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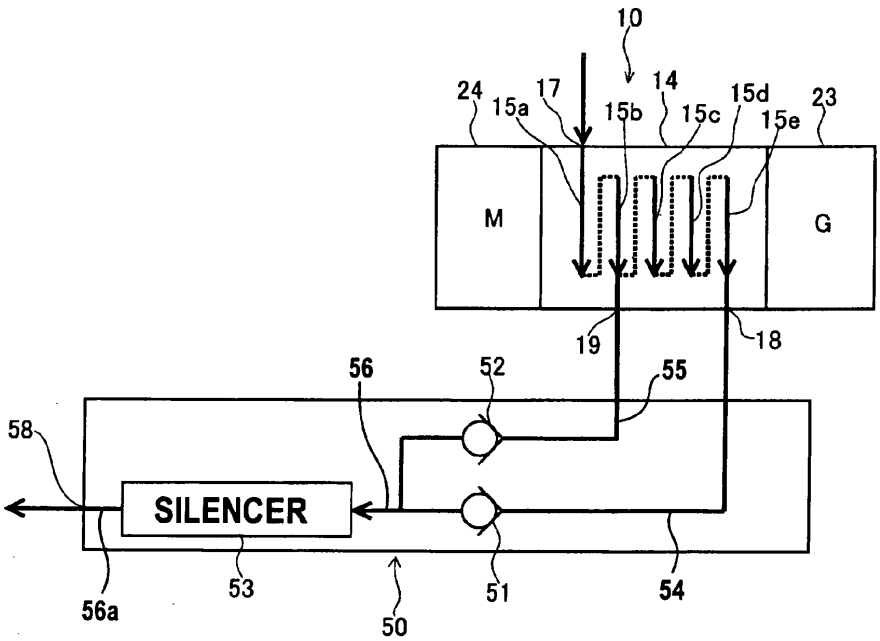
(54) Dry vacuum pump apparatus

(57) A dry vacuum pump apparatus includes a dry vacuum pump (10) having a final outlet port (18) and an intermediate release outlet port (19), an exhaust section check valve (51) connected to the final outlet port (18) and having an outlet port, an intermediate section check valve (52) connected to the intermediate release outlet port (19) and having an outlet port, and an exhaust passage (56) connected to the outlet port of the exhaust section check valve (51) and the outlet port of the intermediate section check valve (52), a silencer (53) connected to the exhaust passage (56) and having an outlet port connected to a final exhaust passage (56a) which is vented to the atmosphere.

FIG. 4



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Description

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] The present invention relates to a dry vacuum pump apparatus including a multistage positive-displacement dry vacuum pump such as a multistage roots-type dry vacuum pump or the like and designed to reduce noise produced when a gas is discharged from the dry vacuum pump.

Description of the Related Art:

[0002] In recent years, dry vacuum pump apparatus, which can be operated under the atmospheric pressure to produce a clean vacuum environment easily, have been used in a wide range of applications including semiconductor fabrication facilities. In particular, semiconductor devices are fabricated according to a fabrication process including more than 300 steps, and there are many vacuum pumps used in the fabrication process. It is, therefore, very important to reduce the footprint of vacuum pump apparatus for effective utilization of the ground-floor area of the fabrication factory. In particular, attempts to reduce the width of vacuum pump apparatus are of importance because a plurality of dry vacuum pump apparatus are installed side by side in many applications. Since vacuum pumps are sometimes installed in semiconductor fabrication apparatus in order to reduce pipe resistance between the vacuum pump and the semiconductor fabrication apparatus, it is important to reduce the size of vacuum pumps.

[0003] Dry vacuum pump apparatus produce noise when a gas is discharged from the vacuum pump. For reducing the noise, it is necessary to include a silencer in an exhaust section of the vacuum pump. Silencers are available in two types, expansion type and resonance type. The expansion-type silencer is capable of silencing (reducing) noise in a wide range of frequencies. However, since the frequency that can be silenced by the expansion-type silencer is in inverse proportion to the length of the silencer, if the expansion-type silencer is to silence noise in a low range of frequencies, the silencer needs to be long, presenting an obstacle to the efforts to reduce the size of dry vacuum pump apparatus. Though the resonance-type silencer can be reduced in size and does not impede the flow of a gas to be discharged, it can silence noise in a range of frequencies that is smaller than the expansion-type silencer.

[0004] There has been proposed a silencer wherein a gas discharged from an exhaust port of a vacuum pump is caused to flow successively through two or more large chambers, a first throttle throat between the large chambers, and a second throttle throat through which a final one of the large chambers is vented to the atmosphere, so that noise produced by the gas will be reduced before being discharged into the atmosphere (see Japanese laid-open patent publication No. 2001-289167 (Patent document 1)). In this proposed silencer, the opening of the first throttle throat is adjusted to a wider setting or a narrower setting depending on the pressure or rate of the gas that passes through the first throttle throat.

[0005] When a gas is exhausted from a large-volume chamber by using a multistage roots-type dry vacuum pump, the gas flows at a high rate therein and is expressively compressed in the pump due to different exhaust speeds at the respective stages of the pump. In the pump, compressive power becomes so high that a rotational speed control mode is triggered to lower the rotational speed of the pump for preventing the pump from operating under an excessive load. When the rotational speed of the pump is lowered, the exhaust speeds in the pump are also lowered, resulting in an increase in the time required to exhaust the gas from the chamber and hence in the lead time of a semiconductor or liquid crystal device fabrication facility which is combined with the multistage roots-type dry vacuum pump. One solution to the problem is to provide an excessive compression preventing mechanism which includes a intermediate release outlet port disposed in a middle stage of the pump for discharging the excessively compressed gas from the pump therethrough, thereby to prevent the gas from being excessively compressed in the pump.

[0006] Multistage dry vacuum pump apparatus generally include a silencer disposed in the exhaust section of a gas passage and a check valve disposed downstream of the silencer.

SUMMARY OF THE INVENTION

[0007] The silencer disclosed in Patent document 1 adjusts the opening of the first throttle throat to a wider setting or a narrower setting depending on the pressure or rate of the gas that is discharged from an exhaust port of a vacuum pump that operates under various operating conditions or a vacuum pump that may be a large size or a small size, for thereby efficiently reducing noise produced by the gas discharged from the exhaust port of the vacuum pump while minimizing a power loss of the vacuum pump. Accordingly, the silencer disclosed in Patent document 1 is unable to effectively reduce noise in a wide range of frequencies from low to high frequencies produced when a gas is discharged from a vacuum pump, and is not of a structure suitable for reducing the size of the silencer.

[0008] During operation of the multistage positive-displacement dry vacuum pump, when the gas is excessively compressed in the middle stage of the pump, the rotational speed control mode is triggered to lower the rotational speed of the pump for preventing the pump from operating under an excessive load. When the rotational speed of the pump is lowered, the exhaust speeds in the pump are also lowered. According to one solution, as described above, a intermediate release outlet port for discharging the excessively compressed gas is disposed in the middle stage of the pump, in addition to a final outlet port for finally discharging the gas from the pump, for discharging the excessively compressed gas from the pump. Consequently, it is necessary to effectively silence noise of the gas discharged from the final outlet port and noise of the excessively compressed gas discharged from the intermediate release outlet port. There have been demands for the development of a dry vacuum pump combined with a silencer which meets such requirements. The conventional dry vacuum pump provided with the intermediate release outlet port cannot silence the noise of the excessively compressed gas because the intermediate release outlet port is disposed downstream of the silencer.

[0009] In the multistage roots-type dry vacuum pump, the volume of a rotor chamber in an initial stage is generally determined by the exhaust speed of the vacuum pump to be designed. Therefore, if a vacuum pump is designed for a high exhaust speed, then it is necessary to increase the volume of a rotor chamber in an initial stage. On the other hand, the volume of a rotor chamber in a final stage needs to be reduced in order to reduce heat (compression heat) to be generated by the pressure difference between front and rear pressures in the rotor chamber in the final stage and also to reduce the power consumption of a motor which rotates a rotor against the pressure difference. However, if the volume of the rotor chamber in the final stage is reduced, it cannot smoothly discharge the gas. As there is a trade-off relationship between the volume ratio and the heat generation, it is determined whether the volume ratio (compression ratio) is to be increased or reduced depending on which of the volume ratio and the heat generation is to be emphasized in designing vacuum pumps. The volume ratio (compression ratio) and the position where the excessive compression preventing mechanism is installed are important in lowering the exhaust speeds.

[0010] Conventional dry vacuum pumps have a silencer disposed in an exhaust section thereof and a check valve disposed downstream of the silencer independently of the silencer. Since the silencer and the check valve are thus disposed independently of each other in the exhaust section, parts for interconnecting the silencer and the check valve are required in addition to the silencer and the check valve. Therefore, the number of parts used is increased, making the dry vacuum pumps large in size. The dry vacuum pumps cannot be reduced in size and are costly to manufacture.

[0011] Multistage roots-type dry vacuum pumps include a motor unit having a motor for actuating a pump unit. Generally, the motor unit is integrally coupled to the pump unit by a flange. Therefore, heat generated by the pump unit is transferred through the flange to a motor casing. The temperature of the motor casing rises due to the heat from the pump unit and also the heat generated by the motor itself. Heretofore, the motor casing is cooled by a coolant flowing through a coolant passage that is defined in an outer circumferential region of the motor casing around a motor stator. Therefore, as the motor casing needs to be thick enough to accommodate the coolant passage therein, it has prevented the multistage roots-type dry vacuum pumps from being reduced in size.

[0012] The pump unit also includes a rotor casing which generally comprises separate upper and lower members that have respective mating surfaces held against each other and are coupled to together by a plurality of bolts arranged at axially equal intervals. The rotor casing has gas flow passages in multiple stages defined therein for delivering a gas compressed in each of the rotor chambers to a next one of the rotor chambers. The bolts coupling the separate upper and lower members together are disposed at the axially equal intervals around the rotor chambers so as to be out of interference with the rotor chambers. Therefore, the rotor casing has a large thickness, which makes the multistage roots-type dry vacuum pumps large in width, preventing them from being reduced in size.

[0013] The present invention has been made in view of the above situation. It is, therefore, an object of the present invention to provide a dry vacuum pump apparatus which includes a single multistage positive-displacement dry vacuum pump or a plurality of series-connected multistage positive-displacement dry vacuum pumps, and a silencer, which can be reduced in size, for effectively reducing noise of a gas discharged from a final outlet port and an intermediate release outlet port of the multistage positive-displacement dry vacuum pump or pumps, in a wide range of frequencies from low to high frequencies.

[0014] A second object of the present invention is to provide a dry vacuum pump apparatus which includes a multistage roots-type dry vacuum pump having an excessive compression preventing mechanism, which is disposed in an appropriate position, for preventing a gas from being excessively compressed in the pump to prevent the rotational speed of the pump from being unduly lowered due to an excessive load, thereby shortening a time required for the pump to discharge the gas.

[0015] In order to achieve the above first object, the present invention provides a dry vacuum pump apparatus comprising a multistage positive-displacement dry vacuum pump having a final outlet port in a final stage for discharging a gas and an intermediate release outlet port in an intermediate stage for discharging an excessively compressed gas, an exhaust section check valve connected to the final outlet port and having an outlet port, an intermediate section check valve connected to the intermediate release outlet port and having an outlet port, an exhaust passage connected to the outlet port of the exhaust section check valve and the outlet port of the intermediate section check valve, and a silencer connected to the exhaust passage and having an outlet port connected to a final exhaust passage which is vented to the atmosphere.

[0016] The exhaust section check valve, the intermediate section check valve, the exhaust passage, and the silencer are preferably integrally combined as an exhaust unit.

[0017] The multistage positive-displacement dry vacuum pump preferably comprises a five-stage dry vacuum pump, the intermediate release outlet port being connected to a second stage of the five-stage dry vacuum pump.

[0018] The silencer preferably comprises a composite silencer including a resonance-type silencer and an expansion-type silencer, and wherein the resonance-type silencer is disposed in an upstream region of the silencer with respect to the direction in which the gas flows through the silencer, and the expansion-type silencer is disposed in a downstream region of the silencer with respect to the direction in which the gas flows through the silencer.

[0019] The multistage positive-displacement dry vacuum pump preferably comprises a single multistage positive-displacement dry vacuum pump or a plurality of series-connected multistage positive-displacement dry vacuum pumps.

[0020] With the above dry vacuum pump apparatus, the exhaust section check valve is connected to the final outlet port of the multistage positive-displacement dry vacuum pump, the intermediate section check valve is connected to the intermediate release outlet port of the multistage positive-displacement dry vacuum pump, the exhaust passage is connected to the outlet port of the exhaust section check valve and the outlet port of the intermediate section check valve, and the silencer is connected to the exhaust passage and has the outlet port connected to the final exhaust passage which is vented to the atmosphere. Therefore, it is possible to effectively silence (reduce) noise of the gas discharged from the final outlet port and noise of the excessively compressed gas discharged from the intermediate release outlet port.

[0021] In order to achieve the above second object, the present invention provides another dry vacuum pump apparatus comprising a multistage roots-type dry vacuum pump having a final outlet port in a final stage for discharging a gas and an intermediate release outlet port in an intermediate stage for discharging an excessively compressed gas, an exhaust section check valve connected to the final outlet port and vented to the atmosphere, and an intermediate section check valve connected to the intermediate release outlet port and vented to the atmosphere.

[0022] Preferably, the multistage roots-type dry vacuum pump comprises a five-stage roots-type dry vacuum pump including rotor chambers in five stages and rotors disposed respectively in the rotor chambers, the intermediate section check valve communicates with the rotor chamber in the second stage, and the rotor disposed in the rotor chamber in the first stage has an axial width which is twice or more the axial width of the rotor disposed in the rotor chamber in the second stage.

[0023] Preferably, the dry vacuum pump apparatus further comprises an exhaust passage connected to an outlet port of the exhaust section check valve and an outlet port of the intermediate section check valve, and a silencer connected to the exhaust passage and having an outlet port connected to a final exhaust passage which is vented to the atmosphere.

[0024] The exhaust section check valve, the intermediate section check valve, the exhaust passage, and the silencer are preferably integrally combined as an exhaust unit.

[0025] Preferably, the multistage roots-type dry vacuum pump comprises a booster pump and a main pump, the booster pump has a final outlet port connected to an inlet port of the main pump, and the exhaust unit is connected to the main pump.

[0026] With the above dry vacuum pump apparatus, the multistage roots-type dry vacuum pump has the intermediate release outlet port in the intermediate stage for discharging the excessively compressed gas, and the intermediate section check valve is connected to the intermediate release outlet port and vented to the atmosphere. As a result, the dry vacuum pump is prevented from operating at a low rotational speed under an excessive load, and hence can reduce the time required to discharge the compressed gas.

[0027] The multistage roots-type dry vacuum pump preferably comprises the five-stage roots-type dry vacuum pump, the intermediate section check valve is connected to the rotor chamber in the second stage, and the rotor disposed in the rotor chamber in the first stage has the axial width which is twice or more the axial width of the rotor disposed in the rotor chamber in the second stage. The intermediate section check valve is connected to the intermediate release outlet port which is connected to the rotor chamber in the second stage with a high compression ratio, and vented to the atmosphere. Therefore, the dry vacuum pump is prevented from operating at a low rotational speed under an excessive load, and hence can reduce the time required to discharge the compressed gas.

[0028] The outlet port of the exhaust section check valve and the outlet port of the intermediate section check valve are connected to the exhaust passage, and the silencer connected to the exhaust passage. The outlet port of the silencer is connected to the final exhaust passage which is connected to the exhaust port vented to the atmosphere. Therefore, it is possible to effectively silence (reduce) noise of the gas discharged from the final outlet port and noise of the excessively compressed gas discharged from the intermediate release outlet port.

[0029] As the exhaust section check valve, the intermediate section check valve, the exhaust passage, and the silencer are preferably integrally combined as the exhaust unit, the number of parts of an exhaust system of the dry vacuum pump is reduced for scaling down the exhaust system, so that the dry vacuum pump apparatus can be reduced in size and manufactured inexpensively.

[0030] The present invention may provides an exhaust unit adapted to be connected to a multistage vacuum pump having a final outlet port in a final stage for discharging a gas and an intermediate release outlet port in an intermediate stage for discharging an excessively compressed gas. The exhaust unit comprises an exhaust section check valve adapted to be connected to the final outlet port of the multistage vacuum pump, an intermediate section check valve adapted to be connected to the intermediate release outlet port of the multistage vacuum pump, and a silencer connected downstream of the exhaust section check valve and the intermediate section check valve. The an exhaust section check valve, the intermediate section check valve, and the silencer are integrally combined with each other.

[0031] Since the exhaust section check valve, the intermediate section check valve, and the silencer connected downstream of the exhaust section check valve and the intermediate section check valve are integrally combined with each other in the exhaust unit, the exhaust unit is made up of a small number of parts, can be reduced in size, and can be manufactured inexpensively.

[0032] Simply when the exhaust unit is installed on the multistage vacuum pump such that the final outlet port is connected to the exhaust section check valve and the intermediate release outlet port is connected to the intermediate section check valve, the multistage vacuum pump is combined with the exhaust section check valve, the intermediate release outlet port, and the silencer. Consequently, they can easily be assembled into a dry vacuum pump apparatus, which is reduced in size and cost as much as the exhaust unit is reduced in size and cost.

[0033] The present invention may provide a silencer comprising a resonance-type silencer disposed in an upstream region with respect to the direction in which a gas flows through the silencer, and an expansion-type silencer disposed in a downstream region with respect to the direction in which the gas flows through the silencer. The resonance-type silencer and the expansion-type silencer are integrally combined with each other.

[0034] The present invention may also provide a silencer comprising a lid, and a silencer casing in the form of a thick plate, the silencer casing having a resonance chamber serving as a resonance-type silencer, an expansion chamber serving as an expansion-type silencer, and a gas passage which are defined in a side surface thereof and which are open in the side surface. The resonance chamber communicates with the gas passage through a resonance port, and the expansion chamber communicates with the gas passage through a throttle throat downstream of the resonance port with respect to the direction in which a gas flows through the silencer casing. The side surface of the silencer casing is covered with the lid, thereby integrally combining the resonance-type silencer and the expansion-type silencer with each other.

[0035] Inasmuch as the resonance-type silencer is disposed in the upstream region with respect to the direction in which the gas flows through the silencer, and the expansion-type silencer is disposed in the downstream region with respect to the direction in which the gas flows through the silencer, wherein the resonance-type silencer and the expansion-type silencer are integrally combined with each other, the silencer is capable of silencing (reducing) noise in a wide range of frequencies and can be reduced in size.

[0036] The silencer casing of the composite silencer may have the resonance chamber serving as the resonance-type silencer, the expansion chamber serving as the expansion-type silencer, and the gas passage which are defined in the side surface thereof and which are open in the side surface. The resonance chamber communicates with the gas passage through the resonance port which is open in the side surface, and the expansion chamber communicates with the gas passage through the throttle throat downstream of the resonance port with respect to the direction in which the gas flows through the silencer casing. The side surface of the silencer casing is covered with the lid, thereby integrally combining the resonance-type silencer and the expansion-type silencer with each other. With this arrangement, the silencer is capable of silencing (reducing) noise in a wide range of frequencies and can be reduced in size. The expansion chamber may be divided into a first expansion chamber and a second expansion chamber. The resonance chamber and the first expansion chamber may share a wall, and the first expansion chamber and the second expansion chamber may share a wall. This makes it possible to further reduce the size of the silencer.

[0037] The resonance-type silencer is disposed in the upstream region with respect to the direction in which the gas flows through the silencer, and the expansion-type silencer is disposed in the downstream region with respect to the direction in which the gas flows through the silencer. Consequently, the silencer is capable of silencing noise of a gas discharged from a dry vacuum pump in a wide range of frequencies to keep a silent environment around a dry vacuum pump apparatus including the dry vacuum pump and the silencer. As the silencer can be reduced in size, the dry vacuum pump apparatus can also be reduced in size.

[0038] The present invention may provide yet another dry vacuum pump apparatus comprising: a pump unit including a rotor casing, a pair of rotational shafts rotatably supported in the rotor casing, a pair of sets of rotors in multiple stages which are fixedly mounted on the rotatable shafts, and a plurality of rotor chambers in multiple stages defined in the rotor casing, the sets of rotors being disposed in the rotor chambers; a motor unit including a motor for rotating the rotational shafts for delivering a gas compressed by the rotors in the rotor chambers successively through the rotor chambers; and a flange integrally coupled the motor unit to the pump unit, the flange having a coolant passage for a coolant to flow therethrough.

[0039] With the above dry vacuum pump apparatus, when the coolant flows through the coolant passage provided in the flange coupling the motor unit and the pomp unit together, heat transferred from the pump unit to the motor casing is absorbed and blocked against being transferred to the motor by the coolant flowing through the coolant passage. Consequently, the motor casing does not need to have any other cooling means for dissipating the heat from the pump unit. The widthwise dimension of the motor casing is thus smaller than the conventional motor casing which may be defined a coolant passage therein.

[0040] The present invention may provide yet another dry vacuum pump apparatus comprising: a pump unit including a rotor casing, a pair of rotational shafts rotatably supported in the rotor casing, a pair of sets of rotors in multiple stages which are fixedly mounted on the rotatable shafts, and a plurality of rotor chambers in multiple stages defined in the rotor casing, the sets of rotors being disposed in the rotor chambers, the rotor casing having a plurality of gas passages; and a motor unit for rotating the rotational shafts for delivering a gas compressed by the rotors in the rotor chambers successively through the rotor chambers and the gas passages. The rotor casing comprises a pair of separate members having respective mating surfaces held against each other and coupled to together by a plurality of bolts arranged at axial intervals, the bolts extending through the separate members at regions free of the gas passages and between the gas passages closely to circumferential positions where the gas passages are defined.

[0041] With the above dry vacuum pump apparatus, inasmuch as the separate members of the rotor casing are coupled to together by the bolts extending through the separate members at regions free of the gas passages and between the gas passages closely to circumferential positions where the gas passages are defined. Consequently, the regions where the bolts extend through the separate members may be close to an inner circumferential surface of the rotor casing. The rotor casing can thus be reduced in widthwise dimension, making it possible to reduce in the size of the pump unit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0042]

FIG. 1 is a vertical sectional front view of a dry vacuum pump apparatus according to an embodiment of the present invention;

FIG. 2 is a cross-sectional view taken along line A - A of FIG. 1;

FIG. 3 is a front view showing rotational shafts and rotors of a multistage roots-type dry vacuum pump provided in the dry vacuum pump apparatus shown in FIG. 1;

FIG. 4 is a schematic diagram of the dry vacuum pump apparatus shown in FIG. 1, showing gas flows therein;

FIG. 5 is a schematic diagram of the structure of an exhaust unit of the dry vacuum pump apparatus shown in FIG. 1;

FIG. 6A is a plan view showing the structure of the exhaust unit of the dry vacuum pump apparatus shown in FIG. 1;

FIG. 6B is a front view showing the structure of the exhaust unit of the dry vacuum pump apparatus shown in FIG. 1;

FIG. 7A is a side sectional view showing the structure of a silencer of the exhaust unit of the dry vacuum pump apparatus shown in FIG. 1;

FIG. 7B is a cross-sectional view taken along line B - B of FIG. 7A;

FIG. 8 is a vertical sectional view of another dry vacuum pump apparatus;

FIG. 9 is a cross-sectional view taken along line C - C of FIG. 8;

FIG. 10 is a view showing the positions of bolt insertion holes for inserting fastening bolts therethrough in the rotor casing of a multistage roots-type dry vacuum pump provided in the dry vacuum pump apparatus shown in FIG. 8, and also the positions of bolt insertion holes according to a comparative example; and

FIG. 11 is a schematic diagram of a dry vacuum pump apparatus according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0043] Preferred embodiments of the present invention will be described in detail below with reference to the drawings. FIG. 1 is a vertical sectional front view of a dry vacuum pump apparatus according to an embodiment of the present invention, and FIG. 2 is a cross-sectional view taken along line A - A of FIG. 1. The dry vacuum pump apparatus includes a multistage roots-type dry vacuum pump (hereinafter simply referred to as "dry vacuum pump") 10. The dry vacuum pump 10 is a five-stage dry vacuum pump and has pairs of roots-type rotors 12a, 12b, 12c, 12d, 12e in five stages fixedly mounted on two rotational shafts 11a, 11b that are rotatably supported by bearings 20, 21 on the opposite ends of the rotational shafts 11a, 11b. The rotors 12a, 12b, 12c, 12d, 12e will hereinafter also be referred to collectively as "rotors 12".

[0044] There are small gaps defined between the rotors 12 themselves and also between the rotors 12 and an inner circumferential surface of a rotor casing 14 in which the rotors 12 are rotatably housed, so that when the rotational shafts 11 a, 11 b rotate about their own axes, the rotors 12 are rotated about the axes of the rotational shafts 11 a, 11b out of contact with each other. The rotor casing 14 defines therein rotor chambers 13a, 13b, 13c, 13d, 13e which house the respective pairs of the rotors 12a, 12b, 12c, 12d, 12e. A gas that is pumped by the dry vacuum pump 10 is delivered through the rotor chambers 13a, 13b, 13c, 13d, 13e. The rotor chambers

13a, 13b, 13c, 13d, 13e are arranged in series along the rotational shafts 11 a, 11b in the rotor casing 14. The rotor casing 14 has an upper surface which is covered with a cover member (not shown). The rotor casing 14 has an inlet port 17 defined in the upper surface thereof and communicating with the rotor chamber 13a in the first stage. The rotor casing 14 also has an outlet side surface covered with a first side casing 26 secured thereto. A bearing casing 23, which houses the bearings 21 therein, is fixed to a side surface of the first side casing 26 remote from the rotor casing 14. The first side casing 26 has a final outlet port 18 defined in a side surface thereof, which faces the rotor casing 14, and communicating with the rotor chamber 13e in the final stage. The final outlet port 18 discharges a gas through an exhaust unit check valve and a silencer into the atmosphere, as described later.

[0045] As shown in FIG. 1, a motor (e.g., brushless DC motor) 22 is disposed on one side of the bearings 20 remote from the rotor casing 14. The motor 22 has a motor rotor 22a fixed to an end of one of the rotational shafts 11 a, 11b, and a motor stator 22b disposed around the motor rotor 22a. The motor 22 is supplied with variable-frequency electric power from an electric power supply such as an inverter device or the like (not shown), and a rotational speed including a soft starting mode of the dry vacuum pump 10 is controlled. The motor 22 is housed in a motor casing 24. If the motor 22 comprises a brushless DC motor, then the rotors 12 are synchronously rotated in opposite directions by the brushless DC motor through the rotational shafts 11a, 11b. Specifically, timing gears 29, which are held in mesh with each other, are fixed to the respective ends of the rotational shafts 11a, 11b remote from the motor 22. The timing gears 29 as well as the bearings 21 are housed in the bearing casing 23. The bearings 20, 21 are held by respective bearing cases 40, 41 which are accommodated respectively in the motor casing 24 and the bearing casing 23.

[0046] In each of the rotor chambers 13a - 13e, the gas, which is confined between the rotors 12 mounted on the rotational shafts 11 a, 11b and the inner circumferential surface of the rotor casing 14, is delivered from an inlet side to an outlet side of the rotor chamber. The rotor casing 14 comprises a double-walled casing including inner and outer circumferential walls which define therebetween gas passages 15a, 15b, 15c, 15d, 15e around the respective rotor chambers 13a, 13b, 13c, 13d, 13e. The outlet side of the rotor chamber 13a communicates with the inlet side of the rotor chamber 12b by the gas passage 15a. Similarly, the outlet sides of the rotor chambers 13b, 13c, 13d, 13e communicate with the inlet sides of the rotor chambers 13c, 13d, 13e and the final outlet port 18 by the respective gas passages 15b, 15c, 15d, 15e. Therefore, the gas that is compressed by the rotor 12a in the rotor chamber 13a is delivered from the outlet side of the rotor chamber 13a through the gas passage 15a to the inlet side of the rotor chamber 13b. Thus, the gas is successively compressed in the rotor chambers 13a - 13e and delivered through the gas passages 15a - 15e into the final outlet port 18.

[0047] Generally, in the multistage roots-type dry vacuum pump, the volume of a rotor chamber in an initial stage is determined by the exhaust speed of the vacuum pump to be designed. Therefore, if a vacuum pump is designed for a high exhaust speed, then it is necessary to increase the volume of a rotor chamber in an initial stage. On the other hand, the volume of a rotor chamber in a final stage needs to be reduced in order to reduce heat (compression heat) to be generated by the pressure difference between front and rear pressures in the rotor chamber in the final stage and also to reduce the power consumption of a motor which rotates a rotor against the pressure difference. However, if the volume of the rotor chamber in the final stage is reduced, it cannot smoothly discharge the gas. As there is a trade-off relationship between the volume ratio and the heat generation, it is determined whether the volume ratio (compression ratio) is to be increased or reduced depending on which of the volume ratio and the heat generation is to be emphasized in designing vacuum pumps.

[0048] In this embodiment, the axial width of the rotor chamber 13a in the first stage is twice or more the axial width of the rotor chamber 13b in the second stage. Specifically, as shown in FIG. 3, the axial width Wa of the rotor 12a in the first stage is twice or more the axial width Wb of the rotor 12b in the second stage ($Wa \geq 2Wb$). The axial width Wc of the rotor 12c in the third stage, the axial width Wd of the rotor 12d in the fourth stage, and the axial width We of the rotor 12e in the final stage are progressively smaller at prescribed ratios. The axial widths of the rotor chamber 13a — 13e are substantially equal to the axial widths of the rotor 12a -12e.

[0049] In this embodiment, furthermore, the axial width Wa of the rotor 12a in the first stage is set nine times or more the axial width We of the rotor 12e in the final stage ($Wa \geq 9We$) so as to be effective for pumps wherein the volume of the rotor chamber 13a in the first stage is nine times or more the volume of the rotor chamber 13e in the final stage. The ratio of the axial width Wa of the rotor 12a in the first stage and the axial width We of the rotor 12e in the final stage is equal to the volume ratio of the rotor chamber 13a in the first stage and the rotor chamber 13e in the final stage.

[0050] If the motor 22 comprises a brushless DC motor, then a rotational speed of the motor 22 may be controlled to increase the exhaust speed while making the volume of the rotor chamber 13e in the final stage small in size, and also to reduce heat generated by the motor 22 and electric power consumed by the motor 22. In other words, the dry vacuum pump 10 can achieve the same exhaust speed as the conventional vacuum pumps which employ ordinary motors, have a greater volume ratio (compression ratio) and generate less heat than the conventional vacuum pumps. A brushless DC motor used as the motor 22 for rotating the two rotational shafts 11a, 11b is highly efficient, can deal with large load variations, and can produce large compressive power at the time the dry vacuum pump 10 is activated.

[0051] The bearings 21 are disposed near the final outlet port 18 of the dry vacuum pump 10. The rotational shafts 11a, 11b are rotatably supported by the bearings 21 and the bearings 20 which are positioned near the inlet port 17. The bearings 21 are housed in the bearing casing 23, and the side casing 26 is disposed between the bearing casing 23 and the rotor casing 14. An O-ring seal (sealing unit), not shown, is interposed between the bearing casing 23 and the side casing 26, thereby sealing a small clearance between the bearing casing 23 and the side casing 26. Another O-ring seal (sealing unit), not shown, is also interposed between the side casing 26 and the rotor casing 14, thereby sealing a small clearance between the side casing 26 and the rotor casing 14. The bearings 20 are housed in the motor casing 24. Another side casing 30 is disposed between the motor casing 24 and the rotor casing 14. An O-ring seal (sealing unit), not shown, is interposed between the side casing 30 and the rotor casing 14. Another O-ring seal (sealing unit), not shown, is also interposed between the side casing 30 and the motor casing 24.

[0052] According to the dry vacuum pump having above-described structure, when the motor 22 is energized to rotate the rotational shafts 11 a, 11b, the rotors 12a, 12b, 12c, 12d, 12e are rotated to compress a gas drawn in from the inlet port 17 within the rotor chambers 13a, 13b, 13c, 13d, 13e. The gas as it is progressively compressed is delivered successively through the gas passages 15a - 15e into the final outlet port 18, from which the compressed gas is introduced into an exhaust unit 50 that is connected to the final outlet port 18. The exhaust unit 50 discharges the gas into the atmosphere. The exhaust unit 50 comprises an exhaust section check valve (final check valve) 51, an intermediate section check valve 52, and a silencer 53. The exhaust section check valve 51 is connected through a gas passage 54 to the final outlet port 18. The intermediate section check valve 52 is connected through a gas passage 55 to an intermediate release outlet port 19 (FIG. 4) defined in the rotor casing 14 and communicating with the second gas passage 15b. The intermediate release outlet port 19 serves to release into the atmosphere the gas, which has been compressed to a pressure level higher than the atmospheric pressure, from the second gas passage 15b to reduce the power loss of the dry vacuum pump 10.

[0053] FIG. 4 schematically shows the dry vacuum pump 10 and the exhaust unit 50 of the dry vacuum pump apparatus, and gas flows therein. As shown in FIG. 4, when the dry vacuum pump 10 is in operation, a gas drawn into the inlet port 17 flows through the gas passages 15a - 15e and the final outlet port 18 into the exhaust unit 50, and then flows through the exhaust section check valve (final check valve) 51 and the silencer 53 and is discharged into the atmosphere. If the gas is excessively compressed in the dry vacuum pump 10 when the dry vacuum pump 10 is activated, for example, then the gas flows from the intermediate release outlet port 19, communicating with the gas passage 15b that communicates with the rotor chamber 13b in the second stage, into the exhaust unit 50. In the exhaust unit 50, the gas flows through the intermediate section check valve (excessive-compression preventing check valve) 52 into the silencer 53. As described later, the exhaust section check valve 51, the intermediate section check valve 52, and the silencer 53 are integrally disposed in the exhaust unit 50. Therefore, when the exhaust unit 50 is installed on the dry vacuum pump 10, the exhaust section check valve 51, the intermediate section check valve 52, and the silencer 53 are installed on the dry vacuum pump 10.

[0054] FIG. 5 schematically shows a structure of the exhaust unit 50. As described above, the dry vacuum pump 10 includes the rotor chambers 13a, 13b, 13c, 13d, 13e. As shown in FIG. 1, the rotors 12a, 12b, 12c, 12d, 12e are disposed respectively in the rotor chambers 13a, 13b, 13c, 13d, 13e. The gas, which is compressed in the rotor chambers 13a - 13e of the dry vacuum pump 10 and discharged from the final outlet port 18 that communicates with the rotor chamber 13e in the final stage, flows through the gas passage 54 provided in the exhaust unit 50 into the exhaust section check valve 51. The gas, which flows from the exhaust section check valve 51, flows through an exhaust passage 56 provided in the exhaust unit 50 into the silencer 53. The intermediate release outlet port 19, which communicates with the second rotor chamber 13b in the dry vacuum pump 10, communicates with intermediate section check valve 52 through the gas passage 55 provided in the exhaust unit 50. When the gas is excessively compressed in the dry vacuum pump 50, the excessively compressed gas flows through the intermediate section check valve 52 and the exhaust passage 56 into the silencer 53.

[0055] FIG. 6A is a plan view showing the structure of the exhaust unit 50, and FIG. 6B is a front view showing the structure of the exhaust unit 50. As shown in FIGS. 6A and 6B, the exhaust unit 50 comprises a valve section 50a and a silencer section 50b. The valve section 50a houses therein the exhaust section check valve 51 and the intermediate section check valve 52. As shown in FIGS. 4 and 5, the exhaust section check valve 51 has an inlet port communicating with the final outlet port 18 through the gas passage 54. The intermediate section check valve 52 has an inlet port communicating with the intermediate release outlet port 19 through the gas passage 55. The exhaust section check valve 51 and the intermediate section check valve 52 have respective outlet ports communicating with the exhaust passage 56 which communicates with a gas passage 61 defined in the silencer section 50b. The silencer section 50b, which houses the silencer 53 therein, has a final exhaust passage 56a defined therein which extends downstream from an outlet port of the silencer 53. The final exhaust passage 56a is connected to an exhaust port 58 of the apparatus which is vented to the atmosphere, as shown in FIG. 4.

[0056] The gas, which flows through the exhaust section check valve 51 and the intermediate section check valve 52, flows into the silencer 53. After the noise of the gas is reduced by the silencer 53, the gas is discharged from the exhaust unit 50. FIG. 7A is a side sectional view showing the structure of the silencer 53 in the silencer section 50b, and FIG. 7B is a cross-sectional view taken along line B - B of FIG. 7A. As shown in FIGS. 7A and 7B, the silencer 53 comprises a composite silencer including a resonance-type silencer 53-1 and an expansion-type silencer 53-2 that are integrally combined with each other. A wall 70 is interposed between the resonance-type silencer 53-1 and the expansion-type silencer 53-2. The resonance-type silencer 53-1 and the expansion-type silencer 53-2 communicate with the gas passage 61 which communicates with the exhaust passage 56. The resonance-type silencer 53-1 is disposed upstream of the expansion-type silencer 53-2 with respect to the direction in which the gas flows through the silencer 53. In other words, the resonance-type silencer 53-1 is disposed in an upstream region of the silencer section 50b with respect to the direction in which the gas flows through the silencer 53, and the expansion-type silencer 53-2 is disposed in a downstream region of the silencer section 50b with respect to the direction in which the gas flows through the silencer 53.

[0057] The silencer 53 includes a silencer casing 60 in the form of a thick plate and a lid 69. The silencer casing 60 has, defined in a side surface thereof, the groove-like gas passage 61 which is open outwardly in the side surface and communicates with the exhaust passage 56, a concave resonance chamber 62 which is open outwardly in the side surface and serves as the resonance-type silencer 53-1, and a concave first expansion chamber 63 and a concave second expansion chamber 64 which are open outwardly in the side surface and serve as the expansion-type silencer 53-2. The silencer casing 60 also has a groove-like resonance port 65 which is open outwardly in the side surface and communicates the resonance chamber 62 with the gas passage 61, a groove-like first throttle throat 66 which is open outwardly in the side surface and communicates the first expansion chamber 63 with the gas passage 61, a second throttle throat 67 which communicates the first expansion chamber 63 with the second expansion chamber 64, and a third throttle throat 68 which communicates the second expansion chamber 64 with the external space.

[0058] The side of the silencer casing 60 where the gas passage 61, the resonance chamber 62, the first expansion chamber 63, and the second expansion chamber 64 are defined is covered with the lid 69, which closes the open sides of the gas passage 61, the resonance chamber 62, the first expansion chamber 63, and the second expansion chamber 64. The resonance chamber 62 and the first expansion chamber 63 communicate with the gas passage 61 through the resonance port 65 and the first throttle throat 66, respectively. The first expansion chamber 63 and the second expansion chamber 64 communicate with each other through the second throttle throat 67. The second expansion chamber 64 is vented to the atmosphere through the third throttle throat 68.

[0059] As described above, the silencer 53 comprises a composite silencer including the resonance-type silencer 53-1 and the expansion-type silencer 53-2 which are housed in the silencer casing 60 in the form of a thick plate and which have openings closed by the lid 69. The silencer 53 is of a flat shape and a reduced size as it is made up of the silencer casing 60 in the form of a thick plate and the lid 69. The noise of the gas, which flows from the exhaust passage 56 in the valve section 50a into the gas passage 61 in the silencer section 50b, is silenced (reduced) in resonance with the natural frequency of the resonance-type silencer 53-1 composed of the resonance port 65 and the resonance chamber 62. Then, the gas flows through the first throttle throat 66 into the first expansion chamber 63 wherein the gas is expanded to have its noise silenced (reduced). The gas then flows through the second throttle throat 67 into the second expansion chamber 64 wherein the gas is expanded to have its noise silenced (reduced). Thereafter, the gas flows through the third throttle throat 68 out of the silencer 50 into the atmosphere wherein the gas is expanded to have its noise silenced (reduced).

[0060] The resonance-type silencer 53-1 is advantageous in that it can be reduced in size and does not obstruct the flow of the gas through the gas passage 61. However, the range of frequencies of the noise that can be silenced by the resonance-type silencer 53-1 is relatively narrow compared to an expansion-type silencer. On the other hand, the expansion-type silencer 53-2 is capable of silencing noise in a wider range of frequencies. However, since the range of frequencies that can be silenced by the expansion-type silencer 53-2 is in inverse proportion to the length thereof, the expansion-type silencer 53-2 is increased in length if it is to silence noise in a lower range of frequencies. According to this embodiment, the resonance-type silencer 53-1 which can be reduced in size is used to silence noise of the gas in a low range of frequencies, and the expansion-type silencer 53-2 whose length is in inverse proportion to the range of frequencies to be silenced is used to silence noise of the gas in a remaining high range of frequencies. Therefore, both the resonance-type silencer 53-1 and the expansion-type silencer 53-2 can be reduced in size, thus making it possible to reduce the overall size of the silencer 53 and to silence (reduce) noise in a wide range of frequencies.

[0061] The resonance-type silencer 53-1 does not obstruct the flow of the gas that flows into the gas passage 61. Even though the composite silencer 53 is in a discharge section of the gas passage in the exhaust unit 50, since the resonance-type silencer 53-1 is positioned in an upstream portion of the gas passage 61, any reduction in the gas discharging capability of the exhaust unit 50 can be minimized.

[0062] The valve section 50a and the silencer section 50b of the exhaust unit 50 are integrally combined with each other and constructed as one component of the dry vacuum pump apparatus. As a consequence, the exhaust unit 50 does not need to have parts including pipes and fittings which would otherwise be required to connect the exhaust section check valve 51 to the final outlet port 18 of the dry vacuum pump 10, pipes and fittings which would otherwise be required to connect the intermediate section check valve 52 to the intermediate release outlet port 19, and pipes and fittings which would otherwise be required to connect the gas passage 61 in the silencer section 50b to the exhaust passage 56 in the valve section 50a. Accordingly, the exhaust unit 50 is made up of a reduced number of parts and can be manufactured inexpensively.

[0063] As described above, the exhaust section check valve 51 is connected to the final outlet port 18 of the dry vacuum pump 10, and the intermediate section check valve 52 is connected to the intermediate release outlet port 19 of the dry vacuum pump 10. The outlet port of the exhaust section check valve 51 and the outlet port of the intermediate section check valve 52 are connected to the exhaust passage 56, and the silencer 53 is connected to the exhaust passage 56. The final exhaust passage 56a extends downstream from the silencer 53 is vented to the atmosphere. With this structure, noise of the gas discharged from the final outlet port 18 and noise of the excessively compressed gas discharged from the intermediate release outlet port 19 can be effectively silenced (reduced).

[0064] The intermediate release outlet port 19 is provided in a middle stage of the dry vacuum pump 10 where the compression ratio is relatively high, and the intermediate section check valve 52 is connected to the intermediate release outlet port 19 for venting the excessively compressed gas into the atmosphere. As a result, the dry vacuum pump 10 is prevented from operating at a low rotational speed under an excessive load, and hence can reduce the time required to discharge the compressed gas.

[0065] In the exhaust unit 50, the exhaust section check valve 51 and the intermediate section check valve 52 in the valve section 50a are integrally combined with the silencer 53 that is disposed downstream of the exhaust section check valve 51 and the intermediate section check valve 52. Accordingly, the exhaust unit 50 is made up of a reduced number of parts and small in size.

[0066] The resonance-type silencer 53-1 is disposed in the upstream region of the silencer section 50b with respect to the direction in which the gas flows through the silencer 53, and the expansion-type silencer 53-2 is disposed in the downstream region of the silencer section 50b with respect to the direction in which the gas flows through the silencer 53. The resonance-type silencer 53-1 and the expansion-type silencer 53-2 are integrally combined with each other. Therefore, the silencer 53 is capable of silencing noise in a wide range of frequencies and can be reduced in size. By using the silencer 53 as a silencer in combination with a dry vacuum pump, an exhaust unit including the silencer can be small in size, and the dry vacuum pump, which is capable of silencing noise in a wide range of frequencies, can also be small in size.

[0067] FIG. 8 is a vertical sectional view of another dry vacuum pump apparatus, and FIG. 9 is a cross-sectional view taken along line C - C of FIG. 8. Those parts of the dry vacuum pump apparatus shown in FIGS. 8 and 9 which are identical or correspond to those of the dry vacuum pump apparatus shown in FIGS. 1 through 7 are denoted by identical or corresponding reference characters, and will not be described below.

[0068] The dry vacuum pump apparatus of this embodiment includes a multistage roots-type dry vacuum pump (hereafter simply referred to as "dry vacuum pump") which comprises a pump unit P and a motor unit M. The pump unit P of the dry vacuum pump comprises a five-stage pump, and the motor unit M includes a motor (e.g., brushless DC motor) 22. In FIG. 8, gas passages 15a, 15b, 15c, 15d are defined between the outer and inner circumferential walls of a double-walled rotor casing 14, with a gas passage 15e being omitted from illustration. The omission also holds true for FIG. 10 to be described later.

[0069] According to this dry vacuum pump, the motor unit M has a motor casing 24 coupled to a side casing 30 of the pump unit P by a flange 31 on the side of the motor casing 24 which is joined to the pump unit P. In other words, the motor unit M and the pump unit P are integrally coupled to each other by the flange 31. A gas, which is compressed by successive rotors 12 in the pump unit P, is delivered successively through the gas passages 15a - 15d to the outlet side. As the gas is compressed by the rotors 12, it generates compression heat which is transferred through the rotor casing 14 of the pump unit P, the side casing 30, and the flange 31, to which the motor unit M is attached, to the motor casing 24. The compression head is also transferred through a side casing 26 of the pump unit P to a bearing casing 23.

[0070] As described above, the compression heat, which is generated by the gas that is compressed by the pump unit P, is transferred to the motor casing 24 of the motor unit M. Therefore, the temperature of the motor casing 24 rises to adversely affect the characteristics of a motor 22 housed in the motor casing 24. In this embodiment, to prevent the characteristics of the motor 22 from being adversely affected by the heat, a coolant pipe 32 is embedded in the flange 31 and a coolant, such as cooling water, is supplied to flow through a coolant passage provided by the coolant pipe 32 for absorbing and blocking the heat transferred from the rotor casing 14 of the pump unit P to the motor casing 24 of the motor unit M. The motor casing 24 of the motor unit M does not need to have any other cooling means for dissipating the heat transferred from the pump unit P. Heat generated by the motor casing 24 itself is naturally radiated from the motor casing 24. Instead of embedding the coolant pipe 32 in the flange 31, a coolant passage may directly be defined in the flange 31.

[0071] Heretofore, it has widely been customary to embed a coolant pipe for flowing coolant in the motor casing 24 to prevent the temperature of the motor casing 24 from rising due to the heat transferred from the pump unit P to the motor casing 24. Therefore, the motor casing 24 is required to have a large wall thickness, which has presented an obstacle to attempts to reduce the size of the motor casing 24. According to this embodiment, the coolant pipe 32 is embedded in the flange 31 which is relatively thick as it is fixed to the pump unit P. With the coolant pipe 32 embedded in the flange 31, it is not necessary for the motor casing 24 to have any other cooling means, and hence the motor casing 24 may be reduced in wall thickness to reduce the size and weight of the motor unit M.

[0072] As shown in FIG. 9, the pump unit P has a rotor casing 14 comprises separate upper and lower members 14-1, 14-2 that have respective mating surfaces held against each other and are coupled to together by a plurality of bolts 34. As indicated by the dotted lines in FIG. 10 which only shows a lower member 14'-2, a conventional rotor casing 14' comprises separate members 14'-1, 14'-2 which are thicker than the separate members 14-1, 14-2 of this embodiment by a wall thickness Δ d, and which are fastened to each other by a plurality of (four on each side in FIG. 10) bolts 34 extending through bolt insertion holes defined in outer circumferential regions of the gas passages 15a - 15d in the separate members 14'-1, 14'-2. Though the separate member 14'-1 is not illustrated in FIG. 10, bolts 34 extend through respective bolt insertion holes defined in the separate member 14'-1 at the same positions as with the separate member 14'-2. Consequently, with the conventional rotor casing 14', the wall thickness of the separate members 14'-1, 14'-2 is thicker than the wall thickness of the separate members 14-1, 14-2 of this embodiment by the wall thickness Δ d.

[0073] According to this embodiment, the dry vacuum pump apparatus has its compressive power reduced and its motor efficiency increased to reduce the power consumption. The dry vacuum pump incorporated in the dry vacuum pump apparatus is a multistage roots-type dry vacuum pump which compresses a gas through successive stages from a vacuum to the atmosphere and discharges the compressed gas. The dry vacuum pump optimizes the compression ratios at the respective stages for reducing the power consumption through the reduced compressive power. For optimizing the compression ratios at the respective stages, the dry vacuum pump sets a rotational speed for maintaining a desired exhaust speed and minimizing the mechanical loss caused thereby. It is effective to employ a brushless DC motor to reduce the power consumption. According to this embodiment, furthermore, the motor efficiency is increased by changing the material of the iron core of the motor and improving the windings of the motor.

[0074] According to this embodiment, as described above, the compression ratios of the dry vacuum pump are optimized and the heat generated by the pump is reduced. Therefore, it becomes possible to changed positions where the bolts 34 are arranged to fasten the separate members 14-1, 14-2 to each other, thereby reducing the wall thickness of the rotor casing 14. Moreover, the dry vacuum pump has its rotational speed set to reduce the mechanical loss caused thereby for the optimization of the compression ratios at the respective stages of the dry vacuum pump. The rotational speed thus set allows the material of the iron core of the motor to be changed and also allows the windings of the motor to be improved for increasing the motor efficiency. Thus, the amount of heat generated by the motor 22 is reduced, and the heat generated by the motor 22 can be dissipated only by the coolant flowing through the coolant pipe 31 embedded in the flange 31.

[0075] Accordingly, as indicated by the solid lines in FIG. 10, bolt insertion holes for inserting the bolts 34 therethrough are defined in the separate members 14-1, 14-2 at regions free of the gas passages 15a -15d between the gas passages 15a and 15b, between the gas passages 15b and 15c, between the gas passages 15c and 15d, and on one side of the gas passage 15a remote from the gas passage 15b, closely to circumferential positions where the gas passages 15a - 15d are defined. The bolts 34 are inserted through the respective bolt insertion holes to fasten the separate members 14-1, 14-2 to each other. The bolt insertion holes are positioned more closely to an inner circumferential surface of the rotor casing 14 than those, indicted by the dotted lines in FIG. 10, in the conventional rotor casing 14'. Therefore, the separate members 14-1, 14-2 of the rotor casing 14 may be of a reduced wall thickness in the widthwise directions of the rotor casing 14, thereby reducing the widthwise dimension of the dry vacuum pump and hence the size of the dry vacuum pump apparatus.

[0076] The bearing basing 23 of the pump unit P houses therein bearings (e.g., combined angular ball bearings) 21 and timing gears 29 which generate heat due to a machine loss when the dry vacuum pump apparatus is in operation. To reduce a temperature rise of the dry vacuum pump apparatus due to the heat generated by the machine loss, a coolant pipe 33 is embedded in the bearing casing 23 for a coolant to flow through a coolant passage provided by the coolant pipe 33. Instead of embedding the coolant pipe 33 in the bearing casing 23, a coolant passage may directly be defined in the bearing flange 23.

[0077] As described above, the coolant pipe 32 is embedded in the flange 31 by which the motor unit M is coupled to the pump unit P. When the coolant flows through the coolant pipe 32, the heat transferred from the pump unit P to the motor casing 24 is absorbed and blocked against being transferred to the motor 22 by the coolant flowing in the coolant pipe 32. The heat generated by the motor 22 is naturally radiated from the motor casing 24. Consequently, the motor casing 24 does not need to have any other cooling means for dissipating the heat from the pump unit P. The widthwise dimension of the motor casing 24 is thus smaller than the conventional motor casing which may be defined a coolant passage therein. Therefore, the motor unit M of the dry vacuum pump apparatus can be reduced in size and weight.

[0078] FIG. 11 is a schematic diagram of a dry vacuum pump apparatus according to another embodiment of the present invention. As shown in FIG. 11, the dry vacuum pump apparatus includes a main pump unit MP comprising a multistage roots-type dry vacuum pump 10-2 and a booster pump BP comprising a multistage roots-type dry vacuum pump 10-1. The main pump MP has an inlet port 17 connected to a final outlet port 18 of the booster pump BP. The main pump MP is connected to an exhaust unit 50 which includes an exhaust section check valve 51, an intermediate section check valve 52, and a silencer 53. The main pump MP includes a final outlet port 18 connected to the exhaust section check valve 51 and an intermediate release outlet port 19 connected to the intermediate section check valve 52.

[0079] In the illustrated embodiments, the silencer 53 comprises the composite silencer including the resonance-type silencer 53-1 and the expansion-type silencer 53-2. However, the silencer 53 may be any silencer which is effective to silence the noise of the excessively compressed gas discharged from the intermediate release outlet port 19 and the noise of the gas discharged from the final outlet port 18. Further alternatively, the intermediate release outlet port 19 and the final outlet port 18 may be connected to different silencers, respectively.

[0080] The dry vacuum pump of the dry vacuum pump apparatus is not limited to a roots-type positive-displacement dry vacuum pump, but may be any of various other dry vacuum pumps.

[0081] Although certain preferred embodiments of the present invention have been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.

Claims

1. A dry vacuum pump apparatus comprising:

a multistage positive-displacement dry vacuum pump having a final outlet port in a final stage for discharging a gas and an intermediate release outlet port in an intermediate stage for discharging an excessively compressed gas;
an exhaust section check valve connected to the final outlet port and having an outlet port;
an intermediate section check valve connected to the intermediate release outlet port and having an outlet port;
an exhaust passage connected to the outlet port of the exhaust section check valve and the outlet port of the intermediate section check valve; and
a silencer connected to the exhaust passage and having an outlet port connected to a final exhaust passage which is vented to the atmosphere.

2. A dry vacuum pump apparatus according to claim 1, wherein the exhaust section check valve, the intermediate section check valve, the exhaust passage, and the silencer are integrally combined as an exhaust unit.

3. A dry vacuum pump apparatus according to claim 1, wherein the multistage positive-displacement dry vacuum pump comprises a five-stage dry vacuum pump, the intermediate release outlet port being connected to a second stage of the five-stage dry vacuum pump.

4. A dry vacuum pump apparatus according to claim 1, wherein the silencer comprises a composite silencer including a resonance-type silencer and an expansion-type silencer, and wherein the resonance-type silencer is disposed in an upstream region of the silencer with respect to the direction in which the gas flows through the silencer and the expansion-type silencer is disposed in a downstream region of the silencer with respect to the direction in which the gas flows through the silencer.

5. A dry vacuum pump apparatus according to claim 1, wherein the multistage positive-displacement dry vacuum pump comprises a single multistage positive-displacement dry vacuum pump or a plurality of series-connected multistage positive-displacement dry vacuum pumps.

6. A dry vacuum pump apparatus comprising:

a multistage roots-type dry vacuum pump having a final outlet port in a final stage for discharging a gas and an intermediate release outlet port in an intermediate stage for discharging an excessively compressed gas;
an exhaust section check valve connected to the final outlet port and vented to the atmosphere; and
an intermediate section check valve connected to the intermediate release outlet port and vented to the atmosphere.

7. A dry vacuum pump apparatus according to claim 6, wherein
the multistage roots-type dry vacuum pump comprises a five-stage roots-type dry vacuum pump including rotor chambers in five stages and rotors disposed

respectively in the rotor chambers,
the intermediate section check valve communicates with the rotor chamber in the second stage, and
the rotor disposed in the rotor chamber in the first stage has an axial width which is twice or more the axial width of the rotor disposed in the rotor chamber in the second stage.

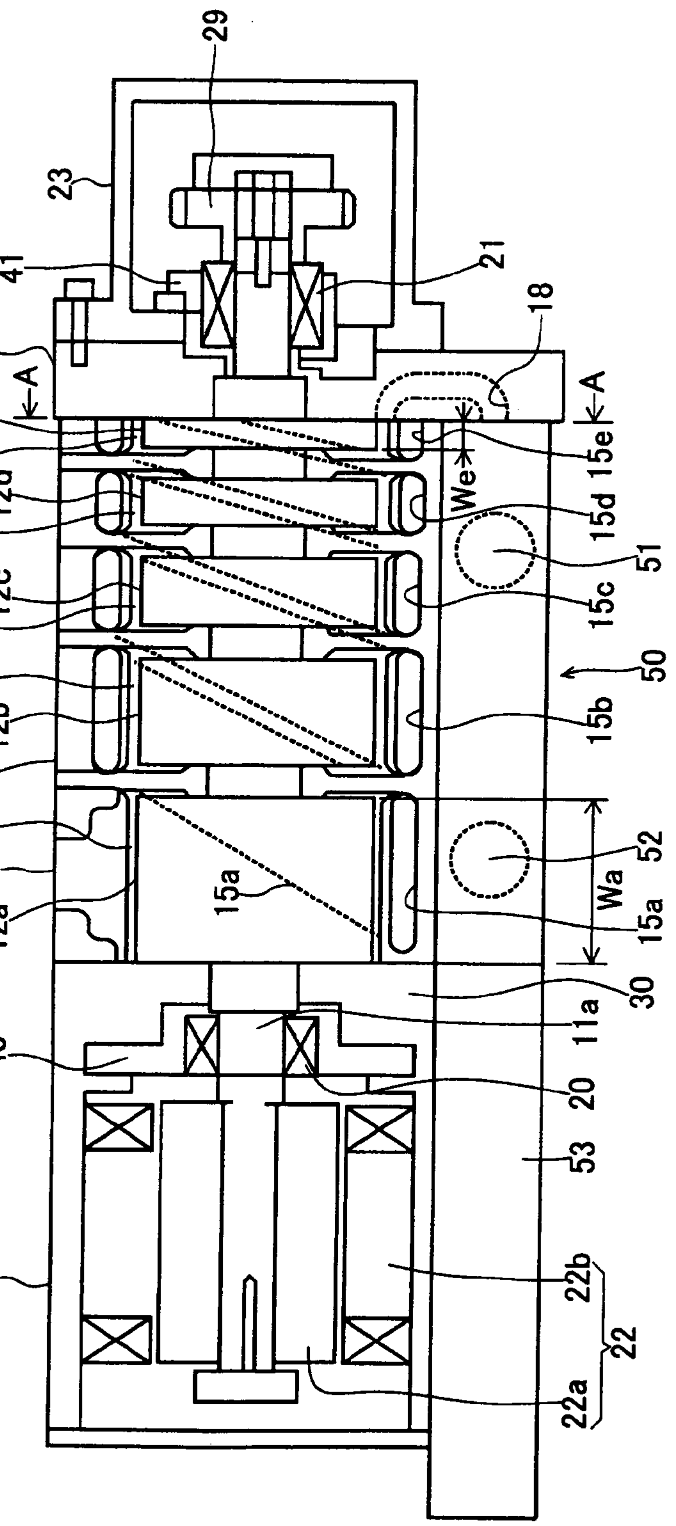
8. A dry vacuum pump apparatus according to claim 6, further comprising:

an exhaust passage connected to an outlet port of the exhaust section check valve and an outlet port of the intermediate section check valve; and
a silencer connected to the exhaust passage and having an outlet port connected to a final exhaust passage which is vented to the atmosphere.

9. A dry vacuum pump apparatus according to claim 8, wherein the exhaust section check valve, the intermediate section check valve, the exhaust passage, and the silencer are integrally combined as an exhaust unit.

10. A dry vacuum pump apparatus according to claim 9, wherein the multistage roots-type dry vacuum pump comprises a booster pump and a main pump, the booster pump has a final outlet port connected to an inlet port of the main pump, and the exhaust unit is connected to the main pump.

FIG. 1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23
41
21
18
26
A
A
12e
13e
15e
We
12d
13d
15d
51
12c
13c
15c
13b
12b
15b
50
14
13a
17
52
12a
15a
15a
Wa
30
11a
40
20
53
24
22b
22
22a

FIG. 2

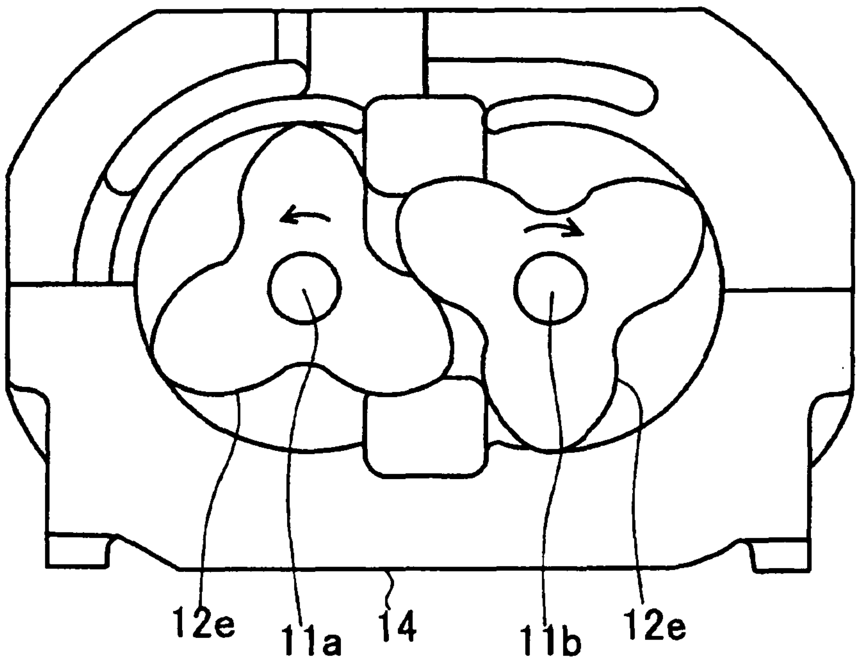


FIG. 3

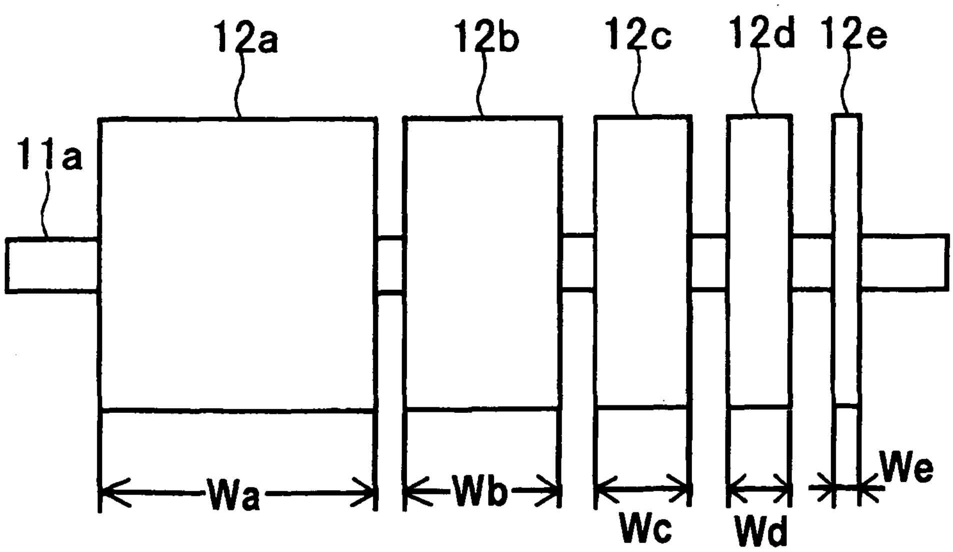
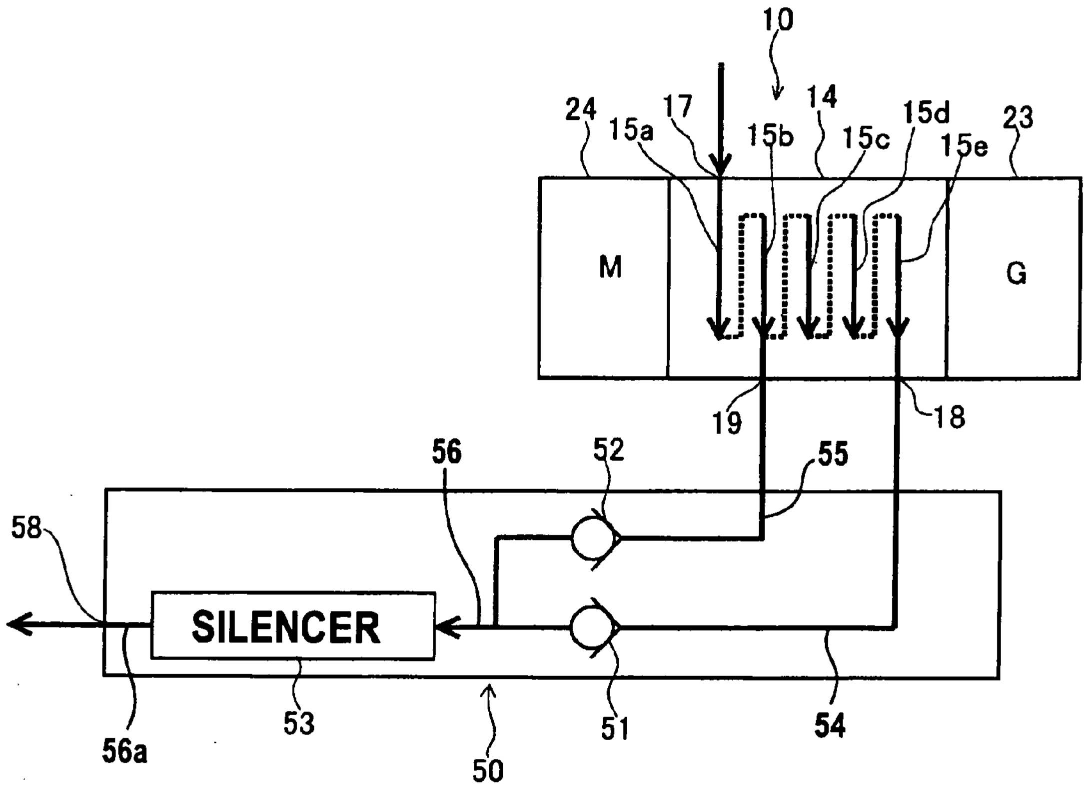


FIG. 4


10
24
17
15a
14
15b
15c
15d
23
15e
M
G
19
18
56
52
55
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53
51
54
56a
50

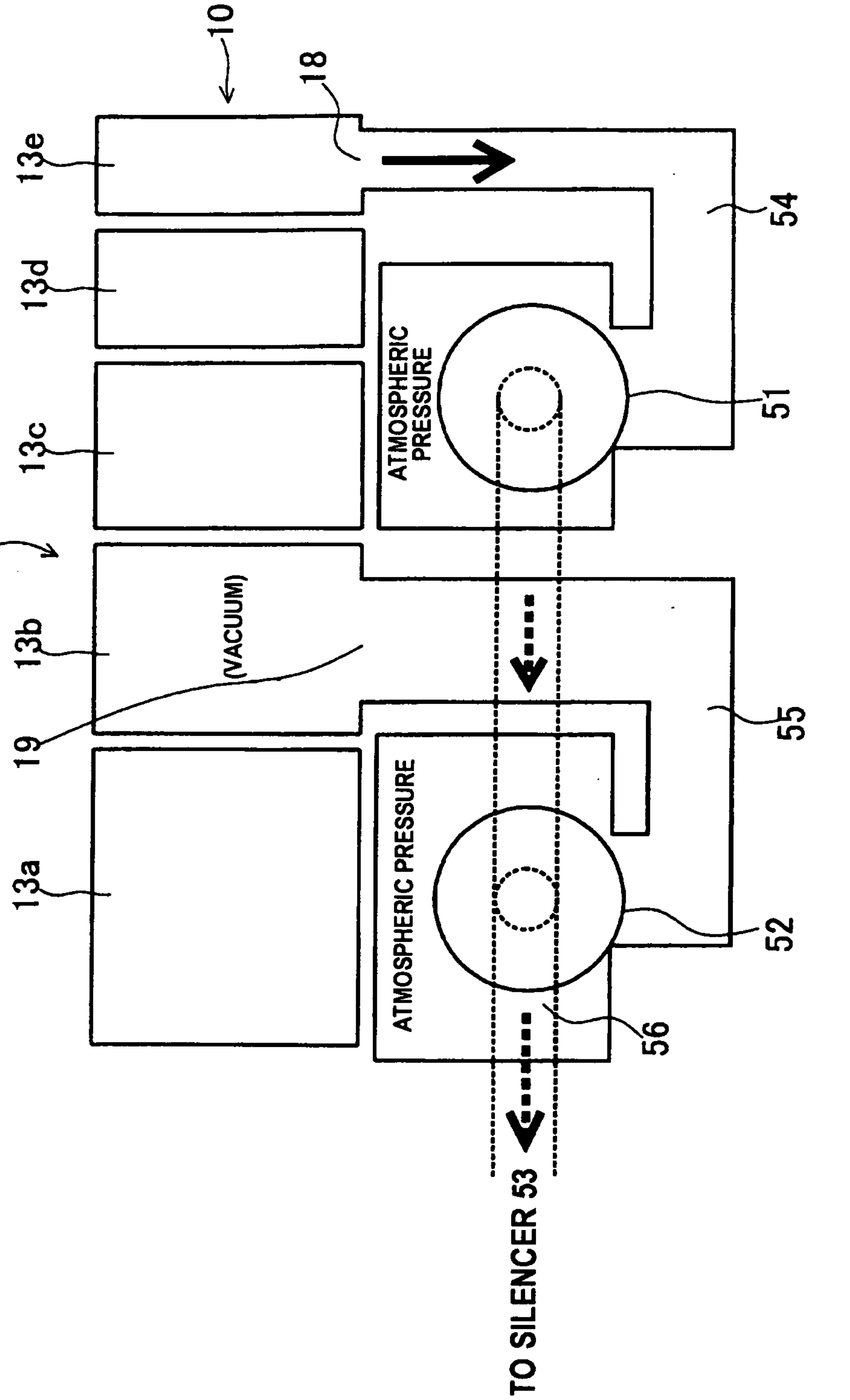

10
18
13e
13d
13c
13b
13a
50
19
(VACUUM)
ATMOSPHERIC PRESSURE
ATMOSPHERIC PRESSURE
51
52
54
55
56
TO SILENCER 53

FIG. 5

FIG. 6A

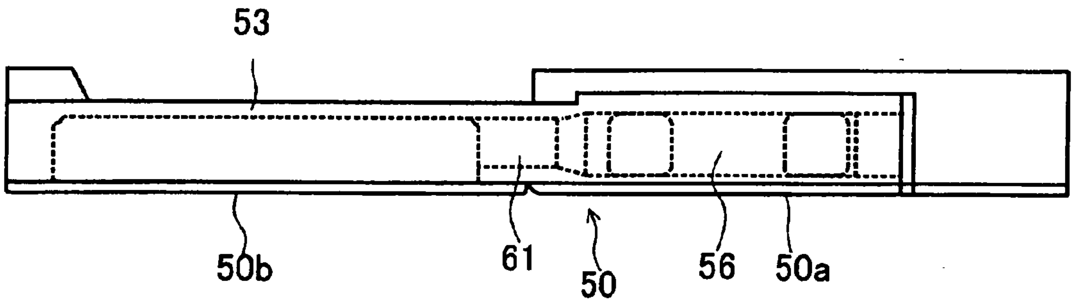


FIG. 6B

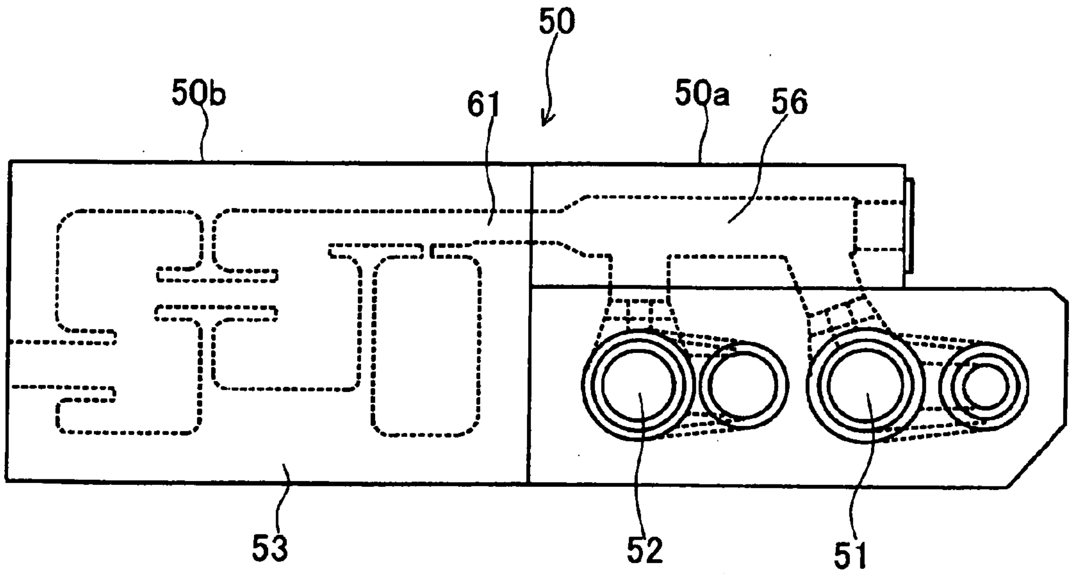


FIG. 7A

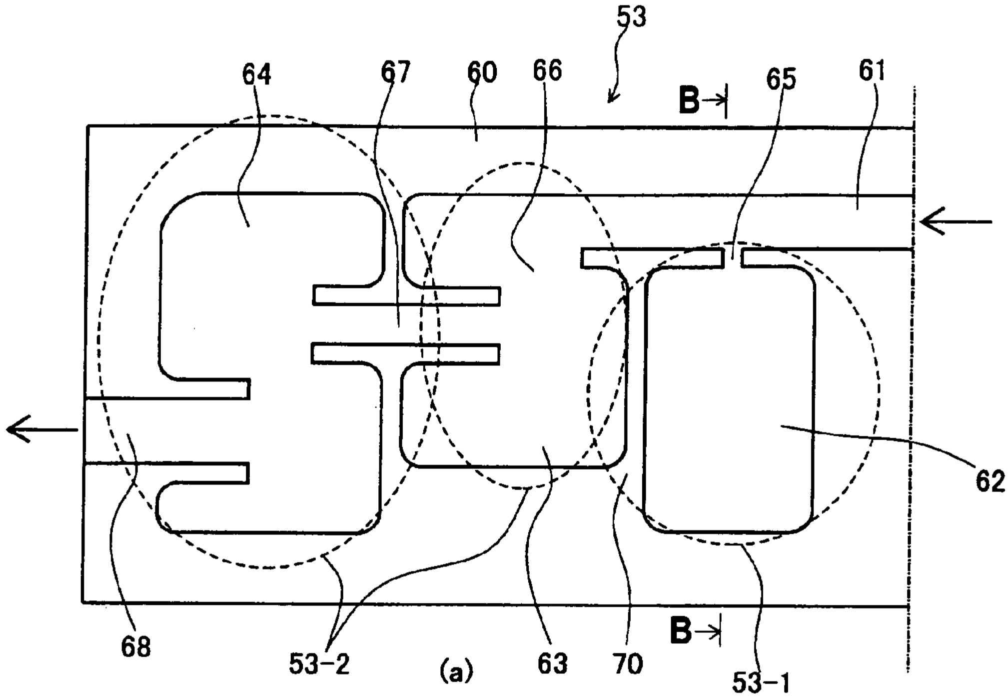


FIG. 7B

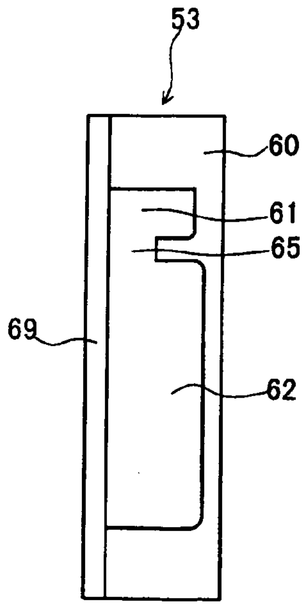


FIG. 8

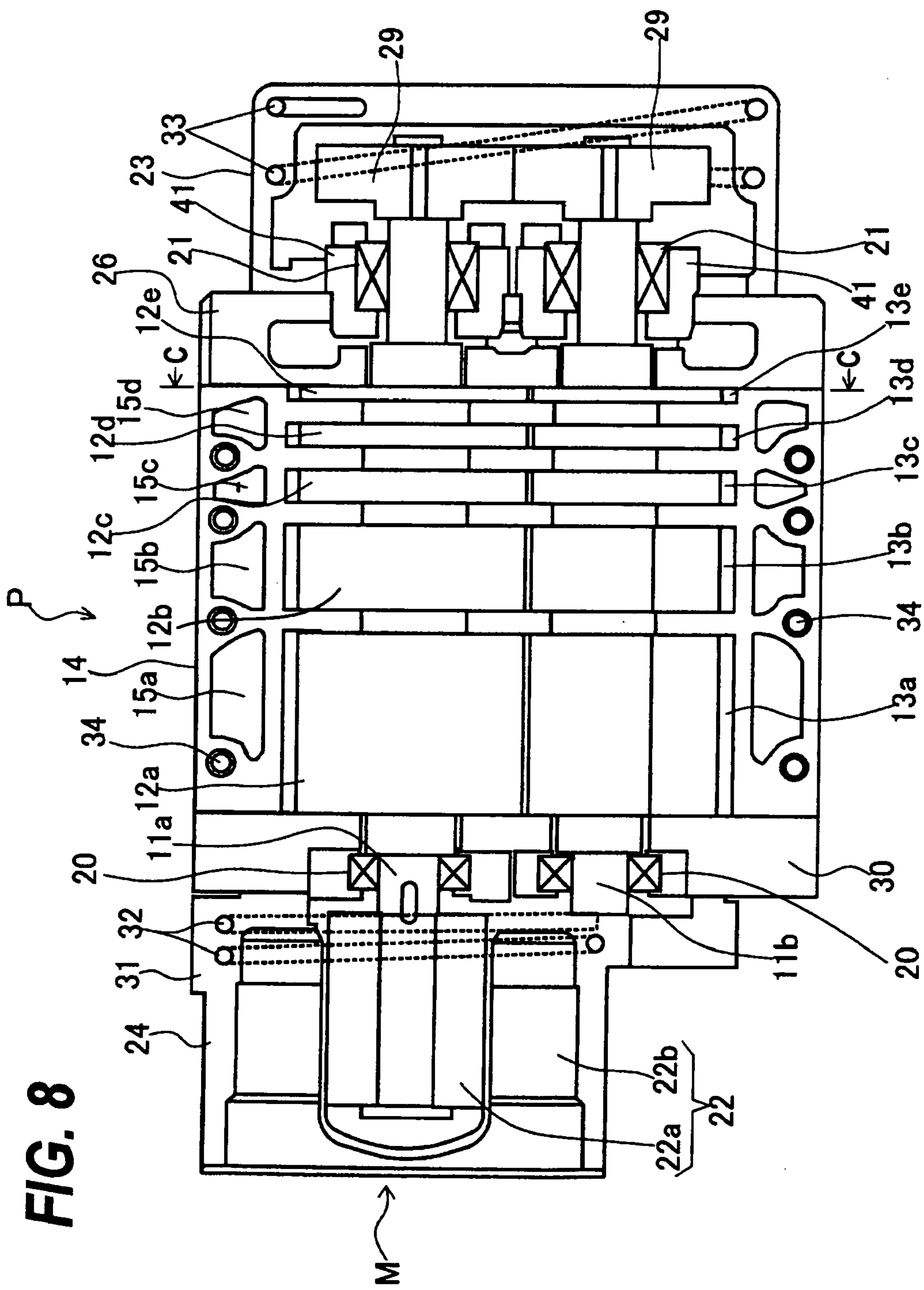

29
29
33
23
41
21
26
12e
C
15d
12d
15c
12c
15b
12b
P
14
15a
34
12a
11a
20
32
31
24
22b
22a
22
M
21
41
13e
C
13d
13c
13b
34
13a
30
11b
20

FIG. 9

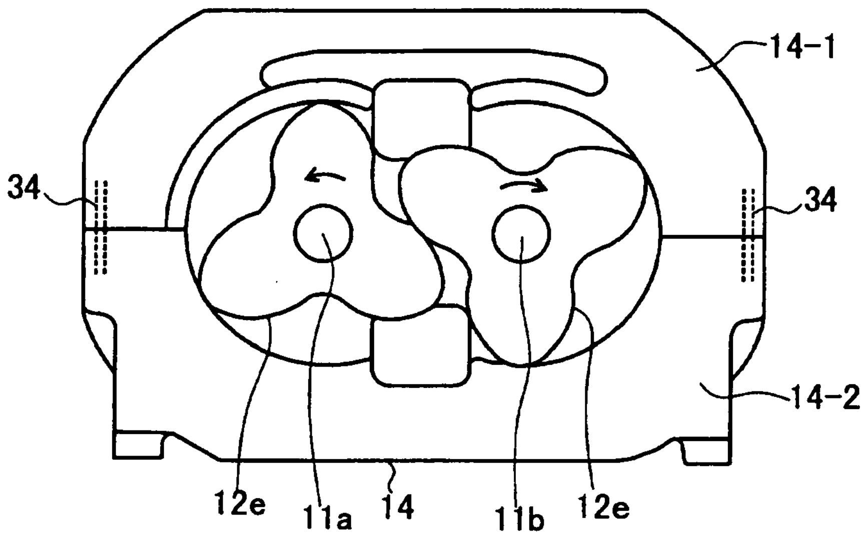

14-1
34
34
14-2
12e
11a
14
11b
12e

FIG. 10

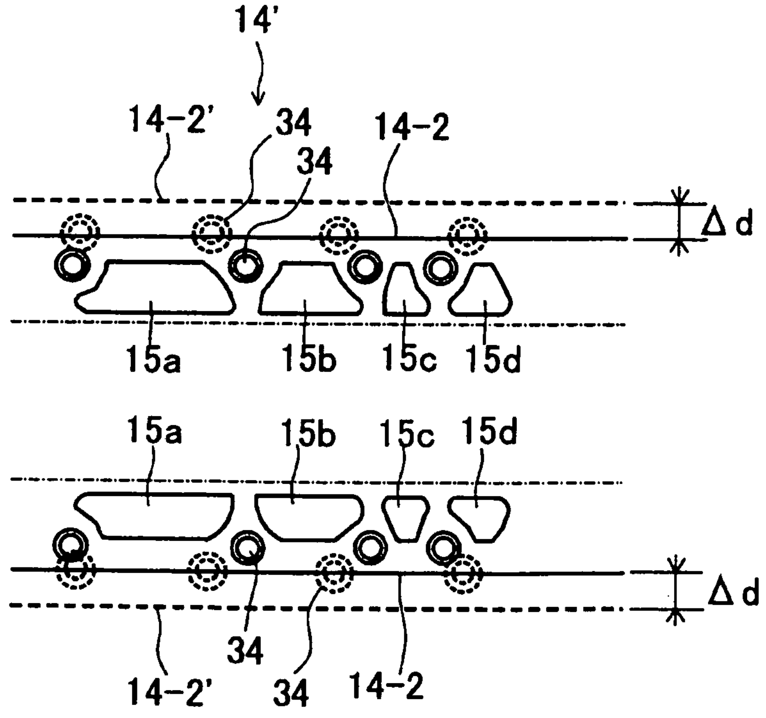
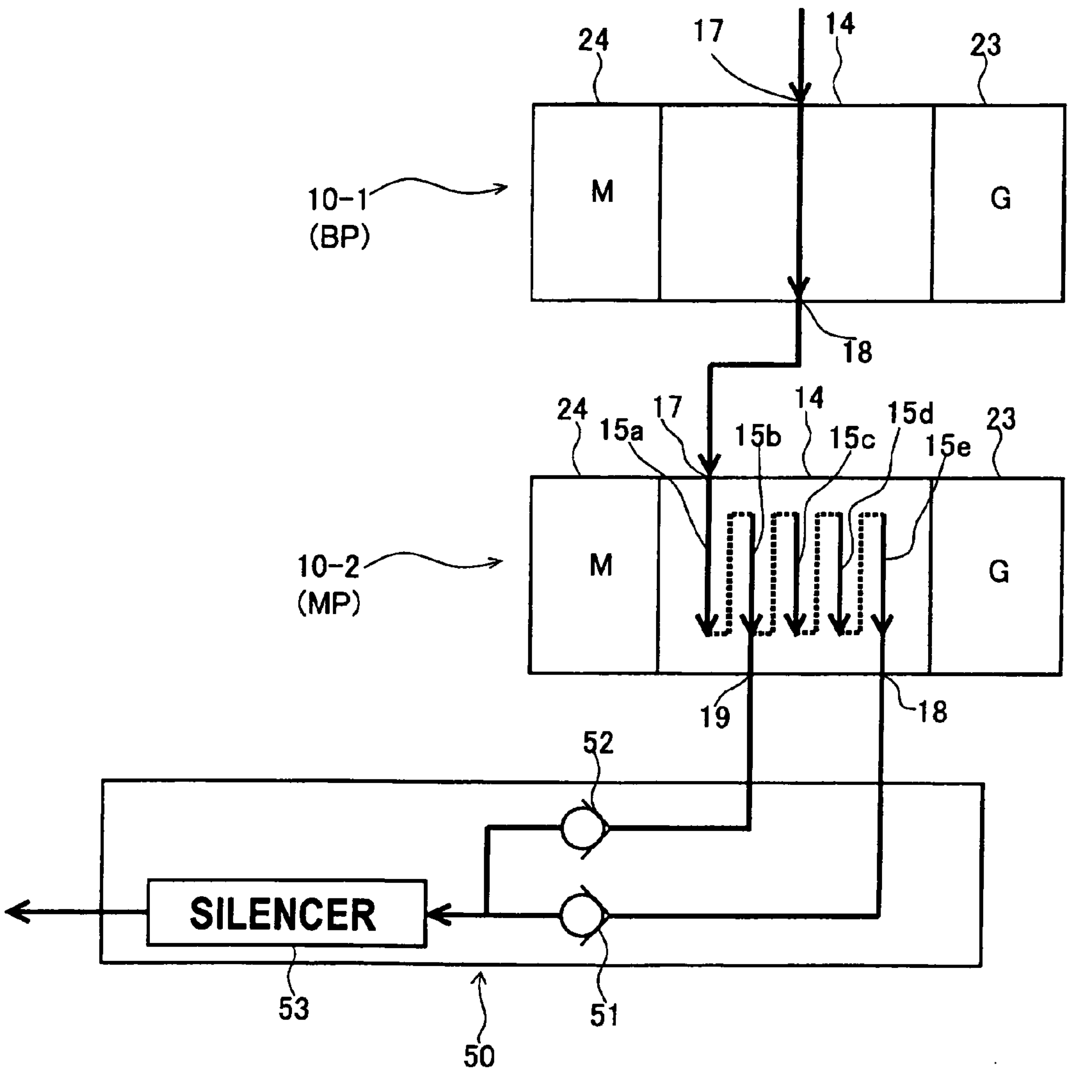

14'
14-2'
34
34
14-2
Δ d
15a
15b
15c
15d
15a
15b
15c
15d
Δ d
34
14-2'
34
14-2

FIG. 11


24
17
14
23
10-1
(BP)
M
G
18
24
17
15a
15b
14
15c
15d
15e
23
10-2
(MP)
M
G
19
18
52
SILENCER
53
50
51

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2001289167 A **[0004]**