 114b. The suction port 114a and the discharge port 114b are provided to a side surface of each of the pump units 11 and 12, the side surfaces of the pump units 11 and 12 being opposed to each other as shown in Figs. 1 and 2.

[0032] The piston 21 has a circular disk shape and is fixed to a first end 221 of the connecting rod 22 via a screw member 25. The piston 21 forms a pump chamber 26 between the piston 21 and the pump head 112. The piston 21 changes the internal pressure of the pump chamber 26 by a reciprocating movement to a direction parallel to the Z-axis direction (second axis direction) within the cylinder 111. The piston 21 alternately performs suction and discharge of air in the pump chamber 26 via the suction valve 112a and the discharge valve 112b, thus performing a predetermined pump action.

[0033] The connecting rod 22 couples the piston 21 and the eccentric member 23 to each other. The connecting rod 22 includes the first end 221 connected to the piston 21 and a second end 222 connected to the eccentric member 23. The first end 221 is formed into a circular form having substantially the same diameter as the piston 21. A circular disk-shaped seal member 24 is attached between the piston 21 and the first end 221. The outer edge of the seal member 24 is folded back to the pump chamber 26 side so as to be capable of sliding on an inner peripheral surface of the cylinder 111.

[0034] It should be noted that in the pressurizing pump unit 12, the outer edge of the seal member is folded back to the pump chamber side, contrary to the example described above.

[0035] A fitting hole 222a into which an eccentric shaft 232 of the eccentric member 23 is fitted is formed in the second end 222 of the connecting rod 22. A bearing 31 that rotatably supports the eccentric shaft 232 is fitted to the fitting hole 222a.

[0036] The eccentric member 23 couples the drive shaft 131 of the motor M contained in the third casing 103 and the connecting rod 22 to each other. The eccentric member 23 includes a base block 230 having a substantially columnar shape. The base block 230 has a surface on the motor M side, to which the drive shaft 131 is coupled, and a surface on the connecting rod 22 side, on which the eccentric shaft 232 is formed. The shaft center of the eccentric shaft 232 is eccentric relative to the drive shaft 131 so as to be biased along with the rotation of the drive shaft 131. The drive shaft 131 is coupled to the base block 230 with a screw 41 fastened to a side peripheral surface of the base block 230.

[0037] A counterweight 51 is attached to the eccentric member 23. The counterweight 51 is fixed to a side peripheral portion of the eccentric member 23 with a fixing screw 42 fastened to the side peripheral surface of the base block 230. The counterweight 51 rotates together with the piston 21 and has an action of cancelling a vibration that is generated when the connecting rod 22 rotates about the eccentric shaft 232 along with the rotation of the drive shaft 131. The counterweight 51 is disposed at a position biased in a direction opposite to the bias direction of the eccentric shaft 232 with respect to the drive shaft 131.

[0038] In the vacuum pump unit 11 configured as described above, the eccentric member 23 rotates about the drive shaft 131 by the drive of the motor M, and thus the eccentric shaft 232 revolves around the drive shaft 131 along a circumference having a radius corresponding to an eccentricity amount from the drive shaft 131. The connecting rod 22 coupled to the eccentric shaft 232 converts the rotation of the drive shaft 131 into a reciprocating movement of the piston 21 within the cylinder 111. Specifically, the piston 21 reciprocates in the Z-axis direction while oscillating in the X-axis direction in Fig. 5 within the cylinder 111. With this, the suction and discharge of air in the pump chamber 26 are alternately performed, and a predetermined evacuation action by the vacuum pump unit 11 is obtained.

[0039] On the other hand, the pressurizing pump unit 12 is configured in the same manner as the vacuum pump unit 11, and the drive shaft 131 also protrudes to the pressurizing pump unit 12 side and is coupled to an eccentric shaft (not shown) of the pressurizing pump unit 12. With this, the pressurizing pump unit 12 is driven by the common motor M simultaneously with the vacuum pump unit 11, and a predetermined pressurizing (boosting) action is performed.

[0040] Here, the vacuum pump unit 11 and the pressurizing pump unit 12 are driven in phases that are different from each other. Specifically, in this embodiment, the piston 21 (second piston) of the pressurizing pump unit 12 is configured such that its phase is advanced with a rotational phase difference of more than 0° and less than 80° with respect to the piston 21 (first piston) of the vacuum pump unit 11.

[0041] In order to provide the rotational phase difference as described above to each piston, in this embodiment, the positions of the eccentric shafts 232 of the respective pumps 11 and 12 are made different. According to this embodiment, since the eccentric members 23 are fixed to the drive shaft 131 by only fastening of the screws 41, it is easy to adjust relative positions of the eccentric shafts 232 of both the pumps 11 and 12.

[0042] Further, since the position of the counterweight fixed to the eccentric member 23 correlates with the bias direction of the eccentric shaft 232, it is also possible to easily determine a rotational phase difference of both the pistons 21 from the outside of the pump device 1. Specifically, as shown in Figs. 1 to 4, a counterweight 52 of the pressurizing pump unit 12 is fixed to a position at which a phase is advanced by the predetermined rotational phase difference (more than 0° and less than 80°) in a rotation direction of the drive shaft 131 (in a clockwise direction about the Y axis in Fig. 3 and in a counterclockwise direction about the Y axis in Fig. 4) with respect to the counterweight 51 of the vacuum pump unit 11.

[0043] Fig. 6(A) and (B) is a schematic view for describing a relationship between an eccentric shaft 232v on the vacuum pump unit 11 side and an eccentric shaft 232c on the pressurizing pump unit 12 side, in which (A) is a front view and (B) is a side view seen from the vacuum pump unit 11 side. As shown in Fig. 6(B), the eccentric shaft 232c on the pressurizing pump side is provided at a position at which a phase is more advanced with a predetermined rotational phase difference φ than the eccentric shaft 232v on the vacuum pump unit 11 side. So, a piston 21v on the vacuum pump unit 11 side and a piston 21c on the pressurizing pump unit 12 side are driven with a shift of a phase difference φ, and the piston 21c arrives at a top dead center earlier than the piston 21v by a time corresponding to the phase difference φ.

[0044] The rotational phase difference φ is set to an appropriate range of more than 0° and less than 80°. With this, as compared to a case where both the pistons 21v and 21c are driven in the same phase (φ=0), the power consumption of the motor M can be reduced. Further, the rotational phase difference φ is set to 40°±15°, and thus the above-mentioned operation of the motor M at low power consumption can be stably maintained.

[0045] Fig. 7(A) shows results of an experiment showing time changes in internal pressure of the pump chamber and in piston position in the vacuum pump, and Fig. 7(B) shows results of an experiment showing time changes in internal pressure of the pump chamber and in piston position in the pressurizing pump. In the figure, solid lines indicate experimental results of the operation in 50 Hz, and broken lines indicate experimental results of the operation in 60 Hz.

[0046] It should be noted that a lifting height of the pump device used in the experiments was set to 40 [kPa (absolute pressure)] in the vacuum stage (vacuum pump) and set to 220 [kPaG (gauge pressure)] in the pressurizing stage (pressurizing pump). The internal pressure of the pump chamber was measured via a tube hermetically inserted into the pump chamber. For the piston position, an output of an accelerometer attached to the lower portion of the connecting rod was used. A cylinder diameter of the pump in each stage was set to φ37 mm, the eccentricity amount of the eccentric shaft to 3.3 mm, and the rotation speed of the motor to about 1400 rpm/1700 rpm-range (50Hz/60Hz). The same holds true for the conditions of experimental results shown in Figs. 8 and 9.

[0047] In the vacuum stage, the internal pressure of the pump chamber is synchronized with the piston position and the internal pressure of the pump chamber and the piston position change in the same phase (Fig. 7(A)), while in the pressurizing stage, the internal pressure of the pump chamber is not synchronized with the piston position and a phase difference is caused therebetween (Fig. 7(B)). More specifically, before the piston of the pressurizing stage arrives at the top dead center, a pressure peak appears in the pump chamber.

[0048] From the experimental results described above, it was found that even when the pistons in the vacuum stage and the pressurizing stage are driven in the same phase, the internal pressures of the pump chambers in the vacuum stage and the pressurizing stage do not change in the same phase and the pump chamber in the pressurizing stage reaches a maximum pressure value earlier than the pump chamber in the vacuum stage.

[0049] Further, since the pump device is configured such that changes in internal pressure of both the pump chambers have opposite phases in the first pump unit and the second pump unit, it was found by the experiments that power consumption of the drive motor can be reduced as compared to a case where the pistons of the respective pumps are driven in the same phase.

[0050] Here, the fact that time changes in internal pressure have opposite phases typically means that pressure waveforms of the both pump chambers have a phase of 180°, but the present invention is not limited thereto and only needs to have such a phase relationship that can be interpreted to be an opposite phase relationship in a practical sense. Here, the opposite phase relationship in the practical sense can be defined as, for example, a phase relationship in which power consumption becomes smaller than in a case where both the pistons are driven in the same phase.

[0051] In the case where the pump device is constituted with a predetermined phase difference between the piston of the pressurizing stage and the piston of the vacuum stage such that the pressure waveform of the internal pressure of the pump chamber in the vacuum stage and the pressure waveform of the internal pressure of the pump chamber in the pressurizing stage have the same phase, the piston of the pressurizing stage is set to have a rotational phase difference that is advanced by more than 180° and less than 260° with respect to the piston of the vacuum stage. The results of an experiment when the rotational phase difference is 220° are shown in Fig. 7(A) to (C). Fig. 7(C) shows a composite waveform of the pressure waveform of the pump chamber in the vacuum stage and the pressure waveform of the pump chamber in the pressurizing stage.

[0052] On the other hand, in the case where the pump device is constituted with a predetermined phase difference between the piston of the pressurizing stage and the piston of the vacuum stage such that the pressure waveform of the internal pressure of the pump chamber in the vacuum stage and the pressure waveform of the internal pressure of the pump chamber in the pressurizing stage have opposite phases, the piston of the pressurizing stage is set to have a rotational phase difference that is advanced by more than 0° and less than 80° with respect to the piston of the vacuum stage. The results of an experiment when the rotational phase difference is 40° are shown in Fig. 8(A) to (C). Fig. 8(A) shows time changes in internal pressure of the pump chamber and in piston position in the vacuum stage. Fig. 8(B) shows time changes in internal pressure of the pump chamber and in piston position in the pressurizing stage. Further, Fig. 8(C) shows a composite waveform of the pressure waveform of the pump chamber in the vacuum stage and the pressure waveform of the pump chamber in the pressurizing stage.

[0053] Subsequently, Fig. 9 shows results of an experiment showing a relationship between a rotational phase difference of the piston of the pressurizing stage with respect to the piston of the vacuum stage and a consumption current of the motor. The rotational phase difference in the horizontal axis indicates a phase advance angle of the piston of the pressurizing stage with respect to the piston of the vacuum stage (phase angle by which the piston on the pressurizing side is advanced more than the piston on the vacuum side in the rotation direction of the drive shaft).

[0054] As shown in Fig. 9, it is found that a current value of the motor changes in accordance with the rotational phase difference φ of the piston of the pressurizing stage with respect to the piston of the vacuum stage. This is thought to be related to a balance of a pressure change between the pump chambers in the respective stages.

[0055] In this experimental example, the rotational phase difference φ at the lowest current value is 40°, and the pressure waveforms of the pump chambers in the respective stages at that time have an opposite phase relationship as shown in Fig. 8(A) and (B). In this case, a composite waveform of the internal pressures of the pump chambers in the respective stages is as shown in Fig. 8(C), and the internal pressures of the pump chambers in the respective stages are canceled by each other. As a result, it is thought that the consumption current of the motor becomes the minimum.

[0056] In contrast to this, in drive conditions in which the internal pressures of the pump chambers in the respective stages have the same phase (the rotational phase difference of the piston in the pressurizing stage with respect to the piston in the vacuum stage is +220°), the internal pressures of the pump chambers in the respective stages are superimposed on each other as shown in Fig. 7(C), and thus a periodic load fluctuation is caused in the motor. It is thought that this leads to an increase in consumption current value.

[0057] Further, as shown in Fig. 9, in the range of more than 0° and less than 80° of the rotational phase difference φ, it was found that the drive current of the motor can be reduced as compared with a case where the rotational phase difference φ is 0° (360°), in the power supply frequency of 50 Hz or 60 Hz. In particular, in the range of 40°±30° of the rotational phase difference φ, the current value can be constantly reduced more than the case where φ=0° irrespective of a difference in power supply frequency. Further, in the range of 40°±15 of the rotational phase difference φ, the power consumption could be effectively reduced more, and the current value could be reduced by about 4.1% in the case of 50 Hz and by about 2.2% in the case of 60 Hz.

[0058] Furthermore, the phase difference φ is set to 40°±15°, and thus it is possible to reduce not only the amount of current consumption but also vibrations generated when the pump device 1 is driven. According to the experiments of the inventors of the present invention, for example, when φ=40°, it was found that a vibration acceleration in each of the X-, Y- and Z-axis directions (see Fig. 1) can be reduced as compared with the case where the pistons of the vacuum stage and the pressurizing stage have the same phase (φ=0°). This vibration reducing effect was found in each of the power supply frequencies of 50 Hz and 60 Hz.

[0059] Hereinabove, the embodiment of the present invention has been described, but the present invention is not limited to the embodiment described above and can be variously modified without departing from the gist of the present invention.

[0060] For example, in the embodiment described above, the vacuum pump unit 11 and the pressurizing pump unit 12 that constitute the pump device are each constituted of an oscillating-type piston pump. However, the present invention is not limited to this and each pump may be constituted of another reciprocating-type piston pump such as a diaphragm pump.

[0061] Further, in the embodiment described above, the pump device including a single drive motor and two pump units has been described as an example, but the present invention is also applicable to a pump device including a plurality of sets (for example, two sets) of pump units each constituted of the drive motor and the two pump units.

Description of Reference Symbols

[0062]

1	pump device
11	vacuum pump
12	pressurizing pump
21, 21v, 21c	piston
26	pump chamber
51, 52	counterweight
131	drive shaft
232, 232v, 232c	eccentric shaft
M	motor

Claims

1. A pump device, comprising:

a drive motor including a first drive shaft and a second drive shaft and being capable of rotating the first drive shaft and the second drive shaft in synchronization about a first axis;

a first pump unit for evacuation, including a first piston that reciprocates in a direction of a second axis orthogonal to the first axis by a rotation of the first drive shaft, and a first pump chamber that has an internal pressure changing in accordance with a reciprocating movement of the first piston; and

a second pump unit for pressurization, including a second piston that reciprocates in the direction of the second axis by a rotation of the second drive shaft, and a second pump chamber that has an internal pressure changing in accordance with a reciprocating movement of the second piston, the second piston having a phase advanced with a rotational phase difference of more than 0° and less than 80° with respect to the first piston.

2. The pump device according to claim 1, wherein the rotational phase difference is 40°±15°.

3. The pump device according to claim 1, wherein the first pump unit further includes a first counterweight that rotates about the first drive shaft together with the first piston, and the second pump unit further includes a second counterweight that rotates about the second drive shaft together with the second piston, with the rotational phase difference with respect to the first counterweight.

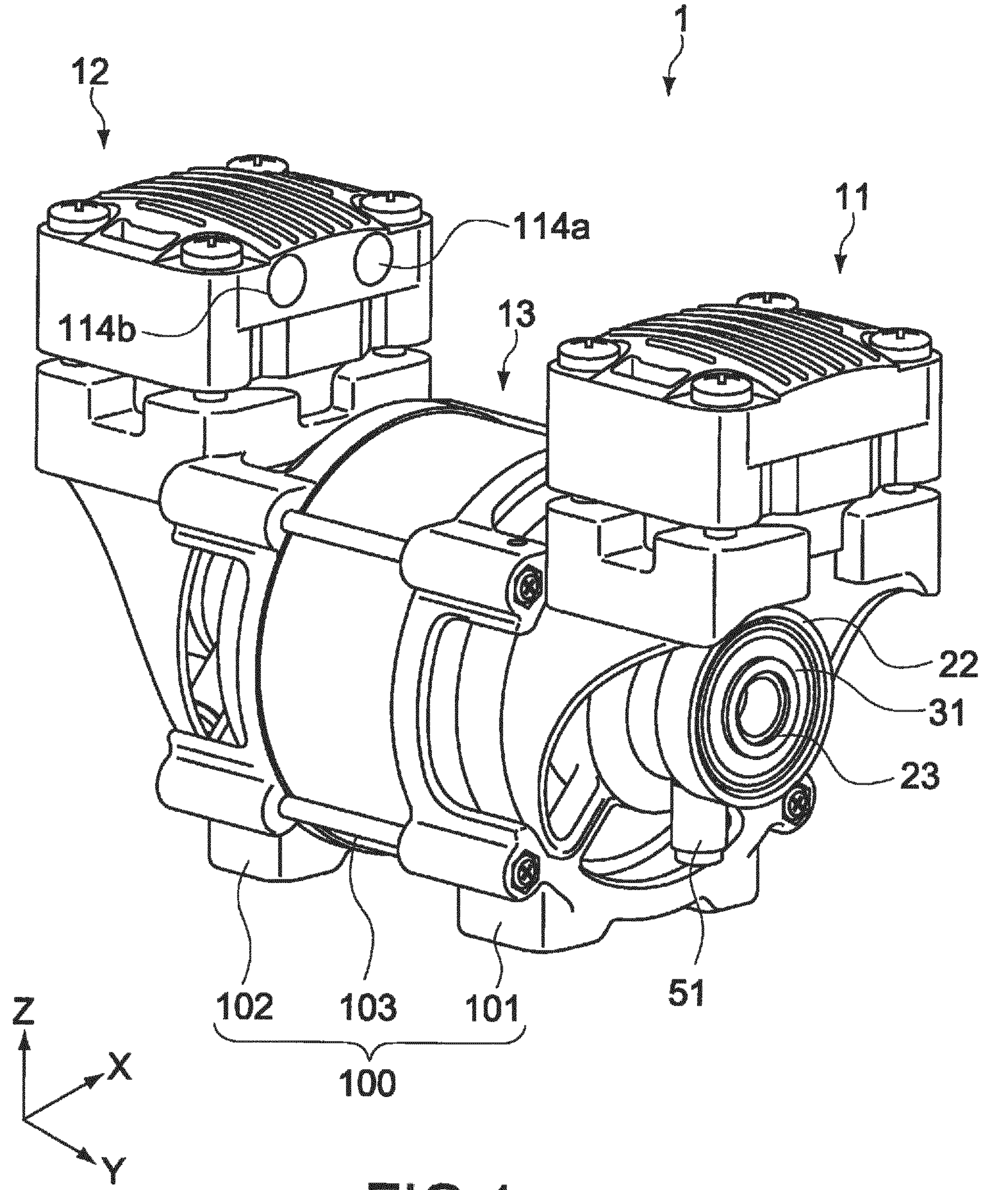


FIG.1

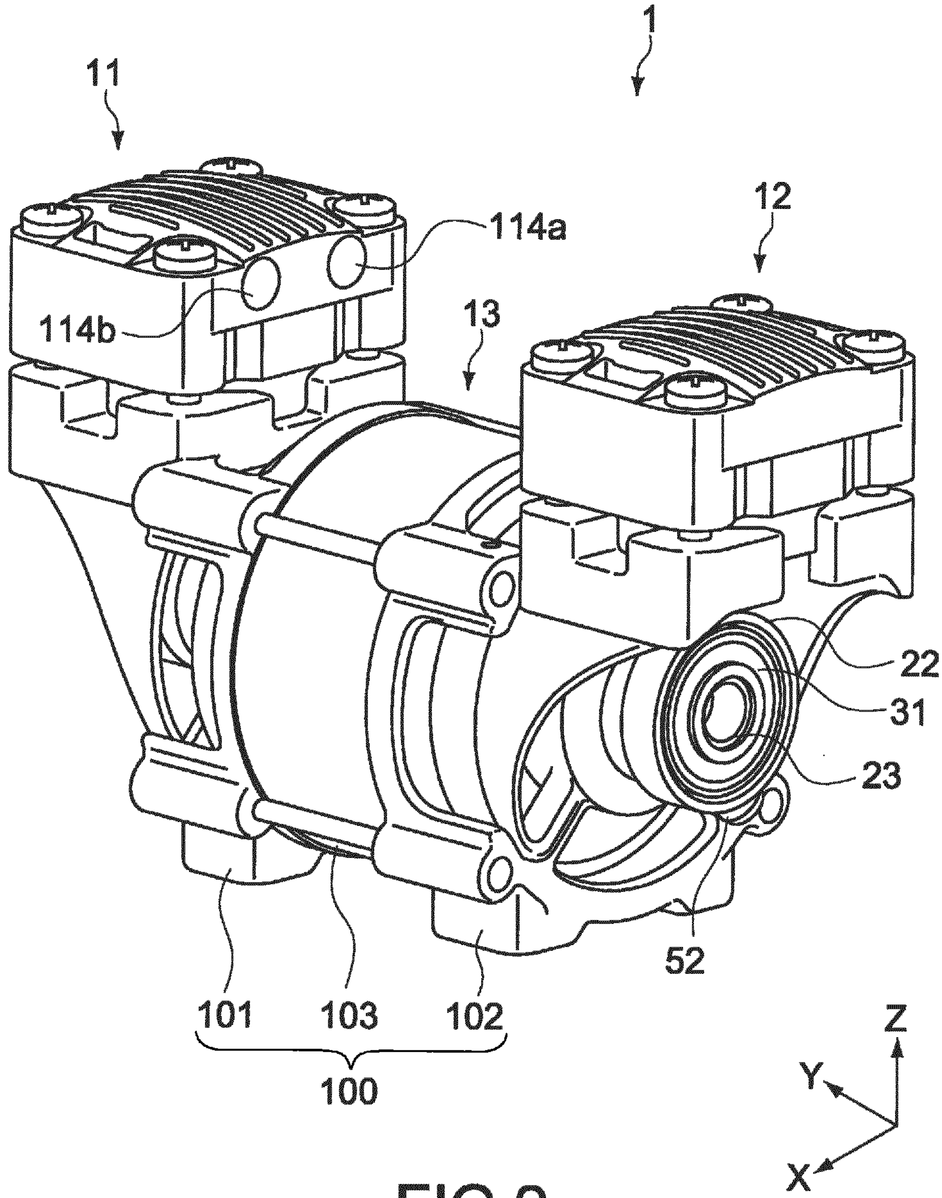


FIG.2

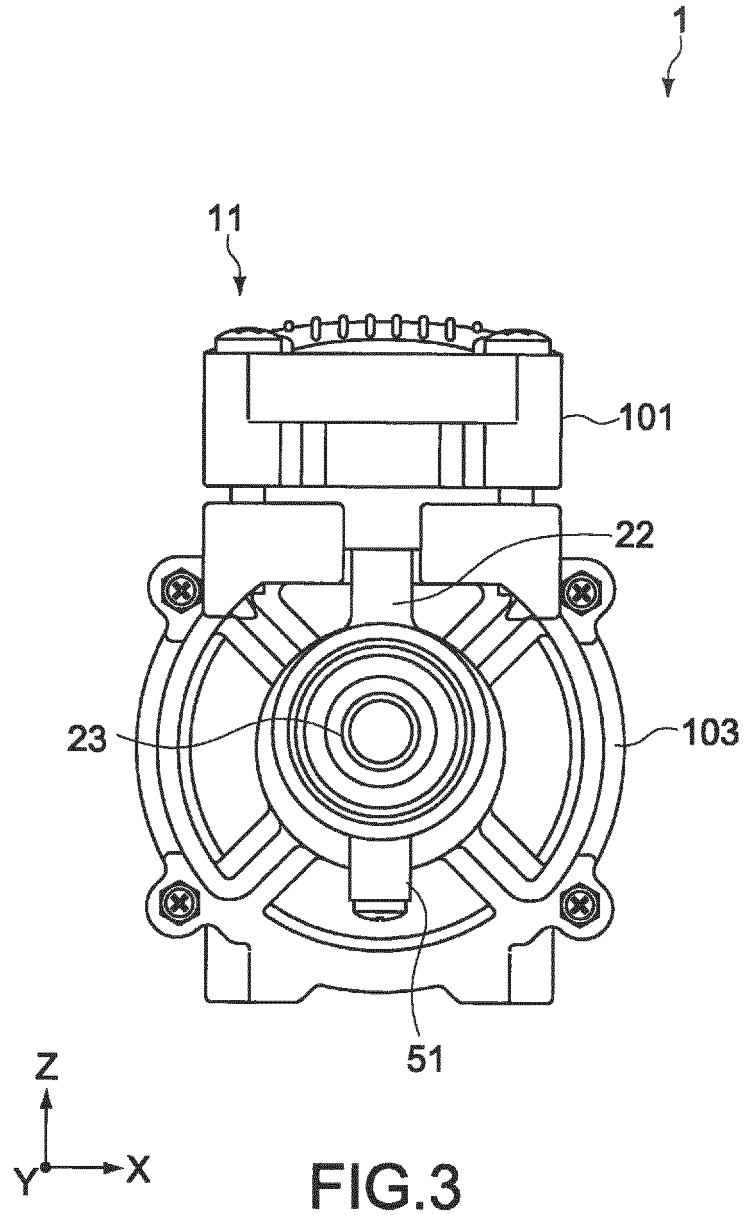


FIG.3

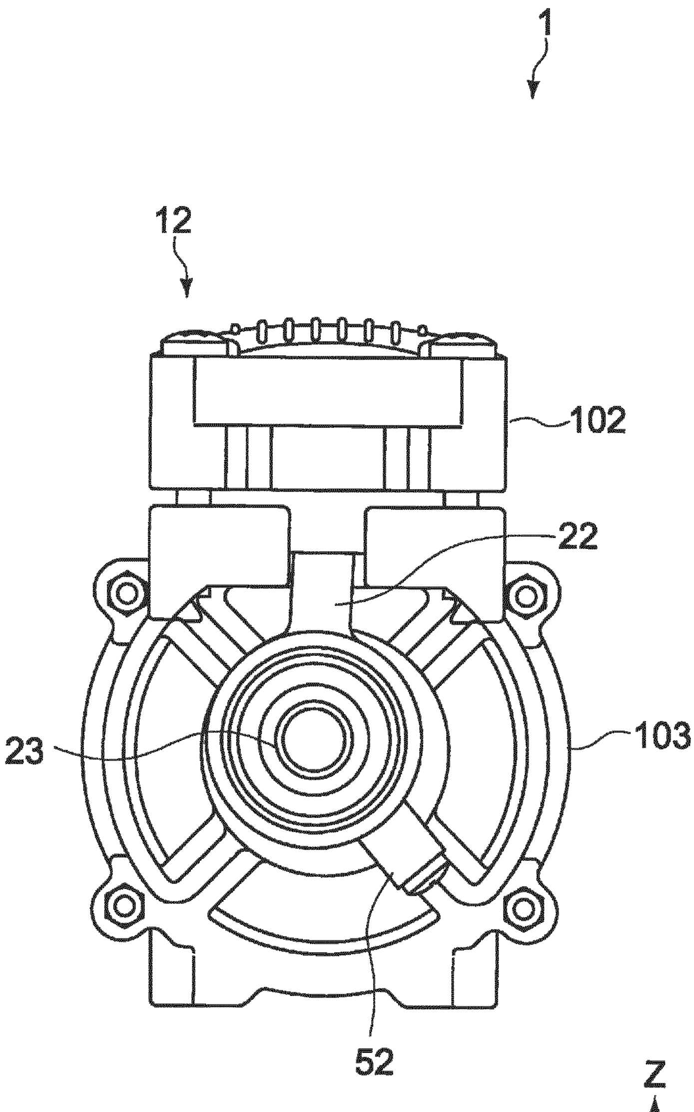
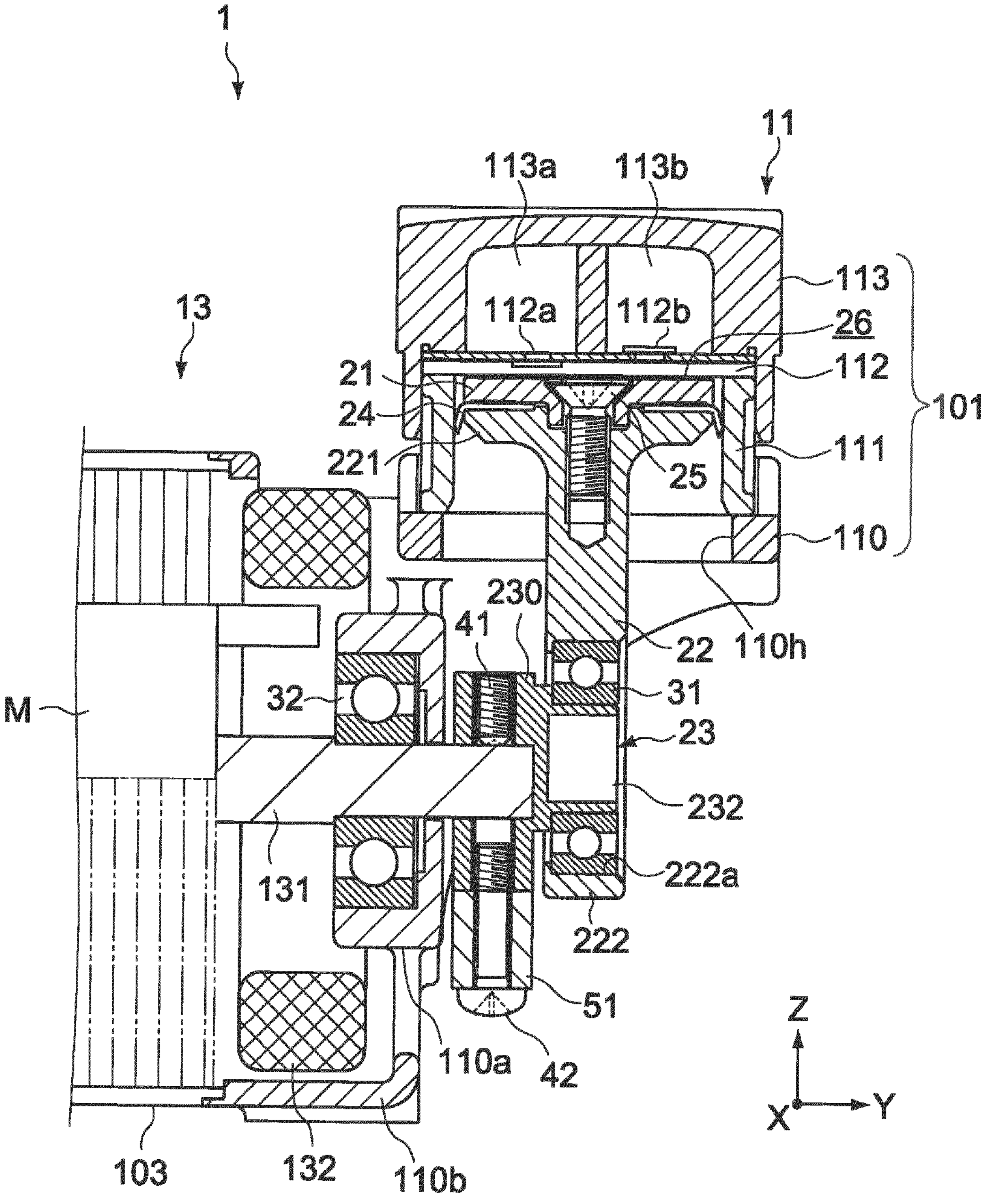


FIG.4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Y
103
132
110b

FIG.5

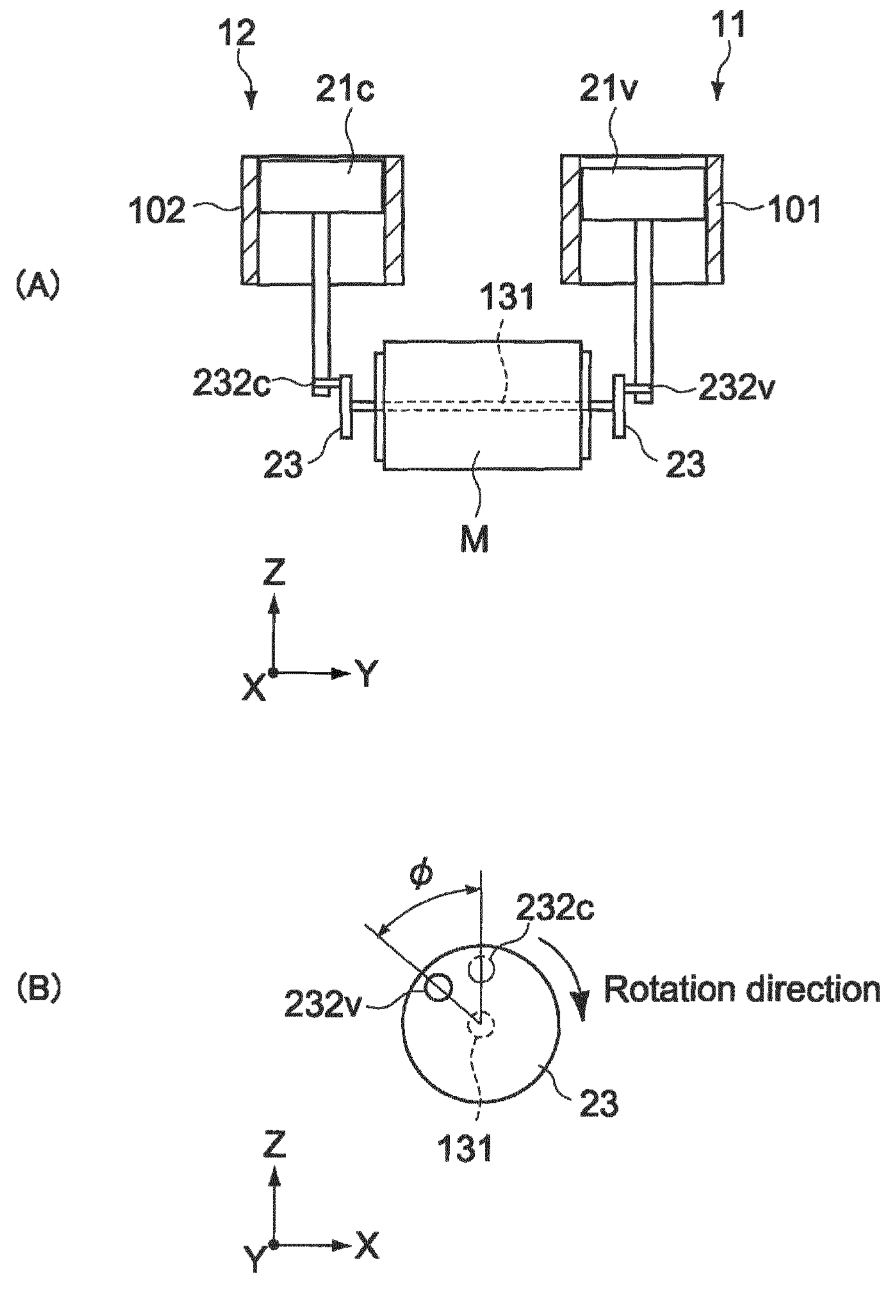

(A)
12
11
21c
21v
102
101
131
232c
232v
23
23
M
Z
X
Y
(B)
ϕ
232c
232v
Rotation direction
23
131
Z
Y
X

FIG.6

(A)

(B)

(C)

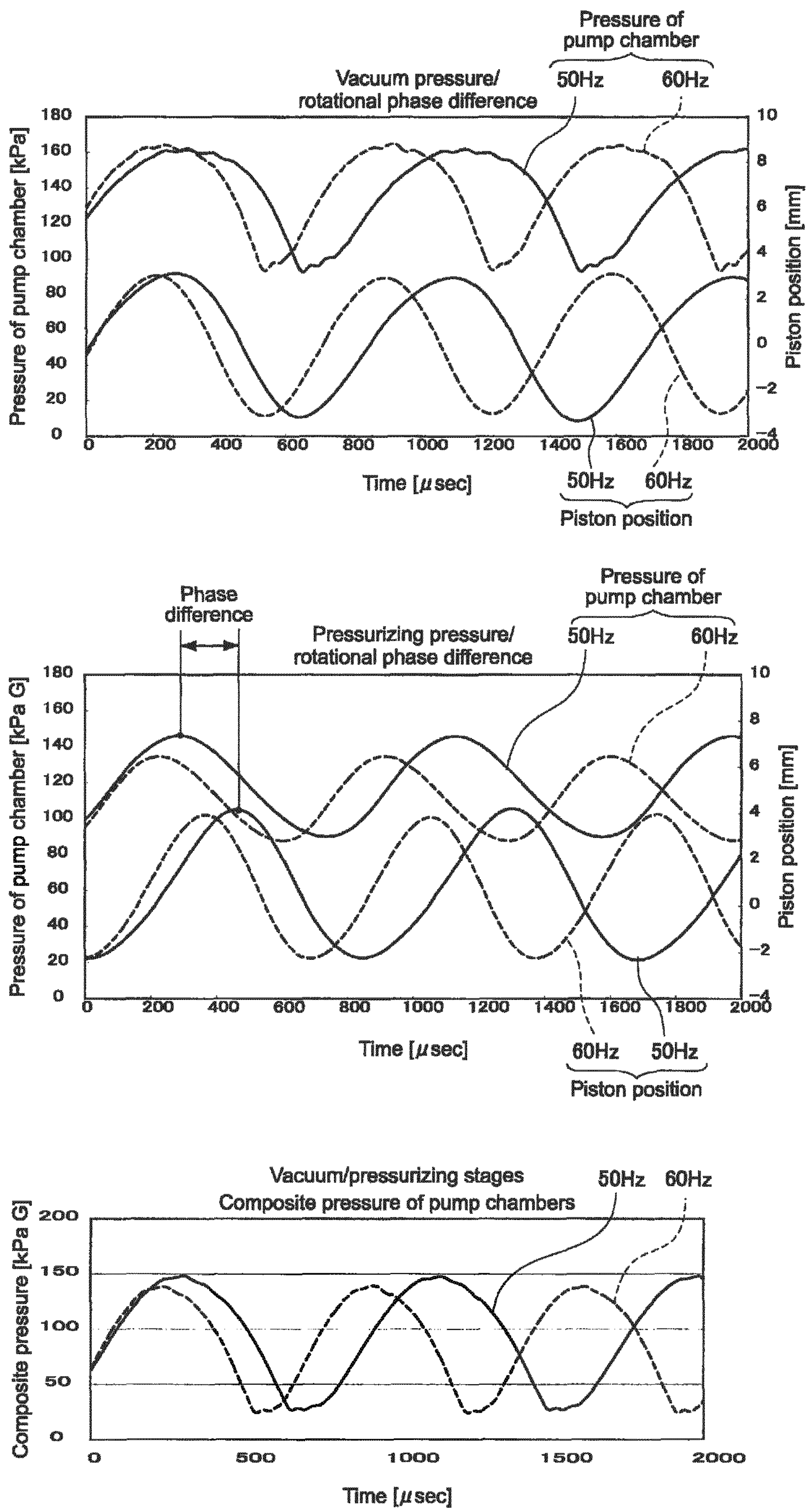
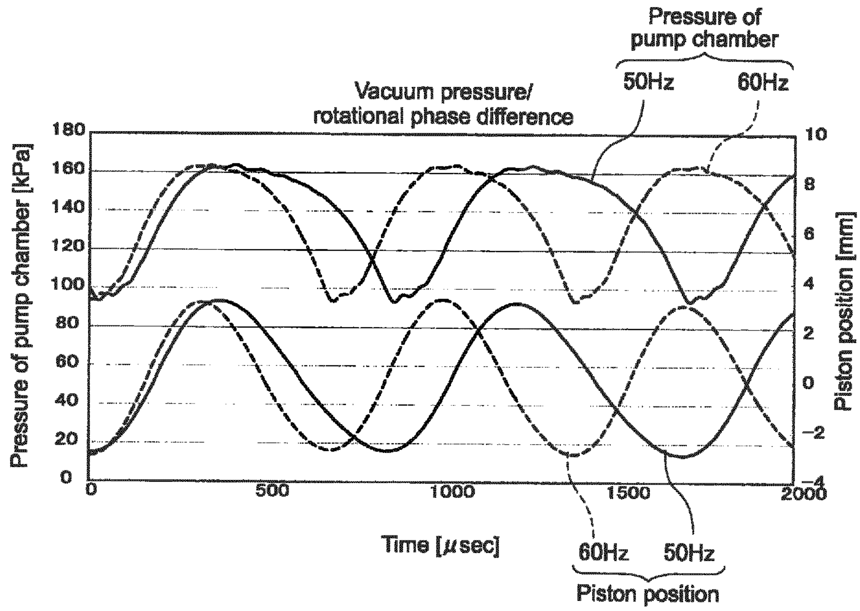
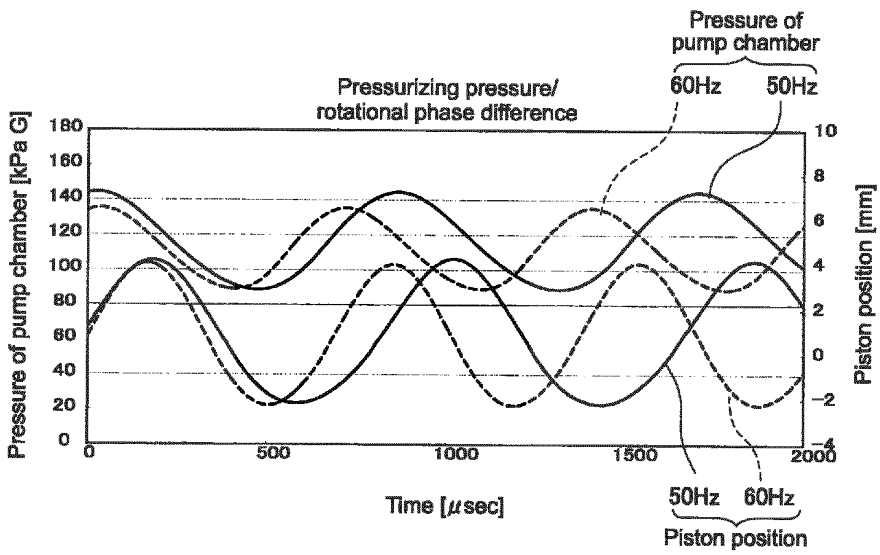

Pressure of pump chamber
Vacuum pressure/ rotational phase difference
50Hz
60Hz
Pressure of pump chamber [kPa]
Piston position [mm]
Time [μsec]
Piston position
Phase difference
Pressurizing pressure/ rotational phase difference
Pressure of pump chamber [kPa G]
Vacuum/pressurizing stages
Composite pressure of pump chambers
Composite pressure [kPa G]

FIG.7

(A)


Pressure of
pump chamber
50Hz
60Hz
Vacuum pressure/
rotational phase difference
Pressure of pump chamber [kPa]
180
160
140
120
100
80
60
40
20
0
Piston position [mm]
10
8
6
4
2
0
−2
−4
0
500
1000
1500
2000
Time [μsec]
60Hz
50Hz
Piston position

(B)


Pressure of
pump chamber
60Hz
50Hz
Pressurizing pressure/
rotational phase difference
Pressure of pump chamber [kPa G]
180
160
140
120
100
80
60
40
20
0
Piston position [mm]
10
8
6
4
2
0
−2
−4
0
500
1000
1500
2000
Time [μsec]
50Hz
60Hz
Piston position

(C)

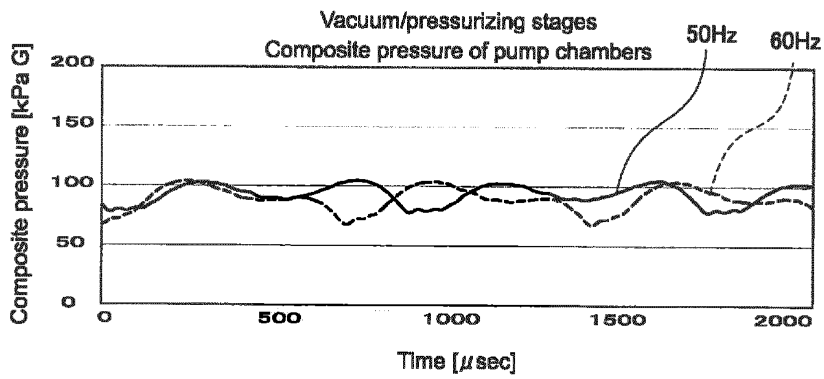

Vacuum/pressurizing stages
Composite pressure of pump chambers
50Hz
60Hz
Composite pressure [kPa G]
200
150
100
50
0
0
500
1000
1500
2000
Time [μsec]

FIG.8

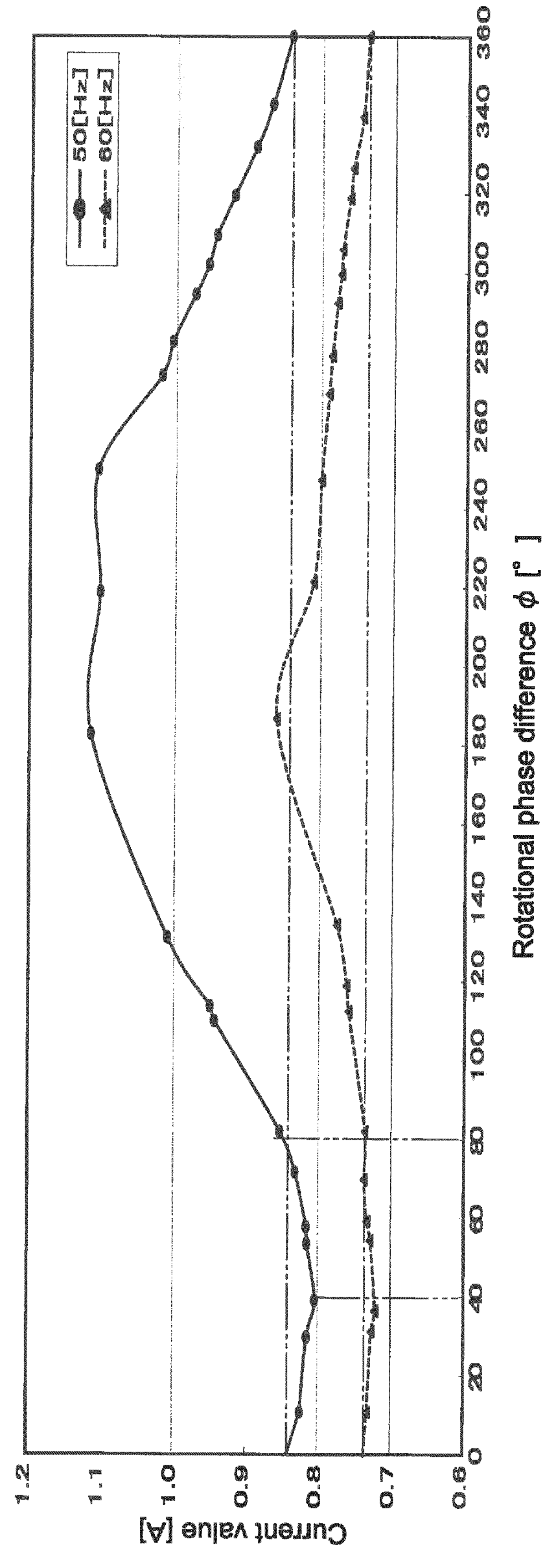

50[Hz]
60[Hz]
Current value [A]
1.2
1.1
1.0
0.9
0.8
0.7
0.6
Rotational phase difference ϕ [°]
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360

FIG.9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/001436

A. CLASSIFICATION OF SUBJECT MATTER
F04B41/06(2006.01)i, *F04B27/02*(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)
F04B41/06, F04B27/02

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 07-310651 A (Toshiba Automation Co., Ltd.), 28 November 1995 (28.11.1995), paragraphs [0013] to [0023]; fig. 1 to 3 (Family: none)	1-3
A	JP 2008-190517 A (Kazumori OTOGAO), 21 August 2008 (21.08.2008), paragraphs [0013] to [0018]; fig. 1 (Family: none)	1-3

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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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
03 June, 2013 (03.06.13)	11 June, 2013 (11.06.13)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP HEI7310651 B **[0005]**