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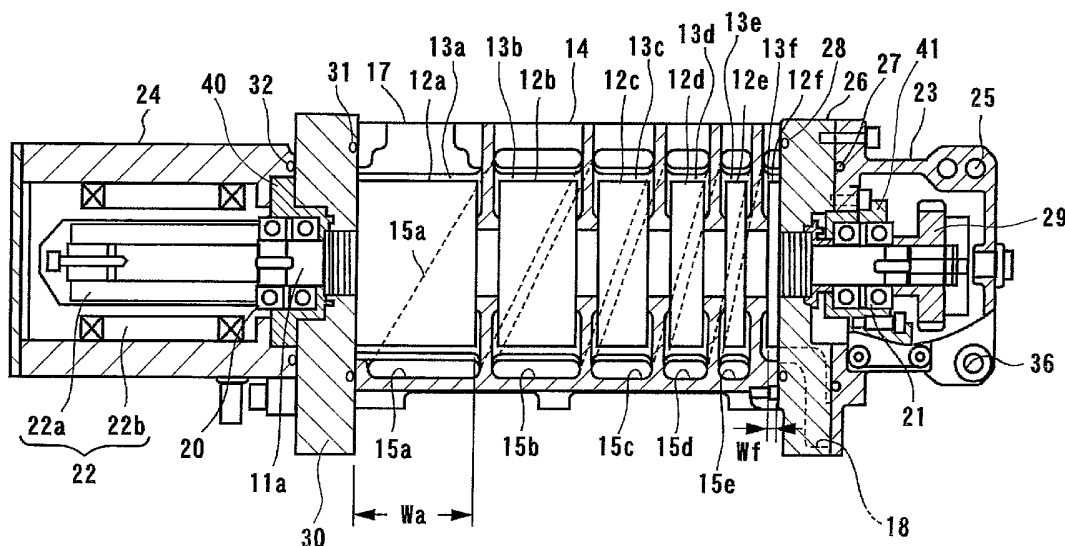
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(54) Title: POSITIVE-DISPLACEMENT VACUUM PUMP



(57) Abstract: The present invention relates to a positive-displacement vacuum pump for evacuating a gas by rotating two rotors synchronously in opposite directions in a non-contact manner. A positive-displacement vacuum pump according to the present invention includes two rotational shafts (11a, 11b) which are synchronously rotatable in opposite directions, a pair of multistage rotors (12, 12) provided on the rotational shafts (11a, 11b), respectively, a rotor casing (14) for housing the pair of multistage rotors (12, 12), a plurality of bearings (21) for rotatably supporting the rotational shafts (11a, 11b), a bearing casing (23) for housing the bearings (21), a cooling mechanism (25) for cooling the bearing casing (23), and a seal member (27) disposed near the bearings (21). The bearings (21) and the seal member (27) are cooled by the cooling mechanism (25).



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DESCRIPTION

POSITIVE-DISPLACEMENT VACUUM PUMP

Technical Field

5 The present invention relates to a vacuum pump, and more particularly to a positive-displacement vacuum pump for evacuating a gas by rotating two rotors synchronously in opposite directions in a non-contact manner.

10 Background Art

A Roots-type vacuum pump is a positive-displacement vacuum pump for discharging a gas from a relatively low vacuum region to an atmospheric pressure region, and is widely used in various kinds of vacuum pumping apparatuses. FIG. 1 is a cross-sectional view showing a conventional Roots-type vacuum pump. A Roots-type vacuum pump shown in FIG. 1 comprises two rotational shafts 53 (one of which is shown in FIG. 1) supported by bearings 55, 56, a pair of Roots rotors 54 fixed respectively to the rotational shafts 53, and a rotor casing 51 in which the Roots rotors 54 are housed. Timing gears 58 are fixed to end portions of the rotational shafts 53, respectively, and the rotational shafts 53 are rotated synchronously in opposite directions by energizing a motor 57. When the Roots rotors 54 fixed to the rotational shafts 53 are rotated synchronously in the opposite directions, a gas confined in a space between the Roots rotors 54 and an inner surface of the rotor casing 51 is delivered from an inlet side to an outlet side. In this manner, vacuum evacuation is performed. The bearings 55, 56 are housed hermetically in bearing casings 60, 61, respectively, and interior spaces of the bearing casings 60, 61 are separated from a pumping chamber 52 in which a gas is delivered. Therefore, there is no oil in a passage for delivering a gas, and

hence this type of vacuum pump is called as a dry pump.

In this type of vacuum pump, an inlet port is connected to a vacuum region and an outlet port is connected to an atmospheric pressure region. Generally, 5 the vacuum pump has multistage rotor chambers comprising three-stage to five-stage rotor chambers, and a gas is compressed in a multistage manner by the Roots rotors housed in each of the rotor chambers. Since a gas is compressed in a multistage manner in each of the rotor 10 chambers, the first-stage rotor chamber disposed at the inlet side has a largest volume, and volumes of the rotor chambers are gradually reduced toward the final-stage rotor chamber disposed at the outlet side.

If a degree of vacuum to be achieved is relatively 15 low, the Roots-type vacuum pump is used by itself, or a plurality of vacuum pumps including the Roots-type vacuum pump and a booster pump which has the same structure are used in such a state that these vacuum pumps are connected in series so as to discharge a gas from the vacuum region 20 to the atmospheric pressure region. If a degree of vacuum to be achieved is high, the Roots-type vacuum pump is used in combination with a high-vacuum pump such as a cryopump or a molecular pump.

Generally, a Roots-type vacuum pump having a large 25 number of rotor stages can smoothly perform a gas compression. However, as the number of rotor stages is increased, a length of the vacuum pump becomes long, thus causing a size and a manufacturing cost of the vacuum pump to be increased. Further, as the number of rotor stages 30 is increased, a length of the rotational shaft becomes long, thus causing a problem such that an installing area is required to be large.

In recent years, a vacuum pump has been widely used

in several kinds of semiconductor fabricating apparatuses. Most of the semiconductor fabricating apparatuses perform a fabricating process under a vacuum atmosphere. Examples of such semiconductor fabricating apparatuses include a vacuum evaporation apparatus, a sputtering apparatus, and a plasma CVD apparatus. When the vacuum pump is used in the above semiconductor fabricating apparatuses, the following problem may arise: A gas to be evacuated may contain a raw material gas used for processing a semiconductor wafer, or may contain a gaseous reaction product which has been produced in the process. If the vacuum pump evacuates the raw material gas or the reaction product containing gas, these gases tend to be solidified into powdery substances which are deposited particularly on the outlet port of the vacuum pump, thus causing the vacuum pump to be clogged. This is because if the raw material gas and the reaction product containing gas are delivered to the outlet port of the vacuum pump and the pressures of these gases are increased to the atmospheric pressure, these gases are solidified due to change in temperature. Specifically, if the raw material gas and the reaction product containing gas have a high temperature, these gases are kept gaseous. However, the temperatures of the raw material gas and the reaction product containing gas are lowered, these gases are solidified into the powdery substances.

Therefore, it is required to keep the temperature of the outlet port of the vacuum pump as high as possible. If the temperature of the outlet port is kept high, the raw material gas and the reaction product containing gas can be prevented from being solidified, thus enabling the vacuum pump to avoid being clogged. However, the rotational shafts having the multistage rotors are

supported by the bearings, and the final-stage rotor chamber of the multistage rotor chambers is positioned near the outlet port. Since the bearings supporting the rotational shafts are generally disposed near the outlet port, the bearings are liable to be heated to a high temperature. If the temperature of the bearings is increased excessively, the service life of the bearings is shortened, thus resulting in a shortened service life of the vacuum pump as a whole. The vacuum pump has a seal member for hermitically sealing a variety of chambers such as a pumping chamber. From the viewpoint of maintaining the function of the seal member, it is undesirable to heat the seal member to a high temperature. Thus, it is required to provide a cooling mechanism for cooling the seal member and the bearings which support the rotational shafts. However, if an excessive cooling is performed, there arises a problem in that the raw material gas and the gaseous reaction product are liable to be solidified on the portion around the outlet port.

Heretofore, it has been customary to use a cooling jacket and an intercooler as a cooling mechanism. For example, as shown in FIG. 1, a cooling jacket 66 is attached on the lower portion of the rotor casing 51, so that the rotor casing 51 is cooled by the cooling jacket 66. However, since the entire rotor casing 51 is cooled by the cooling jacket 66, the raw material gas and the sublimated reaction product are solidified in the rotor casing 51 to obstruct the rotation of the rotors 54, thus causing a problem such that the motor 57 is overloaded. FIG. 2 shows another example of a conventional cooling mechanism. As shown in FIG. 2, the rotor casing 51 is connected to a plurality of intercoolers 72 (one of which is shown in FIG. 2) by introduction pipes 73, so that heat

of compression generated in a gas-compression process is eliminated by the intercoolers 72. However, the intercoolers 72 are installed correspondingly to each of the rotors 54. Accordingly, a large installing area is required for the intercoolers 72, and the vacuum pump becomes large in size as a whole.

Disclosure of Invention

The present invention has been made in view of the above drawbacks. It is therefore an object of the present invention to provide a positive-displacement vacuum pump which can cool a bearing and a seal member to such a degree that a gas to be evacuated is not solidified, and can achieve a small size and an energy saving.

In order to achieve the above object, according to a first aspect of the present invention, there is provided a positive-displacement vacuum pump comprising: two rotational shafts which are synchronously rotatable in opposite directions; a pair of multistage rotors provided on the rotational shafts, respectively; a rotor casing for housing the pair of multistage rotors; a plurality of bearings for rotatably supporting the rotational shafts; a bearing casing for housing the bearings; a cooling mechanism for cooling the bearing casing; and a seal member disposed near the bearings; wherein the bearings and the seal member are cooled by the cooling mechanism.

According to the present invention, the bearings and the seal member can be cooled efficiently by the cooling mechanism such as a cooling liquid passage which is formed in the bearing casing without causing a raw material gas and a gaseous reaction product to be solidified near an outlet port.

In a preferred aspect of the present invention, a

positive-displacement vacuum pump further comprises a side casing disposed between the rotor casing and the bearing casing; wherein the rotor casing is cooled by the cooling mechanism through the side casing.

5 According to the present invention, an appropriate cooling capability of the cooling mechanism can be achieved by appropriately designing a contact area between the side casing and the rotor casing, a contact area between the side casing and the bearing casing, and a
10 thickness of the side casing. For example, if the side casing is designed to be thin and the contact area between the side casing and the bearing casing is designed to be large, then the cooling capability is increased. On the other hand, if the side casing is designed to be thick and
15 the contact area between the side casing and the bearing casing is designed to be small, then the cooling capability is decreased. In this manner, the capability of the cooling mechanism can be adjusted appropriately so that the rotor casing is cooled to such a degree that a
20 gas is not solidified without providing a conventional cooling jacket and intercoolers. Since the rotor casing is cooled indirectly by the cooling mechanism through the side casing disposed adjacent to the rotor casing, the rotor casing is prevented from being cooled excessively.
25 Therefore, a raw material gas used in a semiconductor fabricating apparatus or a gaseous reaction product containing gas can be discharged without producing the solidified components, and the bearings and the seal member can be cooled moderately, thus enabling the vacuum
30 pump to be operated stably. Further, heat of compression of the gas is prevented from being transmitted to the bearing casing by providing the side casing, and hence the bearings and the seal member are prevented from being

heated to a high temperature. If a specification condition of the vacuum pump in the installation site is determined in advance, it is not necessary to provide the side casing between the rotor casing and the bearing casing. In this case, at least one of the rotor casing and the bearing casing may have a thick portion having a certain thickness enough to achieve a required cooling capability, so that the side casing can be replaced with the thick portion.

10 In a preferred aspect of the present invention, the side casing has an outlet port.

Conventionally, the outlet port is provided in the rotor casing, and hence the structure of the rotor casing has been complicated. In the present invention, since the outlet port is provided in the side casing, the structure of the rotor casing can be simplified and a height of the vacuum pump can be lowered.

In a preferred aspect of the present invention, each of the multistage rotors comprises a Roots-type rotor.

20 In a preferred aspect of the present invention, the rotor casing has a plurality of rotor chambers in which the multistage rotors are housed, respectively, and a volume ratio of a first-stage rotor chamber to a final-stage rotor chamber ranges from 8 to 14.

25 In a preferred aspect of the present invention, a ratio of a thickness to a diameter of a final-stage rotor ranges from 0.05 to 0.11.

According to the present invention, the vacuum pump by itself can evacuate a gas from a vacuum vessel to produce a sufficient degree of vacuum in the vacuum vessel without using a booster pump or the like. The final-stage rotor disposed at an outlet side is very thin, and hence the volume of the final-stage rotor chamber can be very

small. In this kind of vacuum pump, the outlet port opens in an atmospheric pressure region. Therefore, load sharing becomes large at the final-stage rotor chamber when the vacuum pump is in a stable operation, and hence a highest amount of energy is consumed in the final-stage rotor chamber. In the present invention, the final-stage rotor chamber is set to be small, and hence the vacuum pump can achieve a high energy saving. Further, because an amount of energy to be consumed in compressing a gas is reduced, heat of compression of the gas can be reduced. Therefore, the rotor casing can be cooled sufficiently by cooling only the bearing casing. As a result, it is not required to provide a cooling mechanism on the rotor casing.

In a preferred aspect of the present invention, the rotor casing has a plurality of rotor chambers in which the multistage rotors are housed, respectively, and the rotor casing has a plurality of gas passages each for introducing a gas discharged from one of the plurality of rotor chambers to another one of the plurality of rotor chambers.

With this structure, a length of the rotational shaft can be shortened, and hence a small-sized and space-saving vacuum pump can be achieved.

In a preferred aspect of the present invention, a positive-displacement vacuum pump further comprises a brushless DC motor for rotating the pair of multistage rotors.

Generally, a volume ratio of the first-stage rotor chamber disposed at the inlet side to the final-stage rotor chamber disposed at the outlet side is high, a high starting torque is required at the time of starting the positive-displacement vacuum pump. In the present

invention, the brushless DC motor is used as a driving source for rotating the rotational shafts. Therefore, it is possible not only to achieve an excellent motor efficiency, but also to cope with large load variation.

5 In a preferred aspect of the present invention, the multistage rotors are disposed in the rotor casing in such a state that the multistage rotors are disposed in alignment with each other.

10 In a preferred aspect of the present invention, the cooling mechanism comprises a cooling liquid passage formed in the bearing casing.

In a preferred aspect of the present invention, the bearing casing comprises a motor casing for housing a motor.

15 In a preferred aspect of the present invention, a positive-displacement vacuum pump further comprises a side casing disposed between the rotor casing and the motor casing; wherein the rotor casing is cooled by the cooling mechanism through the side casing.

20 According to another aspect of the present invention, there is provided a positive-displacement vacuum pump comprising: two rotational shafts which are synchronously rotatable in opposite directions; a pair of multistage rotors attached to the rotational shafts, respectively; a rotor casing for housing the pair of multistage rotors; a plurality of bearings for rotatably supporting the rotational shafts; a bearing casing for housing the bearings; a first side casing disposed between the rotor casing and the bearing casing; and a first cooling
25 mechanism for cooling the bearing casing.
30

In a preferred aspect of the present invention, a positive-displacement vacuum pump further comprises a motor casing for housing a motor; a second side casing

disposed between the rotor casing and the motor casing;
and a second cooling mechanism for cooling the motor
casing.

In a preferred aspect of the present invention, a
5 positive-displacement vacuum pump further comprises a
plurality of bearing cases for holding the bearings;
wherein the plurality of bearing cases are disposed in the
bearing casing and the motor casing, respectively.

In a preferred aspect of the present invention, the
10 first side casing has an outlet port.

In a preferred aspect of the present invention, each
of the multistage rotors comprises a Roots-type rotor.

In a preferred aspect of the present invention, the
rotor casing has a plurality of rotor chambers in which
15 the multistage rotors are housed, respectively, and a
volume ratio of a first-stage rotor chamber to a final-
stage rotor chamber ranges from 8 to 14.

In a preferred aspect of the present invention, a
ratio of a thickness to a diameter of a final-stage rotor
20 ranges from 0.05 to 0.11.

In a preferred aspect of the present invention, the
rotor casing has a plurality of rotor chambers in which
the multistage rotors are housed, respectively, and the
rotor casing has a plurality of gas passages each for
25 introducing a gas discharged from one of the plurality of
rotor chambers to another one of the plurality of rotor
chambers.

In a preferred aspect of the present invention, a
positive-displacement vacuum pump further comprises a
30 brushless DC motor for rotating the pair of multistage
rotors.

In a preferred aspect of the present invention, the
multistage rotors are disposed in the rotor casing in such

a state that the multistage rotors are disposed in alignment with each other.

5

Brief Description of Drawings

FIG. 1 is a cross-sectional view showing a conventional positive-displacement vacuum pump;

FIG. 2 is a front view showing an intercooler incorporated in a conventional positive-displacement vacuum pump;

FIG. 3 is a cross-sectional view showing an entire structure of a positive-displacement vacuum pump according to a first embodiment of the present invention;

FIG. 4 is a perspective view showing an essential part of the positive-displacement vacuum pump shown in FIG 3;

FIG. 5 is a view showing the positive-displacement vacuum pump as viewed in the direction indicated by the arrow V in FIG. 4;

FIG. 6 is a perspective view showing a modification of a cooling mechanism;

FIG. 7 is a cross-sectional view showing an entire structure of a positive-displacement vacuum pump according to a second embodiment of the present invention;

FIG. 8 is a schematic cross-sectional view showing a bearing casing shown in FIG. 7;

FIG. 9 is a schematic cross-sectional view showing a bearing casing of a positive-displacement vacuum pump according to a third embodiment of the present invention;

and

FIG. 10 is a cross-sectional view showing an entire structure of a positive-displacement vacuum pump according to a fourth embodiment of the present invention.

Best Mode for Carrying Out the Invention

A positive-displacement vacuum pump according to embodiments of the present invention will be described below with reference to the drawings. Like or corresponding parts are denoted by like or corresponding reference numerals throughout drawings and will not be described below repetitively.

FIG. 3 is a cross-sectional view showing an entire structure of a positive-displacement vacuum pump according to a first embodiment of the present invention. FIG. 4 is a perspective view showing an essential part of the positive-displacement vacuum pump shown in FIG 3. FIG. 5 is a view showing the positive-displacement vacuum pump as viewed in the direction indicated by the arrow V in FIG. 4.

As shown in FIGS. 3 through 5, the positive-displacement vacuum pump comprises two rotational shafts 11a, 11b, and a pair of six-stage Roots-type rotors 12a, 12b, 12c, 12d, 12e and 12f which are fixed to the rotational shafts 11a, 11b, respectively. The rotational shafts 11a, 11b are rotatably supported by bearings 20, 21. Hereinafter, the pair of rotors 12a, 12b, 12c, 12d, 12e and 12f may be selectively referred to as the rotors 12, 12.

Small gaps are formed between the rotors 12, 12, and between the rotors 12, 12 and an inner surface of a rotor casing 14, so that the rotors 12, 12 are rotatable about the rotational shafts 11a, 11b in a non-contact manner. The rotors 12a, 12b, 12c, 12d, 12e and 12f are housed respectively in rotor chambers 13a, 13b, 13c, 13d, 13e and 13f which are disposed in alignment with each other in the single rotor casing 14 along the two rotational shafts 11a, 11b. A cover member (not shown) is attached on an upper

surface of the rotor casing 14. An inlet port 17 is formed in an upper portion of the rotor casing 14, and the inlet port 17 communicates with the first-stage rotor chamber 13a. A (first) side casing 26 is fixed to an outlet-side end surface of the rotor casing 14, and a bearing casing 23 is fixed to a side surface of the side casing 26. The side casing 26 has an outlet port 18 formed therein. The outlet port 18 communicates with the final-stage rotor chamber 13f and opens in an atmospheric pressure region.

As shown in FIG. 3, a brushless DC motor 22 serving as a driving source is disposed at a left side of the bearings 20. Specifically, motor rotors 22a (one of which is shown in FIG. 3) are fixed to one-side end portions of the rotational shafts 11a, 11b, respectively, and a motor stator 22b is disposed around the motor rotors 22a. The motor stator 22b should preferably be molded or covered hermitically with a can so as not to be brought into contact with a gas which exists in a space between the motor rotor 22a and the motor stator 22b. The brushless DC motor 22 is supplied with frequency-variable electric power from an electric power supply device (not shown) such as an inverter device, so that the brushless DC motor 22 performs a rotational speed control, which includes soft start, of the vacuum pump. With a combination of the brushless DC motor 22 and the electric power supply device such as the inverter device, a high driving torque can be generated when starting the vacuum pump, and an energy-saving operation can be performed by operating the vacuum pump at an appropriate rotational speed when the vacuum pump is in a stable speed operation. The brushless DC motor 22 is disposed in a motor casing 24. The brushless DC motor 22 comprises a two-axes synchronous motor for

rotating the rotational shafts 11a, 11b synchronously in opposite directions. Thus, the rotors 12, 12 are rotated synchronously in the opposite directions by the brushless DC motor 22 via the rotational shafts 11a, 11b. Timing
5 gears 29 are attached to the other end portions of the rotational shafts 11a, 11b, respectively. The timing gears 29 and the bearings 21 disposed at the outlet side are accommodated in the bearing casing 23. The bearings 20, 21 are held by bearing cases 40, 41, respectively, and
10 the bearing cases 40, 41 are disposed in the motor casing 24 and the bearing casing 23, respectively.

In each of the rotor chambers 13a, 13b, 13c, 13d, 13e and 13f, a gas is delivered in the following manner: When the rotors 12, 12 provided on the two rotational
15 shafts 11a, 11b are rotated synchronously in opposite directions, a gas is confined in a space between the rotors 12, 12 and the inner surface of the rotor casing 14, and the gas is delivered from the inlet side to the outlet side. The rotor casing 14 has a double casing structure.
20 Gas passages 15a, 15b, 15c, 15d and 15e are formed between an inner circumferential wall and an outer circumferential wall, both of which constitute the double casing structure. The rotor chambers 13a, 13b, 13c, 13d, 13e and 13f are connected to each other in series through the gas passages
25 15a, 15b, 15c, 15d and 15e, respectively. Specifically, the outlet side of the rotor chamber 13a is connected to the inlet side of the next rotor chamber 13b through the gas passage 15a, and a gas compressed by the pair of the rotors 12a in the rotor chamber 13a is delivered through
30 the gas passage 15a to the inlet side of the rotor chamber 13b. In this manner, a gas is compressed by each of the multistage rotors 12, 12 and delivered through the gas passages 15a, 15b, 15c, 15d and 15e toward the outlet port

18, and then discharged from the outlet port 18 to the atmospheric pressure region.

In this vacuum pump, a ratio of a volume of the first-stage rotor chamber 13a to a volume of the final-stage rotor chamber 13f ranges from 8 to 14. Specifically, a ratio of a thickness W_a of the first-stage rotor 12a to a thickness W_f of the final-stage rotor 12f ranges from 8 to 14, and this ratio, i.e., the thickness ratio, corresponds to the volume ratio of the first-stage rotor chamber 13a to the final-stage rotor chamber 13f.

Generally, a volume of a first-stage rotor chamber is determined by a pumping speed of a vacuum pump to be designed. Therefore, when a vacuum pump is to be designed to have a high pumping speed, the volume of the first-stage rotor chamber is required to be large. On contrast thereto, a volume of the final-stage rotor chamber is required to be small in order to suppress heat generation (i.e., heat of compression) due to pressure difference between the upstream side and the downstream side of the final-stage rotor chamber and also to suppress electric power consumption of the motor for rotating the rotors against the pressure difference between the upstream side and the downstream side of the final-stage rotor chamber. However, if the volume of the final-stage rotor chamber is small, then the vacuum pump cannot perform a smooth evacuation. Thus, there is a trade-off relationship between the volume ratio and the heat generation. Therefore, the volume ratio (compression ratio) is determined whether to be high or low depending on a priority point to be considered when of the vacuum pump is designed.

The vacuum pump of the present invention employs the brushless DC motor which performs the rotational speed

control. With this structure, the pumping speed can be high while keeping the volume of the final-stage rotor chamber small, and hence heat generation and electric power consumption can be suppressed. That is, according to the present invention, it is possible to allow the volume ratio (compression ratio) to be higher while achieving the same pumping speed and also to suppress the heat generation, compared to a conventional vacuum pump using a normal motor.

Generally, the volume ratio of the first-stage rotor chamber to the final-stage rotor chamber is determined by a thickness, i.e., width, of the final-stage rotor for the reason of design matter. In the present invention, if heat generation is acceptable to a certain degree, the volume ratio can be set to range from 3 to 14, preferably from 8 to 14.

In this embodiment, the final-stage rotor 12f has a thickness W_f of 7.5 mm or less. A ratio of the thickness W_f to a diameter D_f (see FIG. 5) of the final-stage rotor 12f ranges from 0.05 to 0.11, preferably from 0.05 to 0.09. Generally, the ratio of the thickness to the diameter of the final-stage rotor is determined by the thickness of the final-stage rotor for the reason of design matter. In the present invention, if heat generation is acceptable to a certain degree, the ratio of the thickness W_f to the diameter D_f of the final-stage rotor 12f can be set to range from 0.05 to 0.11, preferably from 0.05 to 0.09. In this embodiment, the thickness W_f of the final-stage rotor 12f is designed to be as thin as possible within a degree that causes no trouble in a manufacturing process and an operation of the vacuum pump. The six-stage rotor chambers 13a, 13b, 13c, 13d, 13e and 13f are disposed compactly in the double-structure rotor casing 14 having

the gas passages 15a, 15b, 15c, 15d and 15e.

With this structure, when a gas in an inlet-side region has an atmospheric pressure or a substantially atmospheric pressure at the time of starting the vacuum pump, a high pumping speed can be achieved, and hence the vacuum pump can evacuate the gas quickly. Further, when the vacuum pump is in a stable operation, the electric power consumption can be greatly reduced because the final-stage rotor chamber 13f has an extremely small volume. Since the number of rotor stages in the vacuum pump of this embodiment is increased to six stages from three to five stages in the conventional vacuum pump, the vacuum pump of this embodiment can perform a vacuum evacuation effectively and smoothly. If the volume ratio of the first-stage rotor chamber to the final-stage rotor chamber is high, the pumping speed becomes high at the time of starting the vacuum pump. However, there arises a problem in that the compression ratio also becomes high and a driving power for compression is increased at the time of starting the vacuum pump. In this embodiment, the brushless DC motor 22 is used as a driving source for rotating the two rotational shafts 11a, 11b. Therefore, it is possible not only to achieve an excellent motor efficiency, but also to cope with large load variation and an increased driving power for compression at the time of starting the vacuum pump.

The bearings 21 are disposed near the outlet port 18 of the vacuum pump, and the rotational shafts 11a, 11b are rotatably supported by the outlet-side bearings 21 and the inlet-side bearings 20. The bearings 21 are housed in the bearing casing 23, and the side casing 26 described above is disposed between the bearing casing 23 and the rotor casing 14. An O-ring seal 27 serving as a seal member is

provided between the bearing casing 23 and the side casing 26 to seal a small gap between the bearing casing 23 and the side casing 26. In addition, an O-ring seal 28 serving as a seal member is provided between the side casing 26 and the rotor casing 14 to seal a small gap between the side casing 26 and the rotor casing 14.

The bearings 20 are housed in the motor casing 24, and a (second) side casing 30 is disposed between the motor casing 24 and the rotor casing 14. An O-ring seal 31 serving as a seal member is provided between the side casing 30 and the rotor casing 14. In addition, an O-ring seal 32 serving as a seal member is provided between the side casing 30 and the motor casing 24.

A cooling liquid passage (circulating passage) 25 serving as a cooling mechanism is formed in the bearing casing 23. Specifically, a cooling pipe 36 is embedded in the bearing casing 23 to form the cooling liquid passage 25. The cooling pipe 36 is made of a material having a corrosion resistance against a cooling liquid. With this structure, when a cooling liquid such as cooling water flows through the cooling liquid passage 25, the bearing casing 23 is cooled by the cooling liquid. Further, a lubricating oil retained in the bearing casing 23 is cooled by the cooling liquid flowing through the cooling liquid passage 25, and hence the bearings 21 and the O-ring seals 27, 28 are also cooled sufficiently by the cooling liquid through the lubricating oil directly or indirectly. In this manner, according to the present invention, the bearings and the seal member disposed near the bearings are cooled by the cooling mechanism. In this embodiment, the seal members disposed near the bearings include not only a bearing seal, but also the O-ring seal 27 disposed between the side casing 26 and the bearing

casing 23, and the O-ring seal 28 disposed between the rotor casing 14 and the side casing 26. The attachment manner of the O-ring seals (seal members) 27, 28 is not limited to the manner shown in FIG. 3. For example, although the O-ring seal 27 is attached to the bearing casing 23 as shown in FIG. 3, the O-ring seal 27 may be attached to the side casing 26. If the vacuum pump has a structure in which a bearing casing having an inner pressure equal to an indoor pressure (i.e., substantially atmospheric pressure) of an installation room is connected to a rotor casing having an inner pressure lower than the atmospheric pressure, and a rotational shaft extends through the bearing casing and the rotor casing, then the seal members disposed near the bearings are not limited to the present embodiment. With such a structure, the seal members disposed near the bearings include a seal member disposed between an outer circumferential surface of the rotational shaft and the bearing casing or the rotor casing, and a seal member disposed between the bearing casing and the rotor casing. If the cooling pipe 36 is made of a material having a corrosion resistance, the bearing casing 23 is not required to be made of such a high-priced material having a corrosion resistance. Therefore, it is possible to provide a low-priced vacuum pump.

FIG. 6 is a perspective view showing another example of the cooling mechanism. As shown in FIG. 6, the number of turns of the cooling pipe 36 forming the cooling liquid passage 25 is larger than that of the cooling pipe 36 shown in FIG. 3. In addition thereto, the cooling pipe 36 shown in FIG. 6 is positioned more closely to the rotor casing 14 than the position of the cooling pipe 36 shown in FIG. 3. In this manner, temperatures of the rotor

casing 14 and a gas at the outlet side can be adjusted by changing the number of turns and the position of the cooling pipe 36 to be embedded in the bearing casing 23. In this case, for example, metal is cast together with the
5 cooling pipe 36 to produce the bearing casing 23.

When the vacuum pump evacuates a gas from a vacuum vessel to produce a vacuum in the vacuum vessel and then the vacuum pump is in a stable operation, a flow rate of the gas is lowered. At this time, most part of a pressure
10 difference between the atmospheric pressure and the vacuum is applied to the pair of the final-stage rotors 12f. The final-stage rotors 12f are rotated against the pressure difference whose magnitude is nearly atmospheric pressure, and hence a large amount of heat is generated in the
15 final-stage rotor chamber 13f to heat a portion around the rotor chamber 13f. When the portion around the final-stage rotor chamber 13f is heated to a high temperature, it is possible to prevent a process gas used in a semiconductor fabricating process and a gaseous reaction
20 product from being solidified. However, the bearings 21 and the O-ring seals 27, 28 are also heated to a high temperature, thus causing the bearings 21 and the O-ring seals 27, 28 to be damaged or deteriorated.

Therefore, in this vacuum pump, the cooling liquid
25 passage 25 is formed in the bearing casing 23. The cooling liquid flowing through the cooling liquid passage 25 can cool the bearings 21 and the O-ring seals 27, 28, which should not be heated to a high temperature. The cooling liquid can also cool the side casing 26 and the
30 rotor casing 14 to such a degree that a gaseous component contained in a discharge gas which exists near the outlet port 18 is not solidified. Accordingly, it is possible to dispense with a conventional cooling jacket or the like

which has heretofore been required to be provided on the circumferential portion of the rotor casing 14, thereby reducing the manufacturing cost. Simultaneously, the portion around the outlet port 18 can be prevented from being cooled excessively, and hence a gaseous component such as a reaction product contained in a discharge gas can be prevented from being solidified.

The vacuum pump of this embodiment has a high volume ratio of the first-stage rotor chamber 13a disposed at the inlet side to the final-stage rotor chamber 13f disposed at the outlet side. The final-stage rotor chamber 13f has a small volume, and the gas passages 15a, 15b, 15c, 15d and 15e for connecting the respective rotor chambers 13a, 13b, 13c, 13d, 13e and 13f to each other are disposed radially outwardly of the rotor chambers 13a, 13b, 13c, 13d, 13e and 13f. Although the compression ratio becomes high with this structure, the brushless DC motor 22 performs a rotational speed control for thereby enabling a smooth starting and an energy-saving operation. In addition, the cooling pipe 36 is embedded in the bearing casing 23 to form the cooling liquid passage 25 near the bearings 21 and the O-ring seals 27, 28, so that the portion around the outlet port 18 of the vacuum pump is cooled by the cooling liquid flowing through the cooling liquid passage 25.

Accordingly, it is possible to dispense with an external cooling jacket or the like. Therefore, the vacuum pump can be small in size and compact as a whole, and an amount of the electric power consumption can be greatly reduced. Further, it is possible to cool the bearings 21, the O-ring seals 27, 28, and the like while preventing a gaseous component such as a reaction product from being solidified, thus enabling the vacuum pump to be

operated stably. Furthermore, a whole length of the vacuum pump can be shortened and a height of the vacuum pump can be lowered, and an additional mechanism such as an external cooling jacket can be eliminated. Therefore, a simple and compact structure of the vacuum pump can be achieved.

FIG. 7 is a cross-sectional view showing a positive-displacement vacuum pump according a second embodiment of the present invention. FIG. 8 is a schematic cross-sectional view showing a bearing casing shown in FIG. 7. Structures of the positive-displacement vacuum pump according to the second embodiment which will not be described below are identical to those of the positive-displacement vacuum pump according to the first embodiment.

As shown in FIG. 7 and FIG. 8, a part of the bearing casing 23 has a double wall structure comprising an outer wall 23a and an inner wall 23b, and a cooling liquid passage 25 is formed between the outer wall 23a and the inner wall 23b. A cooling liquid inlet 33 is provided on a lower portion of the bearing casing 23, so that a cooling liquid is supplied into the cooling liquid passage 25 through the cooling liquid inlet 33. A cooling liquid outlet 34 is provided on an upper portion of the bearing casing 23, so that the cooling liquid which has flowed through the cooling liquid passage 25 is discharged from the cooling liquid outlet 34. The bearing casing 23 is cooled by the cooling liquid flowing through the cooling liquid passage 25. In this embodiment also, temperatures of the rotor casing 14 and a gas at the outlet side can be adjusted by changing the width and position of the cooling liquid passage 25. The rotor casing 23 is made of a material having a corrosion resistance against the cooling liquid.

FIG. 9 is a cross-sectional view showing a bearing casing of a positive-displacement vacuum pump according a third embodiment of the present invention. Structures of the positive-displacement vacuum pump according to the
5 third embodiment which will not be described below are identical to those of the positive-displacement vacuum pump according to the first embodiment.

As shown in FIG. 9, two cooling jackets 35 each serving as a cooling mechanism are attached to a
10 circumferential surface of the bearing casing 23. Specifically, the cooling jackets 35 are provided on an upper portion and a lower portion of the bearing casing 23, respectively. In this embodiment also, as with the first and second embodiments, temperatures of the rotor casing
15 14 and a gas at the outlet side can be adjusted by changing the size and attachment position of the cooling jackets 35.

FIG. 10 is a cross-sectional view showing an entire structure of a positive-displacement vacuum pump according
20 to a fourth embodiment of the present invention. Structures of the positive-displacement vacuum pump according to the fourth embodiment which will not be described below are identical to those of the positive-displacement vacuum pump according to the first embodiment.

25 The vacuum pump of this embodiment has the same basic structure as the vacuum pump of the first embodiment, but is different from the vacuum pump of the first embodiment in that the vacuum pump of this embodiment has a second cooling mechanism disposed near the inlet-side
30 bearings 20 in addition to the cooling liquid passage 25 serving as a first cooling mechanism. Specifically, as shown in FIG. 10, a cooling liquid passage 38 serving as a second cooling mechanism is formed in the motor casing 24.

A cooling liquid is supplied from a cooling liquid inlet 39 to the cooling liquid passage 38, so that the motor casing 24 is cooled by the cooling liquid flowing through the cooling liquid passage 38.

5 Generally, if a flow rate of a gas introduced from the inlet port 17 is large, then a large amount of heat is generated in the first-stage rotor chamber 13a. Accordingly, it is required to cool the rotor chamber 13a and the inlet-side bearings 20. In this case, if the
10 rotor chamber 13a is directly cooled, a gas is liable to be solidified to produce solid components in the rotor chamber 13a. In this embodiment, the rotor casing 14 is indirectly cooled by the cooling liquid flowing through the cooling liquid passage 38 through the side casing 30.
15 With this structure, the bearings 20 accommodated in the motor casing 24 can be cooled by the cooling liquid while preventing the rotor casing 14 from being excessively cooled.

When the motor casing 24 is cooled by the cooling
20 liquid flowing through the cooling liquid passage 38, the side casing 30 adjacent to the motor casing 24 is also cooled. Accordingly, the O-ring seal (seal member) 32 disposed between the side casing 30 and the motor casing 24 can be cooled, and the O-ring seal (seal member) 31
25 disposed between the side casing 30 and the rotor casing 14 can also be cooled. In this manner, according to this embodiment, the bearings 20 and the O-ring seals 31, 32 disposed at the inlet side can be cooled, and the bearings 21 and the O-ring seals 27, 28 disposed at the outlet-side
30 can also be cooled. The motor casing 24 accommodates not only the brushless DC motor 22 but also the bearings 20. From the viewpoint of this structure, the motor casing 24 can serve as a bearing casing. The cooling liquid passage

25 formed in the bearing casing 23 and the cooling liquid passage 38 formed in the motor casing 24 can be connected to each other to form a single cooling liquid passage. In this case, a cooling liquid flows through the cooling liquid passage 25, 38 in this order.

The embodiments described above are merely preferred embodiments, and it should be understood that various changes and modifications may be made therein without departing from the scope of the present invention.

As described above, according to the present invention, it is possible to provide a high-performance vacuum pump which is small in size and compact and can greatly reduce an amount of an electric power consumption.

Industrial Applicability

The present invention is applicable to a positive-displacement vacuum pump for evacuating a gas by rotating two rotors synchronously in opposite directions in a non-contact manner.

CLAIMS

1. A positive-displacement vacuum pump comprising:
two rotational shafts which are synchronously
5 rotatable in opposite directions;
a pair of multistage rotors provided on said
rotational shafts, respectively;
a rotor casing for housing said pair of multistage
rotors;
10 a plurality of bearings for rotatably supporting
said rotational shafts;
a bearing casing for housing said bearings;
a cooling mechanism for cooling said bearing casing;
and
15 a seal member disposed near said bearings;
wherein said bearings and said seal member are
cooled by said cooling mechanism.
2. A positive-displacement vacuum pump according to
20 claim 1, further comprising:
a side casing disposed between said rotor casing and
said bearing casing;
wherein said rotor casing is cooled by said cooling
mechanism through said side casing.
- 25 3. A positive-displacement vacuum pump according to
claim 2, wherein said side casing has an outlet port.
4. A positive-displacement vacuum pump according to
30 claim 1, wherein each of said multistage rotors comprises
a Roots-type rotor.

5. A positive-displacement vacuum pump according to claim 1, wherein said rotor casing has a plurality of rotor chambers in which said multistage rotors are housed, respectively, and a volume ratio of a first-stage rotor chamber to a final-stage rotor chamber ranges from 8 to 14.

6. A positive-displacement vacuum pump according to claim 5, wherein a ratio of a thickness to a diameter of a final-stage rotor ranges from 0.05 to 0.11.

10

7. A positive-displacement vacuum pump according to claim 1, wherein said rotor casing has a plurality of rotor chambers in which said multistage rotors are housed, respectively, and said rotor casing has a plurality of gas passages each for introducing a gas discharged from one of said plurality of rotor chambers to another one of said plurality of rotor chambers.

8. A positive-displacement vacuum pump according to any one of claims 1 to 7, further comprising:

a brushless DC motor for rotating said pair of multistage rotors.

9. A positive-displacement vacuum pump according to any one of claims 1 to 8, wherein said multistage rotors are disposed in said rotor casing in such a state that said multistage rotors are disposed in alignment with each other.

10. A positive-displacement vacuum pump according to claim 1, wherein said cooling mechanism comprises a cooling liquid passage formed in said bearing casing.

11. A positive-displacement vacuum pump according to claim 1, wherein said bearing casing comprises a motor casing for housing a motor.

5 12. A positive-displacement vacuum pump according to claim 11, further comprising:

 a side casing disposed between said rotor casing and said motor casing;

 wherein said rotor casing is cooled by said cooling
10 mechanism through said side casing.

13. A positive-displacement vacuum pump comprising:
 two rotational shafts which are synchronously rotatable in opposite directions;

15 a pair of multistage rotors attached to said rotational shafts, respectively;

 a rotor casing for housing said pair of multistage rotors;

 a plurality of bearings for rotatably supporting
20 said rotational shafts;

 a bearing casing for housing said bearings;

 a first side casing disposed between said rotor casing and said bearing casing; and

 a first cooling mechanism for cooling said bearing
25 casing.

14. A positive-displacement vacuum pump according to claim 13, further comprising:

 a motor casing for housing a motor;

30 a second side casing disposed between said rotor casing and said motor casing; and

 a second cooling mechanism for cooling said motor casing.

15. A positive-displacement vacuum pump according to claim 14, further comprising:

a plurality of bearing cases for holding said bearings;

5 wherein said plurality of bearing cases are disposed in said bearing casing and said motor casing, respectively.

16. A positive-displacement vacuum pump according to claim 13, wherein said first side casing has an outlet port.

17. A positive-displacement vacuum pump according to claim 13, wherein each of said multistage rotors comprises
15 a Roots-type rotor.

18. A positive-displacement vacuum pump according to claim 13, wherein said rotor casing has a plurality of rotor chambers in which said multistage rotors are housed,
20 respectively, and a volume ratio of a first-stage rotor chamber to a final-stage rotor chamber ranges from 8 to 14.

19. A positive-displacement vacuum pump according to claim 13, wherein a ratio of a thickness to a diameter of
25 a final-stage rotor ranges from 0.05 to 0.11.

20. A positive-displacement vacuum pump according to claim 13, wherein said rotor casing has a plurality of rotor chambers in which said multistage rotors are housed,
30 respectively, and said rotor casing has a plurality of gas passages each for introducing a gas discharged from one of said plurality of rotor chambers to another one of said plurality of rotor chambers.

21. A positive-displacement vacuum pump according to any one of claims 13 to 20, further comprising:

5 a brushless DC motor for rotating said pair of multistage rotors.

22. A positive-displacement vacuum pump according to any one of claims 13 to 21, wherein said multistage rotors are disposed in said rotor casing in such a state that
10 said multistage rotors are disposed in alignment with each other.

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FIG. 1

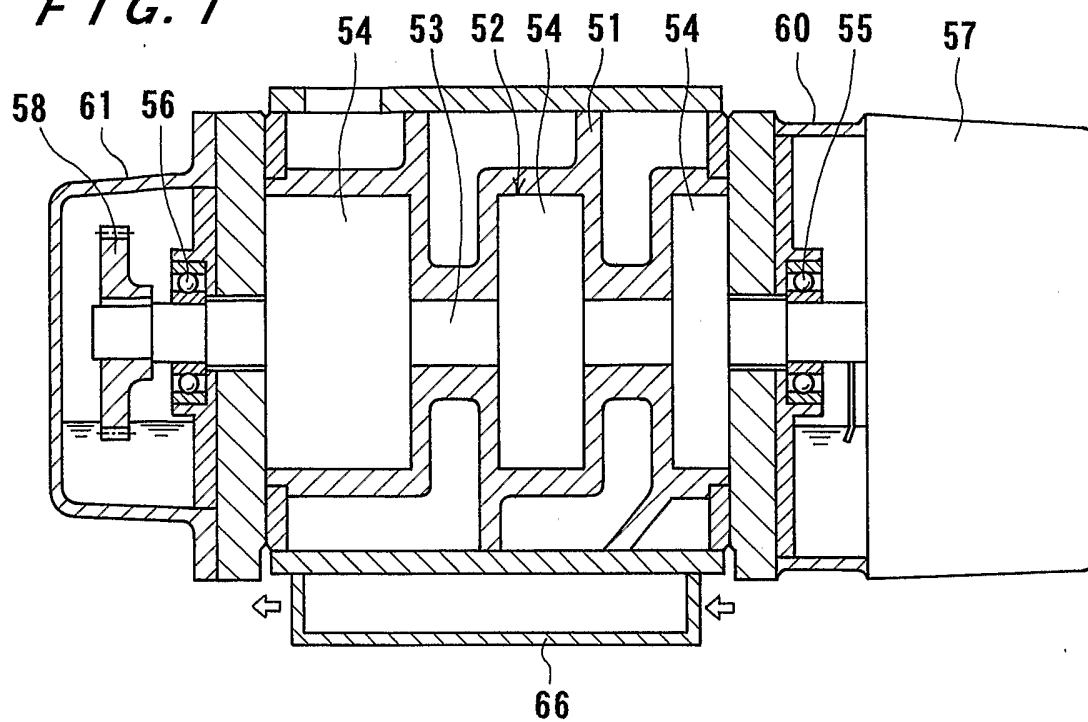


FIG. 2

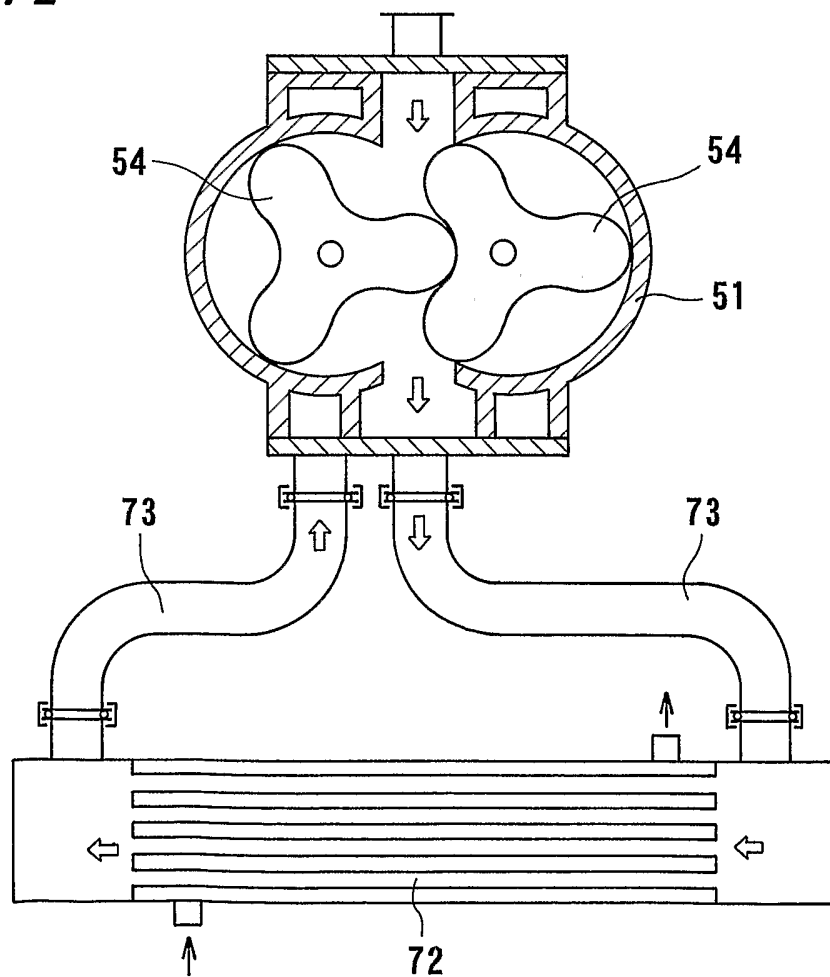
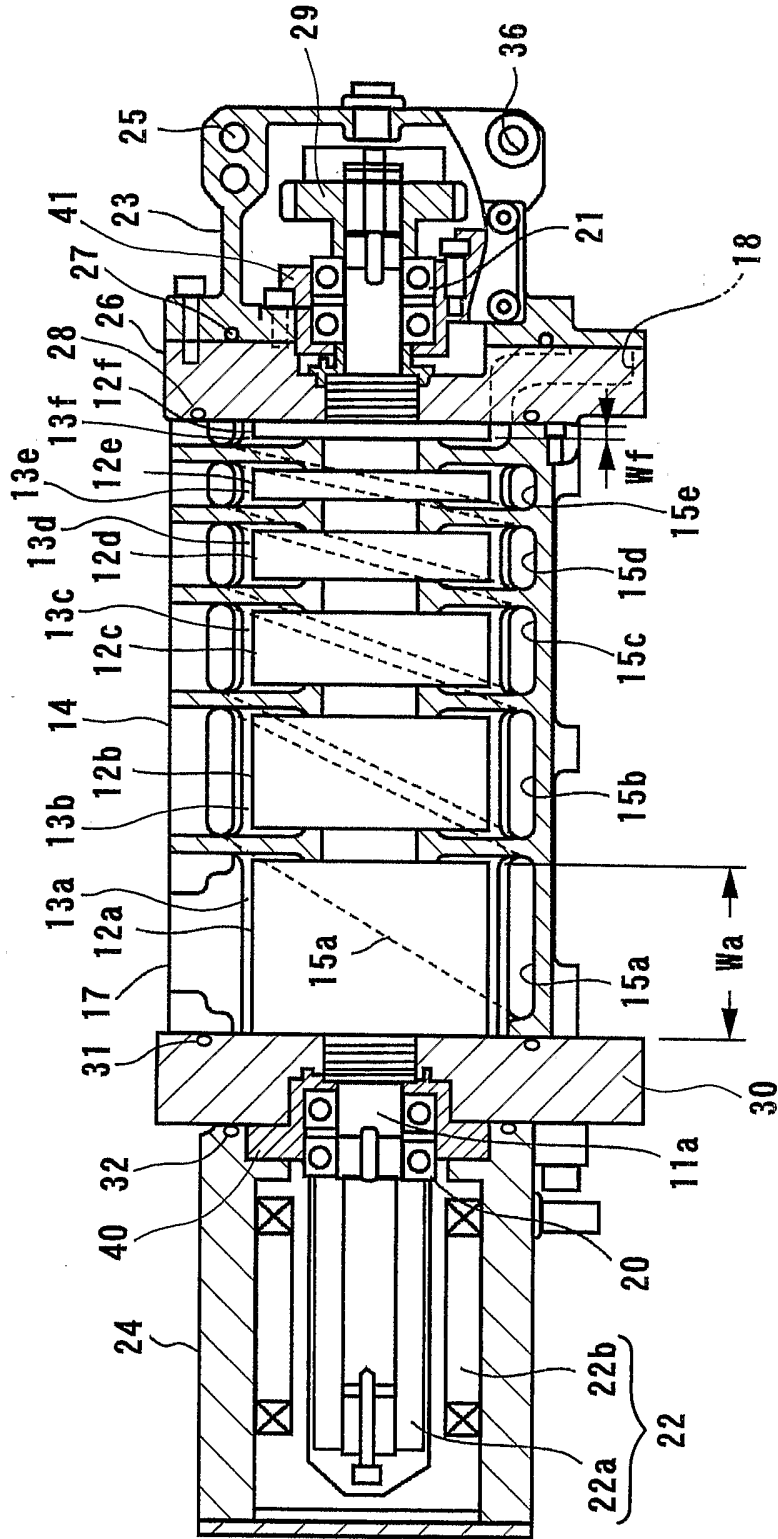
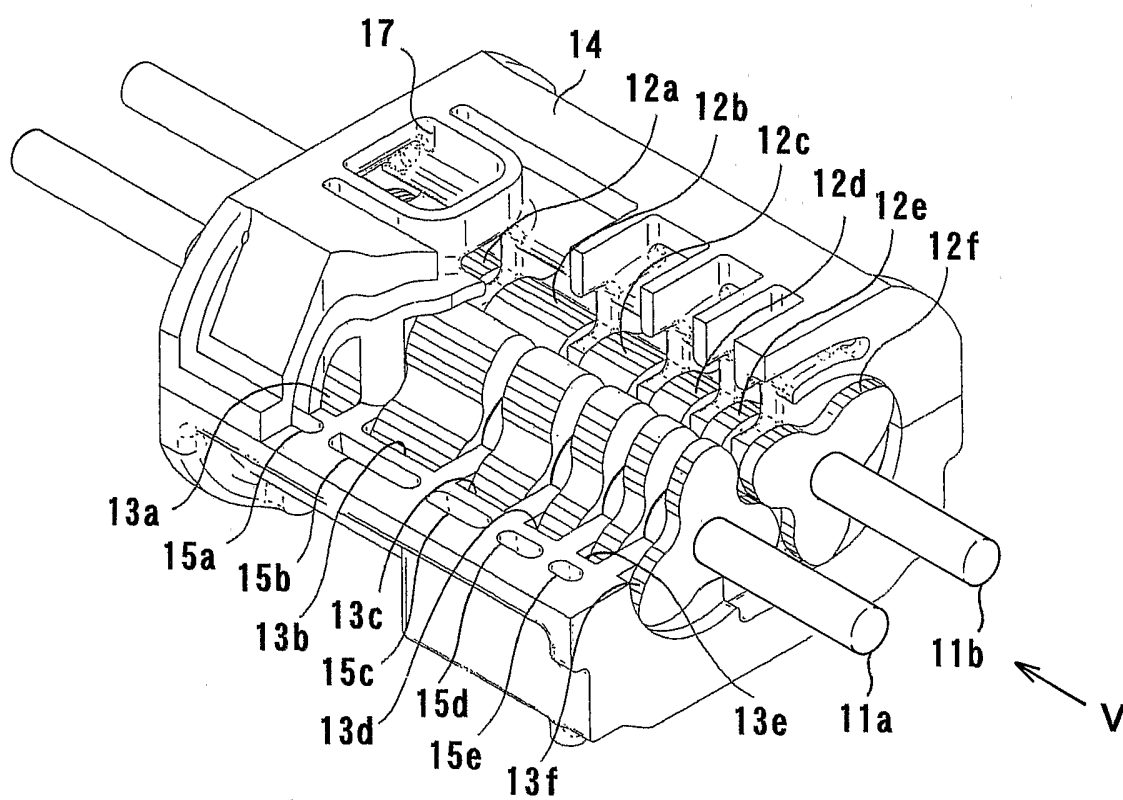


FIG. 3



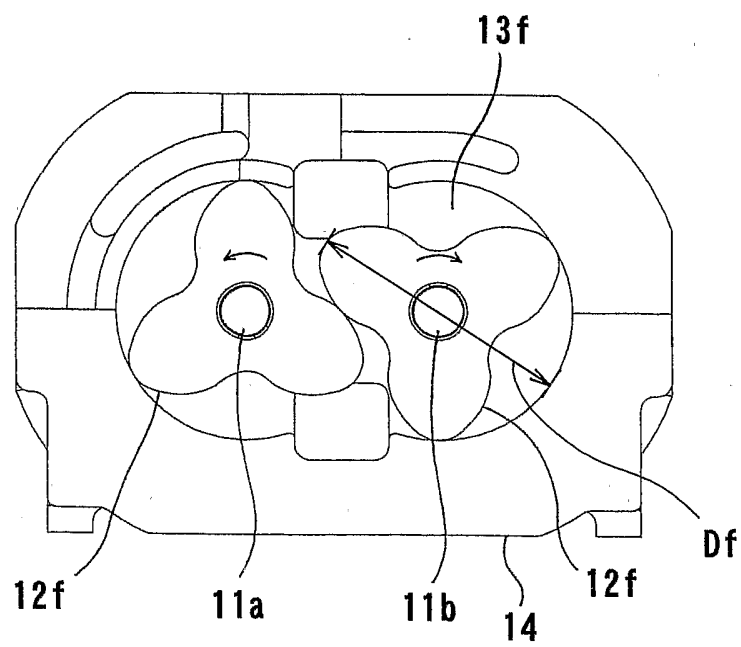
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FIG. 4



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F I G. 5



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FIG. 6

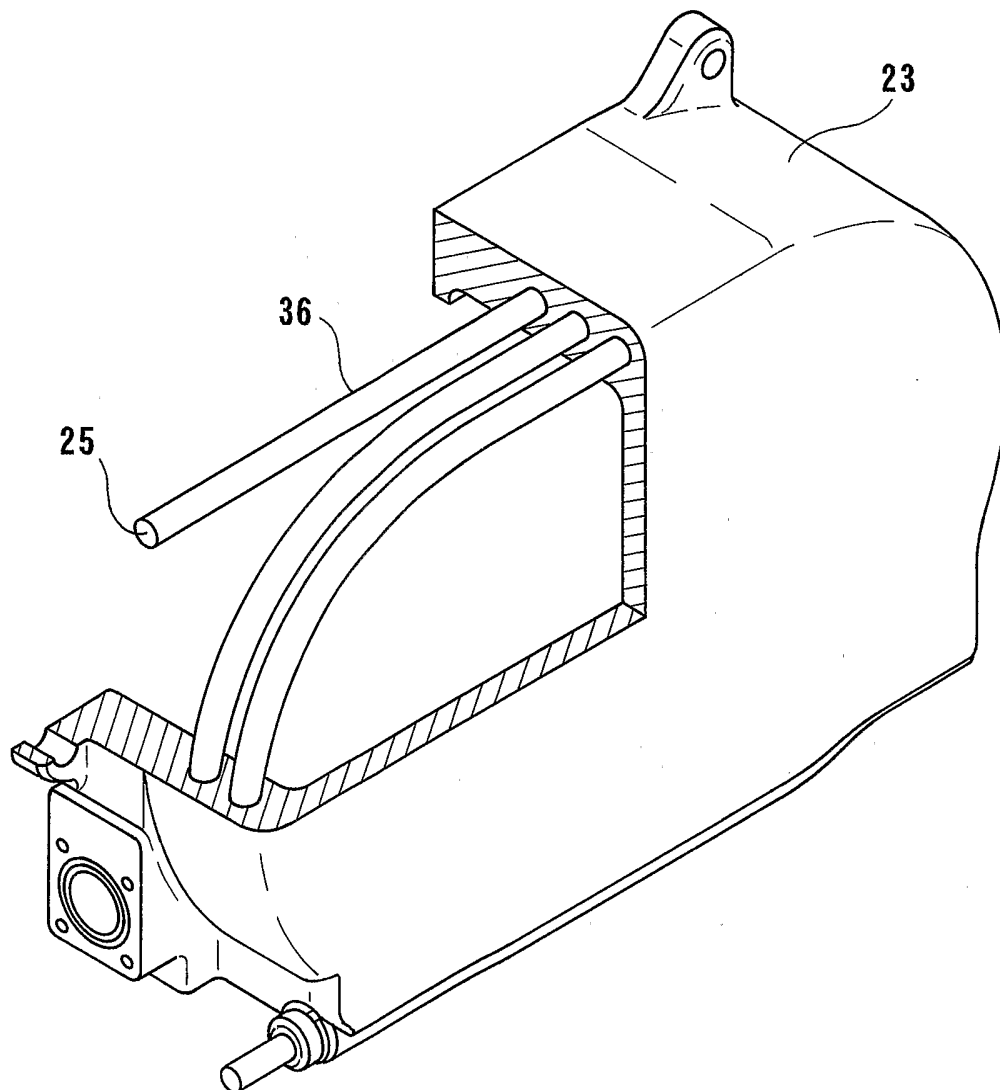
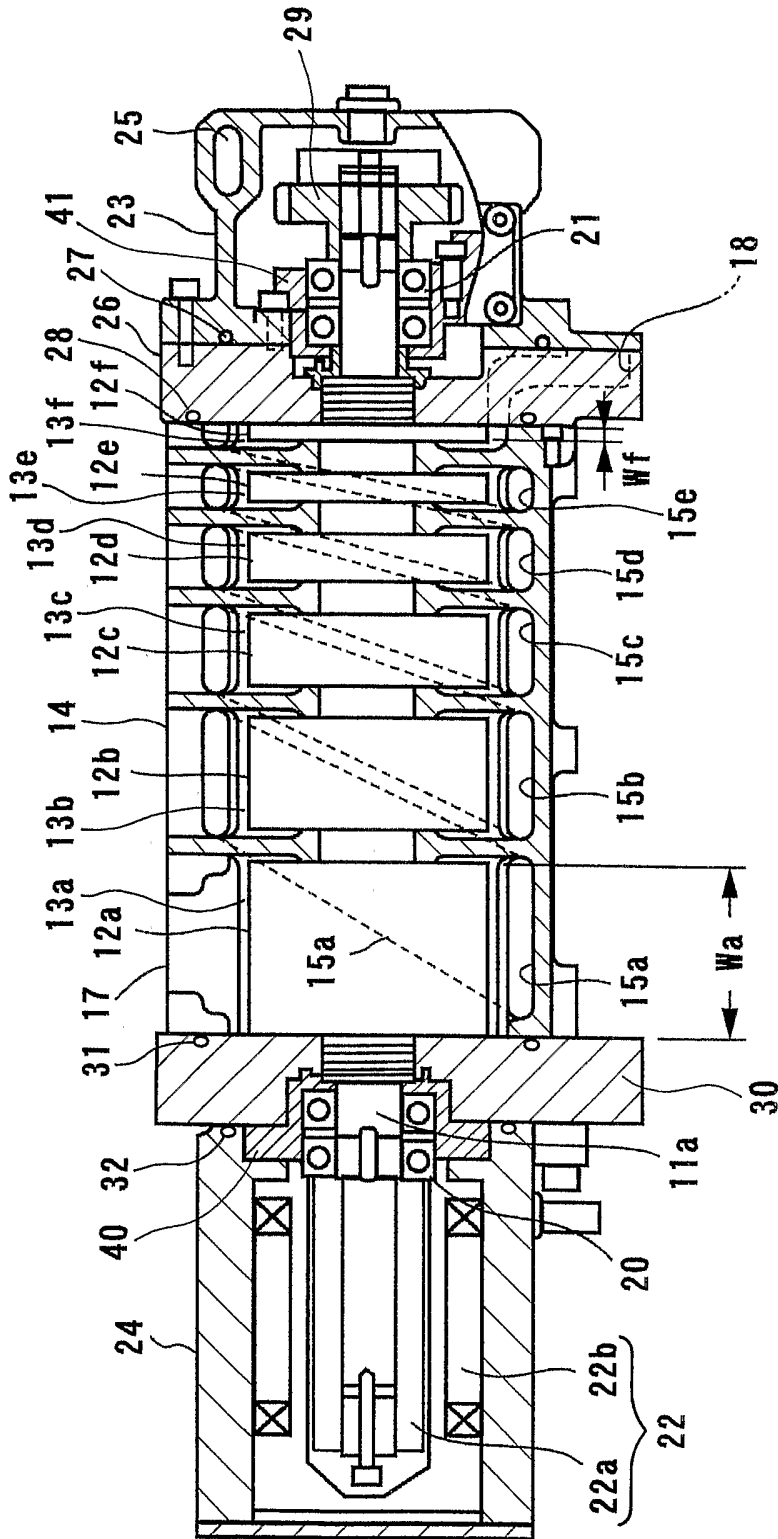
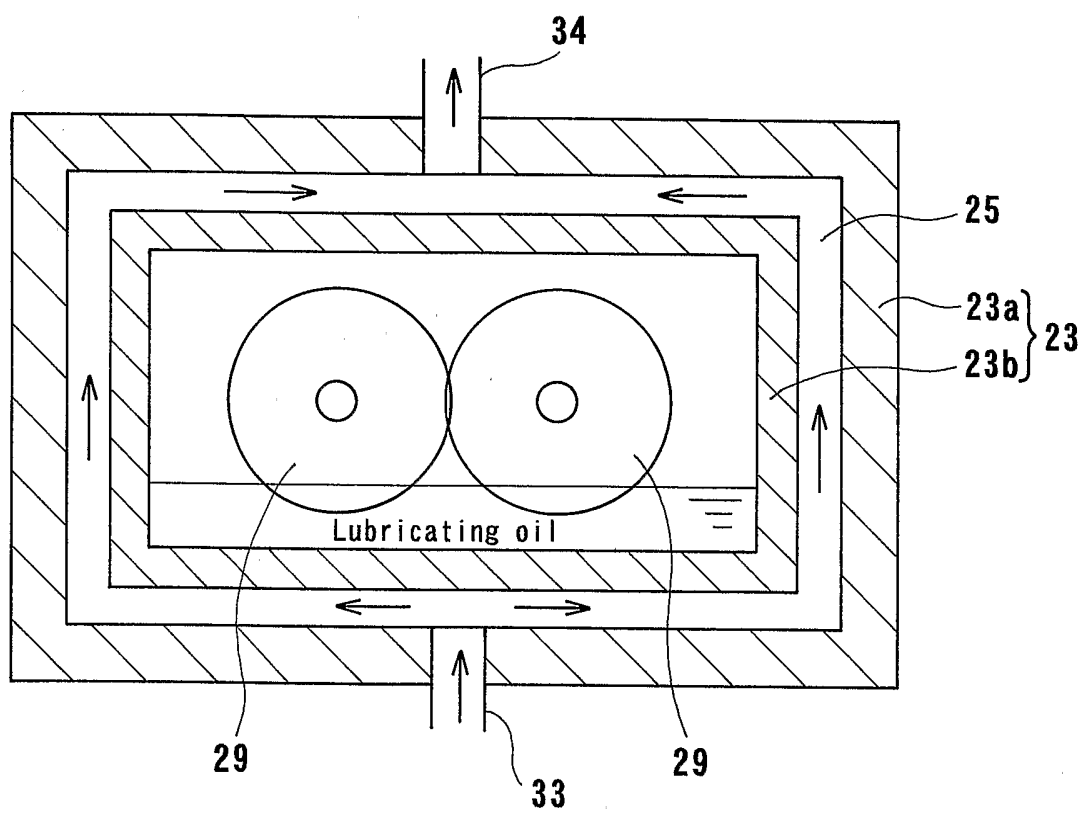


FIG. 7



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FIG. 8



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FIG. 9

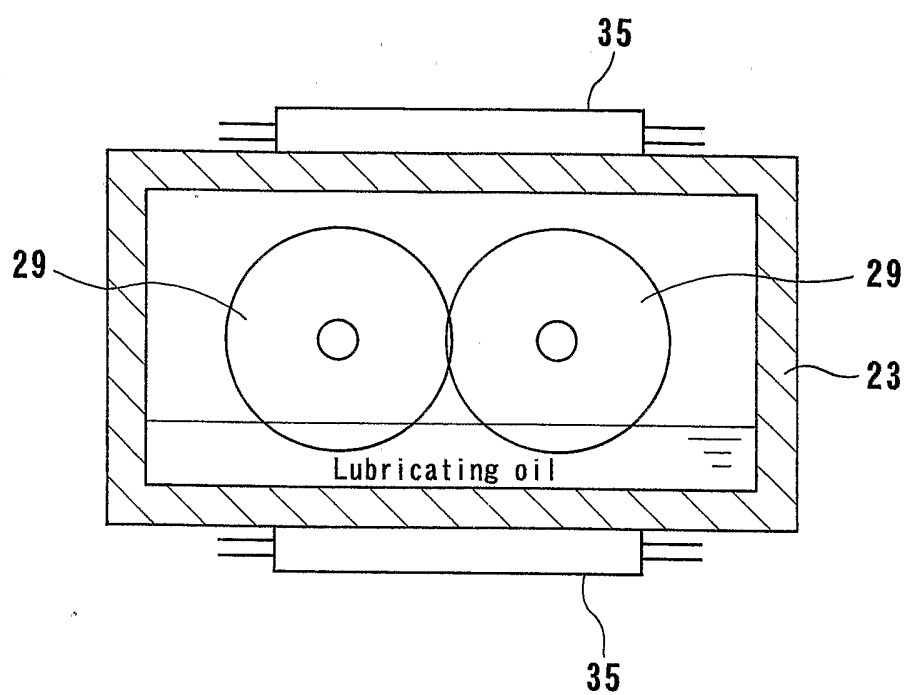
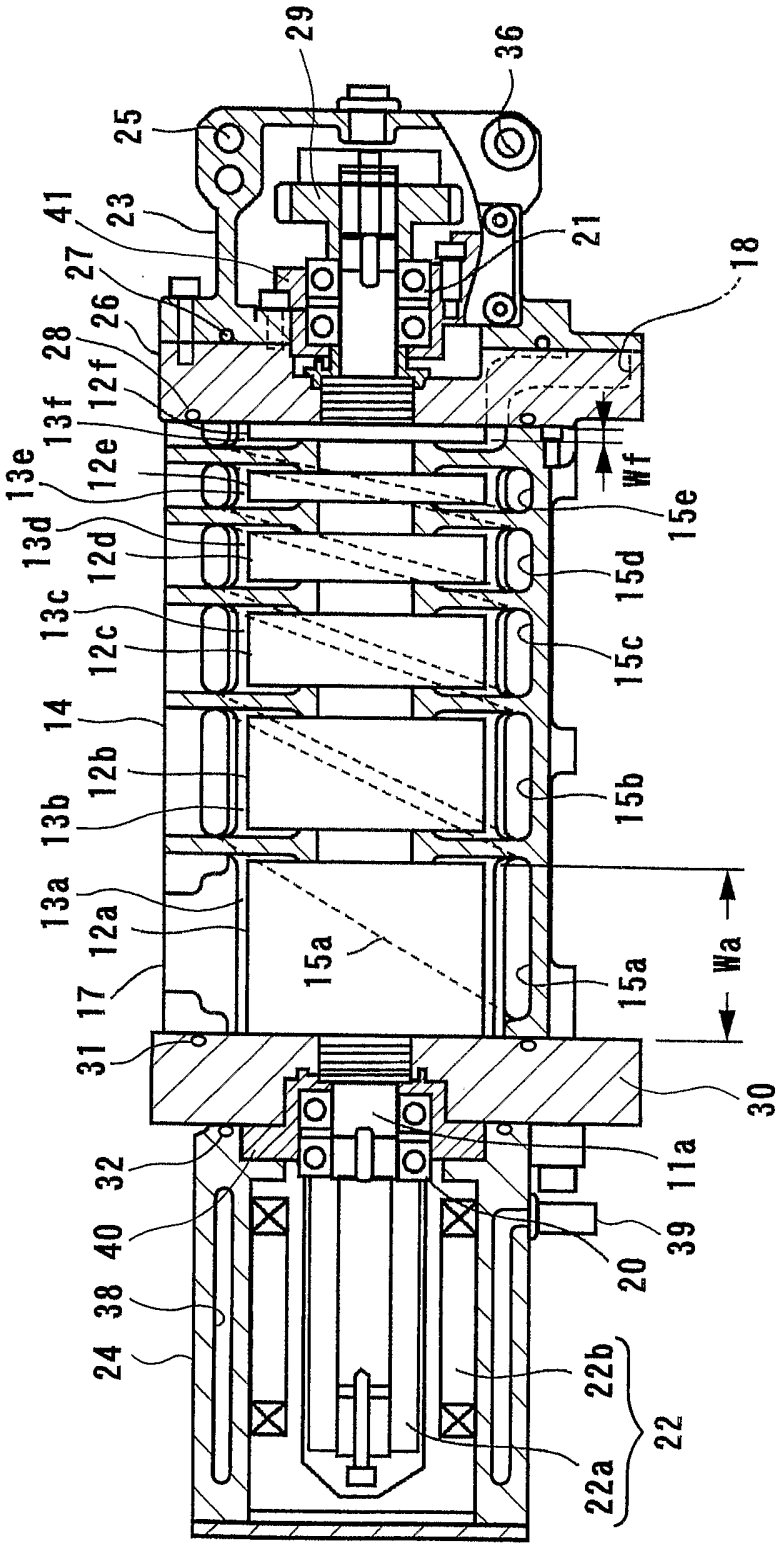


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP 2004/003705

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl⁷ F04C29/04

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.Cl⁷ F04C25/02, F04C29/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 Japanese Utility Model Gazette 1922-1996, Japanese Publication of Unexamined Utility Model Applications 1971-2004, Japanese Registered Utility Model Gazette 1994-2004, Japanese Gazette Containing the Utility Model 1996-2004

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.
X Y	JP 5-1188288 A (EBARA CORPORATION) 1993.05.14 line 43, column 2, page 2 to line 31, column 3, page 3, figs 1-3 (Family:none)	1, 2, 4-6, 9, 13 , 17, 18, 19 3, 7, 8, 10, 11, 12, 14, 15, 16, 20, 21, 22
X Y	JP 2002-115688 A (TOYOTA INDUSTRIES CORPORATION) 2002.04.19 (Family:none)	1, 2, 4-6, 9, 13 , 17, 18, 19 3, 7, 8, 10, 11, 12, 14, 15, 16, 20, 21, 22
Y	JP 2002-364569 A (ULVAC, Inc.) 2002.12.18 (Family:none)	3, 7, 8, 15, 16, 2 1, 22
Y	EP 733804 A2 (EBARA CORPORATION) 1996.09.25 Fig.1 & JP 8-319967 A & US 5779453 A1 & DE 69625401 T	8, 10, 11, 12, 1 4, 21, 22

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

* Special categories of cited documents:

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Date of the actual completion of the international search

02.07.2004

Date of mailing of the international search report

27.072004

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INTERNATIONALSEARCHREPORT

International application No.

PCT/JP2004/003705

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Microfilm of the specification and drawings annexed to the written application of Japanese Utility Model Application No. 27372/1990 (Laid-open No. 40186/1992) (ANLET Co., Ltd.), 1992.04.06 (Family:none)	3,7,8,15,16,21,22
Y	US 2002/131870 A1 (ALCATEL) 2002.09.19 Fig.2 & FR 2822200 A & EP 1243795 A1 & JP 14-339864 A	14,21,22